Guardian Angels

FET Flagship Pilot

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1 Guardian Angels Summaries

1.1 Executive Summary

The “Guardian Angels for a Smarter Life” (GA) FET Flagship project will create intelligent, autonomous electronic personal companions that will assist us from infancy to old age. These devices will be private and secure systems featuring sensing, computation, and communication beyond human capabilities. Three families of life-enhancing demonstrators will offer instant availability of relevant information, interconnectivity between devices fitted with all sorts of sensors, and intentional and intuitive usability: (I) **Physical GAs** will have the capacity to monitor the physical and/or physiological status of individuals in healthcare, rehabilitation, and sports, with an awareness of the context of activity of these individuals. With a strong focus on prevention and early diagnosis, these devices will help keep healthcare affordable and accessible to all. (II) **Environmental GAs** will observe ambient conditions for environmental threats and communicate with each other to expand their information base. In combination with functionality from Physical GAs, it will be possible to correlate a person’s physical state with the environmental context. (III) **Emotional GAs** will be able to perceive emotional or affective conditions, and will both support patients and enhance the performance of healthy people, such as with smart-drive assistants for improved safety. The ethical aspects of GA applications will be assessed from the beginning of the project, through interactions between researchers, an ethics board of experts and end users, and privacy and security will be the highest priorities.

The technology-related project goal is the exploration and development of “zero-power” technologies for these electronic personal assistants, so that they will harvest their own energy rather than requiring an external power source. This flagship proposal is driven by the fundamental scientific challenges related to achieving energy efficiency in complex systems, and will impact the development of Information and Communication Technology (ICT) future and emerging technologies through multidisciplinary research targeting long-term goals.

The zero-power requirement of the project has two sides: the acquisition of energy through harvesting, and the development of ultra-low power systems, whose energy consumption is as close as possible to theoretical limits. The devices will have the ability to scavenge energy in very diverse environments and store what is needed for the system functions. This will, however, require disruptive scientific progress in the field of novel concepts and technologies for energy harvesting; both for known types of energy harvesters such as solar, thermal, vibrational, and electromagnetic, as well as for new bio-inspired energy scavengers that are bio-chemical or synthetic photosynthesis-based. The target power density will be up to a few mW per cm² (or cm³), achieved by integration of existing and disruptive concepts. At the same time it is indispensable to minimize the energy consumption of the system. The scientific and technological challenges of the project thus include developing an ultra-low energy innovation chain: from materials and devices, to heterogeneous system integration, to software and communication techniques enabling the reduction of energy consumption by up to three orders of magnitude compared to existing state-of-the-art technologies. Compared to existing ENIAC, CATRENE and ICT initiatives, this FET Flagship will not be limited to segments of the nanoelectronics innovation chain, but will instead unify energy-efficient technologies and integrated energy scavengers within one long-term design and integration platform.

The objectives of the project are divided into three main categories: (i) scientific objectives centred on ultra-low power concepts, (ii) novel (nano)technology, materials and device integration solutions (based on advanced silicon platforms but including novel families of nanomaterials such as graphene, carbon nanotubes and/or organic semiconductors on flexible substrates), and (iii) three families of visionary zero-power autonomous systems demonstrators. These categories of objectives are interdependent and are designed to result in a
platform of ultra energy-efficient technologies for system integration, which will be applied in an unprecedented number of applications far beyond the GA idea.

As the application scenarios above suggest, the impact of Guardian Angels on society and the economy is very broad. On an individual level, anyone could benefit from a personal assistant acting as a modern day Guardian Angel, focusing on the improvement of health and on personal safety, with the goal of enhancing quality of life in a sustainable society. To achieve this, the GA consortium will work in close cooperation with different social stakeholders, interest groups and future users. Special attention will be paid to energy-efficient, economically feasible and environmentally friendly solutions. Additionally, the consortium will explore novel opportunities for human-machine interaction. Undoubtedly, in the course of the project, further beneficial applications using GA technology will be explored to make our environment more interconnected and smarter, more energy-efficient and safer.

The benefits of developing the enabling technologies for ultra-low energy consumption are widespread and lie beyond the immediate applications in smart systems. The novel electronic GA technologies developed in this project will contribute to the reduction of the energy consumption of systems: the estimated reduction may be worth more than 7% of the worldwide gross domestic product (GDP), as estimated by IBM analysts in 2010.\(^1\)

The project will strengthen the leading role of Europe in zero-power technologies by reinforcing the activity of manufacturing in Europe and improving the competitiveness for leading communication, equipment and tools companies and service providers. Overall, the project will result in the creation of new employment in Europe in many fields, including advanced Information and Communication Technology.

1.2 Summary for EU Decision Makers

The “Guardian Angels for a Smarter Life” (GA) FET Flagship project addresses challenges which are of utmost importance for Europe’s society, economy and environment and which will have to be tackled in the next 10-15 years. Health and an ageing society, safety and security, and transportation, will all be addressed by the energy-efficient systems of the GA project. Imagine mobile electronic personal assistants being 1000 times more energy-efficient than they can be today, so that they could be powered by the energy available in your environment without any power plugs. Imagine part of the energy savings transformed into sensing, communications and interface functions of an invisible system that becomes your day-to-day Guardian Angel. This project will address the grand scientific, technological and system engineering challenges in a time frame of 10 years to transform this vision into a reality.

The GA FET Flagship project will develop technologies for extremely energy-efficient, smart, electronic personal companions that will assist humans from infancy to old age. These devices will be private and secure systems featuring sensing beyond human capabilities, computation, and communication. Three pre-defined families of demonstrators will show the feasibility and functionality of the systems: (I) Physical GAs will have the capacity to monitor the physical and/or physiological status of individuals in health care, rehabilitation, and sports, with an awareness of the context of activity of these individuals. With a strong focus on prevention and early diagnosis, these devices will help keep healthcare affordable and accessible to all. (II) Environmental GAs will observe ambient conditions for environmental threats and communicate with each other to expand their information base. In combination with functionality from Physical GAs, it will be possible to correlate a person’s physical state with the environmental context. (III) Emotional GAs will be able to perceive emotional or affective conditions, and will both support patients and enhance the performance of healthy people, such as with smart-drive assistants for improved safety. The ethical aspects of GA applications will be assessed from the beginning of the project, through interactions between researchers, an ethics board of experts and end users, and privacy and security will be the highest priorities.

\(^1\) Dario Gil, presentation at International Workshop on Future Information Processing Technologies (IWF IPT), 2010.
The contribution of the Guardian Angels FET Flagship on the European economic value chain is completely in line with what the European Commission expressed in its Communication of September 2009: “A significant part of the goods and services that will be available in the market in 2020 are as yet unknown, but the main driving force behind their development will be the deployment of key enabling technologies (KETs). Those nations and regions mastering these technologies will be at the forefront of managing the shift to a low carbon, knowledge-based economy, which is a precondition for ensuring welfare, prosperity and security of its citizens. Hence the deployment of KETs in the EU is not only of strategic importance but is indispensable.”

In particular, the supporting zero-power technology platform itself forms a KET (or can be considered a collection of future KETs working toward a unified goal) that integrates all the levels of the value chain needed to develop the GA autonomous systems. Each layer of the GA systems, from materials, to systems, to applications, has its own impact, all based on one common vision. These impacts, separately and combined, will generate economic and societal benefits for many key domains of strategic importance for Europe.

The project will use a multidisciplinary approach to make disruptive scientific progress. The enabling technologies created in the GA project will substantially advance and expand innovation in Information and Communication Technology, and will manifest Europe’s leading position in low power nanoelectronics and nano/microsystems. Many important European industry sectors such as health, energy, environment, transportation, and security will significantly benefit from these novel technologies.

The project goal is to develop zero-power technologies for these electronic personal assistants, so that they will harvest all the energy they need rather than requiring an external power source. The objectives of the project are divided into three interdependent categories: (i) scientific objectives centred on ultra-low power concepts, (ii) novel technologies, material and device integration solutions, and (iii) visionary zero-power autonomous systems demonstrators.

GA is a visionary project that takes on technological challenges for which no feasible solutions are currently available. GA research is goal-oriented, and the envisioned products have a wide range of applications in different areas. These in turn will require new fabrication equipment and tools as well as methods for the analysis of process results. Here, the potential benefit for European SMEs is especially high. The innovation process is thus not limited to fundamental research in science labs, but also encompasses application sectors and those benefiting from the results. Compared to existing ENIAC, CATRENE and ICT initiatives, this FET Flagship will not be limited to segments of the nanoelectronics innovation chain, but will instead unify energy-efficient technologies and integrated energy scavengers within one long-term design and integration platform. The proposed approach is based on heterogeneous integration of the best existing and emerging materials, technologies and devices for dedicated functions, each used for its best performance and most innovative functionality. It will improve the competitiveness of leading communication, equipment and tools companies as well as service providers.

Uniting 58 partners from 16 countries, the GA consortium is already cooperating closely with companies interested in future technologies and potential products. While established European companies with access to GA technologies will reach new markets, the range of multidisciplinary research results will lead to the creation of new start-ups and hence of new jobs. Since GA is a truly pan-European venture – from Ireland to Poland, from Finland to Italy – the funds, as well as the future benefits, are well distributed all over Europe.

1.3 Summary for the General Public

Guardian Angels are tiny, autonomous, wearable systems that we can choose to integrate into our everyday lives where needed, in a wide range of situations. They are based on networks of intelligent nanosensors designed to safeguard our health, safety and general well-being, and to improve our quality of life. Currently, high energy consumption and the short lifespan of batteries are obstructing further progress in autonomous systems.
Guardian Angels will meet the technological challenges of weaving together energy-efficient information processing, sensing, communication, and energy harvesting, into a zero-energy (battery-free) concept.

There will be three families of GA devices, all based on the concept of a smarter life: a lifestyle that benefits from the instant availability of relevant information, whether that information comes from within our own bodies (heart rate, insulin level, the amount of stress we feel, our attention or distraction levels) or outside them (pollutants, pollen, obstacles in our way). The three GA families: (1) **Physical GAs**, which can give us information about our physical and physiological status, for purposes including health care, rehabilitation, or sports. If we choose, the information will be communicated securely with doctors or others in our sphere of health care providers. These devices, with their strong focus on disease prevention and early diagnoses, will help keep healthcare affordable and accessible to all. (2) **Environmental GAs** will focus their sensing on environmental conditions, serving as a sort of 6th sense to allow us to know what is in the air around us. For visually impaired people, they could help fill in visual information by “seeing” for them. In combination with the Physical GAs, it will be possible to correlate our physical state with the environmental context. (3) **Emotional GAs** will be able to perceive emotional or affective conditions such as stress or attention level, so that we become more self-aware in situations where it can work to our advantage, whether we are driving a car or are in a learning environment. The applications mentioned here are only a fraction of what can be created during the ten-year project, and are a tiny sampling of what is possible.

Strokes, autism, stress and other neurological disorders are affecting a growing number of people worldwide. Their consequences are devastating for the patients, their families, and society. GA will reduce the impact of these disorders by allowing patients to become more autonomous and to participate in activities that weren’t possible before. GA’s easy-to-use, low-power, wearable systems - based on the analysis of behavioural, contextual, and physiological signals (including brainwaves) - will enable independent rehabilitation and management of both motor and cognitive disorders. A stroke patient will play chess with the help of a neuroprosthesis that, upon recognising that he wants to reach for a piece and that his eyes are looking at the knight, will compensate for the missing motor capabilities in order to move the knight. An autistic girl will attend school with the help of “emotional” glasses that, by keeping track of the teacher's and other children’s behaviour as well as of her engagement, will stimulate her to make eye contacts and participate in the activities of the class.

Security and privacy are top priorities in the GA project. The data gathered will be yours; it will always be your decision to keep or to share it. In addition, the ethical aspects of GA applications will be assessed from the beginning of the project, through interactions between researchers, an ethics board of experts, and end users.

The technology-related project goal is to develop environmentally-friendly, battery-free technologies for these electronic personal assistants, so that they will harvest all the energy they need rather than requiring an external power source. GA devices will be 100 times more efficient than existing energy scavengers, harvesting energy from diverse sources including light, heat, and motion. In addition, the circuits and systems that need to be powered by these energy scavengers will use new technologies that consume less energy than any technologies existing today. All this will happen in a system so tiny that you will be able to wear it comfortably, in clothing, temporary skin patches, or “electronic skin.”

The economic advantages will be numerous. European industry already has a solid base in the fields of microsystems, low-power electronics and system integration, encompassing communication, software, analytical instruments and fabrication equipment. Guardian Angels will build on this existing expertise, bringing economic benefits to the sector. The range of multidisciplinary research results will also lead to the creation of new start-ups and hence of new jobs. As GA is truly a pan-European venture – from Ireland to Romania, from Finland to Italy – the funds as well as the future benefits are well-distributed all over Europe.
In our project vision, GAs will provide data which will allow you to extract relevant information for a smarter life: making life easier when you are well, and maintaining or improving quality of life for those with health problems. Imagine mobile electronic personal assistants being 1000 times more energy-efficient than they can be today, so that they could be powered by the energy available in your environment without any power plugs. Imagine part of the energy savings transformed into sensing, communications and interface functions of an invisible system that becomes your day-to-day Guardian Angel. This project will address the grand scientific, technological and system engineering challenges in a time frame of 10 years to transform this vision into a reality.
2 S & T Quality

2.1 Scientific Vision and Unifying Goal

2.1.1 The big picture: Guardian Angels at the core of the information revolution

The Guardian Angels for a smarter life FET Flagship project is designed as a visionary, science driven, goal-oriented, large-scale, multidisciplinary research initiative, centred on ICT future and emerging technologies. Today everyone is a user of ICT technology and benefits from the tremendous progress offered by silicon-based nanoelectronics. As with past technology waves, computer technology is currently reaching a plateau phase and facing fundamental limits and challenges from energy and economy-of-scale points of view. Our proposal will directly contribute to establishing new generations of ICT technologies and applications, and will unite three major innovation waves of the information revolution: (i) computer technology, (ii) distributed intelligence, and (iii) nanotechnology (see Fig. 1). The Guardian Angels (GA) project vision encompasses extraordinary societal benefits and applications, enabled by the autonomy of future energy-efficient nanoelectronic systems, powered by energy harvesters. Such autonomy requires disruptive progress in the fundamental principles and the engineering of low-energy systems. The project vision prioritises energy efficiency as the main driver for the information revolution, for creating autonomous smart systems that can act as true Guardian Angels for people, offering personalized advice and thus enabling a better life.

Fig. 1: Depiction of technology waves of the industrial and information revolutions. The Guardian Angel FET Flagship vision unites the distributed intelligence, the nanotechnology and the computer waves, setting a common driver for applications: energy efficiency.

2.1.2 The Vision and Benefits of GA

GAs are foreseen as interconnected, smart, autonomous systems enabled by energy-efficient nanotechnology, constituting the outer circle of applications depicted in Fig. 2; they can be considered as the future of wireless sensors networks 3 (WSN), and by their functionality they can include components of the internet of things 4. They will be interconnected, not only between themselves, but also through the gateway layer (mobile phones, PDAs, notebooks, tablets) to the inner circle of cloud (high-performance) computing. By their smartness and complexity they will enable personalized advice and assistance, concerning health and interaction with the environment, far beyond what today’s WSN and internet-of-things devices can provide. GA technology will offer unique solutions for new generations of non-invasive biological monitoring, and for future smart apparel with embedded powering and sensing. They will enable unforeseen generations of autonomous robots. The supporting GA zero-power technology platform will impact development within other domains such as

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2 Adapted from a graph by Norman Poiré, Merrill Lynch.
environmental, building and industrial monitoring, and efficient transportation. It will offer new progress paths for energy-efficient data processing in cloud computing, and change the way mobile computing interacts with humans’ needs.

![Diagram of Guardian Angels in a zero-power ecosystem](image)

Fig. 2: Positioning of GA zero-power technology and applications with respect to cloud computing and gateway (mobile communications and computing) technologies. Guardian Angels are smart, autonomous systems that are beyond wireless sensor networks in terms of functionality and powering, and include a higher complexity than the simple sensor nodes foreseen today for the internet of things. GA will strongly interact with the gateway and cloud layers, and the project will create direct benefits for the future of mobile computing, and more energy-efficient architectures for high-performance computing.

In our project vision, GAs will provide data which will allow us to extract relevant information for a smarter life: making life easier when you are well, helping to efficiently use energy sources, and maintaining or improving mobility and industrial processes without exhausting natural resources. GAs will also play a vital role for those of us who need increasing, or even continuous, support and services due to health problems or reduced mobility or sensory capabilities. Imagine mobile electronic personal assistants being 1000x more energy-efficient than they can be today, so that they could be powered by the energy available in your environment without any power plugs. Imagine part of the energy savings transformed into sensing, communications and interface functions of an invisible system that becomes your day-to-day Guardian Angel. This project will address the grand scientific, technological and system engineering challenges in a time frame of 10 years to transform this vision into a reality.

### 2.1.3 Unifying goal: the science of zero power

Guardian Angels are defined as future zero-power, intelligent, autonomous systems featuring sensing, computation and communication beyond human aptitudes. The science of zero-power involves exploratory research at the level of novel materials, devices, and system architecture that could enable energy savings by a factor of up to 1000 for the computation, communication and sensing functions. These will be combined with novel, smart, multi-harvesting interfaces able to detect and adapt to the most appropriate sources of energy, which will lead to an improvement of a factor of 100 in the harvesters’ energy output. Fig. 3 summarizes the
integration of the main constituting functions into a single GA system, showing the driving force of the R&D, which is the improvement of the energy efficiency by orders of magnitude. As will be shown later, the GA consortium has identified the most credible technology principles and candidates to address these extraordinary challenges.

*The zero-power GA is, therefore, the unifying goal of the project,* and is defined as a system’s ability to feed from the energy existing in dynamic environments, by harvesting various types of energy sources. The project will devise novel device concepts and material integration technologies for solar, thermal, vibration, and electromagnetic energy harvesters, and it will explore new bio-inspired, e.g. bio-chemical or synthetic photosynthesis-based energy scavengers, which will target power densities of 10 mW per cm² (or per cm³) by a combination of different types of harvesters depending on the application context. These battery-free, or in other words, zero-power systems will enable non-intrusive, independent and cost-efficient intelligent devices, which will communicate with each other and will support human beings by sensing biological signals and the environment.

2.1.4 Overview of main objectives: enabling GA autonomous personal assistants

The GA objectives are categorized into three groups:

(I) **Scientific Objectives (SO)** – These objectives concern fundamental research and involve the identification of underlying principles, devices, system architectures, algorithms and techniques that can advance the limits of today’s energy consumption for each of the elementary functions composing the GAs, in order to achieve the required system autonomy.

- **(SO1) Energy limits of computation:** reduce the energy per binary switching from 100,000 k_BT down to 10-100 k_BT (or from 100 aJ to 0.1 aJ per binary switching event). This research involves new switch concepts (like sub-thermal subthreshold switches), based on different physical mechanisms than conventional field effect transistors. It also involves new architectures. The goal is to devise principles and technologies that allow the voltage supply of logic circuits to be scaled from 1V down to 0.2V, with negligible leakage current, which will offer a power gain larger than 100x.

- **(SO2) Energy limits of communication:** to reduce the total end-to-end energy consumption of communicating a useful information bit from 10nJ down to 10pJ/useful bit, including transmitter and receiver processing energy, RF front-end energy and transmitted energy. Candidate technologies are combining (1) flexible and adaptive radios, (2) reduced complexity radios, and (3) extreme duty-cycled burst-mode radios. For each research line, innovation is proposed at 4 different granularity levels of the communication sub-system: system level, algorithm level, circuit and antenna level, and device level.

- **(SO3) Energy limits of sensing:** reduce the energy per integrated sensing event (including the first stage of the read-out interface) from 100 µW to 100 nW. Small size and ultra-low energy bring noise limitations, as well as challenges in terms of response time, selectivity and stability. We will explore principles and test paradigms that will allow the reduction of energy consumption by a factor of 1000. Such energy savings, along with nanotechnology, will enable multi-sensing or sensor arrays in a single smart system. The fusion of sensor data with ultra-low power will play a vital role in accomplishing the goals of the project.

- **(SO4) Energy limits of human-machine interfaces:** the project will address the limits of zero-power human-machine interfaces and multi-modal sensing for affective state categorization. This includes scientific and technical energy challenges for brain-to-machine interfaces (including electroencephalography (EEG) and electrooculography (EOG)), in which there is no need to speak, gesture, or type into a keyboard to communicate with machinery.
- **SO5 Energy limits of harvesting**: the project will explore and push the limits of energy scavengers, which should operate both in outdoor and indoor conditions and achieve levels of energy needed for GA systems 100x higher than the state-of-the-art. Several types of scavenger principles could be combined in a GA system, requiring disruptive materials and devices for solar, thermal, vibration, and electromagnetic, and significant advances in bio-chemical and synthetic photosynthesis scavengers. Research will include novel energy storage elements that could be hybridized with the electronic systems to facilitate a realistic transition to the final zero-power autonomous systems.

![Image of sensing, computation, communication, and energy harvesting technologies](image)

**Fig. 3**: Novel sensing, computation, communication and energy harvesting technologies are the basic blocks that will constitute the GA systems. A dedicated operation system, communication and data security techniques will be combined with the hardware components to enable the GAs. (The energy limits shown are based on theoretical calculations, while the limits shown in the roadmaps are re-evaluated at the system level, corresponding to an energy limit per function.)

**(II) Technology and Integration Objectives (TIO) for implementing the zero-power technology platform supporting the GA demonstrator systems.**

One of the main goals of the project is to develop and implement a zero-power technology platform as a combination of future energy-efficient technologies and disruptive energy scavengers. The main components of the platform that together form the technology and integration objectives:

- **TIO1 Energy-efficient technologies** (computation, sensing, communication)
- **TIO2 Highly-efficient energy harvesting and energy storage**
- **TIO3 Zero-power system design.**
- **TIO4 Heterogeneous integration**
- **TIO5 Software: operating system, communication and power management:**
  This objective also includes software-hardware interaction and all software-level components: operating system, power management, data security techniques and energy efficient algorithms and software codes.

The zero-power technology platform is designed such that it can enable the implementation of two categories of demonstrators: (i) **full-hardware demonstrators**, and (ii) **virtual demonstrators**, as illustrated in Fig. 4. Early in the project, a full-hardware demonstrator will be the implementation of a GA system using existing mature technology blocks, already available for full integration at a given moment in time, for the experimental proof-
of-concept of all GA functions with energy efficiency. Then, the virtual demonstrators will create the link between full-hardware demonstrators using existing technologies, and emerging technologies that have achieved measurable device or elementary circuit block characteristics, without featuring full integration. At that point, calibrated libraries of models for multi-scale and multi-physics simulation will make it possible to evaluate the impact of an emerging energy-efficient technology at the system level, in order to facilitate benchmarking and the selection of the most promising emerging technologies for the next generation of full-hardware GA demonstrators.

![Fig. 4: Full-hardware and virtual platforms for demonstrators in the GA project.](image)

(III) Zero-Power System Objectives (SysO)

GAs are personal companions, electronic devices or electronic systems, which are small and thus inconspicuous and nonintrusive; they are autonomous and thus easy to use; they are personalized, secure, and under full control of their users, and thus safe and trustworthy. Guardian Angels will actively assist humans from their infancy to
old age in complex life situations and dynamic environments by offering access to an augmented reality that includes biological and environmental signals. Three families of GAs are targeted, each constituting measurable objectives of the proposed systems; progress on these families will be reported in terms of *full-hardware* and *virtual demonstrators* in a well-defined time frame (year 3, year 7, year 10). Fig. 5(b) shows the main components of a wireless, autonomous sensor system node. In this section we describe some of the main characteristics of the three GA families that form the system objectives.

- **(SysO1) Physical Guardian Angels**

  The Physical Guardian Angels are quasi-invisible, zero-power body area networks or, if appropriate, implantable devices, monitoring vital health signals and offering the necessary information for taking appropriate actions to preserve human health. They will acquire a well-defined view of the state of a person’s health adapted to individual needs, by using a real-time, ultra-low-power, multi-parametric combination of non-intrusive, bio-signal sensors (ECG, accelerometers, gyroscopes, pulse oximetry, etc.) to allow for early warning and thus enhancement of the quality of life. They can employ future GA technologies such as electronic skin or wearable networks of sensors with wireless interfaces. These systems will be compatible, from the communication point of view, with existing gateways (such as mobile phones) to serve as smart parts of a future vision of the *internet of things*\(^5\). First medical applications of Physical Guardian Angels will deal with monitoring of the elderly for frailty assessment, exploring metabolic diseases, and offering prevention solutions, early diagnosis and response to therapeutic interventions.

- **(SysO2) Environmental Guardian Angels**

  The Environmental Guardian Angels extend their abilities from the body to monitoring of our daily environment, featuring zero-power, bi-directional interfaces, full battery-free operation, disruptive scavengers (biochemical, thermolectric, synthetic photosynthesis), personalized data communication, and algorithms permitting decisional processes. These devices will offer access to an augmented reality including alerts for hazards, e.g. electromagnetic or ionizing radiation, extended UV exposure, the concentration of allergens, pollens and harmful gases. Moreover, they will be designed as real personal assistants to protect our children and maintain quality of life for elderly people. These sophisticated GAs will guard people from diverse environmental dangers, including pollution and catastrophic events, rendering our environment safer. These devices will feature complex, energy-efficient communication technologies (based on novel materials like graphene), both from GA to GA, and from GA to other gateways, offering complete networking capabilities. The environmental Guardian Angels will be developed for various scenarios: (1) as smart air quality companions for indoors and outdoors, (2) as enablers for the inclusion of visually impaired and blind people in society and (3) as a trusted personal device for complex disaster management. Extensions of these GAs can be foreseen for other types of smart monitoring, for industrial, environmental and transportation applications.

- **(SysO3) Emotional Guardian Angels**

  The Emotional Guardian Angels are intelligent personal companions with zero-power human-machine interfaces to sense the body’s reactions to one’s emotions or state of mind, correlated with environment and context, in order to provide objective and holistic information to improve services, benefiting both society and the economy. Emotional GAs will offer two major categories of services: (1) enhancing the performance or well-being of healthy people and (2) supporting patients to ensure that they live as normal a life as possible, or even recover lost motor functions and cognitive abilities. They are expected to play an important role in society, and will form a completely new generation of devices, not even imaginable today, based on human-technology interaction. They could assist people in capacities such as smart automobile driving assistants or air traffic controls, providing feedback if the user is too tired or emotional to control a vehicle, or using their inter-GA communication interface to avoid accidents. They could potentially aid elderly people with Alzheimer’s disease. They could provide quadriplegic sufferers with greater control of their environment, by enabling nonverbal

\(^5\) http://www.iot-visitthefuture.eu/fileadmin/documents/researchforeurope/
decision-making and communication. These GAs could also help families and educators of those with autism spectrum disorders to understand and use alternative means of nonverbal communication. Emotional Guardian Angels may be the first intelligent systems of their kind for maintaining or even extending quality of life for patients who suffer from physical and mental health problems; they may interpret intentions and communicate with people in a completely new way, disruptive in comparison with existing technology.

(IV) Governance, Management and National Matching Objectives (Gv&MgO)

The objectives listed under this section are designed as a part of the GA strategy for efficient yet dynamic governance and management along the ten-year lifetime of the FET Flagship. The governance and management of the GA FET Flagship shall be conducted based on an operational model that takes two key boundary conditions into account: (1) a 30-month ramp-up phase funded as a CPCSA FP7 instrument, followed by a more flexible, adapted funding mechanism under FP8, (2) the matching of the FET Flagship by national states and/or by combined ERA-NET+ instruments. The following main objectives are proposed to encompass both the high-risk science and the high-impact ICT engineering specific to the concept of FET Flagships, with a goal-oriented governance structure.

- **(Gv&MgO1) Implement a goal-oriented and milestone-based strong internal governance.** The governance should be capable of defining and enforcing the major scientific milestones of the project. For this purpose, a Scientific Steering Board will include key scientific representatives of core EU partners. A Board of Directors will professionally implement the strategic direction into a work programme with clearly-defined major milestones for 3 major periods of scientific and technical reporting. In addition, a Board of National State Representatives will help the project integrate research activities within the member states (notably by adopting the FET Flagship’s milestones) and achieve maximum national impact and the needed matching.

- **(Gv&MgO2) Implement a strong management capacity of the leading houses.** The objective is to implement a professional management structure at all levels. The organisational model will co-integrate scientists and expert managers from outside academia and will follow a roadmap-based strategy, creating the necessary conditions for interactive work with a FET Flagship spirit. This includes the implementation of a Project Office with public relations and dedicated departments for finance, legal affairs, intellectual property rights, communication, project evaluation and internal auditing, and the development of organizational strategies to recruit and remunerate suitable management staff. The GA leading houses are EPFL and ETHZ; the two Swiss Federal Institutes of Technology, the major components of the ETH domain in Switzerland, will define their joint management with the establishment of a non-profit Guardian Angels Swiss Foundation and a clear split of responsibilities and tasks.

- **(Gv&MgO3) Hybrid operation with a well-defined balance between a project, a program, and a dynamic partnership.** The GA FET Flagship will have an early identification of key contributors to the zero-power technology platform and system demonstrators and applications. This will be reflected in clear roles in the CPCSA, from the ramp-up phase that will bring together Core and Associated Partners. The Openness of the Consortium, initiated in the Pilot Phase with 2 calls attracting 30 new partners, will continue with one call during the ramp-up phase and three other calls through the end of the FET Flagship. The GA FET Flagship will create the right conditions for goal-oriented networking, where the selection of the new partners will be based on excellence criteria needed to achieve concrete priorities in research, as defined by the project governance and the scientific and technology objectives.

(V) Dissemination, Exploitation and Intellectual Property Objectives (DEO)

- **(DEO1) Define and implement a dissemination strategy covering both scientific and non-scientific communities.** The scientific dissemination will include the very early identification of high-impact scientific journals, conferences and technical events, and a strategy for coordinated publication of
topical high-level reviews specific to the flagship roadmaps. Specific dissemination channels (media, social networks, Wikipedia, etc.) for a larger audience will be set. Additionally, GA partners will act as everyday knowledge disseminators through their work in universities, their teaching and as members of governing committees. They will be able to impact the course syllabi and research activities to focus on future and emerging technologies in the information and communication sector. In order to enable collaboration between companies, the project will use open innovation principles. Additionally, the long-term scientific roadmap will be made public.

- **(DEO2) Define and implement a flagship-specific exploitation strategy and associated intellectual property rules** for transferring knowledge and new technologies to industry, in order to apply the resulting technologies widely for the benefit of society and the economy. Given the complexity of the FET Flagship and the particularly high involvement of industry in GA, a specific Consortium Agreement will be designed and adopted. It will include the possibility to define IP-protected sub-projects together with a pre-competitive knowledge zone where the project partners will be able to share advances in research (lying between fundamental basic research conducted mainly in universities, and proprietary research performed in corporate laboratories) concerning the zero-power technology platform. A unique feature of GA will be to install an Intellectual Property and Exploitation Committee that, via a concrete mechanism, will create and support the creation of a minimum of 10 start-ups emerging from the project. Additionally, the industrial partners within GA will drive an effort for standardization of the technology platform components.

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**(VI) International Collaboration Objectives (ICO)**

In the global picture of advanced nanoelectronics and smart systems, globalization is a reality and international collaboration is a must for success and wide impact; therefore, the GA Flagship has defined some concrete objectives for international collaboration outside Europe.

