ARCHITECTURE DESIGN CONSIDERATIONS FOR THE EVOLUTION OF SENSING AND ACTUATION INFRASTRUCTURES IN A FUTURE INTERNET

Timothy Baugé
Thales Research and Technology (UK)
Reading, UK

Alexander Gluhak
LM Ericsson Ireland, Ericsson
Ireland Research Centre
Dublin, Ireland

Mirko Presser
The University of Surrey, CCSR
Guildford, UK

Laurent Herault
Commissariat à l'énergie atomique - LETI
Grenoble, France

ABSTRACT

The Future Internet will be an inherently cyber-physical system, providing native support for many forms of real world interaction, including sensing and actuation. This will place unique requirements on its architectural design, as a vastly heterogeneous set of stakeholders tussling to promote business and social opportunities, while addressing technical and incentive barriers. This paper describes a set of high level architectural models which can be used for including sensing and actuation services into the Future Internet. As such architectures can only be implemented through the cooperation of a wide variety of business actors, the ultimate design will not be under the control of any single entity. Tussles will be played out during the lifecycle of the system, which will cause an evolution of the approach to specific functions. We therefore apply an analysis of these tussles to derive architectural boundaries and interfaces which will allow the system to evolve through these tussles, but without breaking the cohesion of the overall architecture.

I. INTRODUCTION

The growing development of cyber-physical systems is highlighting the potential of adding real world interaction into digital applications. For example context awareness is enabling autonomous decision making and system operation, proactive service adaptation and delivery. Initial work in wireless sensor and actuator networks (WSAN) has taken a vertically integrated approach to particular problems, envisaging real world interaction infrastructure deployed for a specific application and purpose. Recent work has begun to address the integration of WSANs into a common framework (e.g. IRIS [1], GSN [2], SenseWeb [3], SWE [4], e-SENSE [5]). These efforts develop the concept of horizontal integration, providing reuse of the WSAN infrastructure for many applications, and coordinating access to services it offers. While the existing work concentrates on the technical feasibility of such an integration, little attention has been devoted to weaving these solutions into a compelling trading environment in which very diverse entities (ranging from private individuals to large corporations or government institutions) can provide and access context information and actuation services, in a secure and trusted fashion. While specific solutions may prove technically feasible, they may also be too restrictive or too open to be practically adopted by the full breadth of interested parties. Solutions must be fit for purpose, not only technically, but also from a business perspective. Assessing the latter is one aspect of the work carried out in the SENSEI project, and the purpose of this paper.

The SENSEI project vision is the inclusion of real world sensing and actuation services as a fundamental component into a global networked infrastructure, making the Future Internet an inherently cyber-physical system. One of the major stepping stones in realising this integration is to provide a compelling rational for owners of sensor and actuator island to join this global infrastructure, as well as mechanisms to support consumers of these services in accessing them. In other words, a trading model is required to steer the integration framework’s service layer requirements. We use the term “trading” in its broadest sense, covering selling, but also bartering or free sharing of services. Considering that island owners may range from private individuals (home or car WSAN for example), to businesses (building WSAN for example), or public institutions (road WSAN for example), the trading model must support all combinations of interaction between these very diversely capable stakeholders.

It must be noted however that developing a full e-commerce business model for WSAN services in the Future Internet is not the purpose of the work presented here. Indeed, such an attempt may be futile. Developments in e-business models in the last few years have considerably expanded commonly accepted wisdom about revenue models, business roles and market approaches. The Future Internet will evolve its own business rational in time. While an electronic trading infrastructure has many components [6], we focus in this work on defining the nature of integration points (i.e. the systems, mechanisms and platforms which enable the interactions between the business entities).

The goal of this paper is to gain an understanding of an architecture for a global marketplace for real world information and interaction in the Future Internet. Our contributions are an exploration of the design space for such architecture and an initial analysis of the possible ways of interaction between entities participating in such eco-system. Based on a study of possible tussle spaces [7] we provide initial architecture design considerations for its functional decomposition and characteristics of important interfaces.

The remainder of this paper is structured as follows. Section II describes an analogy which has been used to map the architecture design space, and section III offers a discussion of the resulting design options. Section IV introduces the notion of tussles, which enables us to derive further architectural constraints. Finally, section V draws some concluding remarks on the discussion in the paper.

II. MARKETPLACE MODELS

To describe possible trading models used between the sensor and actuator service providers and the role of the SENSEI
framework in enabling them, we use an analogy from the retail world, as the parallel seems particularly relevant. The terminology is however only illustrative, as in particular SENSEI scenarios do not necessarily involve retail-style financial transactions. The intention is to investigate the relationships which may exist between 4 very high level roles: Producer, consumer, 3rd party service provider, and SENSEI framework provider (while it is envisaged that the SENSEI framework may be provided by a combination of providers, for the purposes of this work, we consider them as a whole and refer to the “framework provider” as a single entity).

