PROJECT FINAL REPORT

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4.1 Final publishable summary report

WISEBED Project Summary

Executive Summary

The main goal of the European project WISEBED was to create a large-scale integrated sensor network testbed consisting of single testbeds provided by different sites throughout Europe. In order to achive this goal, the WISEBED partners engaged in four technical areas, namely hardware, software, algorithms, and data.

The main results of the project can be summarized as follows:

- After the project, a stable experimental platform exists which consists of up to 1500 sensor nodes and a considerable number of gateways, test servers etc. The platform is easy to be used and is available for the European research community.
- Two major software packages have been produced and placed in the public domain:
  - A complete set of programs to run a sensor network testbed which adheres to the standards defined in WISEBED. With this software package, it is possible to let experimenters log into an experimental platform, design and deploy experiments, run the experiments, and finally collect data traces and analyze them. The software can be used by everybody, either to set up their own testbed, or to implement a WISEBED partner testbed to be integrated in the overall WISEBED experimental platform, or to further develop the software.
  - A library of algorithms called the Wiselib to solve all kinds of standard problems in sensor networks. The availability of this library eases the life of sensor network application developers dramatically, because many algorithms that typically have to be developed by the application developer himself are already available. Even better, the library is very generic and can be used on virtually any sensor node platform available on the market today. All in all, the Wiselib contains nearly 80 algorithms today, with new contributions constantly being added.
- The project has developed an XML-based language called WiseML the purpose of which is to describe experimental setups and results. An experimenter uses WiseML (or rather tools based on this language) to describe for instance the topology of the network he wants to use for the experimentation. The WISEBED testbed management software collects the experiment's traces and translates them into WiseML before passing it on to the user. Further tools can then be used to analyze the results. WiseML is meanwhile in use in several other European projects.

Context and Objectives of the project

WISEBED was a project in the context of the FIRE initiative, running from June 2008 to May 2011. FIRE hosts projects of two different types, namely those that build experimental facilities for Future Internet research, and those which use these facilities. WISEBED was one of the facility projects.

The aim of the project WISEBED was to provide an infrastructure of interconnected test beds of large-scale wireless sensor networks for research purposes. The consortium intended to bring together different test beds across Europe and form a federation of distributed test laboratories. It wanted to provide services for allowing advances in theoretical computer systems to be tested, at least as a proof-of-concept, in large-scale environments, so as to assess the feasibility of the new concepts and verify their large-scale effects. It wanted to engage on implementing recent theoretical results on algorithms, mechanisms and protocols and transform them into software that is independent from current technologies. Furthermore, the consortium planned to evaluate code independence by using the different hardware available across WISEBED and place the resulting code under the scrutiny of large-scale simulations and experiments. This evaluation was intended to provide valuable feedback and derive further requirements, orientations and inputs for the long-term research. In particular, it was planned to do the following.

- Deploy large numbers of wireless sensor devices of different hardware technologies in different types of terrains to use for evaluating solutions at large scale.
- Operate the test beds to collect traces of data from the physical environment and derive models of real-life situations and scenarios. These scenarios would then be used to evaluate the performance of algorithms and systems and draw conclusions on their operation and how it can be improved.
- Interconnect these wireless networks with the Internet and especially with other test beds from FIRE in order to provide a virtual unifying laboratory to enable testing and benchmarking, in a controlled way, in different "real-life" situations.
- Researchers would be able to use the facilities remotely, thus reducing the need for a local, private test bed and, more importantly, reducing the cost for research.
- Convert existing theoretical solutions into software and provide a repository of algorithms, mechanisms and protocols that can be directly used in future experiments as reference for benchmarking purposes. Such mechanisms were then intended to be tailored to small devices implementations of proxy and scaled-down solutions.
- Use the repository of algorithms and develop a library WISELIB that can be directly used in future system or integrated in order to deal with the vital challenges of the wireless sensor networks and offer efficient interconnection with the Internet.

The consortium's involvement in the above activities were hoped to lead to the development of a collective understanding on how to conduct research on wireless sensor networks and the Future Internet. Starting out from concrete applications, it was intended to include all aspects of appropriate modeling, algorithm design, the implementation of robust and efficient software, algorithm analysis and evaluation by experiments.

All these elements have equal importance, and the focus was to get a deeper understanding of the gap that exists between theory and practice and why it is hard to conduct all these steps in parallel and in continuous interaction. Therefore, the consortium's objective was to identify a broader methodology that proceeds in a cyclic development and improvement process between theory and practice. It was intended to consist of design, analysis, implementation and experimental evaluation of practicable algorithms. Realistic models for both, computers and applications, as well as algorithm libraries and collections of real input data allow for a close coupling to applications.

Finally, these distributed laboratories were intended to be made available to the European scientific community and the methodology was to be disseminated to research groups of both theoretical and practical background. It was the goal to establish a process of joint research activities, in which both theoreticians and practitioners would get together and use the facilities in order to interact and put the methodology into action. Contacts into the European industries, research groups and universities were intended to be used to create an impulse for innovation in the application of algorithms, providing a broad basis for a strongly interconnected, interdisciplinary research community.

Main S&T results/foregrounds

The work in WISEBED was carried out in six work packages, with four of them dealing with technical work, one being responsible for dissemination and joint research activities and one for the management. The four technical areas cover the main problem areas to be addressed when creating a federated test bed for sensor network algorithms and applications, namely hardware, software, algorithms, and data. In the following, we first present the general architecture of the WISEBED Experimental facility which then had to be implemented and "filled with life" by the different work packages. Then, we describe in detail the achievements of the work packages in these fields, separated along the three phases of the project. Afterwards, we summarize the main achievements in bullet lists.