- **(ICO1) Setting a collaborative effort with leading partners from the USA.** This particular objective is motivated by the fact that some of the leading research institutions in the US have needed particular expertise in the research field proposed by the GA project, and some of them are mother companies of some of the European partners. The objective is to identify clear mechanisms for concrete collaborations (beyond the co-organization of scientific events) with some already-identified US partners (MIT, Stanford, UC Berkeley, IBM and Intel) that will have national fund-matching to contribute to the GA scientific and technological challenges. We will also target particular win-win collaborative efforts with complementary US initiatives having a similar size as our FET Flagship such as the One Mind for Research initiative of the medical community.

- **(ICO2) Setting a collaborative effort with leading partners from South Asia and Japan.** Some specific technologies and application innovations will be the subject of a collaborative effort defined outside Europe, and supported by matching with national programs in Japan and/or South Asia. This action will ensure an even more global impact of the GA Flagship by considering world-wide societal aspects and the interest of these technology-hungry regions of the world for novel electronic technologies for new services. European companies will benefit from the new markets and business resulting from these collaborations.

- **(ICO3) Setting a collaborative effort with other world-wide partners.** Under a more generic collaborative effort, GA will consider collaborative efforts for new ideas for applications of the GA demonstrators, and/or for enlarging the project vision with a priority on solutions addressing the issues of sustainability and the role of affordable (low-cost) energy-efficient technologies.
2.2 Main Scientific Objectives

2.2.1 Grand scientific challenges for energy-efficient computation

Guardian Angels will include logic and memory functionality for many purposes, including processing the output signals of the various sensors, decision algorithms, running the operating system, and running specific software for energy optimization, communication, and other uses. The ambition to attain zero-power systems requires a radical (1000-fold) reduction of the energy consumption for computation.

**Fundamental scientific limits:** Thermodynamics and quantum mechanics set fundamental limits for the energy transfer during binary switching. For the relationship between switching energy $\Delta E$ and transition time $t_d$, the Heisenberg uncertainty principle requires that $\Delta E \geq h/t_d$. The minimum energy required to preserve a binary state can be estimated from the Boltzmann probability as $E_{b,\text{min}} = 3k_B T \ln(2) \approx 10^{-21}$J ($T=300$K). 6,7

Irreversible or many-to-one operations such as AND or ERASE require dissipation of at least $E_{b,\text{min}}$ for each bit of information lost. In principle, reversible or one-to-one logical operations such as NOT can be performed without dissipation, as shown by Landauer. 8

The drawback of reversible or adiabatic computation is that system switching speed is proportional to the energy dissipation; hence to achieve significant energy savings, prohibitively low speeds may be required. A detailed discussion of the ultimate limits of a computer was proposed by Lloyd: he suggests that the speed per logical operation is limited by its energy, and the amount of information that can be processed is limited by the number of degrees of freedom of the computing system.

**State of the art:** Historically, the advancements in digital technology have reduced the dissipated energy per operation by roughly one order of magnitude every five years. Today’s advanced CMOS technology operates at energies on the order of $10^4 - 10^5$ kT per binary switching event using MOSFET switches and von-Neumann architectures. 10 Several (quasi-)adiabatic circuit designs have been implemented. Typically, power reduction compared to standard CMOS lies within one order of magnitude. However, maximum transition frequencies lie in the 100MHz regime and considerably larger circuit footprints are required. 11 The need for alternatives to charge-based logic are being explored. 12,13

**Challenges to be addressed:** It is the goal of the project to propose, demonstrate and exploit highly efficient computation technology, devices and software to reduce this energy by a factor of 1000 while safely operating one hundred times higher than the fundamental $k_B T \ln(2)$ limit. Combining device and architecture research with the goals of maximizing energy efficiency while maintaining realistic operating speed, room temperature operation and cost figures of merit will enable truly useful applications.

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2.2.2 Grand scientific challenges for communications

An essential feature of zero-power Guardian Angels autonomous systems is the ability to communicate wirelessly using minimal energy per information bit. In a typical state-of-the-art sensor node, the wireless communication, necessary to upload sensed data and receive configuration settings, often consumes a significant part of the available energy. The GA project therefore aims at a radical energy reduction for communication by a factor of 1000 compared to current state-of-the-art. The goal is to achieve a transmitted energy per bit of 1pJ, approaching the fundamental scientific limit, with a total system energy of 10pJ/bit.

**Fundamental scientific limits:** A fundamental performance limit for the required transmitted energy in a wireless communication system can be deduced from the Shannon capacity theorem, which assumes that the transmitted signal is Gaussian using an infinite block code interval, the channel is constant and perturbed by additive white Gaussian noise (AWGN), and the detector knows the deterministic channel state. One of the most fundamental implications of the capacity theorem is that communication is not possible below the received signal-to-noise ratio per bit of -1.6 dB in the wideband limit. Assume optimistically that only the thermal noise with density affects a communication device. At room temperature, the minimum required transmitted bit energy versus the allowed signal attenuation resulted from the capacity theorem is shown in Fig. 7 (assuming that the receiver is noiseless), showing that communication with 1pJ/bit is feasible when transmit-receiver attenuation is limited below 85dB.

**State of the art:** A general objective in the design of wireless communication systems has been the information-theoretic capacity limit discussed above. In order to achieve this goal in AWGN channels, very powerful coding schemes were developed including iterative turbo and low density parity check decoding methods. The effect of multipath fading was reduced by using time, frequency, or spatial diversity techniques. These approaches, however, all aim to approach the Shannon limit at the expense of a large increase in computational complexity, hence possibly negatively affecting the overall energy consumption of the transmitter and receiver. Until recently, very little attention has been paid to minimising total energy consumption. State-of-the-art systems typically consume less than 1nJ/bit in terms of transmit power, though their overall energy per bit goes up to 10 to 100nJ.

**Challenges to be addressed:** In order to achieve zero-power systems, the GA project will aim at a reduction of the overall system energy for communications. To this end, the target energy per bit metric encompasses all energy spent in the transmitter (signal processing and analog front-end), the receiver (signal processing and analogue front-end), as well as the actual energy transmitted into the air. Moreover, this energy per useful bit metric differs from the plain energy per bit metric, as it incorporates all MAC and network layer overhead, as well as all energy spent in sleep, stand-by or listen mode. Under this definition, the GA project targets an energy per useful bit of 10pJ for communication over a 2m distance. Cross-level and cross-domain research will allow the assessment of trade-offs between transmitted energy and signal processing energy, between transceiver front-end performance and back-end complexity, between active modes and sleep states, and between the upper and lower limits of operation.

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lower communication layers (network, MAC, PHY). Additionally, the communication subsystem should be truly adaptive and linearly scalable in terms of system parameters like data rate, communication distance, number of nodes, etc., to enable dynamic adjustments towards minimal energy under all circumstances.

### 2.2.3 Grand scientific challenges for low-power sensing

In Guardian Angels, sensors will collect physical, physiological, chemical and biochemical data. Multiple sensor data will be fused to interpret and monitor a person’s physiological and emotional status, in relation to the actual environmental and social/situational context. By definition, a GA sensor refers to the functional device transforming real world information to electronic information. To afford several sensors per GA, the power consumption target per sensor element/function was set to 100 nW. This power consumption target includes readout electronics, signal conditioning and AD conversion, but excludes digital signal processing such as linearization, pattern recognition and sensor fusion.\(^{18}\)

**Fundamental limits in low-power sensing**: Limits in sensor systems are well represented by the signal-to-noise ratio (SNR), which incorporates the sensitivity, bandwidth and noise spectral density of a sensor and determines its limit of detection (LOD) and resolution. Miniaturization reduces the power and energy needed to drive the sensor due to the smaller number of charge carriers requiring transport, or simply by avoiding heater elements. However, it has been observed that electronic and mechanical noise, in particular 1/f noise, increases with smaller device dimensions. In nanostructures, excess electronic noise (carrier number and mobility fluctuations) can span from µHz to kHz, posing severe constraints on signal evaluation techniques, which are not discussed here. Consequently, the limits in sensor systems should be described by SNR, LOD or resolution – in ambient conditions – with respect to the size and power consumption of a sensor.

**State of the art**: In Fig. 8, we use accelerometers as representatives of a class of highly developed sensors to visualize the state-of-the-art for this category of sensors and the trade-off between power consumption and the noise spectral density (which gives the LOD when multiplied with the square root of the bandwidth) without any loss of generality for other sensor categories. Today’s low power solutions are still 2-3 orders of magnitude away from the objectives in GA.

**Challenges to be addressed**: The grand scientific challenges for GA sensors are both to explore low power transducer concepts for the GA functions mentioned above and also to push the power consumption of the sensors down to the order of magnitude of 100 nW per function. It is obvious from the analysis above that pushing the front (Fig. 8, dashed line) requires a non-incremental paradigm shift, such as nano-devices and – materials, for example. However, as soon as one of the relevant dimensions of a sensor reaches the nano scale, noise increases considerably, SNR approaches unity and the sensor characteristic itself becomes nonlinear. This trend has been captured explicitly in the model equations governing nano-electro-mechanical systems in particular,\(^{19}\) but it probably applies to other sensors. Importantly, though engineers attempt to avoid non-linearity and noise, biological sensors typically operate in a noisy, non-linear regime. For example, our visual system, which allows detection of a single photon, operates over 14 orders of magnitude. Similarly, sound

\(^{18}\) Power consumption of digital circuits is considered in section 2.2.1 about “energy-efficient computation”

pressure detection in our inner ears allows detection of both a flying mosquito and the noise of thunderstorms. Inspiration by biological principles is expected to improve ultra-miniatuerized sensors in important ways, and allow the GA challenges to be met. Indeed, scientists have already begun adopting similar mechanisms in their sensors.20,21 Another strategy worth pursuing would be to combine several functions within one device, as has been demonstrated with a CNT that serves as all essential components of a radio, 22 and predicted for piezoelectric nanowires who could supply their own energy source.23

### 2.2.4 Grand scientific challenges for energy harvesting, storage and power management

Research within the consortium will address the fundamental challenges involved in converting different forms of energy available in the environment (solar, thermal, chemical, and mechanical) into electric energy, and efficiently storing and managing the converted energy to power the autonomous, zero-power Guardian Angels.

<table>
<thead>
<tr>
<th><strong>Fundamental limits</strong></th>
<th><strong>State of the art</strong></th>
<th><strong>Challenges to be addressed in Guardian Angels</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Harvesting (EH)</strong></td>
<td><strong>Solar Cells</strong></td>
<td><strong>Shockley–Queisser (SQ) limit of 33.7% efficiency for single junction solar cells</strong></td>
</tr>
<tr>
<td><strong>State of the art</strong></td>
<td><strong>Surpassing SQ limit with new device architectures (tandem solar cells) and new materials (multiple exciton generation, etc.); Development of light trapping structure for bulk heterojunction polymer &amp; DSSC cells</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Thermoelectric</strong></td>
<td><strong>Carnot efficiency:</strong> (1-Tcold/Thot), T in K. 4% for Thot=37°C and Tcold = 25°C</td>
<td><strong>Efficiency; dimensionless figure of merit ZT = 1 at room temperature</strong></td>
</tr>
<tr>
<td><strong>Biofuel Cells</strong></td>
<td><strong>Maximum cell voltage due to fixed concentrations of glucose (e.g. 8 g cm⁻³ in blood) and dissolved oxygen (e.g. 2 g cm⁻³ in blood) and fixed operating temperature (37 °C)</strong></td>
<td><strong>Development of 3D structures to allow direct electron transfer between the electron and the enzyme to improve the operating cell voltage</strong></td>
</tr>
<tr>
<td><strong>Mechanical</strong></td>
<td><strong>Electro-mechanical energy conversion efficiency:</strong> spring constant, damping (Q factor in resonant systems) and electro-mechanical coupling coefficient. Band width for a single generator</td>
<td><strong>Low frequency, wideband / non linear, small optimal load, resonant/non resonant, vibration harvesters, High k spring structures, nano-engineered epitaxial and nanowire materials (flexo, multi-ferroics, lead free materials). MEMS to NEMS hybrid generators</strong></td>
</tr>
<tr>
<td><strong>Energy Storage (ES)</strong></td>
<td><strong>Batteries/ Microbatteries</strong></td>
<td><strong>Anode and cathode material determines capacity and cell voltage; Lithium diffusion and electronic transport in micro-energy storage applications</strong></td>
</tr>
<tr>
<td><strong>State of the art</strong></td>
<td><strong>New materials such as iron fluorites; Integrated on chip solution, 3D nanostructuring of electrodes (e.g. CNTs)</strong></td>
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</tbody>
</table>

| Power Management (PM) | Threshold voltage of diodes and transistors; For sub-threshold operation physical limits- called ‘Boltzmann tyranny’. Fundamental limits from thermodynamics and quantum mechanics results in forbidden operating regions. PM needs to operate at very low input voltages, 10 mV or lower with fast transient response required by the load. For RF WPT the input voltages can be below 1mV while subthreshold operation is further compromised by the high signal frequencies, especially for mm-wave WPT. | Use of floating gate transistors or trapping charge into the gate oxide (referred to as Vth-programming); Power converters for low input voltage (eg for TEGs) - LTC®3108, Efficiency 50% RF WPT at 94GHz for space applications at high power levels (>1W/cm²) Efficiency > 70% using optimized (expensive/non-monolithic) technologies. | Development of Sub-threshold power harvesting circuits; Monolithic integration of passives in SMPS (switched-mode power supply) with efficiency >80%; Development of a lower power (<10uW) MPPT (maximum power point tracking) circuit and development of power electronic interfaces that can achieve tuning and/or stronger transduction by impedance emulation. Development of efficient & integratable mm-Wave rectifiers for low power levels (<1mW/cm²) |

### 2.2.5 Grand scientific challenges for human-machine interfaces

The Emotional Guardian Angels will be able to sense and communicate user emotions, enhancing the interactivity between human and machine. They will assist users with mental and emotional communication such as monitoring emotional inputs for enhanced task performance. Deployed on a large scale, they will allow emotionally-enhanced social networking, while maintaining privacy and security of the data.

**State of the art:** Today’s technologies for monitoring emotions have focused on creating highly wearable devices at the expense of multi-modality and accuracy, or highly accurate devices at the expense of wearability. The Emotiv EPOC headset is a 14-channel, wet-electrode wearable headset used primarily for gaming applications, measuring emotional states through brain activity. It provides interpretation and wireless transmission of 4 emotional states continuously for 8 hours. In contrast, the Neurosky MindSet, is a single-channel dry-electrode, 2-emotion state EEG headset. The HeartMath EmWave is a simple hand-held device measuring heart rate variability coherence as an indication of emotional state along a continuum. In laboratory-based experiments using wired systems, discrete emotions have been distinguished with up to 84% accuracy for 8 discrete emotions in the same subject using physiological measures alone,\(^24\) up to 82% for 4 discrete emotions in different subjects using EEG alone,\(^25\) and up to 67% for three emotional classes in different subjects using a combination of physiological and EEG signals.\(^26\)

![Power (mW)](image)

**Fig. 9:** Goal: Emotional Guardian Angels should match the performance of state-of-the-art systems but at very low power.

**Challenges to be addressed:** Creating the Emotional Guardian Angel system will require new sensing methods which are integrated into everyday objects such as clothing and furniture, or which adhere to the body as electronic tattoos, in a way that the user is not bothered by them. To achieve this, the wearable sensors need to be small < 1 cm\(^3\), flexible and conformable to natural body

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\(^26\) Chanel et al., Lecturer Notes in Computer Science, Springer, 2007, pp. 530-537.
movements, and of materials consistent with clothing and environmental objects. Hormonal sensors will need to be sensitive down to hundreds of pmol/L, with analysis happening in real-time through sensors inside the body connecting to monitoring devices outside the body. In addition, multiple physiological systems (brain, autonomic and endocrine) need to be measured and analyzed simultaneously to discriminate between emotional states with accuracy above 95%. The main challenge to be addressed in developing the Emotional Guardian Angels is to achieve a highly ubiquitous, connected, secured, intelligent platform that performs as well – in terms of accuracy of emotion detection – as the leading state-of-the-art systems, while maintaining zero-power consumption. Aside from these technological challenges, measuring and processing brain (up to seconds), autonomic (up to 2 minutes) and endocrine (longer than 2 minutes) information together with contextual information, and interpreting the emotional responses presents a challenge in itself. Further, it is unknown today how these physiological responses vary as the user ages and their emotional responses change, both with and without mental disorders. As a consequence, these models need to continuously learn and update, depending on the user – a challenge both in designing the emotional detection algorithm itself, as well as integrating it into the zero-power Emotional Guardian Angel platform.

2.2.6 Grand scientific challenges for embedded software for low-power computing

The technology of embedded systems will play a dominating and strategic role in future efforts towards applying IT to “make our planet smarter”. However, the success of any such efforts will crucially depend on increasing the computing power of even the tiniest embedded systems like nano-devices and sensors by an order of magnitude, while at the same time decreasing their energy consumption and cost by a comparable factor. Such demands can no longer be accomplished on the basis of the general-purpose von-Neumann computer that has been serving as a reference model for the past five decades across all applications from embedded systems to personal computers, main frames and servers. Projecting recent and current developments notably in the areas of configurable and programmable hardware and POST-CMOS technology (such as quantum computers and neuro-computers) into the future, it is easy to predict that future generations of software-controlled systems will differ substantially from today’s state-of-the-art IT architectures both conceptually and from an implementation perspective. The three conventional layers generic hardware platform, operating system and application will dissolve into one heterogeneous, miniaturized distributed system design.

On the meta-level, this paradigm shift implies the need for new programming/computing models and languages. Holistic system design principles accompanied by a new generation of models, languages and tools will be paramount if future demands are to be satisfied for substantially higher computing performance in combination with higher availability and reliability, and lower energy consumption across all system sizes, from embedded systems to server farms.

**Challenges to be addressed:** Some particular challenges and objectives in the context of the Guardian Angels framework can be described as follows.

*Resource Awareness:* The high demands of GA applications require completely new ways of incorporating resource awareness across all system levels. Programming needs to undergo a basic paradigm shift in two ways. At first, programming models and languages need to seamlessly integrate resource awareness, and not just concentrate on functional aspects. Secondly, an integration of high-level synthesis and software compilation will lead to an expected improvement in resource consumption by at least one order of magnitude.

In the context of GA, two crucial points are code generation for very low consumption devices, an area of active research in compiler construction and optimization; and programming for very small memory usage, where advances beyond current techniques are needed since the expected memory size of GA devices is smaller than even the “small” memory resources usually considered by existing work.

The demand for high-performance computing on embedded systems and other custom systems requires a library of self-contained functional components serving a certain purpose with the highest-possible degree of
efficiency. While the notion of “silicon compilation” is currently hyped as an advanced co-design technology, future approaches will have to go far beyond the algorithmic level. For example, on-chip communication will become an integrated player in future computing models, and it will replace (or enhance) the method call paradigm as an interoperability primitive. As such, it will decisively influence both the computing power and the energy consumption of the entire system. Communication will become a first-class citizen in future computing, and research into customized protocols will be indispensable.

Next, the complex node and system architecture envisioned in GA systems exhibits a high degree of concurrency, and must rely on a comprehensive concurrency model. Composability of software components must include resource awareness, leading to new concepts of resource-aware interface specifications.

Software Development Process: The GA project not only leads to highly distributed architectures, but will be highly distributed in its own mode of development, involving software contributions by institutions of diverse natures: universities, research centers, and private companies. Managing this process raises problems of five different kinds: (1) devising distributed application development techniques appropriate for the GA model of development; (2) developing a set of standard GA software libraries to provide a common, certified basis for all GA software development, a key step toward providing a level of guaranteed quality; (3) defining a standard set of GA development rules, including approved best practices and reuse guidelines; (4) defining a set of techniques for the particularly challenging problem of system deployment for distributed, embedded, low-power devices, which raises deployment issues more complex than those of ordinary software-intensive systems; and (v) since systems are not just delivered once but continue to evolve thereafter, devising software update mechanisms for distributed, embedded, low-power devices.

More challenges for embedded software, including data security, correctness, and fault tolerance, will be discussed in the software roadmaps.

2.3 Matching of the GA Proposal with the Flagship Concept

<table>
<thead>
<tr>
<th>Flagship Concept</th>
<th>Guardian Angels Flagship Proposal</th>
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<tbody>
<tr>
<td>• visionary</td>
<td>• addresses new paradigms for energy-efficient nanoelectronics, coupled with visionary Guardian Angel autonomous systems</td>
</tr>
<tr>
<td>• science-driven</td>
<td>• fundamental scientific limits of low-power computation, communication, sensing, energy scavenging, and interfacing will be understood, and solutions explored to approach those limits</td>
</tr>
<tr>
<td>• building on areas of established European excellence</td>
<td>• smart systems, technology transfer platforms, collaborative research, communication technologies, biomedical research</td>
</tr>
<tr>
<td>• oriented towards a unifying goal</td>
<td>• zero-power, intelligent, autonomous systems featuring sensing, computation, and communication beyond human aptitudes</td>
</tr>
<tr>
<td>• via a multidisciplinary approach</td>
<td>• zero-power platform based on heterogeneous integration of micro- and nano-scale devices, with self-configuring and self-maintaining communication networks, and context-based intelligence. Scientific progress, technology development, and impact analysis will work hand-in-hand.</td>
</tr>
<tr>
<td>• nucleated from ICT future and emerging technologies</td>
<td>• includes all components of the ICT value chain from new technologies to software and system design</td>
</tr>
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to generate waves of technological innovation and economic exploitation, ideally in a variety of areas and sectors
will carry an important societal impact

- envisioned to run for at least 10 years, on a budget in the range of 100 M€ Euros per year and per initiative
- of such magnitude that they can only be realised through a federated effort of the different EC programmes, along with Member States, funding agencies, and where appropriate, global partners and industry

- singular opportunity for Europe to take over leading position in zero-power technology, which will then boost European manufacturing in all related sectors
- will have impacts on quality of life, health care, security and safety, human-technology interaction, and communication, by creating competitive, ubiquitous products enabling affordable long-term services
- The development of a zero-power technology platform with three families of concrete demonstrators fully justifies an investment on this scale.
- The large range of competencies, skills, infrastructure, and fundamental and applied research necessary for this project requires participation on a European scale. Only close collaboration of research labs and companies of all sizes can create technologies that will quickly penetrate the market and generate new employment all over Europe.

### 2.4 Methodology

The GA FET Flagship is a very complex project that addresses the full value chain of ICT in a unique way, from technology to the design and fabrication of complex autonomous systems, made of a large variety of components and operated by specific software. This shows the high originality but also the challenge of the methodology described here: how to create and manage a complete and efficient framework that will operate for 10 years, integrating all competences and focusing on system-able technologies. Therefore, from the basic methodology level, the project must create progress and potential disruption by closing existing gaps between

- emerging (nano)technology, and the design of complex systems that can benefit from these new technologies
- the ever shorter cycles of advanced nano-technology nodes, and the ever longer cycle of optimized design, specific tools, and models for tera-systems
- communities: there is an increased need of interaction between technologists and physicists, and high-level design, circuit and architecture designers or software programmers
- focused developments in highly specialized disciplines, and the multi-disciplinary framework of GA, which together could generate new levels of innovation
- fundamental research and ICT applications.

The specific methodology for the science management of the GA FET Flagship has thus been established according to the following strategy:

- A strong interaction between the components of the zero-power technology platform and the GA demonstrator families (systems) all along the project lifetime.
- Definition of an interactive matrix between all the technology roadmaps and the three demonstrator families (physical, environmental, emotional) that develops according to metrics and milestones along three reporting periods of the projects (Period 1: 3 years, Period 2: 4 years and Period 3: 3 years), Fig. 10.
- Alignment of the technically-specific structure of the roadmaps and demonstrators with a management structure of the Board of Directors (see section 3.2.3), which follows and implements a milestone-based management for highly interactive technical domains.
- Derivation of a budgetary strategy based on the priorities for roadmap blocks needed to achieve the system milestones in terms of energy efficiency and functionality, in three successive reporting periods.
Identification of the outstanding European research groups (in the consortium or by an Open Call strategy) able to carry out the respective research.

- Implementation of an Open Call strategy in cooperation with the funding agencies (European Commission and national states) that empowers the project management with an effective tool for openness and dynamic adaptation to state-of-the-art evolution and innovation opportunities.
- Definition of a ramp-up phase approach which will make the project manageable and also create a snowball effect for the project continuation, with a true federating FET Flagship spirit. For this purpose, a group of 20-25 core partners will address the biggest challenges of the ramp-up phase by a joint effort from the beginning via the CPCS A instrument. They will then benefit from a network of 35-40 more partners that will boost the benchmarking effort and will cluster to propose a focused project on the most critical emerging needs based on the internal and ERA-NET+ instruments.
- Create the necessary governance and management structure centred on a Scientific Steering Board for long term strategic decisions, and a Board of Directors to implement the milestone-base management strategy. Such governance should be aligned with the critical scientific/technical needs and operate with the best efficiency throughout the project lifetime.

2.5 Guardian Angels Demonstrator and Roadmap Executive Summaries

2.5.1 Physical GA Demonstrator Family Summary

**Motivation and Goal**

The Physical GA family consists of wearable, miniaturized, non-invasive devices designed to accurately and robustly monitor physical and physiological parameters in humans. Physical GA systems integrate multiple sensors, securely communicating with each other and central nodes. They allow on-board analysis of the acquired biosignals to support real-time feedback to the user, while preserving user privacy and making data accessible to health care professionals. These Physical GA devices are relevant for a myriad of applications in personalized health and wellness management. We focus on three applications: (1) monitoring the functional physical and nutritional status in the elderly, (2) early diagnosis and management of metabolic disorders and
their complications, and (3) characterising the impact of Alzheimer’s disease on physical and bio-chemical body processes.

Ageing is associated with reduced mobility and increased morbidity. It has been established that increased physical activity and adequate nutrition can attenuate the decline of and even restore musculoskeletal health, for optimal daily functioning, prevention of falls and improved quality of life. Physical GAs will support the objective assessment and continuous monitoring of the physical functional and nutritional status of the elderly, and the deployment of personalized lifestyle interventions for healthy and independent ageing. Physical GAs will provide motivational and practical feedback to boost compliance with a healthy lifestyle, enhancing wellbeing. The system will be tested in a population exhibiting different health statuses in field trials conducted in collaboration with clinical partners.

Metabolic disorders (e.g., obesity and type II diabetes) are major public health concerns. Lifestyle changes (like dietary habit modification and increased physical activity) are key prevention factors for obesity and its associated metabolic disorders (e.g., diabetes). Physical GAs will support the monitoring of personalized lifestyle interventions for these disorders, including accurate estimation of energy expenditure and dietary intake. Also, physiological parameters and biomarkers associated with diabetes will enable prevention and early diagnosis of complications and response to therapeutic interventions.

The third major direction will set the basis of concrete cooperation with medical projects targeting the understanding of the impact of the progression of Alzheimer’s disease on physical and bio-chemical processes in the body (cf. cooperation with One Mind for Research project, Emotional GA section). Thus, Physical GAs will capture objective physical and biochemical data from patients with brain disorders in an unobtrusive, comfortable and quasi-continuous way, according to medical community specifications.

**How the zero-power platform leads to disruptive progress for the demonstrator family**

Although monitoring of physiological parameters provides decisive information in medical investigation, the state-of-the-art use is restricted to medical environments. The main reasons are (1) the apparatus size, energy requirements and limited connectivity and (2) the necessity of medically trained personnel for data interpretation. The design of new sensor devices with reduced invasiveness and high sensitivity with minimal power consumption is key to enable continuous monitoring. Complemented by specially-designed networking systems, their concept of small and smart building blocks including multi-parametric distributed sensing and automated diagnosis will drastically reduce development costs, and will open up the possibility of single-use autonomous health monitoring devices comparable to today’s disposable bandage. Overall, this increased monitoring in a wider population will enable risk factor screening on a large scale in modern society, and result in a new dimension of preventive health care for a better life.

**Milestones**

*Monitoring the functional and nutritional status in the elderly to support personalized lifestyle interventions for healthy and independent ageing*

Y3: M-PHYS-1: Physical GA with inertial, physiological and biochemical sensors and an electronic nutrition assessment tool for objective status diagnosis in controlled environments.

Y7: M-PHYS-2: Autonomous Physical GA with online physical activity and real-time nutritional status assessment.

Y10: M-PHYS-3: Field trials with final Physical GA for online objective status assessment and personalized lifestyle interventions in free-living conditions.

*Early diagnosis and management of metabolic disorders and their complications*

Y3: M-PHYS-4: Physical GA with punctual measurements of metabolic parameters, wearable inertial sensors and electronic diet recording.

Y10: M-PHYS-6: Physical GA with seamless energy expenditure and intake estimation, and metabolic biomarker monitoring to provide personalized lifestyle recommendations.

*Characterising the impact of Alzheimer’s disease on physical and biochemical body processes (in cooperation with the One Mind for Research Project)*

Y3: M-PHYS-7: Assessment of a Physical GA system designed to continuously and unobtrusively investigate the activity of patients with brain disorders – collaborative effort with the One Mind Project.

### 2.5.2 Environmental GA Demonstrator Family Summary

**Motivation and Goal**

Our environment impacts our health and our lives directly through the air we breathe, the water we drink, the food we eat, and the buildings in which we live and work. Many important factors cannot be noticed by humans at all; we have no biological senses for pollutants created by our industrialized world, since evolution will be slow to catch up. We need artificial “sixth senses” that assist our biological ones. The environmental Guardian Angels stand at the interface between people and their environment, providing relevant and real-time information, acting as personal assistants to guide, enable, and protect us all, and to make our lives more enjoyable as a result. Selected cases of this application family will be demonstrated by the GA consortium through three sub-projects:

- **Smart air quality companion for indoors and outdoors:** Is our indoor air fresh and healthy or not? Is it a good time now to go walking outside with our babies or to do our sports workout, or should we wait until the pollen or traffic burden eases and air quality clears up? These GAs will guide us.
- **Effective inclusion of visually impaired and blind people in society:** Visually impaired people are able to help themselves, yet supplying tools for orientation and information about what is going on in the surrounding environment will assist their full integration into society.
- **Guardian Angels for disaster management:** Disasters need to be detected early, and in critical situations, everyone needs some emergency guiding, not just first civil responders.

**How the zero-power platform leads to disruptive progress for the demonstrator family**

The recurrent theme in all the applications to monitor our close environment is that we need many miniaturised and affordable sensing systems that can be self-sustaining over long periods of time, and they need to be a wirelessly-communicating mesh. For sensing systems that we wear on our body, zero-power system technology is essential. The same holds true for sensing locations in buildings: The current state-of-the-art is wired sensors (energy and data lines) with high cost due to installation effort, only affordable for industrial monitoring...
purposes like fire detection. Battery-based consumer devices lack communication functionality and run into problems with empty batteries. To bring the cost down to a level that allows widespread use in our private environment, with full functionality including networked communication, the reduction of installation cost is essential. In addition, the devices need to be self-sustaining over long periods of time (with no battery changing) to allow for proper wireless communication in a self-configuring manner. The same thing holds for the GAs that are located outdoors that report on the status of the environment and communicate this information indoors. Ease and cost position of deployment are decisive in order to make such devices usable in our daily lives.

Despite some isolated attempts to create such useful functionalities, such systems, or even first steps toward them, are unavailable today. Some isolated solutions appeared in the sensor domain, but these systems never became a reality since the energy and communication issues were not yet solved. To bring these systems into being, the Guardian Angels technology is desperately needed.