To support the description in the rest of this section, we define the following terminology:

- **Trade services**: The sensor and actuator services which are integrated into the Future Internet. These encompass the whole context and actuation value chain (high and low level context processing, high and low level actuation tasks, etc).
- **Support services**: The services which are provided to support and enhance the provision of the trade services. For example, identity management, accounting, service discovery, etc.
- **SENSEI community**: All the entities which use the SENSEI framework to either offer or consume trade services. This community may be of varied size and nature depending on the SENSEI system implementation.

The marketplace analogy is structured as follows: the SENSEI community members are the producers and consumers, and the SENSEI framework is the trading floor, which could be a supermarket, a shopping mall or a street market for example. The SENSEI framework provides the infrastructure which enables the trade flow from producers to consumers.

In the next section we explore this analogy using the three examples highlighted above: SENSEI system as a street market, a supermarket or a shopping mall.

A. Typical models

Before describing each model in turn, it must be noted that these are only 3 typical examples among many. The choice of these 3 comes from the retail analogy, but should not limit the flexibility of the actual SENSEI system.

1) Street market model

In this model, providers and consumers are provided with a very lightly managed “space” to trade. In the most extreme case, the “space” does not provide any services at all to support the trade, and requires the community to look to itself or 3rd parties for support services. This extreme case is not envisaged within the project, as it reduces SENSEI to providing the underlying connectivity services while pushing all the service level issues into the community.

The distinctive features of this model are as follows. The SENSEI framework does not address any service layer issues, but is restricted to providing connectivity solutions. At most SENSEI may recommend a set of interfaces and protocols that enable providers (data, added value services,… ) and consumers to interact.

SENSEI does not interfere in the transactions/relationships between providers and consumers, only providing the environment for them to occur. In particular, SENSEI does not itself enhance the trading relationships (it does not provide reputation guarantees, quality guarantees, etc), but does allow 3rd parties to provide such overlay services if the “market place” accepts them. There are no inherent boundaries around this model, and the size of the market depends on how many people turn up (both producers and consumers).

The World Wide Web is a leading example of this model. Apart from a few very basic services, for example name resolution services, to resolve high level connectivity issues, everything is provided by independent producers (content, security related services, …), either as end-user services, such as e-shops, or as support services, such as secure payment services, or trust authorities.

2) Supermarket model

This model is at the other extreme of the spectrum to the street market, and provides a highly managed space for trade. The supermarket (SENSEI framework) exists as a business entity and has 3 main interfaces: one to its suppliers (community producers), one to its customers (community consumers), and one to providers of 3rd party services. The goods traded are owned by the supermarket from the time they are supplied until they are sold. From the customer’s point of view, the services are purchased from the supermarket, irrespective of the ultimate provider which the supermarket has subcontracted to deliver. 3rd party services, where available, are also accessed via the SENSEI framework.

In Figure 2 we show the SENSEI framework as a central entity which mediates all services. Consumers cannot access the producers directly, but have to use the SENSEI framework interfaces to do so. The framework has to operate some peering functions to interact with other SENSEI systems. The distinctive features of this model are as follows. The supermarket exists as a business entity independently from producers and consumers. It plays a central role in all interactions within the system. Trade is between the suppliers and the SENSEI system, and independently between the
SENSEI system and the customer. The customer does not have a direct relationship with the supplier.

![Figure 2: Supermarket model](image)

The system is very tightly controlled, as the SENSEI system is responsible for all the goods it trades. As a reseller, it must have tight control over the suppliers. The SENSEI systems can peer or be hierarchically organised (one system acts as a supplier into another system).

“Walled garden” approach of cellular operators (up until recently) provides an example of such an approach. The operators have relationships with the content provider, but users purchase services from the operator.

3) Shopping mall model

This model is an intermediary approach. Producers, consumers and 3rd party service providers are not the only business entities as in the street market model. The shopping mall itself is a business entity, which provides more than just a “space” to trade in, and provides a number of services to support the trade between producers and consumers. However, it does not necessarily control nor act as a middle man in the trading. The relationships are flexible. The shopping mall analogy must not be taken too strictly, as we envisage this model to have a wide spectrum of possible approaches depending on the level of services which the shopping mall provides (which is not the case for real-world shopping malls, which tend to all operate a very strict model).

So, for example, we could envisage this model covering an approach where the “shopping mall” provides “aggregated shops” where multiple individual boutiques’ goods would be presented together. We could envisage a “shopping mall” which provides its own currency or credit card system.

In Figure 3 we show the SENSEI community and 3rd party service providers as a set of actors able to interact either directly or via the SENSEI framework, which provides an infrastructure of support services. The SENSEI framework may:

- support the relationships between community members without being involved in the trade itself (so the producers and consumers trade directly but use the framework for security management for example)
- or take an active part in the trade, for example taking on the role of a producer (producing high level context services from low level sensor services offered in the community).

![Figure 3: Shopping mall model](image)

The distinctive features of this model are as follows. The shopping mall exists as a business entity independently from producers and consumers. It is able to support the community interactions within the system, but does not necessarily control them all. The producers and consumers are able to trade directly, although consumers may choose to use the framework as a “super producer” if such services are available. The SENSEI framework’s capability can be enhanced by 3rd party service providers which it establishes relationships with. This is transparent to the community members and does not require them to establish additional relationships to invoke these services. Traders are dependent on the underlying services provided by the SENSEI system to trade within the system. These may include services to enhance the producer/consumer relationship (identity, reputation or quality management services for example). As trade is direct between providers and consumers, there is a greater flexibility of service provision (the SENSEI system does not resell the services).