WISEBED Experimental Facility Architecture

The WISEBED Experimental Facility (WEF) is basically a virtual network of sensor networks. It currently consists of a number of independent sensor networks located at different locations throughout Europe. Through a number of federation mechanisms, these independent networks can be configured into an individually-tailored experimental platform, just according to the needs of the researchers.

Figure 1 gives an overview of how the infrastructure works:

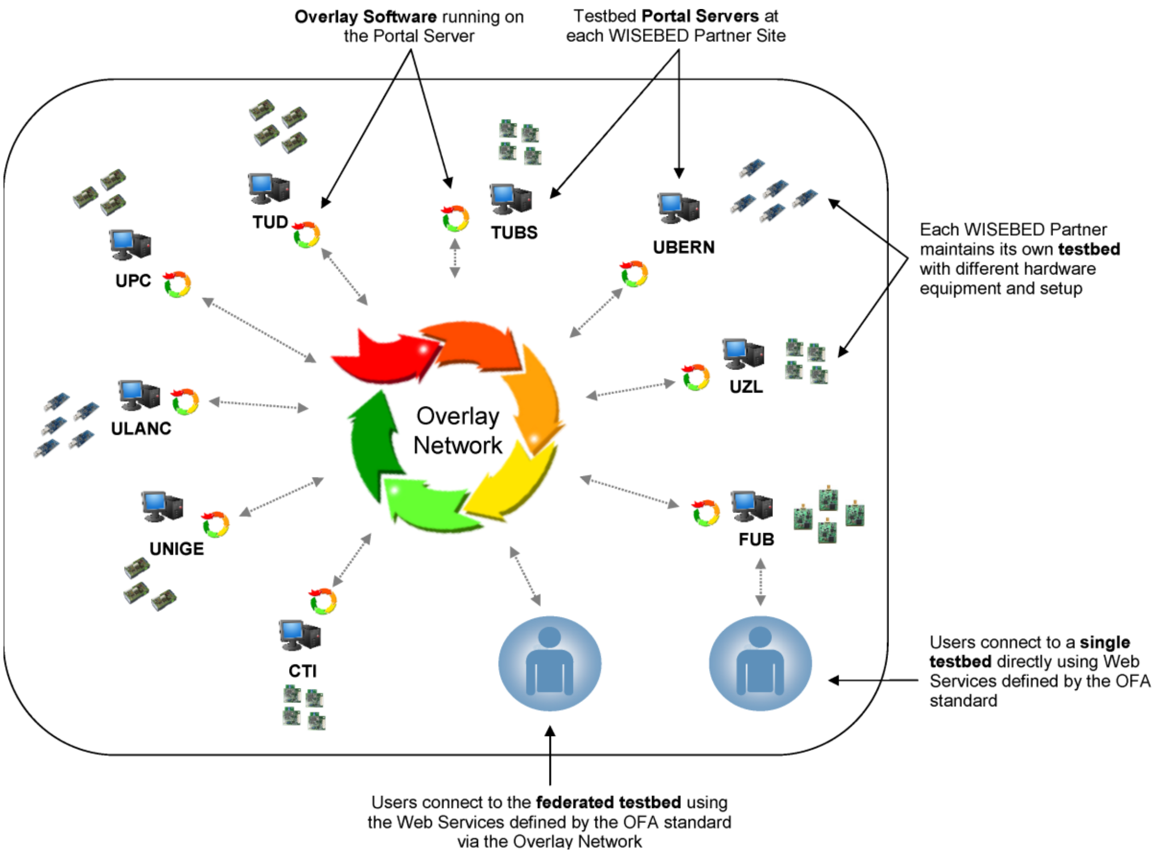

Figure 1: Architecture of the WISEBED Experimental Facility

In a nutshell, it is possible to use a single sensor network through its portal server, but there is also an overlay software which allows for the creation of virtual sensor networks built from physical networks and/or single nodes of networks. Through this mechanism, the researcher can build a virtual entity according to his/her needs and then deploy the experiment onto it.

Based on the available sensor networks and their sensors, basically all kinds of protocols, algorithms, middleware, and applications can be tested as long as the run on top of the MAC layer. Users are free to configure virtual networks as needed, and they can use different sensor node configurations. Those who want to test their own middleware can build on top of the MAC, those who want to create new algorithms or applications can use our own middleware and/or the library of sensor network algorithms, WISELIB.

Hardware

In Work Package 1 (Hardware), considerable work has already been done during the first period. A lot of effort has been invested in building the hardware infrastructure for all the test beds since it provides the basis for visualizing the goal of a pan-European network of wireless sensor networks. A wide variety of hardware resources have been deployed to furnish the test beds at the partners. The variety of sensor node types in all the test beds promises heterogeneity, enabling the wide range of application fields for the test beds. After this first period, more than 500 wireless sensor nodes are deployed across all the partners. An extensive overview of the individual test beds at WISEBED partners is given in the deliverables D1.1 and D1.2. Most of the partners have, already after this first phase, deployed a wireless or wired backbone to facilitate the communication between the sensor nodes and the local server. Another dimension in which work has been started in this period is the support of mobility in sensor networks. Moreover, some initial work has been done to deploy wireless sensor nodes outdoors.

Figure 2 shows a typical WISEBED sensor node used at the University of Lübeck. Actually, it is a box consisting of three sensor nodes, namely a Pacemate, an iSense and a Telos B node. Such nodes are usually connected to gateways which in turn are connected to portal servers. The hardware topology as used in Lübeck is shown in Figure 3.