**Milestones**

**Smart air quality companion for indoors and outdoors**

Y3: M-ENV-1: Wireless systems to monitor some indoor (smell, VOC) and outdoor (O₃, NO₂) pollutants

Y7: M-ENV-2: Increase of lifetime through low-power electronics with a system showing increased functionality (CO₂ indoors, specific carcinogenic HC, formaldehyde)

Y10: M-ENV-3: Fully autonomous system (energy harvesting without batteries) that includes outdoor nanoparticle and pollen detection

**Inclusion of visually impaired and blind people in society**

Y3: M-ENV-4: Indoor and outdoor semantic localisation in static environment

Y7: M-ENV-5: Indoor and outdoor semantic localisation in dynamic environment with one year lifetime

Y10: M-ENV-6: Fully autonomous systems for semantic localisation and danger analysis in dynamic environment

**Disaster management**

Y3: M-ENV-7: Detection of heavy metals in water and main pollutants in air with one year lifetime

Y7: M-ENV-8: Water and air quality analysis with increase of lifetime in extreme conditions

Y10: M-ENV-9: Fully autonomous systems for water and air analysis and long distance communication in extreme conditions

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**Environmental GA Roadmap**

<table>
<thead>
<tr>
<th>Year 3</th>
<th>Year 7</th>
<th>Year 10</th>
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<tbody>
<tr>
<td><strong>Smart air quality companion</strong></td>
<td><strong>Effective inclusion of blind people in the society</strong></td>
<td><strong>Guardian Angels for disaster Management</strong></td>
</tr>
<tr>
<td>Outdoor O₃, NOₓ, indoor smell</td>
<td>Localisation in a stat. environment</td>
<td>Detection of air, water pollutants</td>
</tr>
<tr>
<td>Wireless, µ-batt. 1 year</td>
<td>Wireless, µ-batt. 1 year</td>
<td>Wireless, µ-batt. 1 year</td>
</tr>
<tr>
<td>Nano-particles (PM2.5), allergy creating pollen, CO₂, all CEC “Index” gases</td>
<td>Semantic localisation in a dynamic environment and semantic alarming</td>
<td>Analysis of air and water quality in extreme conditions</td>
</tr>
<tr>
<td>Full zero power, wireless, lifetime 10 years</td>
<td>Full zero power, wireless; lifetime 10 years</td>
<td>Full zero power, wireless, lifetime 10 years</td>
</tr>
<tr>
<td>2013 - 2015</td>
<td>2017 - 2019</td>
<td>2021 - 2023</td>
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2.5.3 Emotional GA Demonstrator Family Summary

Motivation and Goal
The goal of this demonstrator family is to sense the body’s reactions to one’s emotions or state of mind, correlated with environment and context, in order to provide objective and holistic information to improve services delivered to people, benefitting both society and the economy. These services can be targeted at enhancing the performance or well-being of healthy people, but also at supporting patients to ensure that they either live a life which is as normal as possible, or recover lost motor functions and cognitive abilities.

Sub-project 1: Enhancing the (emotional) performance or well-being of healthy people. Emotions influence everyday intelligent functions in humans: problem solving, reasoning, learning, perception, language and cognitive tasks. Stress and fatigue are components of everyday life, and affect a large number of persons in a wide number of situations. For surgeons during surgery, pilots and air traffic controllers, students at school, business people making important decisions, athletes, and public speakers, the ability to perform a task safely and efficiently is affected by performance anxiety, emotions, stress and fatigue. The aim of the Emotional Guardian Angels for monitoring (mentally) healthy persons is to enhance their ability to perform a given task through monitoring stress, attention and fatigue levels, and providing feedback and advice or actions to increase the happiness people experience in life and to reduce the risk of adverse outcomes.

Sub-project 2: Supporting patients. With combinations of the invisible, wearable Guardian Angels sensing platform with specialized embedded algorithms for emotion state detection, the Emotional GAs supporting patients will allow deeper understanding of the effects of various treatments on an individual, and the creation of personalized treatments. Many applications of this concept are envisioned: monitoring the efficacy of psychiatric drugs by complementing subjective patient reports with objective body response data, pain therapy based on physiological body reactions, providing feedback from Amyotrophic Lateral Sclerosis (ALS) patients and other non-communicators that get locked into their own bodies and cannot provide feedback to their care givers, understanding Autism Spectrum Disorders, enabling motor neurorehabilitation, beating addiction, and managing stress and mental health.

How the zero-power platform leads to disruptive progress for the demonstrator family
All applications of Emotional GAs share the same requirements. Privacy, security and authentication are of utmost importance. Extreme emphasis is put on comfort and discreteness; the ultimate goal is to let the sensor systems completely disappear within a person’s personal environment: in his/her clothes, watch, spectacles, jewellery, car, home, working environment, or in the seat or the steering wheel of the car. Recharging secondary batteries or replacing primary batteries is considered cumbersome, too bulky and a source of discomfort. The usage scenarios also put extreme requirements on signal capturing and conditioning, especially when the sensors embedded in clothes and jewellery with poor body contacts, are combined with the large motion artefacts from real life situations, quite different from conditions in controlled clinical environments. Today, countermeasures to cope with all of the above typically require high power consumption. Since state-of-the-art solutions, even when they do not cope with the above requirements, need at least 10x more power than is available from today’s scavengers, it is clear that zero-power platforms are an absolute must. Without them, such systems will not be adopted.

The socio-economic benefits of Emotional GAs are threefold: they increase people’s efficiency and performance helping with stress management (improved decision-making, learning, etc.); they reduce the risk of adverse outcomes (less accidents, etc.); and they improve the efficacy of medical treatments (improved monitoring). All three reduce economic cost and at the same time improve quality of life.

Milestones
Enhancing the (emotional) performance or well-being of healthy people:
Y3: M-EMO-1: Sensor system, using wearable bio-sensing and in-car sensors like cameras, to monitor alertness and attention-to-the-driving, integrated in a driving simulator in the lab.
Y7: M-EMO-2: Sensor system, only using in-car sensors (e.g. bio-sensing integrated in the seat or steering wheel), to monitor and interpret alertness and attention-to-driving, integrated in a car and evaluated in real conditions.

Y10: M-EMO-3: Zero-power, emotionally intelligent human machine interface system combined with environmental monitoring to provide feedback and autonomously react, based on contextually interpreted state-of-mind and intentions of the driver, evaluated in real driving conditions.

Supporting patients:

Y3: M-EMO-4: Real-time stress monitor based on ANS, cortisol, physical and environmental measurements with embedded feature extraction algorithms and personalized interface, tested in a controlled environment.

Y7: M-EMO-5: Unobtrusive, comfortable stress monitoring and analysis/prediction device in conjunction with a physiological/psychological knowledge base, tested in medium activity real life conditions.

Y10: M-EMO-6: Zero-power invisible interactive and contextual mental health assistant capable to create personalized treatment plans to improve quality of life in all conditions.

2.5.4 Computing Roadmap Summary: Switches, Memories, and Architecture

**Motivation and Goal**

Low-power logic devices are the basic building blocks for any digital circuit that performs computation, including signal processing and communication, at the lowest achievable power consumption in stand-by mode as well as during operation. Extremely low supply voltage combined with reasonably high current level in on-state and negligible off-current in off-state are essential for reducing power consumption. Thus, logic devices that operate at extremely low voltages are a key technology for energy-efficient circuits, and are important for all GA demonstrators. Our goal is to reduce the power consumption of digital computational circuits by 1000x over the course of the ten-year project. Using new nanodevices with improved or different characteristics (e.g. in terms of $I_{on}/I_{off}$) compared to CMOS will lead to novel architectures for both memories and computational circuits like processors. This roadmap shows the link between technology parameters such as $I_{on}/I_{off}$ and architectural parameters such as parallelism. The impact of technology (new switches) on the design level of complex architectures including embedded software and memories is of primary importance. Memory hierarchy, degree of parallelism, flexibility provided by embedded software, specialized hardware accelerators, and bio-inspired architectures are some of the key architecture parameters for reducing power consumption in combination with very advanced MOSFETs and beyond-CMOS devices.
How to get the 1000x improvement: numerical estimations

There are four levels for reducing the energy consumption of GAs: switch and memory technology, circuit design techniques, architecture design and embedded software. A reduction of 1000x in energy consumption could, to first order, entail an energy reduction factor of 6 for each of these levels. The achievable energy reduction of circuits implemented with emerging devices could be very large\textsuperscript{27} (for instance, TFET switch\textsuperscript{28}: factor of 10 at very low $V_{dd}$, NEMS leakage\textsuperscript{29}: factor of 1000). On the device level we estimate on average a factor of 20 to 50 over the 10 years of the project. Regarding circuit techniques, innovative logic design with beyond-CMOS devices and zero-leakage NEMS (factor of 2) as well as adiabatic circuits\textsuperscript{30} (factor of 10) and new types of memory technology (factor of 5) would provide on average a factor of 6 in power reduction. At the architectural level, the use of very large parallel architectures (provided $I_{off}$ is very small) and very low $V_{dd}$ (factor of 2), of very specialized architectures like hardware accelerators (factor of 10), reconfigurable architectures (factor of 2), inexact arithmetic (factor of 2), 3D stack (factor of 2), neuromorphic architectures (factor of 100) and new memory hierarchy (factor of 20) will certainly achieve more than a factor of 6 in energy reduction. New embedded software techniques like power-aware compilers, parallelizing compilers for multicore, power aware operating systems and hardware-software co-design may also achieve a factor of 6 in power reduction. The improvements gained on each of the four levels mentioned above can reasonably motivate the target of 1000x in power reduction when all levels are jointly optimized in the end-of-the-roadmap GA system.

Added value compared with existing roadmaps

The GA roadmap is built based on a combined approach between bottom-up (technology driven) and top-down (application driven) strategies, in contrast with ITRS where the projections over time for an established technology like CMOS are explored through the impact of additive technology boosters for high performance and scaling. In the GA computation roadmap, we focus on low power and introduce additional benchmarking not present in ITRS, based on well-defined, measurable criteria for energy and power at the device, circuit and system levels. For memory, the roadmap aims at technology efforts to replace the incumbent charge-based concepts with low-voltage/low energy, resistive, non-volatile options. System architecture will be concurrently designed to handle the novel performance/energy trade-offs made possible by these revolutionary devices. Additionally, we will define a new benchmarking metric and the most adapted circuit architecture to assess it and to compare different switch and memory technology candidates: the energy-per-digital-computation function, starting from the idea of single-bit adder block.

Milestones

Y3:
M-COMP-1-1: Selection of the most energy-efficient switch option for low-$V_{dd}$ circuits or adiabatic logic applicable to GA demonstrators.
M-COMP-1-2: Selection of resistive non-volatile memory technology for low-voltage operation and development of embedded memory macros resulting in 3x energy efficiency improvement over current state-of-the-art.
M-COMP-1-3: Virtual demonstration of 1-bit adder based on TFET and/or NEMS to achieve 10x energy improvement compared to state-of-the-art.
M-COMP-2: Specialized architecture with hardware and inexact accelerators demonstrated to achieve factor of 2 in energy reduction.

Y7:
M-COMP-3: Demonstration of energy-efficient optimized switch, low-power memory and 1-bit adder circuit with 10x improvement compared to conventional devices.

M-COMP-4: New architectures for 3D stacks and/or 3D interconnect achieving a factor of 5 in energy reduction, exploiting energy-efficient, optimized devices.

M-COMP-5: Novel devices for neuromorphic architectures identified and adiabatic logic, extreme low-V\textsubscript{dd} circuits (sub-0.2V), and new memory types demonstrated with 100x in energy reduction.

Y10:

M-COMP-6: A low-energy, full-computation function demonstrated based on highly energy-efficient memory and logic devices integrated in a novel system architecture 1000x more efficient than the industrial state-of-the-art in Y1.

### Computation – Device Roadmap

#### Conventional Technology Roadmap (not part of GA device development)
- FinFET, FDSOI
- Nanowire FET, III-V FET

#### Low Power Device Roadmap (developed with GA project)
- TFET, NEMS, Junction-less, CNT-FET
- Negative-C FET, Spin Devices, 2D-FET, …

#### Options chosen based on technical potential & implementation within 10 years

**Year 3**
- Year 7
- Year 10

### Memory Roadmap

**Year 3**
- Embedded systems with Resistive memories as Replacement of incumbent technologies
- Back-end LP storage (Redox RAM – STT-MRAM)
- 3D Integration in novel computing architectures (Neuromorphic and extreme low V\textsubscript{dd} circuits)

**Year 7**

**Year 10**
- New types of memories

**Year 2013**
- Year 2015
- Year 2017
- Year 2019
- Year 2021
- Year 2023
2.5.5 Communications Roadmap Summary

**Motivation and Goal**
An essential feature of zero-power Guardian Angels autonomous systems is the ability to communicate wirelessly using minimal energy per useful bit. In state-of-the-art sensor nodes, the wireless communication often consumes a significant part of the available energy, which prompts further optimization of the energy efficiency in this domain. The GA project aims toward an energy of only 10 pJ per useful information bit for communication over a distance of 2m. This energy metric should include all energy used in the transmitter and receiver, used for transmitted power, in radio front-end operation, as well as for signal processing (PHY+MAC+network layer). Current state-of-the-art transceivers report a total energy consumption of 100 nJ/bit (commercial devices) down to 1 nJ/bit (partial and immature research devices) for communication over 0.5 to 100m. Our goal is thus to reduce the energy consumption of short-distance communications by 100x to 1000x over the course of ten years.

**How to get the 100x improvement**
The total energy consumption target of 10pJ per useful bit, together with the targets concerning communication distance, data rate, node size, node cost and number of nodes (network density), will be achieved by pursuing three aggressive research lines: (1) flexible and adaptive radios, (2) reduced complexity radios, and (3) extreme duty-cycled burst-mode radios. For each research line, innovation is proposed at 4 different granularity levels of the communication sub-system: system level, algorithm level, circuit and antenna level, and device level.

Crucial to achieve low-complexity, energy-efficient radios is the co-design of the communication technology building blocks. Studying interdependencies between all communication levels will result in the construction of a multidisciplinary virtual platform/model for calculating the energy-per-bit as a function of relevant system parameters like antenna size, centre frequency, bandwidth, data rate. This will also allow the choice of the best communication technology, as well as circuit and device technology, for every GA family. To this end, specific research tasks are allocated to explore the technological limits at each granularity level. Examples are the deployment of new devices for RF circuitry, like III-V antimonide RF devices, TFETs, and carbon RF; the design of low-voltage analog blocks; or assessing the complexity-performance trade-off at the algorithmic level. The implementation of wideband, burst-mode radios together with a wake-up radio and efficient synchronization protocols is another promising driver for improved energy efficiency, requiring innovation regarding efficient duty
cycling, fast turn-on/off, synchronization, sleep states and narrow-band MEMS/NEMS based wake-up radios. The ultimate GA devices will have to be end-to-end adaptive communication systems, which can reconfigure according to the instantaneous application requirements in order to only provide the minimum required performance at minimum energy consumption. Reconfigurability also has to be introduced at every layer of the system, from smart interference management and adaptive coding schemes, to highly linear and low loss MEMS-enabled reconfigurable front-end circuitry and antennas. The GA devices should be able to perform this adaptation autonomously, becoming holistic, energy-aware, self-adaptive communication systems.

**Added value compared with existing roadmaps**

The GA roadmap is built from a system-level perspective, in contrast with other roadmaps which typically only look at small parts of the bigger picture. The success of this roadmap will stem from grouping experts across all these levels and tightly integrating their results to minimize the overall energy consumption in a systematic and balanced way. This is very exceptional in the communications world, where algorithm designers, circuit designers, and device specialists seldom talk. To ensure such improved interaction and achieve a fully-adaptive, energy-aware, complete communication sub-system, research topics are clustered across levels according to the parameters they impact.

**Milestones**

Y3: M-COMM-1: Construction of a multidisciplinary virtual platform/model for calculating the energy-per-bit as a function of relevant system parameters like antenna size, centre frequency, bandwidth, data rate. Selection of best communication access technology for all three GA demonstrator generations.
Y7: M-COMM-3: Top-down design and implementation of advanced synchronization strategies and supporting circuits for dense, many-node networks (interference management protocols, wake-up radios, fast start-up circuits, low-leakage devices) resulting in sleep mode of 150 nW on average.
Y7: M-COMM-4: Achieve 100 pJ/useful bit for communication over 10m distance, through a combination of low complexity front-ends, on-die impairment analysis and correction, smartly mixing heterogeneous nodes, collaborative communication algorithms and advanced interference mitigation.
Y10: M-COMM-5: cm²-size node and antenna capable of communicating over 1 m distance with 1 pJ/useful bit transmitted power and 10pJ/bit total energy/bit.
Y10: M-COMM-6: Fully cross-layer self-adaptive and energy-aware communication sub-system though on-die performance monitors, reconfigurable RF and antennas, flexible MAC and PHY protocols.
2.5.6 Sensing Roadmap Summary: Transducers and Readout Electronics

Motivation and Goal

Sensors are the means through which the Guardian Angels acquire information about our health status and our environment. In GA, a sensor is meant to incorporate both the transducer element converting the stimulus into an electrical signal, and the readout electronics converting this electrical signal into a bit stream of adequate resolution for the application. The main goal in GA over the project’s ten year duration is to reduce the power consumption per transducer below 100 nW, while meeting resolution, bandwidth and measurement range constraints, and to reduce the energy for the entire sensor readout 100x, down to the range of 10 fJ per sensor signal conversion. Since this figure includes both the transducer and readout electronics, efforts in reducing the power consumption of individual building blocks, such as transducers, amplifiers and analogue-to-digital converters (ADCs), through technological and circuit innovations would have to be complemented by efforts in developing and applying holistic, optimal design strategies for sensor systems.
How to get to 100 nW per sensor function and to 10 fJ per signal conversion

There are three relevant levels at which the power/energy consumption of a sensor system needs to be approached, namely the transducer, readout circuit and informational levels. Representative of the informational level is compressed sensing (CS), a paradigm showing that it is possible to reconstruct information by adaptive sampling or by sampling at less than the Nyquist rate if the information rate is lower than the signal bandwidth. CS shifts complexity into the presumably more energy-efficient digital domain, opening the way to analogue-to-information converters (AICs) that consume much less energy per conversion than conventional ADCs. At the readout circuit level, reducing power consumption can be accomplished by architectural circuit innovations that avoid precision operational amplifiers, adopting instead time-based, inverter- and/or ring-oscillator-based solutions powered from sub-volt supply sources. New readout architectures seeking to minimize switching, such as for example asynchronous $\Sigma\Delta$, duty-cycling and predictive/adaptive ADC techniques, may result in further power reduction. At the transducer level, the choice of the transduction principle has important consequences. Power reduction while increasing the sensitivity is key. Capacitive transducers, for instance, can be made very low power by miniaturizing them, but at the expense of degrading resolution/increasing noise, whereas resistive sensors do not lose resolution upon miniaturization, but consume static power. Power is lost in having to drive some transducers, such as actuating resonant transducers or heating chemical sensors, which could be addressed by utilizing self-heated nanostructured materials. A general strategy for reducing the power/energy requirements is to increase the sensitivity and to decrease excess noise in transducers, in other words to maximize the intrinsic signal to noise ratio (SNR) via architectural, design and material choices. In many cases, nano-transducers provide substantial gains in sensitivity, provided that their excess noise is either minimized or exploited (e.g. fluctuation-enhanced sensing), and that integration with readout electronics is achieved to reduce parasitic elements.

Milestones

In the timeline figure, each arrow ends in a milestone, specified by a number of targets such as power (shown right before the sensor function), full scale range, resolution and update rate (shown under each arrow). Below are some of the most important milestones.

**Y3:**
M-SENS-1: Demonstration of a biosensor for one of the key analytes (glucose, cortisol, pH, $\text{H}_2\text{O}_2$, electrolytes) that consumes 10 $\mu$W and reports the concentration $\sim$1/min with a resolution of $\sim$10 bits.
M-SENS-2: Demonstration of an accelerometer for the $\pm 2g$ range, consuming 1 $\mu$W and having a 50 Hz output data rate and a 10 bit resolution.

**Y7:**
M-SENS-3: Demonstration of a gas sensor for one of the key analytes ($\text{O}_3$, $\text{NO}_x$, $\text{CH}_4$, CO, VOCs) that consumes 1 $\mu$W and outputs the concentration at 10 Hz with a resolution of $\sim$10 bits.
M-SENS-4: Demonstration of a time-based readout circuit for capacitive, resistive or resonating transducers, with an effective number of bits (ENOB) $\sim$10 and a 500 Hz bandwidth.

**Y10:**
M-SENS-5: Demonstration of a barometer covering the (30,110) kPa range, consuming 100 nW and reporting ambient pressure with a 14 bit resolution every second (1 Hz).
M-SENS-6: Demonstration of a compressive/predictive readout circuit for capacitive, resistive, resonating or other transducers, with $\sim$12 ENOB, and 1 kHz bandwidth.

Note that although individual target specifications mentioned in the milestones might look unchallenging compared to the state of the art, the true challenge is to achieve the target power plus all other specifications simultaneously for a given sensor system. Milestones in italics in the timeline figure will either be virtually demonstrated (e.g. microphones) or present more risks (e.g. particle sensors). The proposed solutions to achieve these targets are outlined in the full roadmap document, but in a few words they involve nano-materials (e.g. (bio)chemical sensors), nano-membranes (e.g. microphones) and innovative design solutions for readout electronics for each transducer type.
### 2.5.7 Energy Harvesting Roadmap Summary: Mechanical, Thermal, Solar, Bio-fuel, Storage and Power Management

**Motivation and Goal**
Future zero-power, autonomous, miniaturized systems based on disruptive nanotechnologies and ambient energy harvesting (EH) will necessarily include energy generation, storage and efficient power management (PM) as key building blocks of the GA power supply platform. GA plans to develop different novel and disruptive harvesting solutions including mechanical, thermal, solar, bio-fuel and RF transduction. The key challenge for the EH platform is to increase the harvested energy level from the present state of the art of 100 μW/cm² to 10 mW/cm² during the 10-year project. This requires us to push the performance of EH devices towards their limits while miniaturizing the overall footprint. The fundamental, technology and context-dependent limits for EHs for Guardian Angels include the Shockley-Queisser (SQ) limit of 33.7% for single junction solar cells, the Carnot efficiency for thermoelectric harvesters (e.g. 4% at ΔT=12K around room temperature), a maximum power transfer from mechanical to electrical of 50% for motion harvesters, and a maximum cell voltage due to fixed concentrations of glucose (e.g. 8 g cm⁻³ in blood) and dissolved oxygen (e.g. 2 g cm⁻³ in blood) and fixed operating temperature for biofuel cells. In addition, the present anode and cathode materials limit the capacity and cell voltage of microbatteries as storage devices. Similarly, the performance of power management circuits is determined by the threshold voltage of diodes and transistors. For sub-threshold operation there is the “Boltzmann tyranny” physical limit. PM needs to operate at very low input voltages, 10s mV or lower with a fast transient response required by the load. The GA project aims to push harvester solutions towards their limits, in order to achieve an increase of two orders of magnitude in the exploitable power.

**How to get the 100x improvement**
The performance of the EH devices is limited by the available ambient power for harvesting and the conversion efficiency of the harvesting mechanisms. This project proposes to overcome current limits, such as the SQ limit in solar cells, with new device architectures (e.g. tandem solar cells), functional materials (e.g. nanowires and quantum dot structures), and phenomena (e.g. multiple exciton generation), along with further development/optimization in bulk heterojunction polymer and DSSC cells particularly for low light indoor conditions.

![Sensing roadmap](image_url)

**Table:**

<table>
<thead>
<tr>
<th>Year 3</th>
<th>Year 7</th>
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<td>1±2g, 10 bit, 50Hz</td>
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1. demonstration
2. virtual demonstration
3. high risk
4. ±50dB SPL, 7bit, 1kHz
5. ±50dB SPL, 7bit, 1kHz
6. ±50dB SPL, 7bit, 1kHz
7. ±50dB SPL, 7bit, 1kHz
8. ±50dB SPL, 7bit, 1kHz
9. ±50dB SPL, 7bit, 1kHz
10. ±50dB SPL, 7bit, 1kHz
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18. ±50dB SPL, 7bit, 1kHz
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20. ±50dB SPL, 7bit, 1kHz
Similarly, GA proposes to advance the SoA performance of thermoelectric generators with a ZT of 1.4 to 2.5, through integration of superlattices, nanowires or quantum dots. Biofuels, with SoA power density of 6.5 μW/mm² at 0.13V, will be enhanced, through the development of 3D integrated structures for direct electron transfer between the electron and enzyme to improve cell operating voltage. Alternatively, nano-engineered epitaxial and nanowire materials (flexo, multi-ferroics, etc.), along with NEMS structures will be investigated and developed for mechanical energy harvesters. Hybrid micro generators will also be investigated as potential solutions for improving the efficiency from ~ 30% (SoA) to over 50%. Pushing the performance of EHs for GA applications towards these targets must be done while keeping in mind the fabrication technologies for material and device integration, which should be scalable and applicable on larger substrate areas.

The development of efficient management and storage for the harvested energy are key research areas within the GA project. New materials such as Fe fluorites, along with 3D nanostructured and integrated electrodes, will be developed to improve the storage density from current 400 mAh/g at 4.5V. Monolithic integration of the switch-mode power management circuits including the passives (magnetic and capacitive) and switches will be developed to achieve overall efficiency of >80% at ultra-low supply voltages. GA additionally proposes the use of graphene for FET and NEMS technology for low-loss, high-power-density reactive components. Further wireless power transfer using RF signals, presently limited to high power (>1W/cm²) applications, will also be explored through the development of efficient and integratable mm-wave rectifiers for low-power (<1mW/cm²) applications.

**Milestones**

**Y3:**
M-ENER-1-1: Achieve device level power conversion efficiency of 13.5% (outdoor) and 30% (indoor) for solar cell for GA demonstrator.
M-ENER-1-2: Demonstrate power density of 0.7mW/cm³ at an acceleration of 1g out of a MEMS based mechanical energy harvester.
M-ENER-1-3: Achieve ZT of 1.5 at room temperature for a thermoelectric energy harvester.

**Y7:**
M-ENER-2-1: Achieve device level power conversion efficiency > 15% (outdoor) and 35% (indoor) for solar cell for GA demonstrator.
M-ENER-2-2: Demonstrate the energy storage capability of 200 mWh/cm³ with a lifetime of 5000 cycles for a Li-ion 3D thin film battery.
M-ENER-2-3: Manage the harvested power efficiently with an efficiency of 75-90 % across a 2 μW load and with a minimum power conversion overhead of 0.1 μW.

**Y10:**
M-ENER-3-1: Demonstrate power density of 3.5mW/cm³ at an acceleration of 1g out of a MEMS based mechanical energy harvester.
M-ENER-3-2: Achieve ZT of 2.5 at room temperature for a thermoelectric energy harvester.
M-ENER-3-3: Achieve power output of 1mW/cm² out of an enzymatic bio-fuel-cell with module level life time of a year.
Solar Cell Roadmap

**Year 3**
- Optimal optical & electrical structure (for indoor white light) - DSSC & OPV
- High quality organic molecules, NWs, QDs, multi-junctions, junctions with low interface recombination. Integration in 3D flexible electronic chip
- Breakthrough in DSSC/NW/QD based cells, tandem, hybrid (e.g. DSSC for indoor and QD/NW for outdoor) & integrated solar cell

- Efficiency >15%
- Efficiency >20% (outdoor), 40% (indoor)

**Year 7**
- Integration in 3D flexible electronic chip
- Optimized optical & electrical structure (for indoor white light) - DSSC & OPV
- High quality organic molecules, NWs, QDs, multi-junctions, junctions with low interface recombination. Integration in 3D flexible electronic chip
- Breakthrough in DSSC/NW/QD based cells, tandem, hybrid (e.g. DSSC for indoor and QD/NW for outdoor) & integrated solar cell

- Efficiency >20% (outdoor), 40% (indoor)

**Year 10**
- Integration in 3D flexible electronic chip
- Optimized optical & electrical structure (for indoor white light) - DSSC & OPV
- High quality organic molecules, NWs, QDs, multi-junctions, junctions with low interface recombination. Integration in 3D flexible electronic chip
- Breakthrough in DSSC/NW/QD based cells, tandem, hybrid (e.g. DSSC for indoor and QD/NW for outdoor) & integrated solar cell

- Efficiency >20% (outdoor), 40% (indoor)

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Mechanical Energy Harvester Roadmap

**Year 3**
- High-Q MEMS, thicker PZ, Electret
- Hybrid generators, non-linear characteristics, new PZ materials
- Heterostructured PZ nanostructures, near-field characterization

- Power density-1.5 mW/cm²
- Power density-3.5 mW/cm²

**Year 7**
- Integrated nano-magnets, increased NW density into devices, new integration techniques

- Power density-10 mW/cm²

**Year 10**
- Integrated nano-magnets, increased NW density into devices, new integration techniques

- Power density-10 mW/cm²

---

Thermoelectric Energy Harvester Roadmap

**Year 3**
- Optimized integration and thermal interfaces

- Power 0.5 mW/K²

**Year 7**
- Material-Modulation doping, devices- surface micromachining, polymer substrate, heat path optimization, BiTe film technology

- Power 1 mW/K²

**Year 10**
- TEG enhancement by nanostructured materials (superlattice structures or high density nanowires) and integration technology, advanced radiator materials & designs, hybridization with PV cells

- Power 4.5 mW/K²

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**Enzymatic Biofuel Cells Roadmap**

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- Electrical connection, device architecture
- Manufacturing including microfluidics
- Enzyme/mediator system, enzyme/mediator immobilization, integrated devices

Power density: $1 \text{ mW/cm}^2$


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**RF Energy Harvesting Roadmap**

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- Platform independence, beam steering, channel modelling
- Large area rectenna, transmit antenna
- 60 GHz wave

Max. Dist.: $10 \text{ m}$, $15 \text{ m}$, $20 \text{ m}$


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**Energy Storage Roadmap**

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- 30x substrate structuring, core shell structure and nanoscale active materials
- Novel green materials, electrolyte development, 3D nano-integration
- Li air electrodes, integrated storage device with high energy density and life cycles

Storage density: $200 \text{ mWh/cm}^3$, $375 \text{ mWh/cm}^3$

Motivation and Goal

The objectives of the integration research activities are (1) to demonstrate at the system level that the GA energy performance is achievable, and to prove that disruptive technologies proposed in the project are efficient (through virtual demonstrators), and (2) to prove at the technology level that heterogeneous technologies for implementing functional complex systems can be combined (through full hardware demonstrators). These objectives lead to three integration research activities in the project:

- Development of a dedicated GA design and engineering methodology
- Development of 3D silicon integration modules and on-foil integration modules
- Development of Heterogeneous Smart System on Foil (HSSOF) integration modules

GA aims to provide unprecedented distributed systems with a low energy footprint. New design tools will be integrated in an engineering platform interconnecting conventional engineering tools, the architecture trade-off support and the multidisciplinary optimiser. An engineering process will be designed to guide the engineering activities from requirements through assembly and manufacturing.

All three types of GA demonstrators (physical, environmental and emotional) will ultimately need to be flexible, customizable, lightweight, thin, large-area (cm²), energy autonomous and multi-functional. The main goal will be therefore to process heterogeneous smart systems on flexible foils, merging two categories of electronics: 3D silicon electronics for high speed/frequency digital signal processing and high packaging density (logic, memory) and electronics on foil for interactions with humans and environments where large-area printed technologies are needed (energy harvesters and batteries, sensors, displays, human-machine interface, antennas).

Complex functions will be achieved on silicon technology for the first system generation, and then some functions will be replaced by technology on foil. Heterogeneous integration will therefore consist of (1) connecting silicon dies on foil equipped with a redistribution layer (RDL) or an interposer, (2) processing several printable components on foil, and (3) stacking foil on foil. One of the main challenges will be to develop integrated interconnects and packaging/encapsulation solutions in order to ensure enhanced durability of these heterogeneous smart systems on foil. Moreover, since GA demonstrators will be worn by users either in their clothes, in wearable fashion accessories (e.g. watches) or directly on skin, packaging solutions will meet comfort requirements for the user, such as biocompatibility, washability, and stretchability.
How to get the 1000x improvement

The main way to decrease the power consumption is to improve interconnection performance while reducing the power consumption per function. This is addressed by 3D integration on silicon for component stacking, as well as by RDL and interposers on foil. Embedded energy sources on foil, and energy scavengers (e.g. MEMS) will make the system on foil autonomous. Si/non-Si co-design and modelling tools will be developed in order to allow the Si design community to perform the best Si/non-Si partition. These design and modelling tools will be achieved thanks to the merging of competencies from designers and technological experts in two technological fields: silicon electronics and printed modules.

Added value compared with existing roadmaps

With heterogeneous smart system on foil, there is a real opportunity to make silicon electronics and printed electronics converge, and no existing roadmaps cover heterogeneous multi-foil systems. Such a convergence will lead to new generations of systems that fulfil GA demonstrator requirements, and will open up new uses and markets. The development of design and modelling tools integrating both of the technologies, Si electronics and systems on foil, will lead to the creation of an ECAD validated co-design environment and libraries available for the zero-power smart system designer community.

Milestones

Y3:
M-INTEG-1: Si to foil and On foil interconnections test vehicle
M-INTEG-2: Biocompatible packaging adapted to HSSOF
M-INTEG-3: 3D medium-density interconnect

Y7:
M-INTEG-4: Modelling and design tools first generation
M-INTEG-5: Si to multifoil interconnection test vehicle
M-INTEG-6: Flexible, washable and biocompatible foils

Y10:
M-INTEG-7: 3D high-density interconnect
M-INTEG-8: Stretchable, washable and biocompatible foils
M-INTEG-9: Full top-down engineering and design tool

Heterogeneous integration roadmap

- On foil and Si to foil interconnections
- Foil on foil and Si to multifoil interconnections
- From one to multiple sensors with low power consumption: Increasing interconnection density & decreasing interconnection consumption
- User-friendly, durable and flexible packaging

GA CAD validated Si and On foil co-design and modelling environment

2013 2015 2017 2019 2021 2023
2.5.9 Software Roadmap Summary

**Motivation and Goal**

GAs fundamentally rely on software support, throughout the architecture of the systems. While GA nodes are in proximity to or even in immediate contact with a human body, other functional parts that do not need the context of the physical world reside elsewhere – typically in the “cloud”, where plenty of energy and other resources, and thus mightier means to process information, are available. Energy-efficient software design has two parts: to execute software in a resource-aware and energy-efficient manner, and to use software to control the system in a way that minimizes total resource usage. Furthermore, software is essential to address the following objectives: (1) reliability, dependability and safety, (2) security and privacy, and (3) distributed system design, integration, and maintenance. All of these objectives need to be considered across all system levels, from the individual sensing and actuating nodes, to some intermediate devices such as mobile platforms, to the “cloud”. In addition, as running software uses energy, programming needs to undergo a basic paradigm shift, elaborated below.

**How to get the 1000x improvement**

**Design issues:** The GA architecture requires self-organizing networks; centralized network architectures with a “master” node are no longer appropriate. Instead, the architectures must consist of a large number of nodes where any management function can be assigned to many possible nodes. Next, it requires a self-reconfigurable system; as any node or link can at any instant become unavailable, the systems must be able to dynamically reconfigure and adapt themselves on all levels. The third requirement, closely related, is fault tolerance; the systems must be able to function properly even in the presence of some faulty components. Next, the needs of GA will trigger the development of new algorithmic techniques, i.e. software and hardware for very low consumption devices, programming and compilation for very small energy and memory usage, and the development of disruptive algorithms to process signals acquired in non-standard (e.g. compressed) domains. Finally, satisfying the requirements will require the use of formal methods: mathematical techniques, supported by automated tools, to provide a rigorous guarantee that key properties of correctness, reliability, security and privacy are met. GA systems exhibit a high degree of concurrency and must rely on a comprehensive concurrency model.

**Human issues:** GAs are human-centred and must be designed with a special regard for their interaction with human users. The first focus is security: preventing unauthorized access to the systems, data, communications, and users. The second major human-related issue, of particular concern to all GA users, is privacy and confidentiality: allowing users to exert strict control over their personal information as manipulated by the system.

**Added value compared with existing roadmaps**

The GA roadmap for software design has a unique position as it is focused on distributed systems of systems, combining resource efficiency, distributed operation, trustworthiness and privacy/security. Examples of recent attempts in restricted domains can be found for self-adaptive systems, model-based software, and embedded systems. In contrast to other domains such as communication and computation, software roadmaps are, in general, of a qualitative nature, focusing on challenges and possible approaches.

**Milestones**

**Y3:**

M-SW-1-1: **Resource Awareness:** Software compilation with resource awareness.

M-SW-1-2: **Power- and Energy-Efficiency:** Power managed at the GA component level; low-energy software stacks and interfaces.

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M-SW-1-3: *Adaptivity, Fault Tolerance and Dependability*: Probabilistic approaches to improve reliability; data-preservation.

M-SW-1-4: *Security and Privacy*: Lightweight cryptographic primitives and protocols; location privacy model and metrics for GA data.

M-SW-1-5: *Distributed Software Development, Integration and Productivity*: Distributed, resource-aware composition; resource-constrained software execution platforms.

**Y7:**


M-SW-2-3: *Adaptivity, Fault Tolerance and Dependability*: Automatic program transformation at circuit level; fault-tolerant software based on hardware monitors.

M-SW-2-4: *Security and Privacy*: Ultra low-power implementations of arithmetic operators and cryptographic building blocks; privacy-preserving solutions; side-channel attacks models and proposal of counter-measures.

M-SW-2-5: *Distributed Software Development, Integration and Productivity*: On-line verification of composition and reconfiguration decisions; new concurrent models of computation and programming paradigms.

**Y10:**

M-SW-3-1: *Resource Awareness*: Formalization of guaranteed quality of services; resource-aware programming models.


M-SW-3-3: *Adaptivity, Fault Tolerance and Dependability*: Automatic fault detection and recovery mechanisms; resilient communication protocols.

M-SW-3-4: *Security and Privacy*: Low power cryptographic systems secured against side-channel and fault injection attacks; lightweight privacy-preserving solutions.

M-SW-3-5: *Distributed Software Development, Integration and Productivity*: Homogeneous modelling of heterogeneous, distributed software; distributed compressed sensing.

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**Embedded Software Roadmap**

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<td>Power and Energy Efficiency</td>
<td>Adaptivity, Fault Tolerance, Dependability</td>
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<tr>
<td>Security and Privacy</td>
<td>Distributed Software Development, Integration and Productivity</td>
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2013 2015 2017 2019 2021 2023
2.6 Work Plan: ramp-up phase and long term

Information provided by the European Commission points out that the ramp-up phase of the selected FET Flagships will be based on a Collaborative Project and Coordination and Support Action (CPCSA) funding mechanism and will have a duration of 30 months. The challenge of any FET Flagship is to organize a workplan that corresponds to such a mechanism and to foresee a smooth continuation after the ramp-up phase under a newly designed FP8 mechanism. Such a workplan should also have a high degree of openness, high flexibility and be manageable in a company style to ensure a unifying spirit towards a common goal that is specific to the FET Flagship. The GA FET Flagship has decided to prioritize a milestone-based management and a very clear initial workplan structure that concentrates on the notion of roadmaps and their interactions, based on the following levels:

- **Projects:** These components of the workplan are the highest level R&D levels and correspond to the technology and demonstrator roadmaps that define the zero-power technology platform and the systems that are demonstrated during the project lifetime. A Project encompasses a major GA research topic and clusters key expert groups in a given scientific and/or technology domain. The Projects are led by Project Directors that form the Board of Directors of the GA FET Flagship. Each Project has a critical mass (more than 5-7 partners) and makes decisions about research priorities, organises thematic sub-projects and identifies the major milestones and deliverables per reporting period. The GA Projects are thematic domains that are considered key for the GA vision and will run for the whole duration of the 10 years. Based on a proposal of the Executive Project Director, the GA Steering Board approves the balance and resources allocated to Projects per reporting period. The GA has defined 9 major Projects (also called roadmaps) for the ramp-up phase:
  - **Technology Project 1: Computation Roadmap** (Leader: IBM Zurich)
  - **Technology Project 2: Communication Roadmap** (Leader: KUL)
  - **Technology Project 3: Sensor Roadmap** (Leader: ETHZ)
  - **Energy Harvesting Roadmap** (Leader: Tyndall)
  - **Heterogeneous Integration Roadmap** (Leader: CEA-LETI)
  - **Software Roadmap** (Leader: ETHZ)
  - **Physical GA Demonstrators** (Leader: EPFL)
  - **Environmental GA Demonstrators** (Leader: Siemens)
  - **Emotional GA Demonstrators** (Leader: IMEC-BE)

- **Non-Technical Projects:** There are 3 non-technical Projects including coordination, support and management actions that are transversal to the technical projects. These Projects are
  - **Dissemination, networking and training** (Leader: SINANO Institute)
  - **Ethics** (Leader: VTT)
  - **Management and exploitation** (Leader: Guardian Angels Swiss Foundation)

- **Sub-projects:** Each Project is divided into a number of sub-projects having specific deliverables and milestones that will receive specific, well-defined resources to achieve the proposed targets. Each sub-project will have a Sub-project Leader who will directly report to the Project Leaders. The number of sub-projects could vary with time, and the Project Directors can propose the termination of a sub-project to the Board of Directors if the respective milestones are not achieved. The sub-projects have a limited yet well-defined time duration and, in principle, are aligned with the three major reporting periods defined for the GA FET Flagship.

- **Workpackages:** The workpackages group specific scientific and technical activities of sub-projects and will be managed by Workpackage Leaders, similar to the management of these same entities in STREPS and Integrated Projects. The Workpackage Leader reports to the Sub-project Leader. They receive a specific budget and have well-defined milestones and deliverables to achieve. They form the bottom level of the workplan, but are crucial for achieving targeted scientific and technical goals based on focused expertise in the constituent groups.
• **Transversal (Internal) Workshops**: The transversal workshops are thematic events, internally organised by the Project Directors following a well-defined agenda and/or based on spontaneous demands of Sub-project or Workpackage Leaders. They are a specific mechanism proposed in the workplan of the GA FET Flagship to create a flagship spirit and to enhance the interactions of the various components of the zero-power technology platform and of GA demonstrators. Each of the Transversal Internal Workshops will have a well-defined scientific/technical theme and will be chaired by a Project Director or by a Sub-project Leader. The Board of Directors will implement at least four Transversal Internal Workshops per year. The Transversal Internal Workshops will also help to integrate the new teams and sub-projects that have been selected following *Open Calls* into the GA FET Flagship. A Project Director together with the involved Sub-project Leaders may decide to have an Open Transversal Workshop in which public information is shared and international leaders can be invited to present their latest results.

Fig. 11: Depiction of the major GA workplan levels: (1) Projects, (2) Sub-projects, (3) Workpackages, and (4) Transversal Workshops.

For efficient management, the GA Workplan is based on three major periods (called Period 1, 2 and 3) that have major associated milestones for each technology roadmap and demonstrator (see section 2.5 Guardian Angels Demonstrator and Roadmap Executive Summaries). These milestones have been designed by the Project Directors in order to track the project progress along the 10 years. A depiction of the milestones along the project timeline and their interactions in successive periods is reported in Fig. 12.
Particular importance is given to the definition of the roadmaps at the end of Period 1 that are key for creating the conditions for the success of the project and for early demonstration of the scientific importance of the GA FET Flagship. In the ramp-up phase, the zero-power technology platform will not have enough maturity to fully sustain all the ambitious demonstrators that are proposed at the end of Period 1; for this reason, outsourcing of components and processes is foreseen for the system-level milestones. The particular structure of GA, with the involvement of major research institutes and industries, enables this type of approach where the longer-term research of universities will be integrated into the system platform in later stages, following periods of R&D.

**Workplan flexibility and openness for the ramp-up phase**

The workplan of the ramp-up phase is based on a combination of Collaborative Project and Coordination and Support Action (CPCSA instrument). Such an instrument allows the support of research, coordination and support activities under the same grant. As detailed information about special conditions that may apply for this call will only be known in July 2012, a more detailed workplan for the ramp-up phase will be included in the CPCSA proposal. However, a number of key characteristics of the workplan have been already established in the pilot phase and are listed below.

- Under the CPCSA, GA will propose the equivalent of a single Integrated Project for a duration of 30 months (if imposed by the Call) or 36 months (preferable, if this possibility is in line with the text of the July Call). The 36-month Integrated Project will have the advantage of a full alignment with the first set of major milestones that have been defined for Year 3 by the scientific leaders of the project. The GA Consortium believes that a flagship cannot operate as a collection of independent FP7 instruments (STREPS and Integrated Projects), which would fragment the spirit of the flagship and would be, in our opinion, in contradiction with the concept itself. Therefore, we will propose a larger Integrated Project that federates all aspects of the GA systems, and maintains the spirit of cooperation coming from the whole consortium working towards a common goal.

- The proposed workplan levels: Projects, Sub-projects, Workpackages and Transversal Workshops under the supervision of a Board of Directors, will reinforce a unified milestone-based management, in a coherent and unified structure.

- The GA Consortium has proactively published two Open Calls in the pilot phase and has enlarged the number of partners from 28 (initial) to 58 (at the end of the pilot phase). The selection of the partners has been carried out based on template forms and well-defined criteria that were published on the consortium web-site. The Steering Committee of GA was the body that approved the new partners by vote. These 58 GA partners are from 16 different countries.

- Based on the identification of the needed effort (resources) by the Technology Roadmap and Demonstrator Directors and contributions by members of the consortium, we have established a detailed calculation of the funding costs needed by the GA FET Flagship per activity domain, along with prioritized actions to reach the project goals during the 10 year duration. This comprehensive table is a result of a joint effort of all partners and is made in a spirit of entrepreneurship. In the preparation phase of the CPCSA, we will identify the partners most suited to fulfil the proposed tasks and address the identified scientific and technical priorities.

- 20% of the CPCSA budget will be reserved for an Open Call that will be published in the first 9 months of the CPCSA and will serve to address remaining gaps.

- A list of major milestones for each of the Technology and Demonstrator Roadmaps has been proposed to measure the progress toward the defined workplan priorities. These milestones and the interaction between the technology and the system demonstrators, including outsourcing needs in the initial project phase, is sketched out by the Gantt chart of Fig. 12.

- For the 3 non-technical projects, the list of major milestones is detailed as follows:  
  *Project Dissemination, Training and Networking*
M-DTN-1: GA International Symposium organized annually and recognized by IEEE and other high-level professional societies
M-DTN-2: Public GA technology and system roadmap published in cooperation with ENIAC and EPOSS
M-DTN-3: GA Summer School organised annually and all courses accepted for Doctoral European Credits Transfer System

Y7:
M-DTN-4: GA International Symposium organized with the medical community (One Mind for Research Community)
M-DTN-5: GA technology and system roadmaps penetrate and extend ITRS roadmaps
M-DTN-6: GA achieves significant portfolio of lectures for engineering in European Universities

Y10:
M-DTN-7: GA International Symposium reaches new dimensions in multi-disciplinary research by gathering together diverse research communities
M-DTN-8: Open door events and booths organized by GA partners for European citizens

**Project Ethics & user evaluation**

Y3:
M-ETH-1: Ethics and end-user evaluation certificates for GA Physical, Environmental and Emotional system demonstrators and scenarios of Period 1 with critical recommendations delivered

Y7:
M-ETH-2: Ethics and end-user evaluation certificates for GA Physical, Environmental and Emotional system demonstrators and scenarios of Period 2 with critical recommendations delivered

Y10:
M-ETH-3: Process of ethics, end-user and impact evaluations of all GA system demonstrators achieved and reflected in a White GA Ethics Book.

**Project Management and exploitation**

Y3:
M-MGT-EXP-1: Timely reporting to the EC and delivery of activity report for Period 1
M-MGT-EXP-2: Implementation and successful completion of Open Call 1
M-MGT-EXP-3: Creation of 3 start-ups based on GA awarding process for innovation

Y7:
M-MGT-EXP-4: Timely reporting to the EC and delivery of activity report for Period 2
M-MGT-EXP-5: Implementation and successful completion of Open Calls 2 and 3
M-MGT-EXP-6: Creation of 5 start-ups based on GA awarding process for innovation

Y10:
M-MGT-EXP-7: Timely reporting to the EC and delivery of activity report for Period 3
M-MGT-EXP-8: Implementation and successful completion of Open Call 4
M-MGT-EXP-9: Creation of 4 start-ups based on GA awarding process for innovation
Fig. 12: Gantt chart with major milestones per Project (Technology and Demonstrator Roadmaps) and their interactions, together with outsourcing needed for the implementation of the workplan.
2.7 Resources to Implement the Roadmaps

The resources needed to execute the workplan have been calculated based on a top-down entrepreneurship approach, prioritizing the challenging needs of the GA system demonstrators in terms of low energy consumption per function and the needed functionalities required by each application. The result is reported in Table 1, which describes the needed resources per roadmap for the 10-year timeframe and can be summarized as follows:

- The total funding needed by the GA FET Flagship is **985.149 MEuros for 10 years**; this includes the contribution from the EC and the various type of matching. The project cost will be higher, depending on the cost models of each partner.
- This cost is divided as follows: **286.34 MEuros (29%)** for the project demonstrators, **590.73 MEuros (60%)** for the zero-power technology platform and **105.959 MEuros (11%)** for management, dissemination, training and innovation support activities. The pie chart in Fig. 13 summarizes this split and shows the amounts needed for each category.
- With an average cost of 10 KEuros per technology person-month, the GA FET Flagship plans an overall effort of **821 person-years for 58 partners**. The number of involved partners will vary during the project lifetime but these numbers show the level of ambition and the complexity of the project, which will necessitate a management structure similar to the one of a medium-sized company, and a strong and well-defined management strategy and empowered bodies to govern it. These requirements are key for the project success.
- A substantial effort on the prioritisation and narrowing of work and on the zero-power technological platform and system demonstrator options has been made, so that the effort for Period 1 stays limited to **130MEuros**, including a **30-month ramp-up phase** with an associated funding of **50MEuros from the EC**, an ERA-NET+ support of **10 MEuros** from the EC matched by **20MEuros** by national states, and a **6-month (full) phase** with a funding of **25MEuros** from the EC and **25MEuros** from the national states.
- For the other periods (Periods 2 and 3), the ambition is in line with the expectation for the FET Flagships to be able to reach a funding on the order of **100MEuros per year** from the EC combined with matching mechanisms.

![Funding Balance Chart]

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**Fig. 13:** Balance of the GA FET Flagship funding between the various categories. The balance is dynamic and can vary according to the projects needs and priorities during the 10-year time frame.
## Table 1: Estimation of the total requested funding of the GA FET Flagship and the detailed split for the 6 roadmaps and 3 demonstrator projects that form the 9 Projects of the FET Flagship. The project and roadmap coordination, the dissemination, networking and training, and the impact and end-user evaluations and the support to innovation form a separate funding category. Each of the Projects is divided in a number of Sub-projects with specific funding and priorities.

<table>
<thead>
<tr>
<th>Sub-projects</th>
<th>REQUESTED FUNDING (Million Euros)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R&amp;D</td>
<td>Subcontract</td>
</tr>
<tr>
<td>Health aging (Frailty)</td>
<td>3.180</td>
</tr>
<tr>
<td>Managing metabolic disorders (diabetes)</td>
<td>2.023</td>
</tr>
<tr>
<td>Alzheimer’s disease monitoring</td>
<td>3.000</td>
</tr>
<tr>
<td>Air quality companion</td>
<td>4.000</td>
</tr>
<tr>
<td>Inclusion of blinds</td>
<td>5.000</td>
</tr>
<tr>
<td>Disaster management</td>
<td>5.000</td>
</tr>
<tr>
<td>Biomedical emotional</td>
<td>5.000</td>
</tr>
<tr>
<td>Switch - NEMS</td>
<td>5.000</td>
</tr>
<tr>
<td>Switch - Benchmark &amp; new</td>
<td>5.000</td>
</tr>
<tr>
<td>Memory - PCM</td>
<td>5.000</td>
</tr>
<tr>
<td>Memory - ReRAM</td>
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</tr>
<tr>
<td>Memory - ITT- RAM</td>
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</tr>
<tr>
<td>Architecture - Specialized</td>
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</tr>
<tr>
<td>Architecture - Reconfigurable</td>
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</tr>
<tr>
<td>Architecture - 3D stack</td>
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</tr>
<tr>
<td>Architecture - Neuromorphic</td>
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<tr>
<td>Architecture - Beyond CMOS</td>
<td>5.000</td>
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<tr>
<td>Architecture - Adiabatic</td>
<td>5.000</td>
</tr>
<tr>
<td>Architecture - New</td>
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</tr>
<tr>
<td>System level</td>
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</tr>
<tr>
<td>Algorithms</td>
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</tr>
<tr>
<td>Circuits &amp; antennas</td>
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</tr>
<tr>
<td>Deploying new devices</td>
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</tr>
<tr>
<td>Inertial (acceleration/gyros)</td>
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</tr>
<tr>
<td>Pressure / acoustic</td>
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</tr>
<tr>
<td>Gas (Ne, CO, CO2, VCO2)</td>
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</tr>
<tr>
<td>Biosensors &amp; microfluidics</td>
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<tr>
<td>Solar</td>
<td>5.000</td>
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<tr>
<td>Vibration</td>
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<tr>
<td>Power Management</td>
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<td>Memory</td>
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<td>Energy Storage</td>
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<tr>
<td>Bio-fuelcell</td>
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<tr>
<td>System design methodology</td>
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<td>3D module modeling</td>
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<tr>
<td>MOSFET modules modeling</td>
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<td>Resistive memory (MOSFET)</td>
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<tr>
<td>Security &amp; Privacy</td>
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<tr>
<td>Adaptivity, Fault Tolerance</td>
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</tr>
<tr>
<td>Distrib. Software</td>
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</tr>
</tbody>
</table>
2.8 Metrics to Measure Progress in the Flagship

2.8.1 Progress monitoring

In order to ensure an appropriate monitoring of the project progress and activities, the Project Office has to establish management objectives and a strong reporting system. The style of the management will be more similar to the management of a company than to that of a conventional EC project; we will reinforce a milestone-based management, with frequent and well-defined control points and continuous quality assessment.

In the first meeting of the Board of Directors, the general reporting models and the timing for that reporting will be refined and officially approved. The Executive Project Director will propose a milestone-based progress monitoring plan that will be implemented by the Administrative & Financial Manager of the Project Office.

The Roadmap and Demonstrator Leaders of the 9 Projects, who are members of the Board of Directors, are particularly responsible for continuous monitoring of the progress of each Project (Technology or Demonstrator Roadmaps), and are instructed to report directly to the Executive Project Director. The milestone/achievement short reports will be collected by the Administrative & Financial Manager since it is his/her duty to prepare the periodical financial and technical reports for the European Commission.

As each Project is composed of a certain number of Workpackages with defined milestones, it will be straightforward to check progress toward the goals of the project. For each Workpackage, a Workpackage Leader will be appointed. Each Workpackage partner will report to the Workpackage Leader, who then reports to the Director of a Project (Roadmap). Workpackage Leaders will provide a short progress report on activity and advancement toward the established milestones every three months. The Directors of Projects will then prepare a roadmap progress report every six months, which is sent to the Administrative & Financial Manager of the PO in due time and discussed with the BoD in their two annual meetings. This should enable comprehensive and functional progress monitoring.

In addition, face-to-face meetings of the consortium (Board of Directors meetings, but also Project meetings and Workpackage meetings, if necessary) at least twice a year will ensure team-building and implementation of the project goals.

If there are significant delays in achieving milestones (a significant delay is considered a delay that is longer than 3 months and/or has a direct effect of delaying key deliverables and/or other milestones), the Workpackage Leader will directly report to the Directors of Projects who will then officially inform the Administrative & Financial Manager. Together with the Executive Project Director, steps will be taken to mitigate the consequences of the respective delay and/or to recover it urgently by appropriate actions, also in accordance with the risk fall-back strategies (see Risk Analysis section). If a delay influences the whole project timetable, strategies will be discussed in the Board of Directors, and appropriate and timely actions will be taken against defaulting participants, in the best interest of the consortium.

2.8.2 Quality Monitoring: Quality Assurance Procedure (QAP)

The Guardian Angels FET Flagship Project is committed to delivering high-level results both in terms of scientific achievements and the quality of the associated deliverables. The quality assurance procedure will be administratively supported by the Exploitation & Intellectual Property Manager of the Project Office and supervised by the Project Executive Director. The Roadmap and Demonstrator Directors will be responsible for verifying the quality standard of each relevant deliverable of their Projects. If very specific expertise is required to assess a deliverable, a request for a scientist specialised in the appropriate area to participate in the assessment could be anticipated. General Quality Standards will be presented by the Exploitation & Intellectual Property Manager of the PO in the first meeting of the Board of Directors. From this discussion the general
Quality Standards will be fixed (upon the advice of the Scientific Steering Board, if necessary) and a database with high-level experts from the consortium institutions will be established.

The **procedure for Quality Monitoring** will be as follows.

1. When one deliverable is finalised by a Project, the Exploitation & Intellectual Property Manager is informed and an electronic copy of the deliverable is provided to him/her. Then within 5 working days he/she will inform and transfer the respective deliverable to the concerned member of the BoD.

2. The contacted member of the BoD can accept the deliverable as it is, or can decide that the respective deliverable should be reviewed by at least two experts for the general Quality Standards. In this latter case, the comments and modification requests will be addressed to the responsible partner within maximum two weeks, and a new iteration begins.

3. If the deliverable is accepted, it is noted as “Has Passed the QAP” and is transmitted to the Executive Director of the BoD. He/she has five working days to decide if the deliverable is communicated as it is to the EC, with the support of the Exploitation & Intellectual Property Manager, or can return the deliverable for further motivated revisions.

If the deliverable should be made *public*, the Communication Manager of the PO can be involved to evaluate whether parts of the deliverable deserve web-based dissemination, a press release (in the case of a major scientific breakthrough) or other appropriate actions.

### 2.9 Coordination of Activities and Research Communities

At the beginning of the FET Flagship, the Who’s Who Guide, realized during the pilot project and including the main competences, facilities and present projects of GA partners, will be updated and widely disseminated.

The GA consortium members will frequently attend and organize conferences, workshops and seminars for the dissemination of the available competences and needs, and for networking with European and International partners in order to create possible synergies and steer GA activities. The workshops/conferences/seminars will be open to European industry, research centres, university labs, National Contact Points and EC representatives interested in this field. These meetings will allow GA partners to develop collaboration with other initiatives and projects (the initial 28 GA partners have recently been involved in 222 National projects, 174 European projects, and 11 International projects), to discuss challenges and possible solutions, to strengthen the added value of the GA vision and activities, and finally to propose the most disruptive solutions for future Zero Power Systems.

We will also organize a yearly GA international symposium in Europe, USA, or Asia/Pacific (Japan, Korea, Taiwan or Australia) to present the main GA results and where renowned international researchers will be invited to discuss their vision in the GA domains. Meetings and workshops will be organized by GA academic partners, targeting industrial teams. They will allow open discussion, and result in the direct transfer of knowledge accumulated within academia to industry, and industrial feedback on roadmapping. In particular, a special biennial Guardian Angels industrial workshop, with participation of the main European companies in the GA application domains, will be organized in different European countries.

Existing networks, e.g. the Sinano Institute, will also be used for the coordination, dissemination and integration of European research efforts in the GA fields. The temporary exchange of personnel from one lab to another, including between academia and industry, will allow us to exchange information and transfer knowledge. These activities will strengthen the structure of European networking, and consolidate the integration of European laboratories and platforms working in the different GA fields. They will reinforce the complementarity of the partners and develop strengthened collaboration between the various scientific communities and companies.

The link with European Technology platforms (e.g. ENIAC, ARTEMIS, EPoSS, NetWorks, Nanomedicine, Photonics21, and Photovoltaics) will allow the development of complementarity with these short/medium term
ETP projects, along with the analysis of the long term vision of their strategic research agendas which could help to optimise GA research activities. The development of a collaborative model between GA, FP7/Horizon 2020 and JTI projects, including national and international activities, in order to present and discuss our vision of future activities in the GA scientific and technological domains, is also an important objective.

It is important for the GA project to identify, in a realistic and effective way, the needed resources for operating the future FET flagship technological platforms, and the coordination on a European scale. The most advanced existing platforms should be exploited, whether at research institutes like CEA-LETI, IMEC, Tyndall, or VTT or at industrial partners such as ST Microelectronics, IBM, or Infineon. The identification of expertise and any complementary technology from outside Europe are also critical.

Other closer cooperative links can be readily activated by Guardian Angels. A few relevant examples are mentioned here. The HTA (Heterogeneous Technology Alliance) alliance groups four members of Guardian Angels (LETI, CSEM, VTT, FHG) in order to offer the most extensive research platform on heterogeneous integration. Several Guardian Angels partners are also heavily involved in the ENI2 initiative, which aims to establish a wider research infrastructure on different topics such as advanced CMOS and smart power systems. Some institutes from Guardian Angels also have strong partnerships in Asia (such as IMEC which has antennas in Taiwan, China, and India), and in the USA. This way, advanced research from most regions can be considered for fast integration.

Strong participation in European and international roadmap working groups will allow Guardian Angels to quickly identify emerging trends and relevant actors to complement the actions of GA. Reciprocally, GA members will be able to communicate both results and research needs in order to ensure take up by industry, research and national public authorities with whom the ETPs have extensive contacts, and the European Commission.

International Collaboration
A collaborative action with matching funds is planned between GA and the Center for Energy Efficient Electronics Science in the US, funded by the National Science Foundation’s Integrative Partnerships Program. Another collaborative action with Japanese partners is currently in progress and will be centered on a collaborative effort on low-power technologies with the Tokyo Institute of Technology and other Japanese companies like Toshiba and Nissan.

Another foreseen cooperation is with the One Mind for Research Project (http://1mind4research.org/) which would encompass US and European medical communities. Guardian Angels builds on Europe’s leading position in smart systems, while One Mind for Research can ensure, through its specification setting, the relevance of the developed GA devices in real medical settings, can organize field trials and can provide the necessary medical guidance and feedback. An early goal of the cooperation is to enable continuous monitoring of the evolution of Alzheimer’s disease, to establish a thorough understanding of the impact of the disease’s progression on physical and bio-chemical processes in the body and how they impact the quality of life of the patient. A Memorandum of Understanding is in preparation by the leaders of the two Consortia, and a public joint event will be organised before the submission of the CPCSA proposal, concretely reflecting this cooperation.

In order to make the dimension and impact of Guardian Angels global, several open workshops and conferences will be supported and organized by the consortium. European and non-European speakers will be invited to present their views concerning the challenges and possible solutions for future zero-power systems. They will also answer questions concerning their vision about "ultimate" ULP computation, sensing, communication and energy harvesting which could be used in GA. The coordinators of major international, European and national projects will give talks to present the status and trends in the GA research fields. During these open meetings, it will be possible to exchange our vision with that of the international researchers attending these conferences.
3 Implementation

3.1 Governance and Scientific Leadership

The Guardian Angels Consortium has highly complementary expertise: academic partners, research laboratories with international leadership, research institutes, leading industries in semiconductors and electronic products, partners with key expertise in ethics and the impact of technology on society, a global healthcare leader, a leading Swiss agency, and more, all making contributions in science, technology and/or education.