Figure 2: Two Lübeck sensor node boxes containing three nodes each

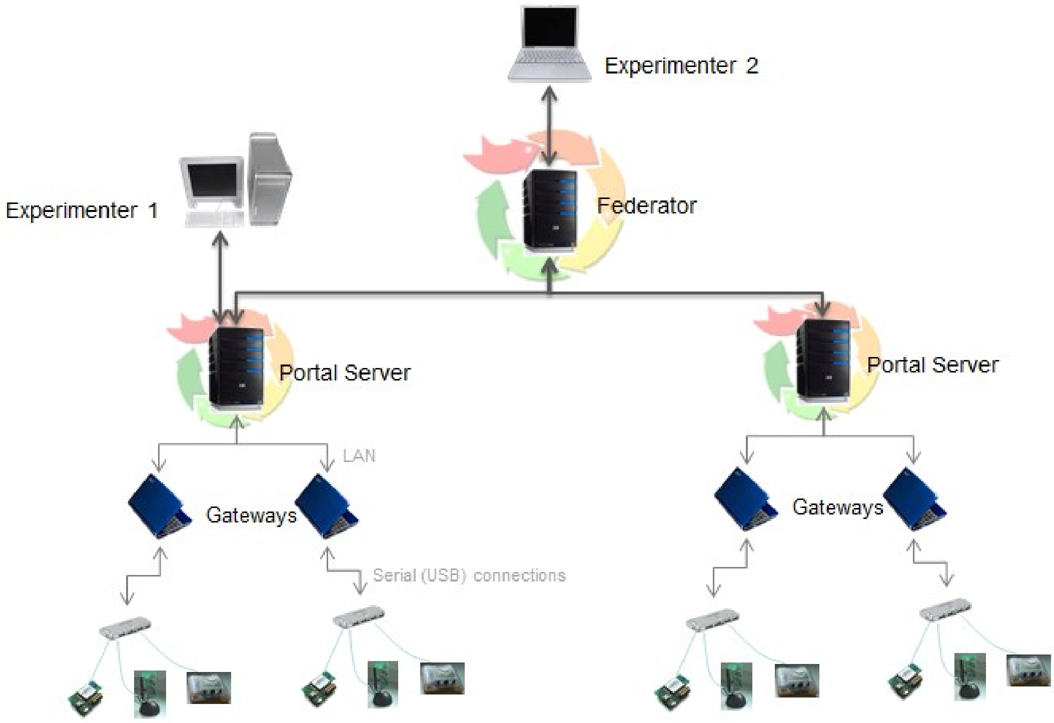

Figure 3: Hardware topology of a typical testbed in Lübeck

Also during the second year of WISEBED, WP 1 proceeded well. Extensions in most of the testbeds at WISEBED partners further improved the hardware infrastructure providing the basis for visualizing the goal of a federation of large wireless sensor network testbeds across Europe. The variety of hardware resources deployed to furnish the testbeds at WISEBED partners is also supplemented by additional wireless sensor network platforms. Heterogeneity has been, therefore, increased resulting in wide range of application areas. After the second period, around 750 wireless sensor nodes of different types are deployed across all the partners. Detailed discussion of the individual testbeds at the partners is given in the deliverables D1.3. After the second period, all the partners are using a wireless or wired backbone to facilitate the communication between the wireless sensor nodes and the testbed portal. A testbed-specific monitoring system has also been made available at most of the partners enabling the wireless sensor nodes to recover in case of failure or malfunctioning. Both automatic and semi-automatic monitoring mechanisms have started to be installed as per the needs and requirements of the respective testbed. Additional wireless sensor nodes supporting low mobility are also deployed at several partners. Few outdoor nodes are also available at some partners to support outdoor experiments.

Figure 4 shows an outdoor node (a) as it is used at the University of Lübeck. Such a node can operate unsupervised more or less forever, since its power supply comes from a solar panel. 35 of such nodes are deployed in a park close to the university as can be seen in Figure 4 (b).

(a) An outdoor node

(b) The outdoor set-up in Lübeck

Figure 4: Outdoor deployments

Finally, in the third period, extensions in most of the test beds at WISEBED partners further improve the hardware infrastructure providing the basis for visualizing the goal of a federation of large wireless sensor network test beds. The variety of hardware resources deployed to furnish the test beds at WISEBED partners is also supplemented by additional wireless sensor network platforms. Heterogeneity is, therefore, increased resulting in wide range of application areas After the third and final period, more than 1000 wireless sensor nodes of different types are deployed across all the partners. Moreover, around 500 wireless sensor nodes are also available on demand as part of non-persistent wireless sensor nodes. Detailed discussion of the individual test beds at the partners is given in the deliverable D1.5. Currently, all the partners are using a wireless or wired backbone to facilitate the communication between the wireless sensor nodes and the test bed portal. Around 300 gateways and at least one portal server per partner are deployed in setting up the infrastructure. A test bed-specific monitoring system is also available at most of the partners enabling the wireless sensor nodes to recover in case of failure or malfunctioning. Periodic maintenance time slots enable the test bed administrator to ensure avoiding any malfunctioning in their respective test beds. Additional wireless sensor nodes supporting low mobility are also deployed at several partners. The number of outdoor nodes has also significantly increased at partners to support outdoor experiments.

Figure 5 gives an overview of what kind of sensor nodes had been deployed at which site at the end of the project.