3.1.1 The Guardian Angels Consortium partners

The GA Consortium has the advantage of being based on a European-wide partnership, including 58 universities, research institutions and industrial R&D labs in 16 countries. The consortium is coordinated by the two federal institutes of technology in Switzerland (EPFL and ETHZ), which have international recognition and the needed experience and infrastructure for this challenging endeavour. The competences are balanced in all the key fields of the proposed research, ranging from fundamental research to industrial applications and supported by technology transfer platforms, which not only shows the high involvement of all the research value chain actors in the project, but also maximizes the chances of success of the FET Flagship. In addition, the majority of the main research clean rooms in Europe (including LETI, IMEC, Tyndall, VTT, CSEM, EPFL, and ETHZ) are participating in the GA project, each contributing its own competences and advantages.

Universities: Newcastle University (UK), Danmarks Tekniske Universitet (Denmark), Ecole Polytechnique Fédérale de Lausanne (Switzerland), ETH Zurich (Switzerland), Imperial College London (UK), Instytut Technologii Elektronowej ITE (Poland), Katholieke Universiteit Leuven (Belgium), Lund University (Sweden), National Technical University of Athens (Greece), Politecnico di Milano (Italy), Rheinisch Westfälische Technische Hochschule (Germany) Aachen University (Germany), Royal Institute of Technology KTH (Sweden), Slovenská technická univerzita v bratislave (fakulta Elektrotechniky a informatiky) (Slovak Republic), Technische Universität München (Germany), Technische Universität Eindhoven (Netherlands), Universität Autònoma de Barcelona (UAB) and Universitat Politècnica de Catalunya (UPC) BarcelonaTech (Spain), Université Catholique de Louvain (Belgium), University of Cambridge (UK), Universidad Complutense, Madrid (Spain), University of Glasgow (UK), University of Liverpool (UK), University of Southampton (UK), Universiteit Twente (Netherlands)

Research institutions: Centre National de la Recherche Scientifique CNRS (France), Centre Technologic de Telecomunicacions de Catalunya (Spain), CNM-CSIC, Barcelona (Spain), CNR, Il Consiglio Nazionale delle Ricerche, Modena (Italy), Commissariat à l’Energie Atomique et aux Energies Alternatives CEA (France), CSEM Centre Suisse d’Electronique et de Microtechnique SA – Recherche et Développement (Switzerland), Forschungszentrum Jülich (Germany), Fraunhofer-Allianz Ambient Assisted Living (Germany), Fraunhofer-Einrichtung für Modulare Festkörper-Technologien (Germany), Grenoble-INP (France), INRIA (France), Institut Català de Nanotecnologia (Spain), Interuniversitair Micro-Electronica Centrum VZW (Belgium), Nestlé Research Center (Switzerland), Stichting IMEC Nederland (Netherlands), Tyndall National Institute University College Cork (Ireland), VTT Technical Research Centre of Finland (Finland)

Companies: Aridhia Informatics Ltd., Edinburgh (UK), GreenTEG GmbH (Switzerland), HiQScreen SARL (Switzerland), IBM Research GmbH (Switzerland), Infineon Technologies AG (Germany), Intel Performance Learning Solutions Limited (Ireland), NXP Semiconductors Netherlands BV (Netherlands), Philips Eindhoven (Netherlands), PSA Peugeot Citroën (France), Sanofi Aventis Recherche & Développement (France), Senarcens, Leu & Partner AG (Switzerland), Siemens AG (Germany), STMicroelectronics Crolles 2 SAS (France), Thales SA (France)
Two additional partners, the SINANO Institute (France) and Consorzio Nationale Interuniversitario per la Nanoelettronica (IUNET, Italy) are open windows for the European Academic Community, and both have previously participated in successful Networks of Excellence.

More detailed participant information is included in Annex B.

The following two tables illustrate the consortium complementarity, showing how the key scientific and technical domains needed for the FET Flagship are covered by the 58 partners. The first partner participation Table 2 consists of the starting GA Consortium in the pilot phase, made up of 28 partners. The analysis of contributions to the GA vision shows that at the starting point there were some important unfilled needs, not only in terms of technologies but also for integration and demonstrator build-up, software, and interaction with end-users. The partners of Table 3 are the result of two successive Open Calls issued by the GA FET Flagship pilot in September 2011 and in January 2012. In the two calls, more than 80 new partners applied based on template forms, well-specified criteria and expressed priorities, and 30 new partners were invited to join the flagship. Many of the other applicants were encouraged to apply to our future open calls. Overall, the European coverage extended to 16 countries, now encompassing all the types of institution profiles critically needed for GA success. This effort should be certainly taken into account in evaluating the degree of openness demonstrated by our consortium from the beginning. Given the limitation of the funding during the ramp-up phase, and to a strategic decision to concentrate the effort on a narrow number of priorities to reach outstanding milestones after 3 years, the Coordinators and the Steering Board of the Pilot Consortium has decided to create two categories of partners (specific only to the ramp-up period):

- **Core partners**: These are the partners that will start to work on the major R&D priorities defined by the GA roadmaps and will received significant funding from the CPCSA funds (80%) at the beginning. Our first analysis and projections show that a group of 20-25 partners from the 58 will form this category. These partners will not be entitled to apply to any of the Open Calls of the ramp-up phase and will contribute to defining, together with the SSB and the BoD, the content of such competitive calls for the most efficient operation of the flagship.

- **Associate partners**: Many of the new partners who were invited after the Open Calls during the pilot phase will form the group of associate partners. These partners have already started to work with the consortium for technology and system benchmarking, will continue this work as partners of the CPCSA (will sign the Grant and Consortium Agreements), and will participate in all the internal meetings and dissemination events. These partners will receive a lump funding for benchmarking and dissemination and will have the right to participate in the Open Calls of the GA during the ramp-up phase as any other external partners. They will be able to apply to the published Open Calls with individual and/or joint proposals with other associate partners, and/or with completely new partners. The integration of these groups from the pilot phase enabled a larger European dimension of the GA Consortium from an early phase and will save a tremendous amount of time in shaping the best consortium for the ramp-up phase.
Table 2: The original 28 GA partners and their planned participation in various areas of the project.

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Table 3: The 30 GA partners who joined during the pilot phase, and their planned participation in various areas of the project.

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<td>Medium</td>
<td>Strong</td>
<td>Medium</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
</tr>
<tr>
<td>58</td>
<td>UTWEN</td>
<td>Strong</td>
<td>Medium</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
</tr>
</tbody>
</table>
3.1.2 Scientific and Technical Leadership and Expertise

The GA partners who have demonstrated scientific and technological leadership at both the institutional and the personal level are key players in the project. The academic partners coordinating the project (EPFL and ETHZ) are among the top-ranked European universities according to criteria of excellence in research.

It is worth noting that based on the EC statistics on FP7 nanoelectronics projects their leaders, our consortium includes 17 institutions out of the top 20 leaders acknowledged by these statistics, with a complete coverage of the full value chain for nanoelectronics and smart systems, from new materials and technologies for novel devices, to design methodology and tools, and heterogeneous system design and validation. These leaders have not only the necessary expertise and recognition, but are also able to position the long term vision and effort of the GA FET Flagship compared to the existing efforts in ENIAC, EPOSS, ARTEMIS and CATRENE, and efficiently leverage the existing know-how and the on-going European effort for the future of Key Enabling Technologies (KETs).

On the other hand, fundamental research is very highly represented in our GA consortium and we are proud to cite some of world’s leading researchers whose labs are directly involved in the proposed research:

- Throughout the years, scientists at IBM Research - Zurich have made significant scientific contributions in semiconductor and nano-technology, data storage and transmission, energy management, deep computing, data security and privacy. Outstanding achievements include two Nobel Prizes in Physics for the discovery of high-temperature superconductivity and the invention of the STM. Gerd K. Binnig was awarded the Nobel Prize in Physics in 1986, along with his colleague Heinrich Rohrer, for his work in scanning tunneling microscopy. Dr. Binnig remains a Fellow Emeritus at IBM's Zurich Research Laboratory and will be an active member of the International Advisory Board of GA.

- Dr. Michael Graetzel, director of the Laboratory of Photonics and Interfaces at EPFL, pioneered research on energy and electron transfer reactions in mesoscopic materials, and discovered a new type of solar cell based on dye-sensitized nanocrystalline semiconductor oxide particles, for which he won the prestigious Millennium Technology Prize in 2010.

- Dr. Dimos Poulikakos holds the Chair of Thermodynamics at the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland, where in 1996 he founded the Laboratory of Thermodynamics in Emerging Technologies in the Institute of Energy Technology. In 2009, he won the Nusselt-Reynolds Prize of the World Assembly of Heat Transfer and Thermodynamics conferences, awarded once every four years, for his scientific contributions. In 2012, he won the Max Jacob Award, for eminent scholarly achievement and distinguished leadership in the field of heat transfer. Awarded annually, the Max Jacob Award is the highest honor in the field of heat transfer.

- Dr. Bertrand Meyer is Professor of Software Engineering at ETH Zürich, and Founder and Chief Architect of Eiffel Software in California. He won the Dahl-Nygaard Award (recognizing pioneering contributions to object technology) the first time it was given in 2005, the ACM Software System Award (the highest award in the field of software systems) in 2007, and the IEEE Harlan Mills Prize (the highest prize in software engineering) in 2010.

Also of major importance is the participation of the two leading technology transfer centres in Europe: CEA-LETI and IMEC. These institutions have made breakthrough contributions to technological innovation, recognized world-wide and adopted by leading industries.

CEA LETI’s major scientific and technical achievements include

- Dr. Simon Deleonibus of CEA LETI, IEEE Fellow, invented the “contact plug” principle in 1984, while at Thomson Semiconductors. This principle is universally used by the Microelectronics industry for
interconnects and via-routing of all integrated circuits produced worldwide. He received the “Grand Prix de l’Académie des Technologies” in 2005.

- Dr. Michel Bruel of CEA-LETI invented the Smartcut process principle in 1991. SOITEC, a spinoff of CEA-LETI, is the leader in the field and uses the invention to fabricate silicon-on-insulator substrates as well as other materials on insulator. He has received many awards, including the 2008 IEEE Cledo Brunetti Award.

- CEA-LETI transferred its accelerometer MEMS-based technology to industry in 2004. This technology, based on CEA-LETI patents and technology by Dr. Gilles Delapierre, has been adopted for acceleration sensing in airbags by the automotive industry.

- In nanomagnetism research, CEA has been active in spintronics for 20 years, since the very discovery of Giant Magnetoresistance. SPINTEC was created in 2001 to create a bridge between basic research and applications in this area. CEA is very active in MRAM, low power logic-in-memory electronics, spin-transfer torque oscillators, magnetic recording technology, and magnetic biotechnology. SPINTEC launched the start-up company Crocus Technology in 2006 on MRAM, which raised 260M€ for its development. B. Dieny is leading this R&D activity within CEA. He is an IEEE Fellow, recipient of an ERC Advanced Grant and finalist of the Descartes Research Prize in 2006.

IMEC’s technology research is used in nearly every integrated chip produced worldwide due to their partnering with most semiconductor technology companies, including the number one in every domain. IMEC has a patent portfolio of 1000 patent families filed in places including the EU, US, JP, and KR, and currently files about 140 patents a year, along with 1600 peer-reviewed publications. IMEC’s patent portfolio covers process technology exploration (US 8037430, US 8036870), ultra-low power communication (EP 1916769, EP 1987589), components such as ADCs, (EP 2053748), amplifiers (EP 2086111), systems (EP 2338413, EP 2299588), energy scavenging (EP 1970973), sensors and microfluidics (EP 2071189), and algorithms (for sensing, MAC-layer).

At a personal level, GA will benefit from the direct involvement of some leading IMEC researchers with outstanding contributions to science and technology:

- Prof. Dr. Rudy Lauwereins, vice president and director of the Smart Systems Technology Office at IMEC and professor at KULeuven, invented the low power specification model CSDF, now in use in all commercial system-level EDA tools. He also pioneered low-power, coarse-grain array multi-core processor architectures which are used in several consumer electronics product lines.

- Prof. Dr. Paul Heremans, IMEC fellow and professor at the KULeuven, editor of Organic Electronics, pioneered thin-film surface textured light-emitting diodes in the nineties and more recently high-performance devices in organic semiconductors, for which IMEC was included in the Scientific American Top 50 in 2006 “for its business contribution for advancing RFID, rewarding the contribution to high-frequency rectifying diodes with organic semiconductors”.

- Many of the innovations of Prof. Dr. Marc Heyns, IMEC fellow and professor at KULeuven, are now current practice in the IC industry. This includes his breakthrough developments on ultra-clean processing technology and high-k dielectrics/metal gates.

- Prof. Dr. G. Groeseneken, IMEC fellow, head of the Device Reliability and Electrical characterization group at IMEC and professor and program director of nanotechnology at KULeuven, made several important contributions to the understanding of failure mechanisms in advanced CMOS technologies and devices. He wrote a pioneering paper on charge pumping for the characterization of MOSFET interfaces.

- Bert Gyselinckx is managing director of the IMEC facility in the Netherlands, part of the Holst Centre. Bert is well known in the scientific community for his pioneering contributions to wireless OFDM communications leading to our current generation of Wi-Fi modems.
• Prof. Dr. Chris Van Hoof, department director of Heterogeneous Integrated Microsystems, program director of Human++ and professor at KULeuven, is a Laureate of the Royal Academy of Sciences, Literature and Fine Arts of Belgium.

These few examples are cited in this intermediate report as clear evidence of leadership in the Guardian Angels research domain.

3.2 Management Plan

3.2.1 Consortium size and management challenges

A project such as Guardian Angels is a very complex organisation in which partners with different cultural backgrounds, languages, operational processes and approaches (due to their different organisational structures, types and sizes) have come together in order to join their knowledge, their creativity and their practical experience toward a common goal. In particular, 58 partners (27 universities, 14 industrial companies, 17 research organisations) from 16 countries have joined together to form the Guardian Angels project, as shown in the figure and table below.

Fig. 14: A geographic overview of the Guardian Angels consortium.

Table 4: The GA partners.

<table>
<thead>
<tr>
<th>Participating Countries</th>
<th>University</th>
<th>Research Organization</th>
<th>Large Industry</th>
<th>SME</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Denmark</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Finland</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>France</td>
<td>0</td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Germany</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Greece</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Ireland</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Country</td>
<td>Partners</td>
<td>Coordinators</td>
<td>pip</td>
<td>Workunits</td>
<td>TOTAL</td>
</tr>
<tr>
<td>---------------</td>
<td>----------</td>
<td>--------------</td>
<td>-----</td>
<td>-----------</td>
<td>-------</td>
</tr>
<tr>
<td>Italy</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Poland</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Romania</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Slovak Republic</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Spain</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Sweden</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Switzerland</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>UK</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>TOTAL</td>
<td>27</td>
<td>17</td>
<td>10</td>
<td>4</td>
<td>58</td>
</tr>
</tbody>
</table>

Due to the flexibility of the consortium, this number could change during the ten-year project, as new partners enter the consortium, and others leave according to defined grant agreement periods.

To incorporate the diversity of partners, it is necessary to create a complex yet lean operational structure with different committees and bodies, able to address all kind of interests and responsibilities in order to achieve the aims of the project, with smooth decision-making and feedback processes, and prompt management of risks and unforeseen events.

### 3.2.2 Management structure versus project organisation

The Guardian Angels management structure consists of three different types of bodies:

- Bodies that enable the effective handling of the project: Steering and coordination bodies such as **Project Coordination**, the **Project Office** (including, as satellite, the **Open Call Office**), the **Board of Directors**, and the **Scientific Steering Board**.
- A body that will enable interaction between the whole consortium and the Project Coordination and provide feedback for the members of the project consortium: the **General Assembly**.
- Bodies that should offer support, consulting and advice: Advisory Boards such as the **International Advisory Board**, the **Ethics Board**, and the **National Representative Board**.

These eight bodies should support the implementation of the project and cover all relevant issues (scientific, administrative, ethics, legal, etc.) which are tackled by the project. The members of the Scientific Steering Board, the Board of Directors and the General Assembly are members of the project consortium or members of the partner organizations, whereas the members of the Advisory Boards will in most cases be external experts.

The Guardian Angels project organisation includes **9** technical **Projects**, led by **Technology Roadmap and Demonstrator Roadmap Directors** and **2** non-technical **Projects** on **Dissemination, Networking and Training (DNT)**, and **Ethics**. These Projects are again divided into Workpackages (steered by Workpackage Leaders). As a general rule, all partners within these Projects have to follow the content and aim of the work programme presented in the submitted project, including the mentioned time table. The Technology Roadmap and Demonstrator Roadmap Directors, the DNT Director and the Ethics Director form the **Board of Directors**, led by the **Executive Project Director**. In addition, all partners of the project are represented in the General Assembly.

To clarify all responsibilities and duties, all partners have to sign a **Consortium Agreement**, which covers the different scientific and administrative tasks of the partners according to the work programme, the responsibilities and commitments of the different bodies of the consortium, and the decision-making process. In this Consortium Agreement, it will also be stated and clarified the length of time for which each partner is joining the project, and how and when a partner can enter and leave the consortium.
In the following pages, the roles of the different bodies, the people involved and the principles of the internal communication structure within the project will be outlined and presented.

3.2.3 Governance and bodies

The eight different bodies of the Guardian Angels project, enabling a company-like governance, are the following:

1. The **Project Coordination**, who has the overall responsibility and leadership for the execution of the project and acts as an intermediary between the EC and the project partners. The Project Coordination is the Guardian Angels Swiss Foundation, equally owned by EPF Lausanne and ETH Zurich.

2. The **Project Office** with its **Open Call Office** satellite, which will support the Executive Project Director, the Chair of the Scientific Steering Board and the other six bodies, according to the rules and tasks defined for each body.

3. The **Board of Directors**, which will enable a smooth fulfilment of the project goals as foreseen in the work programme, and is responsible for the risk management and execution of risk management decisions.

4. The **Scientific Steering Board**, which will decide upon the scientific direction of the project, organize an internal review of the scientific and technology focus of the platforms, and structure and organize the open calls in coordination with the Board of Directors.

5. The **General Assembly**, where all partners are represented and which will enable interaction between the whole consortium and the Project Coordination.

6. The **International Advisory Board**, which should support the decision-making process in terms of the research direction and international alignment, based on their high-level expertise.

7. The **Ethics Board**, which is an external body, to give advice upon ethical matters.

8. The **Board of National Research Representatives**, which will facilitate the handling of the foreseen calls for proposals in the participating countries, and help to identify significant matching through national initiatives during the application of the FP8 instrument (after the ramp-up phase).
The management structure and interactions between the different bodies are shown in Fig. 15.

**Fig. 15: The Guardian Angels management structure.**

**Detailed Description of the different bodies:**

1. **The Project Coordination (PC)**

The Project Coordination carries out the overall leadership of the project. The PC is the intermediary between the project consortium and the European Commission, and will be supported by the Project Office. The project coordination will be done by the Ecole Polytechnique Federale de Lausanne (EPFL) jointly with Eidgenössische Technische Hochschule Zürich (ETH Zürich). Both organisations have extensive experience in handling international projects, especially EU projects. **Prof. Adrian M. Ionescu (EPFL) and Prof. Christofer Hierold (ETH Zürich)** will lead the project together through the functions of Executive Project Director and Chair of the Scientific Steering Committee.

To facilitate and clarify the joint coordination, a legal entity, the “The Guardian Angels Swiss Foundation”, will be founded and jointly owned by EPFL and ETH Zürich. The Guardian Angels Foundation will be coordinated by the **Steering Board of the Guardian Angels Swiss Foundation**, which will include the two presidents of the two Federal Institutes of Technology, the two vice-presidents for research of the two schools, and the two project leaders. The role of this body is to advise the management of the FET Flagship project. The Steering Board of the Guardian Angels Swiss Foundation nominates the project leaders, in case of replacement, for approval by the EC.

The project coordination will be shared by EPFL and ETHZ, represented by Professors Ionescu and Hierold, who will be appointed as the Executive Project Director and as the Chair of the Scientific Steering Board of the GA FET Flagship, respectively. Their short bios are below.

**Prof. Adrian M. Ionescu** is an Associate Professor at EPFL, Switzerland. He held staff and/or visiting positions at LETI-CEA and CNRS, Grenoble, and Stanford University, in 1998 and 1999, respectively. He is currently the Director of the...
Nanoelectronic Devices Laboratory of EPFL. Prof. Ionescu regularly serves on the IEDM and ESSDERC Technical Committees and was the Technical Chair of ESDDERC 2006. He has much experience with the coordination of European projects; he was/is the Coordinator of WIDERF, NANORF, NEMSIC and STEEPER projects. He is a member of the Scientific Committee of the Cluster for Application and Technology Research in Europe on Nanoelectronics (CATRENE) and the national representative of Switzerland to the European Nanoelectronics Initiative Advisory Council (ENIAC). He acts as the European Chair of the Emerging Research Devices Group of ITRS.

Prof. Christofer Hierold has been a Professor of Micro and Nanosystems at ETH Zurich since April 2002. Currently, he is Deputy Head of the Department of Mechanical and Process Engineering and the ETH Zurich Coordinator of the Binnig and Rohrer Nanotechnology Centre in Rüschlikon. Before he joined ETH Zurich in 2002, he was with Siemens AG, Corporate Research, and Infineon Technologies AG in Germany. At Siemens, his major areas of research and responsibility were microsystems, advanced CMOS processes and new materials. In Infineon's Wireless Products Business Group, he was responsible for technology development, intellectual property, and competence management. At ETH Zurich, Christofer Hierold pursues research on the evaluation of new materials for MEMS, on advanced microsystems, and on nanotransducers. He is a member of the international steering committees of major conferences in the field (MEMS, TRANSDUCERS, EUROSENSORS), he was co-chair of MEMS 2009 and he is program chair of TRANSDUCRES 2013. Christofer Hierold is a member of the Swiss Academy of Engineering Sciences (SATW).

Table 5: Overview of the tasks and responsibilities of the Project Coordination.

<table>
<thead>
<tr>
<th>THE PROJECT COORDINATION (PC) = GUARDIAN ANGELS SWISS FOUNDATION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meetings</strong></td>
</tr>
<tr>
<td>The Swiss Steering Committee of the PC meets twice per year.</td>
</tr>
<tr>
<td>The representatives of the PC body, Professors Ionescu and Hierold, will participate in all relevant meetings of the Scientific Steering Board, the General Assembly, The Board of Directors and Advisory Boards.</td>
</tr>
<tr>
<td><strong>Composition</strong></td>
</tr>
<tr>
<td>The Project Coordination is a body named the “Guardian Angels Swiss Foundation”, founded jointly by ETH Zürich and EPF Lausanne, It has a Steering Board, the “Steering Board of the GA Swiss Foundation”, which has 6 members.</td>
</tr>
<tr>
<td>The Chair of the Scientific Steering Board (Prof. Hierold) and the Executive Project Director (Prof. Ionescu) are de facto members of the Steering Board of the GA Swiss Foundation.</td>
</tr>
<tr>
<td>The official contact to the European Commission is the Executive Project Director, which represents the GA Swiss Foundation, .</td>
</tr>
<tr>
<td><strong>Responsibility</strong></td>
</tr>
<tr>
<td>The Project Coordination is the official contact of the GA Flagship Project to the European Commission and has full responsibility for its successful implementation.</td>
</tr>
<tr>
<td><strong>Tasks</strong></td>
</tr>
<tr>
<td>• To act as single intermediary point between the project partners and the EC</td>
</tr>
<tr>
<td>• To coordinate and steer the Advisory Boards if necessary</td>
</tr>
<tr>
<td>• To represent the project in external events</td>
</tr>
<tr>
<td><strong>Via the Executive Project Director:</strong></td>
</tr>
<tr>
<td>• To finally approve the key technical deliverables, the technical reports and the periodical administrative reports and cost breakdowns</td>
</tr>
<tr>
<td>• To ensure that all project deliverables and reports are submitted on time</td>
</tr>
<tr>
<td>• To monitor the implementation of the work programme of the project together with the members of the Board of Directors</td>
</tr>
<tr>
<td>• To represent the project in external activities and/or workshops</td>
</tr>
<tr>
<td>• To support the members of the Board of Directors and the Advisory Boards with which these boards interact</td>
</tr>
<tr>
<td>• To interact and inform the General Assembly about the progress of the project</td>
</tr>
<tr>
<td>• To support the members of the Guardian Angels Swiss Steering Committee</td>
</tr>
<tr>
<td><strong>Via the Chair of the Scientific Steering Board:</strong></td>
</tr>
<tr>
<td>• To propose strategic research lines and dynamically evaluate their alignment with international research</td>
</tr>
<tr>
<td>• To organize and document internal reviews of the strategic research lines and of the scientific and technology progress</td>
</tr>
<tr>
<td>• To decide upon actions following internal reviews and feedback from the General Assembly and the Advisory Boards</td>
</tr>
<tr>
<td>• To support the members of the Scientific Steering Committee</td>
</tr>
</tbody>
</table>
2. **Project Office (PO) and Open Call Office (OCO)**

The Project Office (PO) and the Open Call Office (OCO) give administrative and management support to the **Executive Project Director**, to the **Chair of the Scientific Steering Board** and all other relevant bodies. It will enable smooth communication between the partners and act as a contact point, assisting all participants in day-to-day issues. The administrative managers of the PO report directly to the Executive Project Director. To cover all necessary activities, **four Managers** will be appointed. They will work together closely but have different tasks and responsibilities:

1. **Administrative & Financial Manager:**
   - Coordination of reporting issues including preparation of reporting models and time management
   - Follow-up of progress monitoring and risk management, if necessary, together with the Executive Project Director
   - Follow-up of financial issues, including internal and external financial reporting in collaboration with the partners
   - Organisation and preparation of the Board of Directors meetings and national and international events organized by this body
   - Support and documentation of the IAB meetings
   - Direct contact with the European Commission for all reporting and review issues
   - Organization, support and documentation of the internal review process, with the support of the SSB and the International Advisory Board

2. **Communication Manager:**
   - Preparation of tools for smooth communication within the consortium (webpage, newsletter, etc.)
   - Editor / editorial journalist function for all communication channels
   - Coordination of the execution of the approved dissemination activities and strategy (press releases, press conferences, leaflets, general presentations, info brochures, webpage, organisation of events, etc.)
   - Coordination of international activities (defining the principles of collaborative efforts with leading partners from the USA, South Asia, Japan and others and proposing concrete implementation plans for such international cooperation)
   - Organisation and preparation of the General Assembly
   - Support and documentation of the Ethics Board meetings
   - Coordination of the dissemination activities with the Dissemination, Networking and Training Director.

3. **Exploitation & Intellectual Property Manager:**
   - Follow-up of the exploitation plan and strategy (such as patenting, licensing and other exploitation activities)
   - Implementation and follow-up of start-up creation and related support activities
   - Follow-up of quality monitoring together with the Scientific Steering Board and the Board of Directors
   - Support and documentation of the meetings of the IP and Exploitation Committee

The **Administrative & Financial Manager**, the **Communication Manager** and the **Exploitation & Intellectual Property Manager** will work in the PO created and located at EPF Lausanne, and directly report to the Executive Project Director (Prof. Ionescu). They will share the support of two administrative assistants.

The **Open Call Manager** will be located at ETH Zurich and will report directly to the Chair of the Scientific Steering Board. This manager is responsible for the implementation and all the actions taken for the GA open calls and for joint national calls, in order to achieve the objectives of the workplan. The Open Call Office will be supported by one administrative assistant. Tasks and responsibilities of the Open Call Manager:
Support to the Scientific Steering Board and Prof. Hierold to align the GA research priorities with national priorities in Open Calls

Organization, support and documentation of the meetings of the SSB

Support and documentation of the National Representatives meetings

Communication with the National Representative Board for proper execution of the Open Calls

Publishing of the Open Calls and organisation of the evaluation procedure according to SSB and BoD strategies and project needs

Organisation and preparation of the meetings between the Scientific Steering Board and the National Representative Board

Table 6: Overview of the tasks and responsibilities of the Project Office.

<table>
<thead>
<tr>
<th>PROJECT OFFICE (PO)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meetings</strong></td>
</tr>
<tr>
<td>Representatives of the PO will participate in all relevant meetings of the Scientific Steering Board, the Board of Directors, the General Assembly and the Advisory Boards.</td>
</tr>
<tr>
<td><strong>Composition</strong></td>
</tr>
<tr>
<td>Up to four Project Officers</td>
</tr>
<tr>
<td><strong>Responsibility</strong></td>
</tr>
<tr>
<td>The Project Office (PO) and the Open Call Office (OCO) give administrative and management support to the Executive Project Director, to the Chair of the Scientific Steering Board and all other relevant bodies, according to their task description. The PO and the OCO are responsible for fulfilling the tasks mentioned to enable the successful implementation of the Flagship project.</td>
</tr>
<tr>
<td><strong>Tasks</strong></td>
</tr>
<tr>
<td><strong>Project Office – EPFL</strong></td>
</tr>
<tr>
<td>To support the Executive Project Director and the Board of Directors</td>
</tr>
<tr>
<td>To organise the meetings of the General Assembly, the Board of Directors and all the advisory boards</td>
</tr>
<tr>
<td>To organise the preparation and finalisation of the periodical, technical and administrative reports</td>
</tr>
<tr>
<td>To facilitate and actively support the successful internal project communication through various means (webpage, telephone conferences, etc.)</td>
</tr>
<tr>
<td>To organise and follow-up on all activities regarding dissemination and knowledge-management issues</td>
</tr>
<tr>
<td>To support the anticipated international activities and cooperation</td>
</tr>
<tr>
<td><strong>Open Call Office – ETHZ</strong></td>
</tr>
<tr>
<td>To organise and document the meetings of the SSB</td>
</tr>
<tr>
<td>Organization and documentation of the internal review process</td>
</tr>
<tr>
<td>To support any activities and documentation regarding the development and execution of the future Open Calls within the project</td>
</tr>
<tr>
<td>To support the actions of the Chair of the Scientific Steering Board</td>
</tr>
<tr>
<td>To coordinate joint calls with national initiatives</td>
</tr>
</tbody>
</table>

3. Board of Directors (BoD)

The Board of Directors is composed of the 11 Project Directors (Technology Roadmap and Demonstrator Roadmap Directors, Dissemination, Networking and Training Director and Ethics Director) and is chaired by the Executive Project Director, Prof. Ionescu. The focus of this board, in contrast with that of the Scientific Steering Board, is how to use the project resources to achieve the best project results, to take the most appropriate actions in management of science and of technical activities to achieve the milestones and the deliverables, and to organise the proper and smooth implementation of the workplan. The main responsibilities are therefore focused on the implementation of the project and decisions concerning

- achieving the scientific and technical milestones
- reporting and budget (re)allocation
- enabling the exploitation of the project achievements
- appropriate actions for dissemination, training and networking
• appropriate actions for ethics issues
• interaction with end-users and stakeholders
• proposing measures to cope with delays, unexpected difficulties and defaulting partners.

Table 7: Overview of the tasks and responsibilities of the Board of Directors.

<table>
<thead>
<tr>
<th>BOARD OF DIRECTORS (BoD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meetings</strong></td>
</tr>
<tr>
<td><strong>Composition</strong></td>
</tr>
<tr>
<td><strong>Chair</strong></td>
</tr>
<tr>
<td><strong>Responsibility</strong></td>
</tr>
</tbody>
</table>
| **Tasks** | • To decide on the most effective management approach for scientific and technical activities in order to achieve the milestones of the workplan  
• To support the preparation of the technical and administrative reports and discuss the final versions with the PC  
• To monitor together with the PC the effective and efficient scientific, technical and financial implementation and progress of the project and to propose and adjust technical roadmaps and milestones  
• To make decisions about changes to the project or its structure, the allocation of the project’s resources and the description of work  
• To execute decisions of the SSB  
• To inform the Executive Project Director about potential conflicts and delays, and to seek consensus  
• To follow the risk management plan if necessary  
• To supervise and decide on all activities regarding dissemination and knowledge-management issues  
• To supervise and decide on all activities regarding exploitation and creation of start-ups  
• To participate in the meetings of the Advisory Boards to give feedback if necessary |

The IP and Exploitation Committee will work closely with the BoD, and in particular with the Executive Project Director, to implement the IP and exploitation strategy in the GA project.

4. Scientific Steering Board (SSB)

The Scientific Steering Board is composed of the Chair of the SSB (Prof. Hierold) from ETH Zürich and the Executive Project Director (Prof. Ionescu) from EPFL who also represent the Project Coordination (PC), and one high-level representative of the other 10 core partners of the project.

The Scientific Steering Board is the highest forum for decision-making about the scientific direction and recommendations for technology priorities of the GA FET Flagship. The Chair of the Scientific Steering Board is Prof. Hierold. The number of members can be adapted during the lifetime of the project but must not exceed 15 members.

The responsibilities of the Scientific Steering Board will be to reflect on, discuss, and adjust the scientific goals of the project, especially given that the project duration is long (ten years). In addition, Open Calls for the scientific community should be formulated and organised, which requires a deep knowledge and understanding of future technological and scientific trends. A strong interaction with the Board of Directors and with the International Advisory Board is anticipated.

Table 8: Overview of the tasks and responsibilities of the Scientific Steering Board.

<table>
<thead>
<tr>
<th>SCIENTIFIC STEERING BOARD (SSB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meetings</strong></td>
</tr>
<tr>
<td><strong>Composition</strong></td>
</tr>
</tbody>
</table>
and 10 representatives of the core partners.

<table>
<thead>
<tr>
<th>Responsibility</th>
<th>The responsibilities of the Scientific Steering Board are to reflect on, discuss, and adjust the scientific goals of the project and to steer the Open Call process.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chair</td>
<td>The Chair is Prof. Hierold and the Vice-Chair is Prof. Ionescu.</td>
</tr>
</tbody>
</table>

**Tasks**

- To undertake strategic planning and discussion of the general scientific direction and goal of the project
- To discuss and decide upon major modifications of the scientific and technical strategy in close coordination with the BoD
- To participate in the meetings of the Advisory Boards (especially the IAB and the BNR) to enable intensive knowledge exchange
- To give advice regarding possible premature completion/termination of the project for scientific reasons
- To discuss and decide upon major modifications of the scientific and technical strategy in coordination with the IAB and the Board of Directors
- To discuss and formulate open calls in close coordination with the EC and the BoD
- To discuss and approve new project partners and projects out of the open call processes
- To discuss and offer advice for networking activities with other European and international organisations
- To discuss and offer advice on the dissemination and exploitation strategy proposed by the BoD

5. General Assembly

The General Assembly is composed of one representative person of each partner in the consortium. The representative will have the authority **to make decisions on behalf of his or her organisation** concerning all relevant changes affecting the content of the **Consortium Agreement** and the organisation’s resource allocation within the project. Each representative shall have one vote (voting will be by 2/3 majority) and may appoint a substitute to attend and vote at any meeting of the General Assembly.

The General Assembly will meet at least once a year and should also allow the Project Coordination to inform the whole consortium about the progress of the project and major difficulties, news and changes.

Table 9: Overview of the tasks and responsibilities of the General Assembly.

<table>
<thead>
<tr>
<th>General Assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meetings</strong></td>
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<tr>
<td><strong>Composition</strong></td>
</tr>
<tr>
<td><strong>Responsibility</strong></td>
</tr>
<tr>
<td><strong>Chair</strong></td>
</tr>
<tr>
<td><strong>Tasks</strong></td>
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<tr>
<td></td>
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</tbody>
</table>
6. International Advisory Board (IAB)

The International Advisory Board consists of recognized senior scientists and/or high-level industrial representatives. It is an External Body, which is not involved in any day-to-day business of the Guardian Angels project. The number of members is limited to 10. The IAB will meet as needed, to support the work and decision-making of the Scientific Steering Board and of the Board of Directors.

At the moment the following seven members have been identified (http://www.ga-project.eu/partners/international), but new members could be appointed during the duration of the project.

<table>
<thead>
<tr>
<th>Nr</th>
<th>Name</th>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hugo de Man</td>
<td>Emeritus Status at the Katholieke Universiteit Leuven, Belgium</td>
</tr>
<tr>
<td>2</td>
<td>Magali Haas</td>
<td>Head of Department, Companion Diagnostics &amp; CNS Integrative Solutions, Johnson &amp; Johnson, USA</td>
</tr>
<tr>
<td>3</td>
<td>Gerd K. Binning</td>
<td>Nobel Prize winner in Physics 1986 for designing the scanning tunnelling microscope (STM)</td>
</tr>
<tr>
<td>4</td>
<td>Fabrizio Arigoni</td>
<td>Head of Nestlé Research Tokyo, Japan</td>
</tr>
<tr>
<td>5</td>
<td>Jan Rabaey</td>
<td>Professor at the Berkeley Wireless Research Centre, USA</td>
</tr>
<tr>
<td>6</td>
<td>Hiroshi Iwai</td>
<td>Tokyo institute of technology, Japan</td>
</tr>
<tr>
<td>7</td>
<td>Loïc Lietar</td>
<td>Executive Vice President, STMicroelectronics, France</td>
</tr>
</tbody>
</table>

**Hugo De Man** earned a degree in electrical engineering in 1964 and a PhD degree in Applied Sciences in 1968, both from the University of Leuven. In 1974 he became a Full Professor at the University of Leuven. From 1984 to 1995 he was Vice-President of the VLSI systems design group of IMEC (Leuven, Belgium). In 2005 he was honoured with an emeritus status for his scientific achievements as well as his impact on industry. His research has been published in more than 150 international journal papers and almost 440 international refereed conference papers.

**Mrs. Magali Haas** earned her Bachelor of Science in bioengineering, a Master of Science in biomedical engineering and her medical degree and doctorate in neuroscience from Albert Einstein College of Medicine, New York. Dr. Haas joined the Johnson & Johnson organization in 2001 and has gained extensive end-to-end development experience across the various leadership roles. She currently heads the Department of Integrative Solutions which develops Stratified Medicine strategies and Companion Diagnostics & Solutions for AD, Mood, Schizophrenia and Pain.

**Gerd Binnig** is a German physicist, and a Nobel laureate. In 1978, he accepted an offer from IBM to join their Zürich research group. There, he met Heinrich Rohrer, with whom he shared half of the Nobel Prize in Physics in 1986 for their design of the scanning tunnelling microscope (STM) (the other half of the Prize was awarded to Ernst Ruska). In 1994, Professor Gerd Binnig founded Definiens, which turned into a commercial enterprise in the year 2000. Today, companies and institutions around the world use Definiens' technology to maximize the value of images.

**Fabrizio Arigoni**, obtained a PhD in Life Science from ETH Zürich while working at the Pasteur Institute in Paris. He pursued his career in the Pharmaceutical industry working for Serono in Geneva and later joined the Food industry working at the Nestlé Research Centre in Lausanne. There he was appointed Head of Food and Health Microbiology from 2004 to 2009 and then moved to Japan where he is currently Head of the Nestlé Research Unit located within Tokyo University. Dr. Arigoni is also a Director and Member of the Board of the Nestlé Nutrition Council Japan, a Nestlé sponsored foundation that promotes basic nutrition research in Japan.

**Jan Rabaey** received the EE and Ph.D. degrees in Applied Sciences from the Katholieke Universiteit Leuven, Belgium, in 1978 and 1983 respectively. In 1987 he joined the faculty of the Electrical Engineering and Computer Science department at UC Berkeley, where he now holds the Donald O. Pederson Distinguished Professorship. He was the Associate Chair (EE) of the EECS Dept. at Berkeley from 1999 till 2002, and is currently the Scientific co-director of the Berkeley Wireless Research Center (BWRC, as well as the director of the Multiscale Systems Research Center (MuSyC). He is serving on the Technical Advisory Board of a wide range of companies.

**Hiroshi Iwai** is a professor in the Frontier Research Center and also in the Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology. He received the B.E. and Ph.D. degrees in electrical engineering from the University of Tokyo. He has been worked in the R & D for LSI and nano-device technologies for more than 35 years; at Toshiba for 26 years, and at Tokyo Institute of Technology for 10 years. His current main research fields are Si-nanowire FET and high-k gate insulator below 0.5 nm.
Loïc Liétar is an Executive Vice President of STMicroelectronics in charge of the company’s new venture activities, and has held this position since January 2011. Liétar serves as Managing Director of ST New Ventures, the Company’s corporate venture capital fund set up in late 2011 to invest in start-up technology, product and service companies where semiconductors are key. Loïc Liétar graduated with degrees in Engineering and Microelectronics from the École Polytechnique and Orsay University in Paris, respectively, and holds an MBA.

Table 10: Overview of the tasks and responsibilities of the International Advisory Board.

<table>
<thead>
<tr>
<th>International Advisory Board (IAB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meetings</strong></td>
</tr>
<tr>
<td><strong>Composition</strong></td>
</tr>
<tr>
<td><strong>Responsibility</strong></td>
</tr>
<tr>
<td><strong>Chair</strong></td>
</tr>
</tbody>
</table>
| **Tasks** | • To give a general view of the technical and scientific progress of the project in the international context and to act as an advisory review board  
• To support the members of the Scientific Steering Committee, the Board of Directors and the Project Coordination concerning the project strategy  
• To give feedback to the General Assembly or other bodies |

7. Ethics Board (EB)

The Ethics Board, like the International Advisory Board, is an **External Body** working on questions regarding ethical issues within the project. The Ethics Boards will consist of **10 members** including one representative of the Guardian Angels consortium, who will act as **Chair** of this board (Dr. Eija Kassinen, VTT).

The Ethics Board will meet mainly as needed and the chair will be held by the representative of the Guardian Angels project.

Table 11: The members of the Ethics Board.

<table>
<thead>
<tr>
<th>Name</th>
<th>Organisation</th>
<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Eija Kaasinen (chair)</td>
<td>VTT, Finland</td>
<td>Impact analysis of future technologies</td>
</tr>
<tr>
<td>2 Penny Duquenoy</td>
<td>Middlesex University, UK</td>
<td>Ethical and social issues of ICT, governance models for ethics</td>
</tr>
<tr>
<td>3 Kai Kimppa</td>
<td>University of Turku, Finland</td>
<td>IT &amp; Ethics</td>
</tr>
<tr>
<td>4 Norberto Patrignani</td>
<td>Universita Cattolica del Sacro Cuore, Italy</td>
<td>Inclusion</td>
</tr>
<tr>
<td>5 Olli Pitkänen</td>
<td>Helsinki Institute for IT, Finland</td>
<td>Legal and ethical issues</td>
</tr>
<tr>
<td>6 Marc van Lieshout</td>
<td>TNO, Netherlands</td>
<td>Societal impacts, policy implications</td>
</tr>
<tr>
<td>7 Philippe Goujon</td>
<td>University of Namur, Belgium</td>
<td>Governance models for ethics</td>
</tr>
<tr>
<td>8 Diane Whitehouse</td>
<td>Castlegate Consultancy, UK</td>
<td>Security and privacy</td>
</tr>
<tr>
<td>9 Stephen Rainey</td>
<td>University of Namur, Belgium</td>
<td>Governance</td>
</tr>
</tbody>
</table>

Table 12: Overview of the tasks and responsibilities of the Ethics Board.

<table>
<thead>
<tr>
<th>Ethics Board (EB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meetings</strong></td>
</tr>
<tr>
<td><strong>Composition</strong></td>
</tr>
<tr>
<td><strong>Responsibility</strong></td>
</tr>
<tr>
<td><strong>Chair</strong></td>
</tr>
</tbody>
</table>
| **Tasks** | • To participate in the EB meeting  
• To give advice about ethical matters which might be encountered in the project  
• To give feedback to the SSB and the BoD if necessary |
8. Board Of National Representatives (BNR)

The Board of National Representatives consists of one representative of each participating country of the consortium members (currently 16) and can be enlarged by a decision of the Scientific Steering Board if organisations located in other European countries as well as the relevant governmental institutions are interested in supporting the Guardian Angels FET Flagship via the proposed Open Calls.

The main task and focus of this board will be

- the identification of funding possibilities (mechanisms) within the participating countries, enabling the creation and support of Open Calls within the Guardian Angels project similar to ERA Net activities
- the alignment of the scientific (content) of national calls with GA calls and the final decisions on the funding allocated to these calls
- feedback on national priorities that could come under the technical umbrella of GA and on the applications domains considered high impact and/or of strategic interest for Europe

The representatives of this board must come either from governmental institutions or the relevant research funding organisation having the power and willingness to support universities, research organisations and/or industry doing research in this specific area.

The possible members have already been identified and will be invited at the beginning of the project.

Table 13: Overview of the tasks and responsibilities of the Board of National Representatives.

<table>
<thead>
<tr>
<th>BOARD OF NATIONAL REPRESENTATIVES (BNR)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meetings</strong></td>
</tr>
<tr>
<td><strong>Composition</strong></td>
</tr>
<tr>
<td><strong>Responsibility</strong></td>
</tr>
<tr>
<td><strong>Chair</strong></td>
</tr>
</tbody>
</table>
| **Tasks** | • To give advice and information about the public funding structure and possibilities in each country  
• To enable the possible execution and management of national calls similar to the calls of the ERA Net scheme  
• To inform all relevant bodies in their country about the discussions in the committee meetings |

3.2.4 Openness and Flexibility: Open Calls

The Open Calls constitute a very important mechanism for successful operation of the GA FET Flagship. They are designed to serve the following goals:

- To enable a high degree of openness of the Consortium at the European level, so that GA is ready to regularly take on board new research groups that were not identified in prior phases and/or have achieved key results of great interest for the flagship roadmaps during the ten years.
- To address various types of identified gaps: scientific, technical, user acceptance, technology transfer and innovation, dissemination and networking, training, etc.
- To be an open channel to bring new scientific communities into the project (not limited to engineering) that are identified during the project lifetime as crucial for the emerging demonstrators.
- To bring new life and dynamism into the project and/or replace activities that were not particularly successful (contribute to risk mitigation).
• To enable a competitive approach to reach ambitious, scientific targets for which very few solutions are known, or focused assessment is needed.

• To offer an efficient instrument for the dynamic management of the project (usable by the Steering Board and/or by the Board of Directors) to prioritize and/or boosts fields of research that prove to be more strategic than others.

• To achieve a better alignment with European and national research initiatives.

The Guardian Angels flagship distinguishes three categories of calls:

• **Internal Open Calls**: Such internal open calls will be supported by reserved fractions (%) of the project budget per each major reporting period. The GA project is organized according 3 major periods: Ramp-up (or Period 1 of 3 years), Period 2 (4 years) and Period 3 (3 years). To organise an internal call, a time-frame of up to 4 months between the opening of the call and the final list of ranked proposals has to be anticipated, based on the following steps:
  - Opening (publishing) the call and receiving template applications
  - Applying the selection procedure (evaluation) for ranking of the proposals
  - Selection of the proposals and inclusion of the new partners in the grant and consortium agreements.

The process for Internal Open calls will be managed by the Open Call Office of the GA FET Flagship under the supervision of the Chair of the SSB and the Executive Project Director. During the project lifetime, the GA consortium plans 4 Internal Open Calls, as follows.
  - GA Call 1, published in Y1(M6) of the ramp-up phase based on a reserved amount of 20% of the funding received from the EC. Both GA associated partners and external (new) partners can apply.
  - GA Call, published in Y3 (M30), ensuring the transition from the ramp-up phase (30 to 36 months) to Period 2.
  - GA Call 3, published in Y5, opening the consortium according to the mentioned criteria for continuity and reinforcement of strategic directions for the final phase.
  - GA Call 4, published in Y7, with the main target to boost exploitation and innovation in applications supported by the created zero-power technology platform.

• **ERA-NET+ (or similar) Calls**: These calls are a result of the negotiation between the EC and the member states with the involvement of the PC. They are foreseen as complementary funding mechanisms requiring matching between the EC and national funding; they do not require any of their own funding (from the amount received from the EC) from the flagship but only a definition of the main call content and of the major time line to meet the roadmaps and the milestones of the FET Flagship. These actions require programme owners or programme managers from at least 5 different member states or associated states to plan a single joint call, with a clear financial commitment from the participating national or regional research programmes. Taking the guidelines of the ERA Net+ Scheme established in FP7 into account, the following additional characteristics have to be considered and should be adapted under FP8 (HORIZON 2020):
  - The total planned budget of the joint call should be at least 5 M€, including the EC contribution.
  - The duration of an ERA-NET+ cannot exceed the duration of the GA FET Flagship periods (3, 4 and 3 years, respectively).
  - Each project financed out of the joint call shall be transnational (i.e. have a minimum of two partners from different countries).
  - The selection of proposals from such calls follows a two-step approach: during the first step, pre-proposals or expressions of interest are received in response to a call for proposals, and partners select those to be developed into full proposals. Step two involves a centralised evaluation by an independent international peer review panel of the full proposals on the basis
At this moment, 15 EU member countries and one associated country are involved in the Guardian Angels Flagship Project. Of these 16 countries, about 8 countries have more than 2 organisations participating in the GA consortium. The types of organisations vary, but universities and research organisations are dominant in most of the participating countries. For that reason, relevant representatives of the member states (funding owners or/and funding managers), which have extensive experience in the execution of ERA-NET+ activities will be involved from the beginning and coordinate these type of calls with the Board of National Representatives to ensure smooth implementation.

**Collaborative Calls with National States:** The GA FET Flagship has received strong support letters from some of the EC member states where the alignment and support of national calls in various programmes is foreseen. While defining the content of these calls will be based on a collaborative effort between the GA Open Call Office, the BoNR and the respective countries, the fund matching approaches will be the object of individual negotiations and addressed on a case by case basis.

### 3.2.5 Risk Management

By its nature, a FET Flagship is a high risk project, with a high degree of complexity and highly inter-dependent multi-disciplinary research. The R&D activities encompass many technology roadmaps that should provide key components for building challenging system demonstrators. The proposed management reinforces a milestone-based strategy with dedicated teams and focused actions for project success. However, the risks associated with the proposed research range from the technology to the system level and will need a specific management strategy, beyond the usual measures applied in existing FP7 instruments.

The strategies to manage risks typically include early identification to avoid the risk, transferring the risk to another party, reducing the negative effect or probability of the risk, or accepting some or all of the potential or actual consequences of a particular risk. In this phase of the preparation, the roadmap and demonstrator leaders have been deeply involved in identifying major risks in their domains of activity. In parallel, operational and/or management risks have been identified. A mitigation measure is proposed for each identified risk. The results of this process are summarized in the following table.

<table>
<thead>
<tr>
<th>Risk description</th>
<th>Prob.</th>
<th>Imp.</th>
<th>Control.</th>
<th>Mitigation measure</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Losing critical staff of consortium partners at a crucial point of the project</td>
<td>M</td>
<td>H</td>
<td>M</td>
<td>The consortium has enough diversity and expertise to replace them. In addition all partners should present backups for involved staff at the start.</td>
<td>Y1-10</td>
</tr>
<tr>
<td>Technical/administrative disagreement among partners</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>PC will act as first mediator. The BoD will make the final decision.</td>
<td>Y1-10</td>
</tr>
<tr>
<td>Initial Workpackage resources underestimated or overestimated in one of the projects compared to the real work.</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>Monitoring of the work and the possibilities for its reallocation if needed, by PO and PC from the very beginning (see “Progress Monitoring”)</td>
<td>Y1-10</td>
</tr>
<tr>
<td>Unexpected delays regarding the finalisation of deliverables</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>Monitoring of the work and the possibilities for its reallocation if needed, by PO and PC from the very beginning (see “Progress”)</td>
<td>Y1-10</td>
</tr>
<tr>
<td>Issue</td>
<td>Recommendation</td>
<td>Monitoring (^{\dagger})</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>---------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>-----------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Call procedures not working, no co-financing possible</td>
<td>M M M</td>
<td>The first 3 years have to be used to inform and involve all relevant member states for the scientific content of GA</td>
<td>Y1-10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problems with the exploitation and dissemination strategy (e.g. developed systems are too costly, not accepted by the community)</td>
<td>M H H</td>
<td>Modification of the developed systems by constant screening of public acceptance</td>
<td>Y3-10</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>T1 Computing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problems with fabrication of nanoscale devices in terms of expected performance and development of the related driving circuitry</td>
<td>M H M</td>
<td>The risk is mitigated by the R&amp;D of different prioritized device concepts in parallel.</td>
<td>Y1-3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switch, memory and 1-bit adder not achieving the 10x energy efficiency improvement</td>
<td>M M M</td>
<td>The effect may be compensated at system level by leveraging other over-performing components and by compromising speed performance (programming time).</td>
<td>Y4-7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Some new proposed architectures (adiabatic, 3D, reconfigurable) present a more important overhead than expected, reducing the expected power consumption reduction.</td>
<td>M M M</td>
<td>Many new ideas are available to reduce the overhead and have to be tested; if this fails, the few proposed architectures with too much overhead could be abandoned.</td>
<td>Y7-10</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>T2 Communication</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>A suboptimal or late selection concerning the communication access technology, algorithms, circuits and device technology selected for every individual (Y3) GA demonstrator has large schedule or performance implications</td>
<td>L H H</td>
<td>A separate task has been defined to focus on this early in the project. Project partners assigned to this task have vast cross-layer design expertise.</td>
<td>Y1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design towards truly self-adaptive communication systems will fail without multidisciplinary work combining MEMS and carbon RF technology, reconfigurable circuits and antennas, and adaptive algorithms, all sharing system knowledge</td>
<td>M M H</td>
<td>All adaptively-related research tasks in the roadmap are clustered in a research sub-group to ensure close linking. Additionally, a separate task brings all contributions together at system level.</td>
<td>Y7-10</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>T3 Sensing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small number of partners in the GA for circuit development for ultra-low power sensing</td>
<td>H M M</td>
<td>Sub-contracting, open calls, industrial collaborations</td>
<td>Y1-10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In gas- and bio-sensing the stability / drift and refreshing of miniaturized sensors is a continuous challenge, in particular if the sensors are applied in uncontrolled environments.</td>
<td>H M L</td>
<td>Basic material and engineering research has to be started at the very beginning with a particular focus on such challenges; continuous benchmarking</td>
<td>Y1-10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y10 power consumption targets of many of the proposed sensor concepts require solutions close to the theoretical thermal limit of sensing. Excess noise, parasitic elements and techn. limitations may not allow coming close to the thermal limits.</td>
<td>H H M</td>
<td>Basic engineering science research must be started from Y1 to tackle the identified major research challenges in inertia, pressure, chemical and bio sensing; continuous benchmarking</td>
<td>Y4-10</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>T4 Energy harvesting</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy harvester not delivering enough power, due to material issues/losses , lower conversion efficiency</td>
<td>M H M</td>
<td>Use multiple (array/stacked/hybrid) harvesters to increase the overall output power. Increase total area of harvester in order to generate more power</td>
<td>Y1-3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conversion Power loss of Power Management too high; PM cannot operate at very low input voltages, 10s mV or lower available from the EHs</td>
<td>M L M</td>
<td>Use present state of the art power converters for low input voltage (e.g. for TEGs) - LTC®3108, Efficiency 50%; Increase harvester size for higher input power to PM circuit</td>
<td>Y1-3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery density too low</td>
<td>H M M</td>
<td>Use off the shelf Supercaps. Alternatively, use stacked thin film batteries. All solutions compromise on volume</td>
<td>Y7-10</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>T5 Heterogeneous Integration</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reliability of interconnect in the multifoil approach</td>
<td>H M M</td>
<td>Multifoil technology is necessary only for high complexity systems. Many applications can use monofoil systems e.g. with form factor increase</td>
<td>Y3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feasibility of a full top-down GA design and engineering methodology</td>
<td>M M H</td>
<td>Use only modelling of subsystems in order to avoid heterogeneous systems modelling difficulties. Restrict synthesis tools to conventional areas (electronics, software)</td>
<td>Y10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### T6 Software

<table>
<thead>
<tr>
<th>Description</th>
<th>Impact</th>
<th>Probability</th>
<th>Controllability</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software depends on the underlying hardware platform in terms of (1) computation, memory and communication architecture and (2) physical properties. This information is available too late.</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>Y1-3</td>
</tr>
<tr>
<td>The investigations in the platform activity on software are not relevant for the demonstrators.</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>Y1-10</td>
</tr>
<tr>
<td>Reliability of stretchable complex systems on foil</td>
<td>H</td>
<td>M</td>
<td>M</td>
<td>Y10</td>
</tr>
</tbody>
</table>

**D2 Environmental GA**

<table>
<thead>
<tr>
<th>Description</th>
<th>Impact</th>
<th>Probability</th>
<th>Controllability</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>The power requirements of imaging techniques required by the demo on effective inclusion of visually impaired and blind people in society cannot be met by the energy harvesters.</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>Y3</td>
</tr>
<tr>
<td>Sensor stability limits the lifetime requirements for the smart air quality companion.</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>Y10</td>
</tr>
<tr>
<td>The variety of sensing quantities for the disaster management may exceed the variety of sensors which can be developed within Guardian Angels.</td>
<td>H</td>
<td>M</td>
<td>H</td>
<td>Y10</td>
</tr>
</tbody>
</table>

**D3 Emotional GA**

<table>
<thead>
<tr>
<th>Description</th>
<th>Impact</th>
<th>Probability</th>
<th>Controllability</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is impossible to check the accuracy of the measured emotion because the golden reference does not exist</td>
<td>H</td>
<td>M</td>
<td>M</td>
<td>Y1-3</td>
</tr>
<tr>
<td>The concept of objectively monitoring the body response to emotion is not accepted nor adopted by society</td>
<td>M</td>
<td>H</td>
<td>M</td>
<td>Y1-10</td>
</tr>
<tr>
<td>The current reimbursement business model does not fit the deployment of emotional Guardian Angels in the health care system</td>
<td>H</td>
<td>H</td>
<td>M</td>
<td>Y1-10</td>
</tr>
</tbody>
</table>

**Prob.:** Probability  
**Imp.:** Impact  
**Cont.:** Controllability  
**Levels:** H = High, M=Medium, L=Low.

### 3.3 Resources to be Committed

#### 3.3.1 Guardian Angels budget

In section 2.7, the resources (funding) needed to implement the GA roadmaps have been detailed for the 10-year duration of the FET Flagship. Fig. 16(a) depicts the % balance between the zero-power technology platform, the GA demonstrators, and other activities such as project coordination (management), dissemination, training and networking, and support to innovation. It is worth noting that the total funding budget is 996MEuros, with 89% dedicated to scientific and technical activities. In terms of timelines, the project is divided into Periods 1, 2 and 3 (each ending with major milestones) having 13%, 47% and 40% of the total budget, respectively (Fig. 16(b)). Period 1 includes the 30-month ramp-up phase with a planned funding budget of 130MEuros, distributed between demonstrator and technology roadmaps as per Fig. 17.
3.3.2 The Guardian Angels funding scheme

The GA FET Flagship will operate according to the following governance and funding principles:

- A two-phased approach will be followed consisting of (1) a ramp-up phase of 30 months funded under FP7, possibly complemented by 6 additional months under Horizon 2020 (FP8), forming together Period 1 of the project and (2) a consequent full project phase of 7 years funded under Horizon 2020 (FP8), forming reporting Periods 2 and 3.

- In the Horizon 2020 phase, the EC funds will be matched by national matching funds provided by both the national/regional authorities as well as the individual project partners. The national matching funds will include ERA-NET+ fresh funds, funds from the alignment of existing and/or created national programs, in-kind contributions (infrastructure, equipment, buildings, fabrication, etc.), and institutional and structural funds (see Fig. 19(b)). The balance between EC funding and national matching should be close to 1:1 in the Horizon 2020 (full) phase.

- The budget for the ramp-up phase includes 50MEuros of research funding from the EC attributed to a CPCSa proposal, which is a combination of an Integrated Project (Collaborative Project) and a CSA (Coordination and Support Action), and 10MEuros attributed to an ERA-NET+ action. As the latter needs
to be matched by 20MEuros by the national states, an overall public funding of 80MEuros for 30 months is assumed to be available (see below Fig. 18). Additional public funding could be added via national initiatives (matching), especially for the countries that are not part of the ERA-NET+ action. For the CPCSA budget, a detailed proposal and workplan should be submitted in a dedicated call to the European Commission by October 23, 2012.

- A well-defined process for the Open Calls will concern the use of 20% (10MEuros) of the CPCSA funding from the EC and 10MEuros (matched by 20MEuros from national states) from ERA-NET+. Participation in these calls will be offered to external groups and to the associate partners of the GA FET Flagship. The associate partners of the consortium are distinguishable by their initial involvement in the CPCSA grant only for benchmarking and dissemination activities, having attributed a lumped amount on the order of 150kEuros per partner for 30 months. The process and the selection of new partners for the open calls will be organized by the GA Consortium for the 20% of the CPCSA budget and in cooperation with the EC and the national states for the ERA-NET+.

- The Guardian Angels FET Flagship will operate as a hybrid between a project (fixed consortium) and a program (based on Open Calls). We expect that during the full project phase, the funding associated with the calls will be on the order of 20-30% of the total funding of the project. The Calls will be managed by the FET Flagship management, according to the principles of objective evaluation and confidentiality used by the EC and the national states. For a good balance between openness and management, we have planned four (4) calls along the GA FET Flagship lifetime:
  - Call 1 (budget: 20% of CPCSA): published in Period 1, month 6-9 of the CPCSA with a full process duration (applications, evaluation and signature of the grant agreement by new partners) of maximum 6 months.
  - Calls 2 and 3 (budget: each 20% of the FP8 instrument funding): during Period 2.
  - Call 4 (budget: 30% of the FP8 instrument funding): during Period 3.

![Guardian Angels Consortium](image)

**Fig. 18**: Sources of funding for Period 1 of the GA FET Flagship and graphic depiction of the process of funding of core and associated partners (GA consortium) that benefit in different ways from the available funding through CPCSA and Open Call processes, respectively.
In order to ensure a smooth coordination between the dynamic processes of FET Flagship funding by the EC together with the national states, our flagship has actively participated in the Governance and Funding subgroup created by the FLEET CA. We actively provided feedback and took into account the boundaries of the complex exercise to propose an adapted governance and funding vision and adapted mechanisms to evaluate and implement that vision. Particularly important roles have been played by the two project coordinators and the Governance and Funding Manager of the GA Pilot.