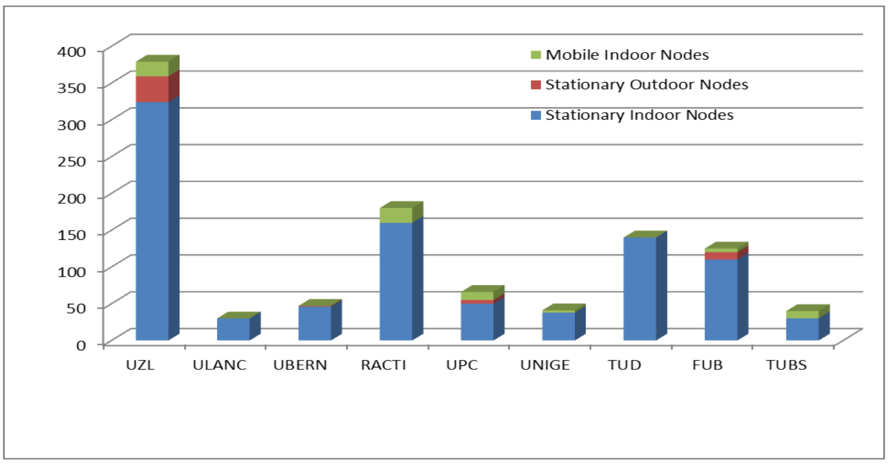

Figure 5: Deployment of nodes in WISEBED

Software

During the first period, in Work Package 2 (Software), the following work has been performed, in four major areas. Firstly, a prototype test bed management system has been developed with which users can upload experimental software and download results, and as part of this system a Shibboleth-based user authentication infrastructure has been deployed at all partner sites. Secondly, a prototype per-node software development kit (SDK) has been developed based on the OpenCom dynamic component model, allowing developers to compose various configurations of component-based systems suited to different deployment requirements. Thirdly, work has continued on the existing Shawn WSN simulator, particularly to integrate it with the aforementioned per-node SDK. And finally, initial development of test bed interconnection systems has been undertaken which both connects the "portal servers" of each partner site into a virtual network and allows sensor nodes in different test beds to communicate with one another as if they were part of the same test bed. As an overall result of this first phase, a first implementation of the architecture described in Figure 1 has been created. Figure 6 shows the set of APIs that has been developed in this work package and which build the interface between software that provides and runs the experimental facility and software that acts as a client, e.g., a user interface. This concept allows a very flexible approach to providing software which (a) follows a standard (the WISEBED standard) and will thus be compatible to existing software solutions and (b) distributing the tasks of client and server software creation. This means that whoever wants to use the WISEBED experimental facility can either use one of the existing clients or create his own one, just by using the interfaces. On the other hand, whoever wants to set up his own WISEBED-compatible testbed can either use the existing testbed runtime software or create his own one – as long as he adheres to the interfaces, every client will be compatible with it.

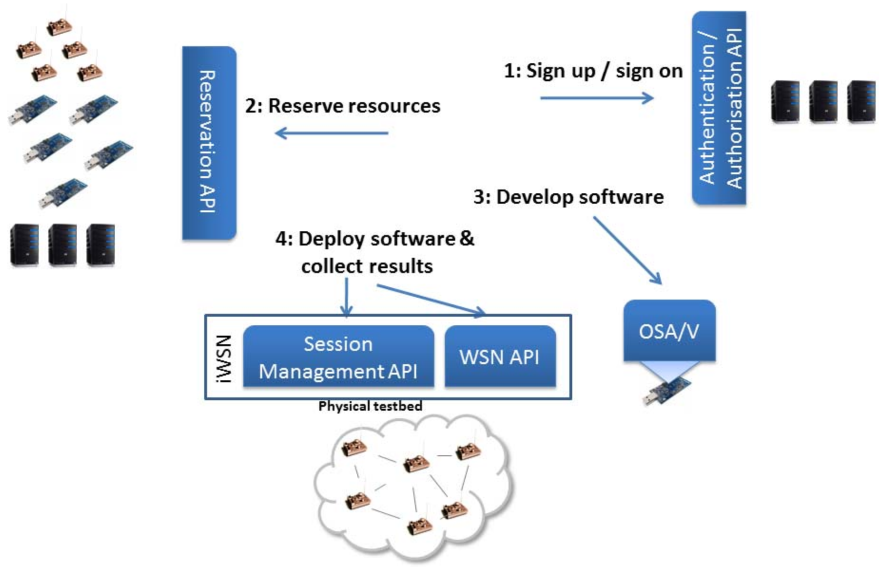

Figure 6: The WISEBED APIs

During the second year, the partners have further developed each of the areas covered by the ‘core’ WP2 tasks: i.e. *Task 2.2: Design and simulation*; *Task 2.3 Execution Framework*; and *Task 2.4 Testbed Operation, Access and Management*. More significantly for the Year 2 work plan, the partners have also carried out, under *Task 2.4 Integration and Evaluation*, a full pass of integration of the work in the above tasks. As indicated in the DoW, the purpose of Task 2.5 is to “*connect packages* *developed in Task 2.2, 2.3 and 2.4 into an integrated toolset along with a common user interface giving support for the complete development cycle*". In practice, this integration has two concrete manifestations. First, a comprehensive integrated software infrastructure now is available that runs on a significant subset of the nine WISEBED sites and covers all aspects of the software lifecycle including design of both experimental software and testbed configurations, testbed resource reservation, secure single sign-on access to testbed facilities, experiment operation including dynamic reconfiguration, and curation of experimental output and results (see Figure 7). The operation of this integrated infrastructure was demonstrated at the Year 2 Review Meeting by means of a scenario-based demo; . Second, the architecture of the integrated software infrastructure has been documented in the format of a journal paper (which was finally accepted for the Communications of the ACM and will appear in January 2012).

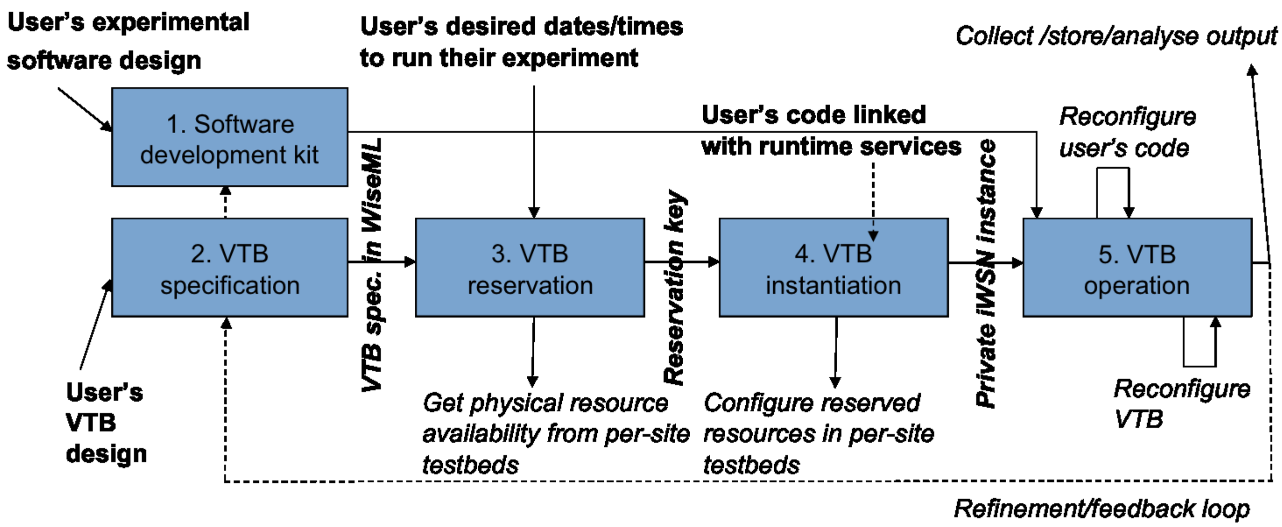

Figure 7: Support of the Experimentation Process

During the final year, the partners have finalized work in each of the areas covered by the core WP2 tasks. All of these tasks were successfully completed in month 30. In the remaining 'live' task, Task 2.5 Integration and Evaluation, the final pass of integration of the work in the above tasks has been completed. The outcome of this integration is the "iWSN" software suite which covers all aspects of the software lifecycle including design of experimental software and test bed configurations, secure single sign-on access to test bed facilities, test bed resource reservation, experiment operation including dynamic reconfiguration, and creation of experimental output and results. iWSN has been through several iterations this year and is now running on all 9 of the WISEBED test beds plus the 'desktop' test bed produced by CTI. Furthermore, three different implementations of iWSN (from UZL, ULANC and CTI) are available. This diversity has been useful in stress-testing the APIs in different hardware and programming language environments and in evaluating different implementation approaches; it is also useful in providing a choice of starting points for future implementations or ports. The operation of the software suite has been demonstrated at the Year 3 Review Meeting by means of a scenario-based demo which highlighted the federation of multiple test bed sites and involved heterogeneous implementations. The software base has been extended vertically—in particular, the SDK package has been expanded through the development of a new WSN operating system, called Lorien, which follows the component-based architecture of the SDK and focuses on the support of dynamic and modular over-the-air-reprogramming of nodes. In terms of documentation, the partners have produced comprehensive wiki-based online documentation for both test bed users and for parties who wish to extend the WISEBED environment by contributing a new site to the federation. This documentation is accompanied by virtual machine based packaging of all the required software.

Algorithms

During the first period, in Work Package 3 (Algorithms), the foundations for the Wiselib have been laid. TUBS has acquired and evaluated a representative set of sensor nodes, and produced a working prototype for the algorithm library that runs on the OSA/V from WP2, as well as natively on most WISEBED platforms, and additionally in simulators. Support for SunSPOT was dropped, as it turned out that the Wiselib would run on either SunSPOTs only, or on every other WISEBED platform. The prototype has proven itself to be highly efficient by its ability to adapt to platform characteristics without paying a runtime price. TUBS engaged in training activities so that the other WISEBED partners were, already after the first period, able to quickly implement algorithms. All WISEBED sites that are involved in WP3 have started evaluating and implementing algorithms, partially already in the Wiselib, partially as pre-studies using other means. To the user, i.e., an outsider, the Wiselib already appears as a well-designed single piece of software, proving that the WP3 partners are working hand-in-hand towards a shared vision.

Figure 8 shows the overall position of the Wiselib in the architecture of a sensor node. Still, application programmers can use the operating system directly if they wish, but they can also make use of the convenience of having a huge number of algorithms already programmed for them.

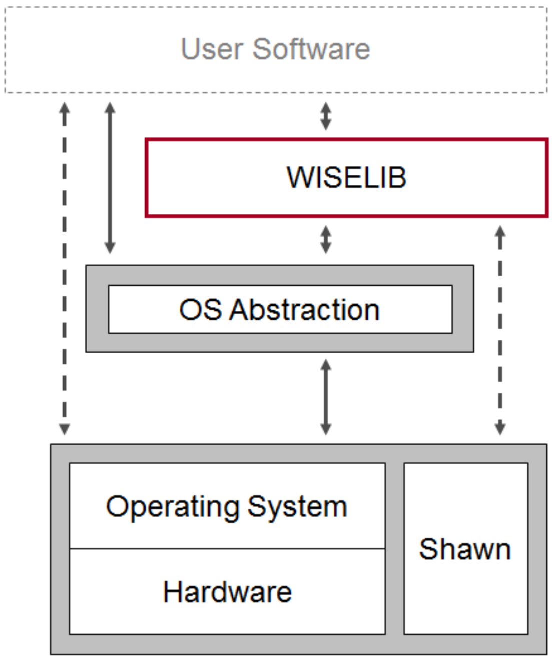

Figure 8: Wiselib usage on a sensor node

During the second period, the Wiselib has been extended and refined. The partners have contributed both implementations of well-known algorithms from the literature and of original WISEBED research, resulting in an overall size of the Wiselib of 60 algorithms in 10 categories. Furthermore, the basic structure of the Wiselib has been extended to allow for easier algorithm development. The feasibility of the design and its efficiency was thoroughly evaluated. This was presented at the 2010 European Conference on Wireless Sensor Networks (EWSN). Interfaces were optimized and improved, so that now more complex algorithm classes are supported. The Wiselib is now accessible through a standalone website, www.wiselib.org, containing download packages, instructions, and documentation.