### 3.3.3 Funding outlook

From the very beginning of the pilot action, public authorities were contacted by GA partners and were informed about the FET Flagship concept in general, and the Guardian Angels project specifically. Discussions on how to possibly co-fund the flagship(s) from a national/regional perspective took place, often in dialogue and coordination with the participants of other Flagship initiatives, and in parallel with related discussions between the EU and MS representatives. GA partners also contributed actively to the Flagship events organised by the EU (FET11 and the Warsaw midterm event) as well as to national FET Flagship promotional events (in Spain, UK, Ireland, France, Switzerland, Japan and the USA) that will continue through the summer of 2012 with events in Germany and Belgium. These events triggered particularly strong support from some of the large countries such as France; the letter from the Ministry of Research in France states that the GA FET Flagship is a “very high priority in France” and that they have “asked the national research agency to launch a specific call” aligned with GA. In the UK, the EPSRC funding agency will send assessment letters directly to the EC and 10M£ seems to be foreseen as the matching funds at the national level for the GA project. It is worth noting that in Switzerland, the support for the winning FET Flagship will be extremely strong. The letter from the Swiss State Secretariat for Education and Research (SER) says that an important budget has been reserved for the shortlisted FET Flagships (GA being included in the three priorities of Switzerland, including support for the ramp-up phase on top of the ERA-NET+). Note that the two coordinators, EPFL and ETHZ, have very concretely committed in-cash contributions of 2.4MCHF and in-kind contributions of 3MCHF for the ramp-up phase of GA in their letters of support.

Quite early in the process, it became clear that the other GA partner countries are also willing to financially support the Flagship initiative as a concept and/or Guardian Angels specifically. Firm commitments could not yet be made, however, especially with regard to the amount of national/regional funds that would be attributed to this and other Flagship initiatives. Countries are waiting for final EC decisions regarding the co-funding requirements and the ERA-NET+ call conditions, and for more information on the actual Flagship content and the contributions of national/regional partners. The latter will become available with this report (of which a version will be made public) and the subsequent CPCSAs proposal. More concrete commitments are thus expected by the submission date of the CPCSAs in October.
Along with the letters of intent from Switzerland and France, letters of intent are also available for Ireland (Science Foundation Ireland), Denmark (Danish Agency for Science, Technology, and Innovation) and Belgium (FWO, FNRS). The letters explicitly express the support of these public organisations for the Guardian Angels project, and the existence of funding instruments which could be used for Guardian Angels co-funding purposes. Although other countries are also supportive of the initiative, as was expressed during individual contacts between GA and funding agency representatives, they preferred not to provide individual letters of intent for Guardian Angels or any other FET Flagship initiative at this time, as they were not yet able to prioritise between the initiatives, and/or had not yet decided what specific funding instrument to use. Among these countries are the UK, Germany, Finland, Sweden, Italy, Spain, Slovakia, Romania, and Poland. The Netherlands and Greece, both in election periods, also did not want to provide explicit letters of intent at this time. However, the different authorities and agencies promised to further consider and discuss the GA co-funding issues during the months to come, and to express their concrete commitments to the EC at a later time.

Besides the financial contribution coming from public authorities in each of the participating countries, industrial GA participants are willing to co-fund their share of the research as they do in other EU and national projects. Universities and research institutes will match EU funds by providing access to their infrastructure, doing research in complementary projects in GA-related domains, assigning professor time, etc. Besides these in-kind contributions, of which more details can be found in the partner-specific letters of intent in appendix to this report, some organisations also foresee additional FET Flagship-specific funding, e.g. ETHZ, EPFL, KU Leuven and DTU.

Finally, one last aspect of the funding outlook concerns the support and coordination with ENIAC Joint Undertaking and EPOSS (the European Technology Platform in Smart System Integration); their directors have expressed a strong support of the GA FET Flagship and pointed out the complementary approaches and reciprocal added value. In the letter of Dr. Andreas Wild, the ENIAC Executive Director, it is mentioned that the “breadth and depth of the research plan exceeds the normal scope of the projects supported in the existing schemes and shall rely on federating various sources of funding at the national level, in the intergovernmental EUREKA cluster CATRENE, in the ENIAC and ARTEMIS Joint Undertakings combining national and European funding, or in the European programmes running under the Framework Programme 7 or in the future Horizon2020 programme. The strategy developed by the ‘Guardian Angels for a Smarter Planet’ project can play a structuring role, enriching the research agenda of all these funding mechanisms; they can surely contribute in implementing specific topics, in addition to the own funding and governance mechanisms of the overarching project described in this proposal”. The Head of the EPOSS office mentions that “EPOSS and Guardian Angels are foreseen to be fully complementary” and highlights the “disruptive” aspects of GA and the highly positive impact on the European economy. In conclusion, GA has carefully aligned its strategy and proposed work with existing major European joint undertakings and/or programs and their funding, for an efficient coordination of effort, funding and priorities.


4 Impact

The future of ICT and sustainability: why GA technology and applications are so important

Information and Communication Technology (ICT), which is now almost entirely built on a platform of electronic devices, has been called a “threshold technology”. This means that it has the potential to move us either toward a truly sustainable future or in the opposite direction: toward a world of ever-increasing socio-economic inequality and environmental damage.

Modern societies in highly industrialised nations increasingly depend on computing and communication with constantly decreasing cost and energy consumption. Indeed, applications built with advanced silicon CMOS technology are enabled by the aggressive scaling of the MOS transistor and the reduction of the cost per transistor by an amazing factor of $10^6$ in only 35 years, a level never reached by any other modern technology. Moreover, in the last two decades we have experienced a revolution in communication. The internet, along with mobile communication, have transformed our society such that information is available almost instantaneously everywhere. We can do business with and interact with people all over the globe in real time, and mobile devices ensure that we are connected at all times. Indeed, ICTs play a crucial role in boosting innovation, prosperity and competitiveness of all industry and service sectors.

On the other hand, the electronic devices and systems that have enabled this information revolution pose more environmental challenges than almost any other category of products. They contain a large diversity of materials, and require extremely precise structure and assembly on a very small scale, which could make them extremely resource-intensive to produce. At the end of their product lifecycles (which are constantly shortened through technological and fashion-induced obsolescence), they are added to the ever-growing flow of e-waste, an increasingly controversial problem.

But ICT also provides us with hope because it has some of the greatest potential for solving our global challenges: to improve the quality of life for impoverished and underserved communities of people worldwide, while simultaneously reducing our overwhelming environmental footprint. The way forward – on the path to true sustainable development – requires that we find a way to increase access to ICT and the services it provides, and at the same time exponentially reduce the environmental impacts associated with electronic products themselves.

In the GA FET Flagship we believe that designing environmentally sustainable (nano)electronics is important. Advances in recycling technologies, smart infrastructures, and technology innovations that enable a better, more enjoyable, more energy-efficient society could serve as a foundation for the transformative leaps that will lead to a sustainable high-tech industry in the near future. The Guardian Angel FET Flagship is contributing to a significant part of these challenges and will have a strong impact on many domains as summarized in Table 14 below, and as explained in more detail in the following sections. The selected demos in Table 14 were chosen for their highest combined impact on science, economy and society. A graphical depiction of some of the GA scenarios is shown in Fig. 20, based on the GA movie conceived during the pilot phase to disseminate major ideas to the general public. (A public version of the movie is at http://www.ga-project.eu/.)
Table 14: The GA demonstrators, and their expected impacts on important areas.

<table>
<thead>
<tr>
<th>Demonstrators</th>
<th>Science and Technology</th>
<th>European Scientific Leadership</th>
<th>Economy</th>
<th>Society</th>
<th>Coop. between ICT and other domains of science and technol.</th>
<th>Environment</th>
<th>Innovation and start-up creation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical GA: monitoring the functional and nutritional status in the elderly</td>
<td>++</td>
<td>+++</td>
<td>++</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Physical GA: early diagnosis and management of metabolic disorders</td>
<td>++</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
<td>=</td>
<td>=</td>
<td>++</td>
</tr>
<tr>
<td>Physical GA: impact of Alzheimer’s disease on body processes</td>
<td>+++</td>
<td>++</td>
<td>+++</td>
<td>++</td>
<td>=</td>
<td>=</td>
<td>++</td>
</tr>
<tr>
<td>Environmental GA: Smart air quality companion for indoors and outdoors</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Environmental GA: Effective inclusion of visually impaired and blind people in society</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Environmental GA: Guardian Angels for disaster management</td>
<td>++</td>
<td>+</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Emotional GA: Enhancing the (emotional) performance or well-being of healthy people</td>
<td>++</td>
<td>+</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td>Emotional GA: Supporting patients</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>=</td>
<td>=</td>
<td>++</td>
</tr>
</tbody>
</table>

Fig. 20: Depiction of general GA system application scenarios, reflected in some of the demonstrators which were analysed for impact.
4.1 Transformational Impact on Science and Technology

We are presently entering a new phase of ICT development that will drive growth and sustainable development for the coming decades. In the future, people, systems and objects will interact seamlessly with each other. Today, there are an estimated 4 billion mobile phone subscribers worldwide,\textsuperscript{34} and by 2015, there will be approximately 1 trillion connected devices in the world,\textsuperscript{35} which overall constitute an “internet of things”. However, current technologies are too energy-inefficient to capture the opportunities and the economic value associated with these changes. Massive improvements in energy efficiency and energy harvesting are needed to enable this new era of ICT.

Today, all electronic systems – whether large, small, mobile or stationary – are confronted with a major challenge. Their energy consumption is continuously increasing due to the increasing functionality and the limits of the conventional technology. The urgency to identify and develop adequate and timely solutions is justified by the alarming trends in global energy demand, the finite nature of conventional oil and natural gas reserves, and the need to dramatically curb greenhouse gas emissions. The urgent need for zero-power electronic systems will also enable new mobile and remote applications not possible today.

A substantial and growing part of the total energy consumption is related to information technologies: the energetic cost of data processing, and along with it the cost of operation, are rising dramatically. They are projected to rise even further, unless disruptive technologies such as those proposed by GA are introduced to reverse this trend. Currently, it is estimated that the overall power consumption of electronic equipment makes up roughly 10% of power consumption worldwide while their energy inefficiency results in an energy waste on the order of 40-50%.\textsuperscript{36}

The core of the GA concept is zero-power technologies, which stem from a combination of extremely low-power devices and systems, combined with versatile and highly efficient energy harvesters. Therefore, the focus of GA on energy-efficient systems drives a holistic view of the technologies, which have so far mainly been explored and developed individually, instead emphasizing a system-level perspective.

4.1.1 Impact on electronic systems

With the technologies developed in the GA, we expect a reduction of static power dissipated by logic circuits by around three orders of magnitude, while the dynamic power will be cut by one to two orders of magnitude. The targeted energy savings, combined with small-size energy harvesting, would alleviate the need for external charging of batteries, and thereby open up completely new areas for R&D and deployment of electronic devices. Also, a zero-power platform would allow for increased integration of functionality and more intelligent portable systems, and thus give rise to an explosion of new applications and devices. The development of new bio-inspired computing schemes may fundamentally re-invent electronic systems, thus transforming software, circuits, system architectures, and programming schemes.

4.1.2 Impact on the scientific community

A unique advantage of GA is its very high level of multi-disciplinarity. It will necessarily bring together researchers from medicine, biology, physics, electrical engineering, and computer sciences, to mention only the core disciplines. This is expected to have a large impact on multi-disciplinary science, combining the knowledge and techniques of the various disciplines to find new insights and new approaches, and create highly innovative solutions and products. For example, both electronic hardware and algorithms may be inspired from biological systems to a higher extent than is the case today. The close collaboration between the different disciplines

\textsuperscript{34} http://www.cellular-news.com/story/35298.php
\textsuperscript{35} http://www.readwriteweb.com/enterprise/2010/06/ibm-a-world-with-1-trillion-co.php
\textsuperscript{36} D. Gill, IWFIP, 2010.
established in GA will have a long-term impact on the scientific community and will launch and foster new research areas.

4.1.3 Availability of vast amounts of data

With the different GA families, we will be able to monitor and measure vast amounts of data pertaining to health, environment and behaviour. The collection of this data naturally poses challenges with respect to privacy and safety of individuals, which must be dealt with accordingly. It is, however, also extremely valuable information for researchers in a broad range of fields. It gives insight into the state of things on many different levels: biological, medical, environmental, behavioural, etc. Furthermore, it allows the coupling of different markers across disciplines to determine "cause and effect". This will lead to more targeted therapies, better-identified safety threshold levels, and the development of new devices and systems to meet our needs.

4.1.4 Impact of prioritizing energy-efficient technologies

The energy harvesting developed within GA is targeted to supply relatively small-size electronic devices, as well as to allow the deployment of autonomous sensor systems throughout our environment. However, once developed, many of these technologies (solar, thermoelectric, green batteries, etc.) might be scalable to much larger systems. This will then promote the development and growth of renewable energy sources. For example, one of the barriers to the more widespread use of renewable energy is the difficulty (technical and financial) associated with storing this energy when it is not used immediately. In this case, research on efficient energy storage can have a wide impact on the attractiveness of such technologies.

4.2 Impact on Society

4.2.1 Impact on Quality of Life

In general, it is recognized that ICT has already played a key role in many aspects of human development. This includes advances in electronic-based services, medical imaging, sequencing technology for the mapping of the human genome, smart vehicles, efficient systems for the climate control of buildings, renewable energy technologies, etc. Furthermore, ICT penetration is strongly correlated with the emergence of democracy, economic development, and the empowerment of under-represented groups. Overall, this collection of technologies has dramatically improved the quality of life for a large part of the world’s population.

The contribution of the GA FET Flagship to quality of life is very clear. First, GA is a project that will directly contribute to disruptive progress in ICT technologies and new related services. It is not only a user of ICT technologies with some limited indirect consequences for ICT but rather its research is placed in the core of ICT research. In addition, the applications generated by the proposed zero-power enabled, smart systems are concerned with new, advanced services in multiple domains of life (medical, transportation, communications, smart buildings, social networking, etc.) which is one of the most effective ways to have a direct impact on improving the quality of life.

4.2.2 Impact on Health Care

The past two decades have seen significant progress in the field of biology, such as the sequencing of the human genome and the resolution of membrane proteins at the molecular level. In parallel, technical developments in medical imaging allow the non-invasive visualization of the brain and its activity. These major accomplishments bring us to the verge of personalized medicine. However, in spite of the large efforts in research and targeted drug design, little progress has been made in improving the treatment of lifestyle-related chronic diseases.

Due to the prevalence of chronic diseases in Europe, and the associated economic and societal burden, it is now recognized that the prevention of chronic diseases and closer follow-up of patients are two key components for improving the quality of life. The efficacy of prevention as opposed to treatment is reflected by the reduction in
the number of cases of lung cancer and heart attacks obtained by adopting a healthy life style (exercising, stopping smoking). The importance of a closer follow-up is shown for chronic diseases that are already diagnosed, such as diabetes, where self-management is the most efficient way to improve quality of life and prevent unnecessary hospitalization. Fig. 21 shows the relevance of prevention and self-management to life expectancy.

The improvement in quality of life and the reduction of hospitalization bring associated cost savings at both the individual and societal levels.

Data collected by the world health organization (WHO) concerning European countries provide a clear picture of the most prevalent chronic diseases, which will become the natural targets for Physical GAs to improve life conditions.

Physical GAs are devices specially designed to simultaneously measure several body parameters such as body sound, electrocardiogram (ECG), blood pressure, or O₂ to CO₂ ratios. Captured data will be analysed in real time to provide the physiological status of the person wearing the device. Such body parameters will be useful for controlling and recording the physiological status of healthy people, as well as that of people with a chronic disease or frailty. Miniaturization of the sensors and processing units, along with minimal power consumption, strive toward long-lasting recordings such that GAs would become “forgettable devices” whose presence would no longer be noticed by users.

Measurements carried out over a long period of time (several days or even months) will provide a follow-up of health status where each individual will become his own self-reference in the case of the significant deviation of a physiological parameter. For example, analysis of heartbeat and its fluctuations will allow the establishment of the effects of exercise or stress, so that deviation from the natural variations will be identified as the signature of a disease trend or onset. Similarly, tracking the circadian rhythms will allow the identification of significant deviations, often the first marker of a psychological or psychiatric disorder. GAs will soon become indispensable health assistants, providing useful records for physicians, and functioning as an alert system by signalling changes or worsening of physical condition. GAs are predicted to generate new habits and healthier lifestyles, and to improve disease management.

Physical GAs can be divided into three categories: a) non-invasive devices, b) minimally invasive devices and c) invasive devices. Non-invasive devices include “smart skin” sensors, smart clothing, etc. Minimally invasive devices include intelligent pills that can be swallowed and miniature sensors that can be injected with a needle. Invasive devices are intended to be put in place during surgical interventions, such as the positioning of a coronary stent, cardiac surgery, etc. Importantly, the zero external power consumption of GAs will enable new applications not foreseen in today’s medicine for several types of interventions, including more benign interventions such as bone fractures and cataracts.

Fig. 21: Expected improvements of quality of life and life expectancy with prevention.
From the individual’s point of view, GA will offer many health benefits. Recordings of their physiological and physiopathological conditions will complement the symptom description for the physician, optimizing evaluation of the database of their health status. It is expected that data sets provided by GAs will help in reducing diagnostic time and therapy, which can be optimized as a function of the personal recordings.

From the physician’s point of view, GA developments are expected to provide better diagnostics, through patient records and the monitoring of physiological conditions, and better information concerning the treatment with follow-up and improvement of patients’ compliance. In addition, whenever required, GA will provide a direct connection through dedicated networks to optimize emergency response.

From a health care management point of view, GA records represent an enormous advantage for the development of a consolidated database. Physiological data and conditions for each GA patient can be stored and when necessary made instantaneously available for physicians in charge of the patient. Epidemiological studies and medical treatment efficacy studies will be greatly improved since more subjects can be followed, more parameters per subject can be logged, and parameters can be captured with a shorter time constant (measuring every second instead of measuring every week).

From a societal point of view, GA developments are expected to delay disease onset through better prevention and self-management of persons at risk. Consequently, reducing treatment and hospitalisation will minimize individual and societal health care costs.

Ageing of the population is a growing concern, and while the fraction of people over 65 years old is still below 20%, it is expected to increase to 54% by 2050. Frailty is generally described as a syndrome of decreased reserve and resistance to stressors, resulting from cumulative decline across multiple physiological systems, and causing vulnerability to adverse outcomes including mortality, disability, institutionalization and falls, especially affecting the elderly population.

Ageing: The major health burdens in terms of decline in physical mobility are the disease states osteoporosis and sarcopenia (age-induced loss of skeletal muscle mass and strength). It is estimated that in Europe, approximately 800,000 older adults will suffer a hip fracture each year and that the cost of all osteoporotic fractures in Europe is provisionally forecasted at €25 billion. Similarly, in the US (2005), the total burden of osteoporosis was estimated to be >2 million incident fractures at a cost of almost $17 billion, and by 2025, the burden is projected to grow by almost 50% to >3 million fractures and $25.3 billion each year; the same trend can be expected in Europe as well.

Depending on various estimations, sarcopenia has been reported to affect 5% to 13% of 60-70 year-olds and 11 to 60% of persons older than 80. Elderly between 70 and 80 years old and in the lowest quartile of muscle density (sarcopenic patients) exhibit a 51% higher risk of hospitalisation than those in the highest
quartile. Sarcopenic patients exhibit an increased risk of falls and fractures, but also of nosocomial infection during hospitalisation. In 2000, the direct healthcare cost attributed to sarcopenia in the United States was estimated at $18.5 billion, which represented about 1.5% of total healthcare expenditures for that year. The excess healthcare expenditures were estimated to be around $900 for every sarcopenic patient. A 10% reduction in sarcopenia prevalence would result in savings of $1.1 billion (dollars adjusted to 2000 rate) per year in U.S. healthcare costs. In fact, loss of mobility associated with skeletal muscle deterioration, is one of the primary determinants of the need for nursing home care. Furthermore, in addition to disability, sarcopenia may also have an effect on osteoporosis, obesity, and type II diabetes mellitus and their associated healthcare costs.

By putting intervention programs in place to address the decline in physical function, as the one proposed in the first demonstrator of the Physical GA roadmap (see annex), the forecasted costs and fracture and muscle-wasting trajectories for both Europe and the US can be favourably altered.

**Metabolic disorders:** According to the World Health Organization, at least 2.6 million people die every year as a result of being overweight or obese. Of these deaths, 44% are attributable to diabetes, 23% to ischaemic heart disease and 7–41% to certain cancers.

A healthy diet and regular practice of physical activity can help prevent obesity and reduce the risks of obesity-associated metabolic diseases like diabetes. In our modern society, where high-calorie foods are easily accessible and opportunities to engage in physical activity are low, there is a need for personalised monitoring and feedback to help people engage in healthier lifestyle habits. Although education is a milestone in developing a healthy lifestyle, adopting and maintaining a healthier diet and regular physical activity remain a challenge. For this reason, one Physical GA sub-project aims to design and deploy a novel system which, through continuous objective monitoring of all relevant physical and biochemical markers and personalized lifestyle recommendations, would support the prevention of metabolic disorders and early diagnosis of at-risk populations.

Diabetes is a major global health concern. In 2011, more than 366 million people suffered from diabetes, compared to only 35 million in 1985. By 2030, this number is expected to reach 552 million. It is evaluated that 183 million of people are undiagnosed. Diabetes caused at least 465 billion dollars (about 355 billion Euros) in health care expenditures in 2011, about 11% of the total health care costs for adults. Diabetes is a chronic disease that arises when the pancreas does not produce enough insulin, or when the body cannot effectively use the insulin it produces, leading to raised blood glucose levels. Type-2 diabetes (the most common form) is generally associated with obesity, a sedentary life-style and an unhealthy diet. Long-term consequences of this chronic disease include the impairment of nerve function and blood vessel function, leading to sensory loss, retinopathy, renal failure and cardiovascular disease. The prevention of diabetes and its associated risk factors, as detailed by the Physical GA sub-project concerned with metabolic disorders, is therefore a major goal for the improvement of health and social care, and the reduction of health costs.

### 4.2.3 Impact on Human-Technology Interaction

Over forty years of happy CMOS scaling brought the room-sized supercomputer for the nerds into everyone’s pocket, literally connecting everybody on earth. In an economy which is based on double digit growth, the obvious next step is to connect everything on earth.

Computing history started with large, power-hungry machines accessible to a lucky few, typically in research laboratories. The use of discrete transistors in the fifties reduced the big-hall size of the former vacuum tube computers to room size. The introduction of small integrated circuits in the sixties further reduced the size to

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occupy a single cubicle and in the seventies even a single desk. In the eighties, the further exponential increase in integration density reduced the size of a computer to fit on top of a desk. This enabled people to install them at home: the desktop personal computer (PC) was born. This increased the market size from a few mainframes to hundreds of millions of PCs. In the nineties, transistor density became so high that a device could not only combine computing and storage like a PC, but could also add communication capabilities: the mobile phone was born. This exponential decrease in feature size enabled today’s information processing and entertainment (often called “infotainment”) industry which is the biggest market for the electronics industry today.

![Today vs. Tomorrow interfaces](image)

Evolving from connecting everybody to connecting everything will grow the potential market to multiple tens of billions of devices. Electronics will become hidden in the background, mostly unnoticed by people. And it will not just provide humans with information processing and entertainment, but will actually help to solve the grand challenges our society faces: better and more affordable health care for everyone, safer and more efficient transportation, a cleaner and more sustainable environment. Realizing this requires changing the way people interact with technology: abandoning the traditional keyboard/screen user interface so that electronic devices become autonomous, independent from a human in the loop, providing services in the background. Autonomous operation hence requires advanced sensors and actuators, energy scavenging from the ambient environment, and zero-power computation, storage and communication. Only through these new ways of interacting with technology, can electronics truly become the enabling technology to solve the world’s social and economic challenges.

### 4.2.4 Impact on Security and Safety

GA technology can capture, process and report a large diversity of data in dynamic, difficult, dangerous, or remote environments. These capabilities will allow the development of a myriad of useful applications in security and safety. Increased safety by monitoring on-the-fly environmental conditions and sensitive area transportation facilities could be the first applications. GA zero power technology could also be the enabler of future generations of autonomous robots used for specific missions concerning security and safety.

Safety and security in transit systems are of major concern because of the open nature of transit and the high density of people transported along thousands of miles of road or track. Maintaining the safety of the public and transit personnel while effectively managing incidents creates challenging demands for transit and emergency management staff. To meet the varying safety and security needs, GAs will be deployable in the various environments that make up the transit industry, and could offer the following useful functions: (1) monitoring and optimization of time and decisions, (2) smart drive assistance for both car and airborne transportation, (3) early signalling for improved prevention of accidents, and (4) automatic action in life-threatening situations following accidents or disasters.

GAs could be used as a security system for the early detection of threats in diverse situations, ranging from environmental disasters to industrial chemical leaks to terrorist attacks. A protection shield against these attacks
is an effective means to improve our security, and can be made available by the usage of zero-power GA technology. This shield could detect toxins and explosives automatically, just as a trained dog would sniff them out. A dense and self-organising network of zero-power GAs could be deployed in buildings, public transportation, and water supply facilities. The GAs would be networked, so that when danger was detected, an immediate warning could be provided to the public and to security forces. Early detection of the location of the source gives warnings, before toxins reach adjacent areas and the source can be encapsulated. Concentrations of security GAs at checkpoints at the entrance of crowded public sites (e.g. to detect people wearing explosives) would be recommended.

Personal safety could also be enhanced by similar networks, or by devices we carry or wear; carbon monoxide (CO) intoxication is still the major reason for unintentional death in US homes, and explosive or toxic gases can emanate from gas pipes or uncontrolled burning or chemical processes. The zero-power Guardian Angels technology networks will make many places safer for us. They could be especially useful for unaccompanied children or old people, who may need a bit of extra help to look after themselves.

4.3 Impact on the Environment

ICT has a unique role in the future of global energy because it can lead to important efficiency gains. In the SMART 2020 report, it was pointed out that while the ICT sector should continue to improve the energy efficiency of its own products and services to limit its environmental impact, its largest influence would be in enabling energy efficiencies in other sectors. According to the same report, this is “an opportunity that could deliver carbon savings five times larger than the total emissions from the entire ICT sector in 2020”, a 15% reduction of emissions over business-as-usual estimates, and a total of approximately 600 billion Euros in cost savings. The impact on environment is therefore obviously high.

Within this framework, GA technologies and services will contribute to the positive effect of the ICT sector on the environment, through dematerialization, the saving of energy and natural resources, and transparency in eco-information. Moreover, GA demonstrators aim to limit their own negative impact. Indeed, the vision of tomorrow’s world with Web3.0, also called the Internet-of-Things (IoT), calls for the deployment of up to a trillion tiny wireless devices. Limiting the environmental impact of each device is thus crucial in order to prevent it from overwhelming the positive effect of the energy savings in other sectors. Design for the environment (DfE) will be kept in mind when possible, in order to limit the environmental impact of GA demonstrators themselves.

- Dematerialisation. The most important prerequisite for human sustainable development is the active, rapid dematerialisation of products and services\(^\text{41}\) (1). By definition, dematerialisation refers to doing more with less; getting the same amount of value or service out of a smaller amount of physical material. Incremental examples of dematerialisation simply refer to material efficiency gains (eco-efficiency). Total dematerialisation involves fully replacing a physical product with a virtual or service-based alternative. Some of the most common ICT-based examples of dematerialisation include digital access to multimedia (replacing CDs and DVDs with digital downloads); e-billing, e-banking, email & other reductions in paper use; and the replacement of transport with improved virtual communication. In terms of the potential carbon savings from ICT, it was estimated that dematerialisation could lead to the equivalent of saving 500 metric tonnes of CO\(_2\) in 2020 – the equivalent of the total global footprint of the ICT industry in 2002. The applications and services enabled by GA demonstrators will help this dematerialization in the following ways:
  - Virtualization of human-centred services,
  - Reduced car travel for medical examination thanks to the physical GA,

\(^{40}\) J. Rabaey, keynote address at Symp. on VLSI, Jun. 2011.
\(^{41}\) S. Heinonen et al., Futures, 33, 2001, pp. 319–337.
• **Gains in energy efficiency and use of natural resources.** Beyond the contribution to dematerialisation, there are multitudes of ways in which the ICT contributions of GAs can lead to efficiency gains in material and energy use. Some of these include
  - Increased use of smart systems in daily life,
  - Reduced waste in manufacturing,
  - Energy-efficient climate in controlled buildings (“smart buildings”),
  - Safer, energy-saving auto travel thanks to smart driving assistance,
  - Optimized public transportation to attract more commuters.

• **Eco-information transparency.** The main idea here is to move towards *environmentally optimized decisions* by a good understanding of our current impacts and their causes, strengthening our understanding of “the interconnections between human activity and natural conditions”\(^42\). We believe that each generation of GAs will contribute to enhancing eco-information transparency in other sectors, and will improve decisions and use of energy in human-environment interactions. Indeed, by providing GA personal assistants with environmental data and eco-awareness, they can become capable of guiding individuals to make eco-friendly decisions. GAs could even implement a personal carbon footprint counter to reach full eco-information transparency.

• **Design for the environment.** As GA demonstrators are autonomous systems that consume zero power, their life-cycle impact is expected to be dominated by the energy and material use required for component manufacturing.\(^43\) Another concern is raised by e-Waste generated at the end of life. Therefore, GA demonstrators will be designed with the target to limit the embodied energy, material use and e-Waste through progress on the following topics:
  - Green battery and energy storage,
  - Energy-harvesting technologies,
  - Organic components (e.g. solar cells\(^44\), large area electronics),
  - Low die area for CMOS chips thanks to technology scaling,
  - More compact packages thanks to 3D assembly.

### 4.4 Impact on the Economy

The development of low-power technologies initiated by Guardian Angels will create an enormous market for new components, devices and systems, which will boost these industries in Europe. Guardian Angels will prompt the IC industry to focus more on reduced power consumption, calling for a heterogeneous approach which will integrate advanced More Moore technologies with Beyond CMOS components and More than Moore systems. This approach will open new opportunities for the introduction and integration of new materials, including complex polymers, III-V and II-VI semiconductors and nanomaterials (e.g. graphene). The high level of innovation will benefit not only component manufacturers but also the new materials and equipment manufacturing industries. The development required by GA will surely lead to completely new, independent applications and new products.

The first key point about the expected market for GA applications is that it will extend to all levels of the semiconductor market (see Fig. 24), which is deeply consolidated\(^45\), allowing low-cost mass production. The expected GA market will be extremely diversified due to the fact that in the GA concept and strategy, all the levels of the semiconductor value chain are addressed (from new materials and equipment up to new systems.

\(^{42}\) [http://greenelectronicscouncil.org/](http://greenelectronicscouncil.org/)


and services, Fig. 24). Certainly some GA components (e.g. microprocessors, memories, energy scavengers) will be produced in a streamlined way as they are today; this is the More Moore path of technology evolution. However, a considerable number of dedicated devices shall be designed, manufactured and tested ad-hoc for specific applications. The increased requirements of customisation will require dedicated design for each subsystem/system as well as for the associated integration processes. The software layers will also require customization. This customization, at multiple stages of the overall system manufacturing and integration process, makes the products which will result from the GA project particularly well-adapted to the European industry of today, as well as to the knowledge-based economy of tomorrow, where high added-value manufacturing and services are expected to feed the European economy.

**Knowledge and technologies in semiconductors generate 10% WW GDP.**

**GA will significantly enlarge their business portfolio.**

Fig. 24: Left: Creation of new materials, electronics and heterogeneous systems and services (beyond the existing portfolio of traditional semiconductors) by the GA technologies and systems. The extraordinary impact of GA is related to the fact that it addresses all the levels of the value chain of the semiconductor business model. Right: The GA research value chain, which includes traditional KETs, as well as emerging solutions at all levels.