One major design concept is the use of C++ templates. As a result, the library can be used very flexibly on many different platforms without having to do much re-programming or porting. Figure 9 gives an example of how for instance a routing algorithm can be used on different hardware platforms.

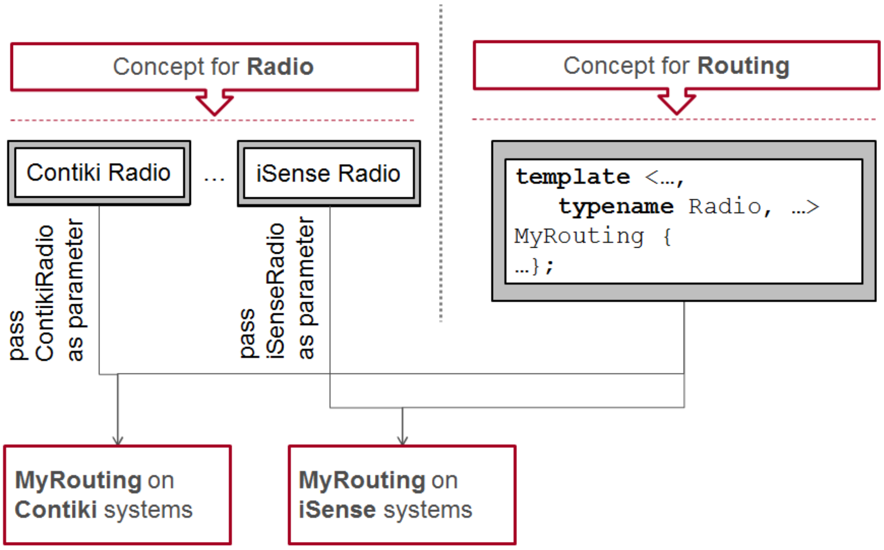

Figure 9: The template concept

During the third period, the Wiselib has been further extended and stabilized, resulting in an overall size of 78 algorithms in 10 categories. In addition, the list of target systems has been extended, from stabilization of existing targets up to support of mobile devices such as iPhone and Android-based smartphones, allowing these mobiles to directly communicate with WISEBED test beds. TUBS organized a Wiselib School in the context of the EU project SPITFIRE to propagate the Wiselib to external partners. Attendees were from EU projects SPITFIRE, FRONTS, and SmartSantander, as well as German projects G-LAB and WSNLAB. In particular, the Wiselib was then used in FRONTS, mainly consisting of partners with a theoretic background, and thus without much experience in algorithm development for hardware platforms. With the aid of the Wiselib, these partners were able to implement their algorithms, and to do experiments on both the simulator Shawn and sensor network test beds. Not only that the partners contributed new algorithm implementations to the Wiselib, they also provided valuable feedback to the design of the Wiselib. After the end of WISEBED, the Wiselib is going to be used in other projects as well, such as the EU project SPITFIRE, and the German projects WSNLAB and MOVEDETECT.

Figure 10 gives an overview on which platforms are supported by the Wiselib. Obviously, Wiselib can be used very easily and flexibly (and without much runtime performance losses) on nearly every known sensor network platform. In addition, due to its template concept, it can be easily ported to new platforms.

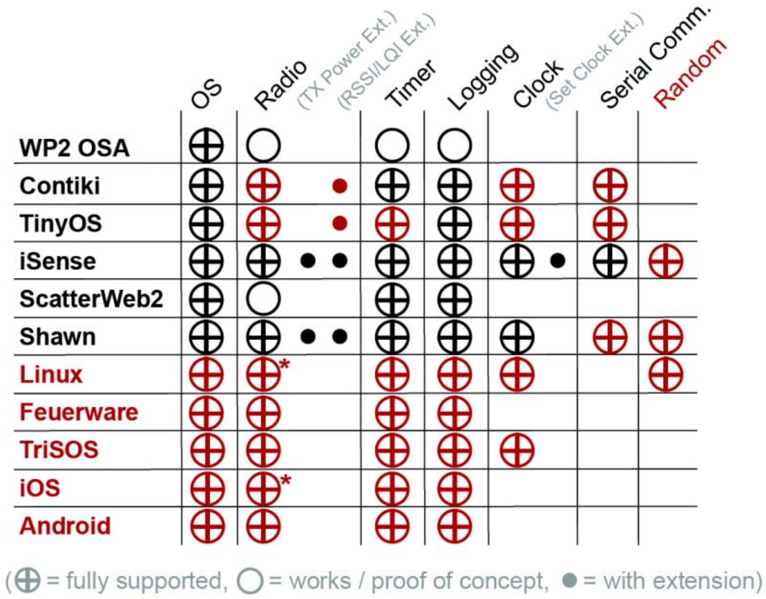

Figure 10: Hardware support of the Wiselib

Data

During the first period, in Work Package 4 (Data), the following work has been performed, in two major areas. Firstly, the partners focused on the design of the application scenarios. The application scenarios which were finally selected (global facility management, object tracking at borders and sports tracking) have been chosen such that they cover a large and diverse set of underlying characteristics for sensor network applications. As part of this study the partners focused on the types of data that could be collected and their characteristics, also from the perspective of time and location. Secondly, based on the study mentioned above the partners focused on the schema for representing this data. The choice was to define an XML format similar to GraphML and import features from KML with which simulation traces could be defined. The chosen format was validated with a first set of data being converted to it and visualized (a validation, visualization and conversion tool has been created). Integration with existing simulators was also considered, and as a starting point, integration with Shawn has been addressed.

During the second period, the WiseML standard trace format has been evolved based on initial experiences and the wish to integrate it firmly in the WISEBED tool chain. The move away from GraphML syntax has opened the road for using common XML-based tools, such as schema verifiers. In addition, a tool (called Weyes) was added to visualize traces, plugins for two simulators (Shawn + COOJA) were developed, and WiseML was integrated with TARWIS. The latter integration allows for automatic generation of trace files from experiments carried out on WISEBED test facilities. Considerable effort has been put into collecting and converting data traces for the three scenarios defined in the first period (global facility management, object tracking at borders and sports tracking). These traces are now ready for use by other researchers to study the behavior of protocols of routing, aggregation, etc. as well as complete applications.

During the third period, the WiseML data format has been finalized based on extensive usage through tools like TARWIS. The collection of trace files was extended, and metrics to classify the traces and benchmark algorithms have been defined. WiseML is now used in, or supported by, a wide range of tools including test bed management systems (TARWIS, the Runtime Test bed), visualizers (WeyesBED, WSNGE), and simulators (Shawn, COOJA, BonnMotion). The collected set of trace files has been made publicly available through the WISEBED website and consists of 22 data sets representing the three application scenarios defined in the first year. Classification metrics have been defined that metrics can be determined automatically and characterize the complexity of a data set in three dimensions (network cohesion, spatial correlation and temporal correlation). The classification aids in benchmarking algorithms as data sets can be ordered according to their difficulty. A pilot has been under taken with three data aggregation algorithms demonstrating the feasibility of this approach.

To summarize, the following main results were achieved during the project runtime:

Work Package 1:

- Deployment of more than 1000 heterogeneous wireless sensor nodes at partners.
- Installation of a self-monitoring mechanism along with periodic maintenance at each partner to help in restoring the wireless sensor nodes to their normal state in case of any failures.
- Deployment of around 70 mobile wireless sensor nodes at different partners.
- Deployment of around 60 outdoor nodes to support outdoor experimentation
- A total of around 300 gateways are deployed for setting up the infrastructure along with at least one portal server per partner.

Work Package 2:

- Full integration and refinement of the iWSN software suite that was developed, in its first version, at the end of year 2. Its highlights are extreme flexibility in terms of support of all kinds of different hardware platforms and support of the newly developed virtual link paradigm.
- The deployment of the integrated system on all nine WISEBED sites.
- The development of a new scenario-based demo that exhibits the operation of the integrated system with a focus on test bed federation.
- Development of the Lorien OTAP-capable WSN OS as part of the WISEBED SDK.
- Comprehensive wiki-based documentation of the iWSN software suite.

Work Package 3:

- Development of a comprehensive and generic library of sensor network algorithms, the so-called Wiselib.
- The Wiselib has a stable design, based on C++ and templates. So far, it runs on nine different mote operating systems, as well as the WISEBED OSA/V API, and the simulator Shawn. It also supports more than 10 sensor node platforms.
- The Wiselib contains 78 algorithms in 12 categories. Six algorithms are based on original WISEBED research. 60 algorithms are in the distributions using the generic C++ framework ("testing" and "stable"). 7 algorithms were contributed by external users.
- The Wiselib has already been used by external users, for instance the EU project FRONTS and German project G-Lab. In FRONTS, the Wiselib was successfully used by theoreticians, not familiar with development on sensor hardware, providing six new algorithm implementa-

tions. The Wiselib is going to be used in other projects over the end of WISEBED, such as the EU project SPITFIRE, and the German projects WSNLAB and MOVEDETECT.

Work Package 4:

- Scenario descriptions (3x) and identification of data types and characteristics to be used in simulations and benchmarking
- Definition of the WiseML (XML) format used to describe application data (experimental set-up. scenario, and traces over tim)
- WiseML plugins for simulators (Shawn + COOJA)
- WiseML verification tools and the Weyes visualizer
- Sample WiseML trace files generated from real experiments covering all 3 application scenarios
- WiseML integration with BonnMotion, WSNGE, and Testbed Runtime
- adoption of WiseML by external parties (research projects and industry)
- development of benchmarking metrics

Dissemination

The following summarizes the dissemination activities:

During the first period, in Work Package 5 (Dissemination and joint research activities), a number of activities were accomplished. As a result of the first year, there are already 20 publications by the members of WISEBED and 4 invited talks where results from the project were presented to the scientific community. To coordinate the project's progress, 10 workshops were held at different sites, each dealing with a specific topic. Apart from that, the progress of the project has been documented on the web portal at www.wisebed.eu. It has been complemented by a separate site for the software distribution and documentation of the Wiselib (www.wisebed.eu/wiselib) and a site for the draft documents of the efforts to standardize the federation protocols called OFA (Open Federation Alliance) at www.wisebed.eu/ofa. To further promote the dissemination of results, a number of training activities were performed. In addition, the members of WISEBED actively contribute to the FIRE community; members of the consortium visited all major FIRE events and participated in the FIRE Expert Group.