The related markets will be based upon the structuring of the (a) product concept and (b) associated services. Each of the areas illustrated in the core of Fig. 24 (left side) describes a specific industry, either existing or upcoming. Existing industries include the materials industry, device structuring (e.g. electronic component and MEMS manufacturers), and system integrators. For these existing industries, growth can reasonably be expected to happen simply through increasing the production of existing devices. A precise evaluation of growth is difficult to predict, in particular if we count the end of the project ten years from its starting point. Domain Market studies realized in 2010 (e.g. for SiC-based sensors or CNT-based sensors) forecast compound growth ranging from 4.3% to 14.9%, with market volume between 10 BEuros and 20 BEuros respectively for their 2017 projections. Therefore, with a horizon 10 years from the beginning of the project, a worldwide market of some tens of billions of Euros can reasonably be expected. This order of magnitude, a multiplicative factor on the order of 10x, can be used as a basis for the generation of services for the semiconductor market.
Another important sector in GA is energy harvesters, a market which is currently invisible compared to the semiconductor market, but which is expected to grow from nearly zero to several billion Euros annually in 10 years.46

Beyond device manufacturing, flexible assembly and/or packaging, which allow the customization of systems for specific applications, are expected to also grow rapidly, at a pace proportional to the growth of device manufacturing.

New (or quasi new) market segments are also expected to appear. One such segment is that of sensor field installation and deployment. Due to the extremely high number of sensors that will be deployed, ad hoc service installation companies with dedicated skills and personnel are expected to emerge.

The next segment expected to be heavily impacted is that of communications, since GA devices will be networked. Exponential growth in complexity is expected, adding to the existing technological and usage-related challenges with respect to the development of such networks. Key issues include data collection, processing (locally or remotely) and storage, and how to network these enormous quantities of nanosystems.

The autonomous devices and key enabling technologies (KETs) forming the core of the GA project are expected to enable new services in several domains (see Fig. 24):

- **Health and an ageing society**, including sectors ranging from sports and well-being, to acute situation monitoring, rehabilitation, and elderly monitoring. Remote health care monitoring allows citizens to age longer at home and avoids hospital overcrowding. In addition, GA technology will be a nest for innovative biochips allowing medical diagnostics to be re-thought, to enable early detection of bird flu, for instance. ICT-based therapy for mental health management improves healthcare productivity and access to care as it provides therapy with 80% savings in therapist time compared to conventional therapy.

- **Intelligent transportation** including electric and conventional auto, marine and rail, and intelligent infrastructures as well as node-to-node interactions. Particular importance is to be given to new type of services related to the refueling of electric-/hydrogen-based cars.

- **Safety and security**: future GAs could employ security chips as electronic (travel) documents, ensuring that data cannot be manipulated and that privacy is fully guaranteed.

- **Education** is expected to undergo dramatic paradigm changes, both in terms of the format (new ways to better teach the content) and the delivery (remote delivery of knowledge and facilitated lifelong education). Very few such service providers exist today.

All these services will have a tremendous economic impact centred on technologies and services for a better quality of life, and fully in line with the European vision of KETs.45

### 4.5 The Impact Analysis Process in the Guardian Angels Flagship

The GA impact analysis work will support the exploitation of Guardian Angels technology, in order to facilitate individually- and societally-acceptable, beneficial services. We will engage different stakeholders and the society at large in an active dialogue with the technology developers. This could also help to identify application possibilities from the market point of view. We have already identified several key application fields for Guardian Angels technology: health, assistive technologies, well-being, transport, traffic, safety and user interaction tools. Furthermore, we have described scenarios of future services for each application field.

This scenario set will act as the communication tool to enable the dialogue with external stakeholders and the general public. It will be continuously refined based on the feedback, and illustrated through various means.

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Some scenarios corresponding to full-hardware demos could be tested on the general public. Our aim is to engage external stakeholders in co-creation; they are not just commenting on our scenarios, but rather actively inventing new usage possibilities, or even new application areas. The most promising application paths will be identified and studied further. We will complement the impact analysis process by studying the most promising application areas and concepts with ethnographic methods to identify user values and current practises. These studies will help us to identify additional application possibilities.

The impact analysis work will include the viewpoints of individual users, society, and business. From an individual user’s point of view, we will study what is valued in GA-based services, what kinds of GAs people are ready to utilise, what are the targeted user experiences for physical, environmental and emotional GAs, and what concerns users have. From a societal point of view, we will study societal acceptance, ethical issues, legal issues, security, and the role of technology in society. From an economic point of view, we will identify and exploit the business possibilities of the GA technologies and services. From an environmental point of view, we will propose a strategy for the sustainability of the solutions and the potential for GAs to protect the environment.

Experts from research and industry from within and outside GA will be invited to advisory boards specific to application fields, to build a common understanding of the application fields and to identify new application possibilities. The most important advisors will be the common public. We will maintain physical and on-line co-creation spaces where we can illustrate possible applications to engage potential users, application field experts and other actors to comment on our ideas and to propose new ones. Fig. 25 illustrates VTT’s Ihme innovation showroom, which we will use to show demos to the public, and to engage them to comment and ideate with us.

Fig. 25: The Ihme innovation showroom at VTT.

4.6 User experience groups

GA consortium member Aridhia, working with our collaborative clinical and academic partners, can provide the consortium with access to clinicians and researchers involved with the management of patients with chronic diseases. There is current active collaboration in the fields of diabetes, chronic respiratory disease, cardiovascular disease and cancer. Aridhia can help with the organisation of clinical trials in healthy volunteers to assess early prototype functionality and efficacy, before supporting trials on patients with chronic diseases in a range of different healthcare environments. This will assess practicality of use in different settings, accuracy of information obtained, ability for clinicians and patients to interpret information presented to them and user tolerance of the sensors. Aridhia’s current ability to gather patient self-reported outcomes using android devices, linked to the ability to provide notifications to healthcare providers, could be exploited further to gather patient feedback and to correlate symptoms to information from Guardian Angel sensors. Further resources for user experience feedback could come from the GA cooperation with the One Mind Project, or from the group of consortium member Dr. José del R. Millán at EPFL.
4.7 Use of Results and Dissemination of Knowledge

4.7.1 Dissemination of the Guardian Angels Project

The participation in events addressed to the general public, and the dialogue with the general public and policy makers will lead to the strengthening of GA visibility. On one hand, this will allow GA to exhibit the socio-economic benefits of the project and on the other, to evaluate the social acceptance. Dissemination via media (newspapers, radios, TV) and ICT trade shows will also be widely used during the 10 years of the FET Flagship Project. A website and newsletters featuring portraits and highlighted success stories will be two additional means to ensure a comprehensive virtual presence. Besides presenting good practices, a crucial message will be to highlight the advantages of emerging ICT over traditional technology.

As a visionary panel inside of the project, the “Guardian Angels Powerhouse” will be established to serve as a think tank to anticipate the dissemination of knowledge and the application of the emerging technologies. This panel will also discuss the societal and ethical dimensions of GA research and will include specialists from sociology, medical ethics, psychology and law. In addition, the GA Powerhouse will be responsible for communicating hands-on examples to a wide audience, to illustrate the accomplished research.

GA researchers will continue to publish in the best peer-reviewed science and technology journals, including many joint publications, with a special emphasis on high impact factor publications. They will also present their findings at the main relevant conferences and workshops, allowing the GA consortium to widely disseminate the research results in large scientific and industrial communities, including applied physics, biotechnology, nanoscience and nanotechnology, artificial intelligence, renewable energy, electronic engineering, healthcare science, energy harvesting, low-power systems, sensors, automation and control systems, communication, and behavioural sciences. Several books and book chapters, jointly edited by Guardian Angels partners, will be published in the main GA scientific and technological fields.

The dissemination via teaching, training, and schools about the GA topics will lead to the development of high competence levels in Europe. The Guardian Angels partners will be actively involved in spreading and communicating new research and technological innovations, as well as incorporating feedback from the research community, stakeholders and target groups. The dissemination of knowledge through the extensive teaching obligations of members of the consortium at Europe’s leading universities will introduce the next generation of scientists to cutting-edge FET research. The academic GA partners will act as everyday knowledge disseminators through their work in university labs, their teaching, and as members of governing committees in their universities. In these functions, they will be able to impact the course syllabi and research activities, to focus more on future and emerging technologies in the information and communication sectors. While supporting the GA Flagship initiative, young academics trained in emerging ICT will also be a tremendous competitive advantage for the European economy in the next decades. Summer schools (such as SINANO and MIGAS) and training within European Doctoral School exchanges (such as the Euro-DOTs FP7 Coordination action) will be targeted.

A database of experienced Guardian Angels lecturers (similar to IEEE distinguished lecturers) with existing or new high-level/high-quality lectures will be created and updated yearly and will be available on the GA website.

In addition, Guardian Angels will propose a strong intellectual property policy encouraging GA partners, especially academia, to develop their exploitable knowledge and its use, to apply for patents and to transfer the main disruptive technologies and breakthroughs to industry. The development of spin-off companies coming from the academic and scientific communities will also be encouraged.
4.7.2 Strategies for raising Societal Awareness

The applicability and user-friendliness of the technologies are at the core of the GA flagship initiative. By engaging in a constructive dialogue with interest groups, early adopters, and the general public from the outset, the GA project ensures that the impact on society is matched with society’s needs and wishes. The envisioned impact of Guardian Angels on society is one of the driving components of the project, of which the public should be made aware. In order to engage in a meaningful dialogue, the consortium has and will continue to organize various outreach actions, including

- knowledge dissemination in the research community through talks and presentations,
- internal / external communication through different media (newspaper, radio, television),
- Science and Society interactions, with the public as well as with industrial partners (open lab workshops, school visits).

In order to gather the feedback from future potential users on important issues such as acceptance, end user value and business opportunities, focus groups will address specific questions, as described in section 4.5 Interactions with users can be web-based, through interactive websites such as Twitter or Facebook, but it is also vital to encourage real-life, face-to-face exchanges in workshops, public discussions, and general-interest conferences. The visibility of these real-life dialogues will be enhanced by documenting and processing the results, to show them publicly on the GA website or to be made available to the media. The Guardian Angels project will make cutting-edge technology research accessible and comprehensible to a wide public. The following strategies and measures will help to achieve this goal.

- Transparent information: GA will communicate in a comprehensible manner through its website, media events, scientific and general-interest conferences such as TED Talks (http://www.ted.com/), and the mainstream (non-specialised) media.
- The benefits for society and the economy will be highlighted by presenting the opportunities for the development of small- and medium-sized businesses, for service innovation, and for leadership by existing industries.
- Open Lab events: at regular intervals, the GA labs will be open to the interested public, who can follow the developments in cutting-edge research and glimpse the future of technology.
- Dialogue portal: GA will seek dialogue with target groups for different demographics (the elderly, young early adopters, parents, etc.), the health sector (medical staff, allergy patients, paraplegic patients, etc.), the entertainment and sports sectors, and the safety sector (risk insurance, safety-at-work organizations, traffic safety, etc.). There will be focused exchange sessions, where the feedback, suggestions and requirements of the various target groups can be received in an unbiased manner.
- The public understanding of science is a key concern for the transparency of the Guardian Angels project. We will engage in a series of talks and workshops with school classes and young students. The goal will be to inform and educate young people and the interested public about the areas of research that go into the GA technology platform, to make engineering and scientific progress comprehensible and transparent. Furthermore, we will take into account their input, collected in interactive workshops. A constructive dialogue will exist throughout the duration of the project.
- At regular intervals, the GA website will feature different application areas for GA devices, and include feedback from the exchange sessions in the form of testimonials, short video clips etc. Different technology areas will be in the spotlight, explained to a broad audience. In addition, different partners from participating countries will be represented and portrayed in more detail, to make the European face of the project visible to the European population.
4.7.3 Exploitation and Technology Transfer Plans

The GA FET Flagship has the advantage of including all the actors in the value chain to bridge disruptive research, technology transfer and exploitation into industrial products. The long-term nature of the proposed research, with efforts dedicated to many emerging technologies, will need an adapted strategy and actions. On one side, the universities can experimentally evaluate many of the new concepts and their integration via the technology facilities of leading technological platforms at CEA-LETI, IMEC, Tyndall and Fraunhofer institutes. These institutes have the know-how and the needed infrastructure to prepare the technology transfer to industry. On the other hand, we strongly enable direct interactions between universities and industries, as a result of some concrete actions of the GA demonstrators and the long-term roadmaps.

In general, we believe that GA has a unique and privileged channel for exploitation due to the existence of the three families of GA systems in both full-hardware and virtual implementations. These are not only measurable milestones but also key progress points in the project where the exploitation and the technology transfer plans should be refined.

The GA exploitation strategy and technology transfer planning will be carried out as a result of detailed analysis at three levels: (1) the project level – concerning the general strategy, principles and the implementation of the Consortium Agreement, (2) the sub-project level – concerning the possibility of protection and exploitation offered to a restricted group of partners that are sharing highly sensitive knowledge and (3) the partner (company) level – with each partner being entitled to protect and exploit the knowledge created in the FET Flagship, in accordance with the principles of the Consortium Agreement.

The exploitation plans will take the form of sales and marketing strategies for the partners involved in industrial exploitation. As a very important measure to promote the timely exploitation of the project’s results beyond the consortium, a repository of applications implementing a first instance of the architecture will be maintained. Detailed exploitation strategies will be elaborated in order to offer the most effective conditions for a successful introduction of the developed GA systems into the markets. Deliverables concerning market and cost effectiveness analysis will be scheduled yearly in the sub-projects, and summarized on a two-year basis as a potential market analysis at the FET Flagship level.

Different scenarios will be investigated for different applications, in order to assess the impact of introducing GA technology. Marketing strategies for the identified business segments will be elaborated by the strategy departments of the industrial partners, evaluating supply chain scenarios and creating business concepts and plans. It will be important to raise the awareness of possible value chain participants with respect to the advantages and effects of the introduction of GAs in business services. Different activities will be planned to represent the project actively and establish liaisons with other relevant projects, standard organizations, and institutions that can be of benefit for the project in terms of technology adoption. These derived products, contacts, potential users and exploitation plans will be documented in exploitation plan reports, and some new partners can be invited to join the consortium.

One of the concrete goals of GA is to move innovations and technologies created in the project to the market; this will be strategically implemented by bringing together individuals with different backgrounds and experiences before negotiating agreements. Such a “move-innovation-to-the-market” team should include experts in business strategy and marketing, as well as legal, scientific, regulatory, production, and finance expertise, and will organized by our Manager for Exploitation, IP and Technology Transfer.

One particular feature of GA is the support of an experienced management team with a dedicated leader, who will supervise the exploitation and technology transfer, and will follow the progress along the project timeline. This manager (who will be selected to come from an entrepreneurial culture) will continuously analyse the outputs of the GA sub-projects. In particular, (s)he will be in charge of the coordination of the following tasks:
• Implementation of the Consortium Agreement policy concerning project exploitation, refining the background IPR included, ensuring that the pre-existing know-how of participants and corresponding access rights are sufficiently detailed.

• Identification of results and knowledge generated by the FET Flagship project in successive generations, and coordination of general reporting and strategy on the market analysis and business opportunities.

• Analysis of the technical annex and early identification of the work that has high promise for patenting and technology transfer.

• Organisation of regular workshops during steering committee meetings in order to review the project progress and identify exploitation opportunities.

• Preparation of the consortium-level exploitation plans on the basis of business plan analysis and studies for each sub-projects and partner.

• Planning and organisation of the consortium’s work on the plan for using and disseminating the knowledge (together with the Management Team for the ramp-up phase and of a similar plan for the full phase of the project).

• Analysis of end-user requirements and a potential market so as to define an exploitation strategy.

• Proposing specific tools for management of knowledge together with the Management Team.

• Addressing conflicts of interests in technology transfer at an early stage, and identifying solutions. The challenge is to manage them in a transparent and consistent manner.
## 4.7.4 Plan for Using and Disseminating the Knowledge (PUDK)

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<thead>
<tr>
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<th>Action</th>
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</tr>
<tr>
<td>2</td>
<td>Organisation of a yearly GA Symposium presenting the main GA results, challenges and possible solutions</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Every year</td>
</tr>
<tr>
<td>3</td>
<td>Organisation of a biennial Workshop targeting European industry</td>
<td>X</td>
<td></td>
<td></td>
<td>Every two years</td>
</tr>
<tr>
<td>4</td>
<td>Exchange of personnel between GA partners and beyond GA consortium for transfer of knowledge, strengthening collaboration and integration of European Laboratories and Platforms</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Every year</td>
</tr>
<tr>
<td>5</td>
<td>Development of strong links with existing European Structures (Sinano Institute, ENI2) and Technology Platforms (ENIAC, ARTEMIS, EPOSS, Net!Works, Nanomedicine, Photonics21, Photovoltaics), and European/National/International Projects through the organisation of several joint Meetings and Workshops, analysis of the Strategic Research Agendas, and the development of complementarity and collaborative models between GA/Horizon 2020 and JTI Projects in order to present and discuss the visions and optimise GA research activities</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Every year</td>
</tr>
<tr>
<td>6</td>
<td>Participation in events addressed to the general public and to policy makers for strengthening GA visibility and in order to exhibit the socio-economic benefits of the project and to evaluate the social acceptance</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Yearly in various European countries</td>
</tr>
<tr>
<td>7</td>
<td>Dissemination via media (newspapers, radio, TV) and ICT trade shows</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Frequent</td>
</tr>
<tr>
<td>8</td>
<td>Use of the website and newsletters for highlighting news and success stories, a comprehensive virtual presence (including competences, platforms, breaking news, events, vision, positions, training, applications, video clips, movies, feedback from the exchange sessions with target groups, etc.)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Annual newsletter and regular update of the website</td>
</tr>
<tr>
<td>9</td>
<td>Creation of the Guardian Angels Powerhouse to serve as a think tank to anticipate dissemination, application, societal and ethical dimensions</td>
<td>X</td>
<td></td>
<td></td>
<td>Frequent meetings of the panel</td>
</tr>
<tr>
<td>10</td>
<td>Publication, including joint publication, in the best peer-reviewed science and technology journals, presentation of the findings at the main relevant international Conferences, and editing of books in the main GA fields</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Frequent</td>
</tr>
<tr>
<td>11</td>
<td>Dissemination via teaching, training, schools and database of GA experienced lecturers about the GA topics for the development of high competence levels in Europe</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Training and summer schools every year</td>
</tr>
<tr>
<td>12</td>
<td>Creation of external advisory groups, in order to receive independent feedback on the project: International Advisory Board with experts in the physical, environmental and emotional aspects of Guardian Angels; Ethics Advisory Board</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Annual meetings of the Boards</td>
</tr>
<tr>
<td>13</td>
<td>Open Lab events with focused exchange sessions for the general public, students, industrial partners, target groups (health, entertainment and sports, safety sectors)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Every year</td>
</tr>
<tr>
<td>14</td>
<td>Proposal of a strong intellectual property policy encouraging GA partners to develop their exploitable knowledge and its use, to apply for patents, to transfer the main disruptive technologies and breakthroughs to industry, to create spin-off companies</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Every year</td>
</tr>
</tbody>
</table>
4.7.5 Intellectual Property (IP)

Guardian Angels (GA) is a scientifically exciting and challenging project that pushes the boundaries of European Consortia. The partners will all have an eye on what they can get out of the collaboration, but the main attraction for all is the ability to undertake research and development that would not otherwise be possible. GA is bold and ambitious in its size, scope and timeframe. It is also unusual and daring to encompass product development, as well as the underlying fundamental research. Start-up (or “spinout”) companies have proved to be an effective way of creating innovative products and economic impact. One of the main goals of the Guardian Angels FET Flagship is to foster an entrepreneurial culture and an intellectual property (IP) regime that will facilitate the creation and growth of start-ups. The IP regime will also enhance product development by the industrial partners of GA.

**Impact on IP:** How do the ambitious goals of Guardian Angels affect the treatment of IP in the project proposal and eventual Consortium Agreement (CA)? What are the opportunities, options and constraints? The usual CA models will not be appropriate because, by promoting generalized, non-exclusive access to foreground IP, they inhibit the licensing of Project IP to start-ups. In a project that encompasses fundamental scientific research and product development, it will be necessary to implement a new way of managing IP that allows a new start-up or a GA Partner to get exclusivity on specific GA foreground.

**Our Way Forward:** Some IP will follow the well-trod path of Framework Consortia Agreements – by using one of the model agreements (e.g. DESCA or IPCA) and following the usual arrangements for IP ownership and management, access rights, publication, etc. But Guardian Angels has more to offer - including the potential to create start-ups - because of the length and breadth of the project.

Part of the foreground IP will be coordinated by the IP & Exploitation Manager, under the supervision of an IP and Exploitation Committee, comprising commercially experienced representatives of the partners. This will facilitate

- an overview of a comprehensive patent portfolio
- economies of scale in technology assessment and valuation
- coherent management of a pool of related IP and the realization of synergies between related IP (“IP subsidiarity”)
- concerted marketing of complementary IP to create a more valuable offering

All partners, through the IP and Exploitation Committee, will have better visibility of the Guardian Angels IP portfolio. Special IP rules will be considered for product development sub-groups and/or for new platform technologies.

**Coordination of IP Management:** Centralised IP coordination, such as that outlined above, will be housed in the Project Office (a part of the GA Foundation) and run by the IP & Exploitation Manager. (S)he will have a budget for IP filing and access to patent agents and market research and the responsibility to track “impact” (not just patent filings and licences, but downstream activity such as the number of start-ups created, the development of products to market, jobs created, etc.). The IP and Exploitation Committee will ensure that all opportunities are handled fairly, that appropriate procedures are followed and that delivery is monitored. If more than one partner/start-up were interested in an exclusive license, then the IP and Exploitation Committee would decide what is in the
best interests of the aims of the Project (e.g. by limiting the scope of the licence by field of use). Beneficiaries of exclusive IP rights under GA will be required to demonstrate diligence in product development and milestone achievement.

**Guardian Angels Start-ups**

Innovative Guardian Angels IP management will allow exclusive licensing of promising IP to start-ups. Moreover start-ups will be facilitated through a package of measures including

- access to a Proof-of-Concept fund, under the supervision of the IP and Exploitation Committee
- a dedicated and independent IP & Exploitation Manager working under the supervision of the IP and Exploitation Committee
- entrepreneurship awareness programmes
- creation of a mentor network
- showcase events for investors
- business plan competitions and start-up days/boot camps

Where there is an opportunity to start up a company, the IP and Exploitation Committee will oversee this, and the IP owners will have an equity stake in any such start-ups.

Partners of the project will benefit via the following measures:

- priority rights to invest in GA start-ups
- participation in the selection process (criteria and priorities) for awarding Proof-of-Concept funds to start-ups (through membership in the IP and Exploitation Committee)
- a close relationship with promising new start-ups via the GA showcase events

The adoption of an innovative IP regime by GA, as outlined above, will enhance the creation of start-ups and will allow GA to develop new products and businesses through more efficient and effective technology transfer. By applying the proposed measures, GA will be able to create 10-12 start-ups during the course of the project.

### 4.8 Education and Training at the European Level

Teaching, training, and schools on the Guardian Angels topics will lead to the development of high competence levels in Europe. The Guardian Angels partners will be actively involved in spreading and communicating new research and technological innovations in the GA domains. The dissemination of knowledge through the extensive teaching obligations of members of the consortium at Europe’s leading universities will introduce the next generation of scientists to cutting-edge FET research. The academic GA partners will act as everyday knowledge disseminators through their work in university labs, their teaching, and as members of governing committees in their universities. In these functions, they will be able to impact the course syllabi and research activities, to focus more on future and emerging technologies in the information and communication sectors. While supporting the GA Flagship initiative, young academics trained in emerging ICT will also be a tremendous competitive advantage for the European economy in the next decades.

The GA training activities will include the following actions:

- Organization of the Guardian Angels Doctoral-Level Summer School (based on the successful models of SINANO, MEAD and MIGAS), targeting to have lectures labelled within European Doctoral School exchanges (such as the Euro-DOTs FP7 Coordination action). The GA
Summer School will be organized on a yearly basis and will encompass multi-disciplinary topics.

- Organization of a series of talks and workshops with secondary school students. The goal will be to inform and educate young people and the interested public about the areas of research that go into the GA technology platform, to make engineering and scientific progress comprehensible and transparent.

- Organization of internal seminars and courses to support the spread of high-level knowledge within the FET Flagship. This will require a database of experienced GA lecturers (similar to IEEE distinguished lecturers) with high-level, high-quality lectures created and updated yearly, available on the GA web-site. The travels of the lecturers at the request of GA partners will be supported, and the information about these regional events will be widely disseminated.

- “Best practice” trainings for technicians/engineers as well as training sessions on particular equipment will be planned. Updating the practical knowledge of technical staff members across Europe is a high value asset/investment for the European research of the future. Calls for such actions will be electronically issued every year.

- The training of consortium researchers, and of researchers, students, and technicians from other European labs, will be proposed electronically (calls for applications by e-mail and through the GA website). Summer schools and European workshops will be organized on most hot topics identified by the partners and not covered by other training at a European level. These will be open to any and all European industries, research centres and university labs interested in this field.

4.9 Potential Ethical and Legal Implications

Ethical principles are the expression of normative ethical theories, which reflect generally-accepted human obligations or duties. They help us to decide among competing moral rules, norms, and values. In the context of the research and development of new technologies, ethical issues can be seen on two levels. The first level requires good scientific practices, procedures for handling misconduct and fraud in science, and the rights of people who are participating in the research, e.g. as interviewees or test users. The Guardian Angels work on the first level will consist of maintaining an ethical handbook for the project. The second level of research ethics relates to the foreseen results of the research and development: what kinds of possible uses there are for the technology, and whether those usages are ethically acceptable. The GA project will include research activities to ensure that ethical concerns are predicted and discussed well before the actual implementation of the technologies. Ethical concerns will be discussed within the project, with the Ethics Advisory Board (described below), with specific experts and stakeholders, and in public discussions. Within the project, the aim is to encourage engagement, prior thinking, and consideration of possible impacts. The aim is to identify ethically-acceptable development paths for the technology, and to foresee areas where regulations need to be developed.

One of the most critical ethical issues related to Guardian Angels technology is the possibility of continuous monitoring of the environment and human beings, including health parameters and psychophysical data. Guardian Angels may be dealing with extremely sensitive data. From the individual user’s point of view, it is important to know where the data is gathered, who has access to the data, and for what purposes the data is being used. User autonomy must be guaranteed, such that (s)he can decide whether the data may be gathered or not in different situations. Privacy and security will also be essential.

From a societal point of view, we must consider whether individual applications of GA technologies are ethically acceptable. GA technologies may improve the quality of life, but some applications could also
contribute to excess supervision in society. They may improve the inclusion of disabled people in the society, but we need to ensure that they will not replace human contact.

The EGAIS project has studied the governance models in European research projects, and claims that current procedures of assessment often lack ethical reflexivity and openness to the society. The ETICA project recommends proactive engagement with technology researchers, organisations, and the civil society on questions of how technological developments should affect social reality. GA aims to learn from the studies by the EGAIS and ETICA projects and to take into account their recommendations in planning the ethical governance. We will follow the co-construction model suggested by EGAIS. In this model, instead of relying on expert approaches alone, a democratic, participative approach is used to engage society at large in debates and discussions. This is important, as stakeholders and users may have a different conception of ethical issues than the ethical experts, and both viewpoints should be taken into account. The key principles will be as follows.

- Ethical sensitivity is in the interest of both technology users and technology providers.
- Ethical issues are context-dependent and need the specific attention of individuals with local knowledge and understanding.
- Ethical issues and their resolutions should be identified simultaneously.
- Broad stakeholder engagement should be encourage in the identification and resolution of ethical questions.

A good basis for ethical issues concerning the foreseen GA applications and services will be the ethical principles for mobile-centric Ambient Intelligence defined by MINAml. The principles are privacy, autonomy, integrity and dignity, reliability, e-inclusion and the role of technology in society. Another possible basis are the more subtle ethical issues related to emerging ICTs, identified by the ETICA project: the view of humans, power relationships, the environment, the nature of society, and changing cultures. Novel technologies for which there is not yet much articulation of the ethical issues, such as bioelectronics and affective computing, will be studied with specific care.

Current legislation, regulations and recommendations will guide the research and development work within the project. While current legislation covers some of the ethical issues foreseen with Guardian Angels, technology development tends to be ahead of legislation, and even social and moral norms require time to adjust. For instance, new privacy issues, untreated by current legislation, are raised by new types of data, new ways of linking data, and new quantities of data. The Charter of Fundamental Rights of the EU sets out the rights to the protection of personal data of an individual, respect for an individual's private life, and the protection of human dignity. Data protection directive 95/46/EC defines the principles for the protection of individuals with regard to the processing and movement of personal data. In addition, there are several directives and national laws that need to be taken into account. The codes of ethics for different professionals such as the ACM Code of Ethics and Professional Conduct (1992, 2003) will be included in the Guardian Angels Ethical Handbook to ensure that the research work within the project will be carried out according to these recommendations. The recommendations of the European Group of Ethics (EGE) in Science and New Technologies will be very useful in the Guardian Angels Flagship, including Citizens’ Rights and New technologies: a European Challenge. Report on the Charter on Fundamental Rights related to technological innovation (2003) and Ethical aspects of ICT implants in the human body (2005).

The ethical approach in Guardian Angels should integrate context-sensitive issues with the more general discussion of norms or ethical principles. This calls for a new kind of approach for thinking, methods and tools. The development of the ethical assessment methodology will be one of the main tasks when studying the potential ethical and legal implications of Guardian Angels.
The EAB (Ethics Advisory Board)

An Ethics Advisory Board consisting of external ethics experts from different European countries will be nominated to support the FET Flagship in ethical issues; ten experts have tentatively agreed to join. They represent different aspects of ethics such as legal-ethical issues, social-ethical issues, e-Inclusion, morals and ethics, environmental ethics as well as ethics and policy. In addition they are focused on specific fields of ethics such as privacy, data protection, trust, and values, or on different application fields such as e-Health. Most of the experts have a background in European research projects focused on ethical issues, i.e. FP7 projects EGAIS (Ethics and Governance in Emerging Technologies) and FP7 ETICA (Ethical Issues of Emerging ICT Applications). In addition, half of them have expertise acting as members of the Ethics Advisory Board in FP6 project MINAmI (MIcro-Nano integrated platform for transverse Ambient Intelligence applications). Thus they have both expertise on ethical issues related to micro- and nanotechnology and practical experience in how an Ethics Advisory Board can support research projects.

The EAB will make a plan of action, checked and updated on a yearly basis. The EAB should foster the attitude that ethics is a part of the GA research process, such that ethics is not seen as a burden but rather as an active, creative contribution to the project. The EAB will have an annual meeting in connection to GA meetings in order to stay in contact with the GA partners. In addition, the Board will be in regular contact by electronic means, and through focused meetings with GA researchers in internal ethics workshops. The EAB will also have focused meetings with industry and stakeholders from key GA application fields, such as health, traffic, transport and security. The EAB will formulate its standpoint as the Ethical Recommendations and Guidelines for Guardian Angels.

The tentative members of the EAB have already given feedback on the vision of the project and the foreseen application possibilities. They report that from an ethical point of view, the least sensitive applications are those of the Environmental Guardian Angels and the most sensitive are those of the Emotional Guardian Angels. The main issue is privacy, since Guardian Angels will enable continuous monitoring of data. Once data has been generated, issues related to access rights, protection for misuse and user control of data are raised. It is crucial that the user can turn off the monitoring whenever (s)he wants. Implanted devices will require specific solutions for informed consent, and the dignity and autonomy of the user must always be protected. With security systems, an important ethical issue is a possible trade-off between increased security and decreased privacy and autonomy. In security solutions, it is important to ensure that complex management tasks are not delegated to technology alone.

The Ethics Advisory Board emphasizes the importance of involving users themselves in the design of the systems, even in initial stages, and taking their opinions and concerns into account. Ethical issues will be a central part of all user studies within the project.