During the second period, 22 scientific papers were published. Three papers and a demo were accepted at the renowned and highly selective EWSN conference presenting key results of WISEBED (Wiselib, Virtual Links, and TARWIS) to the scientific community. In addition, 8 invited talks, a Winter School in Braunschweig and contacts with other European and inter-national projects and partners (e.g., the CONET NoE or partners from Argentina and New-Zealand) helped to disseminate project results and to promote the use of the WISEBED experimental facility. In addition, the members of WISEBED actively contributed to the FIRE community by participating in the major FIRE events and by discussing with researchers from the US during the joint NSF/FIRE meeting in Princeton. To coordinate the project's progress, 8 workshops were held at different sites, each dealing with a specific topic. Apart from that, the progress of the project has been constantly updated on the web portal which now also hosts the technical report series that, at the end of period 2, comprises 12 reports covering APIs, implementation details of the WISEBED software, and download links to the components that are already available under an open source license. This is complemented by a separate site for the software distribution and documentation of the Wiselib (www.wiselib.org). To further promote the dissemination of results, a number of training activities was performed.

During the third period, 31 publications were accepted, 4 new technical reports were published and many existing reports have been updated. The wisebed.eu website has been re-launched to better meet the requirements of new users and now contains with handbooks for developers, test bed users and test bed operators. In 15 invited talks, WISEBED results have been disseminated to the scientific community. A number of teaching activities were conducted at universities and to major events (Joint SPITFIRE School of the EU-projects WISEBED, FRONTS, and SPITFIRE and the SmartSantander Development meeting) were organized to train non-WISEBED partners in using the WISEBED technologies. In addition, some project-internal face-to-face meetings were organized and a vast number of telephone-/Skype-/Chat-conferences took place to enhance and harden the experimental facility. WISEBED collaborated with the CONET Network of Excellence (which now uses the WiseML technology) and the FRONTS project (which extensively uses the Wiselib and has contributed to it). The WISEBED software is re-used by external projects such as EU FP7 SmartSantander, SPITFIRE, FRONTS and the German-funded Real-World G-Lab, WSNLAB, MOVEDETECT projects.

The following list summarizes the dissemination activities of Work Package 5:

- 73 accepted publications and 27 invited talks to disseminate project results
- A vast number of internal workshops at different sites to coordinate collaboration, and virtual meetings via Phone, Skype, and Bravis
- A number of schools, tutorials, and teaching activities
- Two large Winter Schools (Lübeck and Braunschweig) with technical presentations about WISEBED, hands-on sessions, and scientific presentations. Additionally, a number of training activities at different universities took place
- Joint SPITFIRE School of the EU-projects WISEBED, FRONTS, and SPITFIRE on WISEBED and the Wiselib
- Joint SmartSantander Development Meeting
- Many teaching activities at universities (programming courses, diploma theses, etc.)
- Participation at the major FIRE events, the FIRE Expert Group, and a joint NSF/FIRE Meeting in Princeton. In addition, we took part at the Wise Men meeting and the making of the FIRE offer video.
- Website for the project (wisebed.eu), the Wiselib distribution (wiselib.org). Re-launch of wisebed.eu with handbooks for developers, test bed users and test bed operators in year 3.
- Cooperation with non-WISEBED members to disseminate WISEBED technology. This includes partners in Argentina, Brazil, New-Zealand, several European universities, the CONET network of excellence, the FRONTS project and a number of industrial partners.
- A variety of software developed as part of WISEBED is available under open source licenses. A section on the web portal links to the individual components.
- The WISEBED software has been used by external projects such as EU FP7 SmartSantander, SPITFIRE, FRONTS and the German-funded Real-World G-Lab, WSNLAB, MOVEDETECT projects.
- Technical report series (comprises 16 technical reports on different technical aspects of WISEBED)

Impact

Based on the results reported above, the project is expected to have the following impact:

- The WISEBED infrastructure will be continuously supported and will be available to European researchers for their experiments. The partners believe that the WISEBED platform provides an interesting experimental platform and will be used by further FIRE projects, but also by external organizations. Up to today, the platform is in use in a number of European projects already, such as for instance SPITFIRE and certainly SmartSantander, where it builds a major part of the Lübeck deployment.
  In summary, the WISEBED Experimental Facility is ready to be a reliable backbone for wireless sensor network research in Europe. In addition, it is open for additions of new physical testbeds both from Europe and from the rest of the world.
- Second, the WISEBED API and software has been made available as open source. As a result, everybody can take the software package and build his/her own testbed. Since the software is quite mature, the consortium expects a number of sites throughout Europe to follow this path. Users of the WISEBED software have a number of options:
  - They can simply use the complete software to create their own stand-alone experimental facility of virtually any desired size.
  - They can use only parts of the software in order to connect, for instance, to existing testbeds, where no appropriate clients are offered.
  - They can connect their own testbed to the official WISEBED Experimental Facility and become part of it.
  - They can further develop the software and thus improve it. For instance, following this path, it would be possible to add new functionality. Actually, SmartSantander is currently following this path.
- The Wiselib has the potential to become the leading library to support the development of wireless sensor network applications. Even though it is a very generic library (which is good, because it can be used on many different platforms), it has a very good performance and can thuis be used not only in prototype implementations, but also in productive applications. The Wiselib has achieved quite some attention, and meanwhile, new algorithms are added also by non-WISEBED members.
- The language WiseML offers a standardized approach to describing resources for experiments and the resulting experimental data. It has the potential to become a backbone language for experiments in federated environments.

In order to further push these positive developments and to provide an institutional base for the continuous development of the software packages developed within WISEBED, the partners intend to create a foundation. Discussions on this have already started.

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