There are a number of current examples of such an approach, including the Amazon marketplace (an example of a lightly managed model) and Ebay (an example of a highly managed model, providing the reputation service and payment services through Paypal).

III. INITIAL DISCUSSION

The models presented in the previous section are typical examples of trading approaches which have a retail world parallel. While this is helpful to identify classes of interaction models which SENSEI can draw from at the architectural phase, the design options must not be restricted by the analogy. Underlying the aforementioned classes are two fundamental design axes, namely, the level of support and control the SENSEI framework is expected to provide for the trade process. Figure 4 demonstrates the three discussed approaches in the space created by the two dimensions, where the x-axis shows an increasing level trade control, while the y-axis shows an increasing level of trade support provided by framework.

The Supermarket model is the high extreme on the control axes, controlling all the trade. The level of support may vary for different implementations, dependent on the business
model of the SENSEI provider. The street market model falls off the other end of the scale on both axes, providing no support (at the service level), and having no control on the trade. The shopping mall model sits in between, providing some support to the trading community, and allowing some level of control over the trade, but without mandating it. It must be noted that in this model, the level of support and control are business decisions, and at the architectural level we limit ourselves to providing the capability for different levels of service to be provided.

Figure 4: Variation on typical models

It is obvious that the three presented approaches just represent samples within the space created by the two dimensions and many alternative realizations may be implemented with varying levels of control and support. For the designer of such a system, it is impossible to predict which realization may be accepted by a future market space. Additionally, as such a system is not envisaged to be monolithic in its implementation, many independent entities are expected to cooperate to provide its functionality. For example, there will be a wide diversity of autonomous connectivity providers, many independent trade and support service providers, etc. An architecture for such SENSEI framework needs to be capable of instantiating these different realizations in order to cater for different community needs.

We further envisage the sum of these actors to dynamically influence the ongoing realisation of the overall system at run-time. While a particular control and support balance may initially suit a given community, the requirements may evolve over time due to the socio-economic tussles that will inevitably take place between the different actors in the system. Such tussles, played out as the various actors push their own preference and agendas within the context of the system, will challenge the initial design of it. Incarnation of such tussles that impact the architecture are, for example, refusing to make use of existing features or choosing alternative, redesigning existing or designing new protocols and service mechanisms and deploying those along side or instead of others in the system. The ability to evolve is crucial for an architecture in the face of such tussles as is the ability to allow such tussles to take place separately without affecting other aspects of the system or the system in its entirety.

We believe that an architecture tailored for supermarket like model with highly specific control and support functions may be too restrictive to allow tussles between participating actors to be played out adequately. On the other hand a street market model may provide too little architectural guidance, leading to a long and uncertain gestation period until a real eco-system evolves and matures. We therefore believe that the shopping mall model is a good starting point for the envisioned SENSEI system architecture.

For the design of an architecture it is essential to develop an understanding for the tussles that may take place between the different roles in the SENSEI system and the tussles that may evolve with other existing actors in a Future Internet environment. This understanding can be useful to identify how functions in the architecture should be separated, where choice at run-time should be explicitly supported and how interfaces within the architecture should be designed.

The following section will provide a brief overview of potential tussles that may take place in the SENSEI systems and with its surrounding context. We will then explore the initial consequences for the design of the SENSEI system architecture.

IV. CONSIDERING TUSSLES FOR ARCHITECTURAL CHOICES

According to Clark et. al. [7], a tussle can be described as “an ongoing contention among parties with conflicting interest”. Tussles may have an impact on the design and implementation of various parts of the system as parties try to adapt a mix of technology and mechanism to achieve their conflicting interests. The way these tussles are realized may depend on their nature. An architecture should ideally allow such tussles to be carried out, with little or no impact to other aspects of the system and its proper operation. In other words, the architecture should be organised in such a way as to separate out these tussle-spaces and allow them to evolve in a self contained manner.

This section therefore explores the potential tussle spaces that may emerge between the participating parties of the SENSEI community and its surrounding Future Internet environment. We focus on run-time tussles and identify important implications on the architectural design of the envisioned SENSEI eco-system. Each tussle space is briefly characterized by the entities involved in the tussle and the nature of the tussle. As it is impossible to capture and predict all possible tussles in this paper, only to the ones that can be expected to have a significant impact on the architecture are discussed. From the discussion we motivate an initial decomposition of the architecture into service functions that each contain a specific tussle space. The realisation of such functions can be chosen at run-time and potentially undergo change over time due to ongoing tussles without directly impacting other aspects of the system. In addition, the main interfaces located at important tussle boundaries are presented and an initial characterization of those is briefly provided.
A. Tussles and their Impact on Functional Decomposition

The different roles actors can take in the SENSEI community have been already introduced in section 2. In the following the nature of potential tussles between the different entities is briefly explored.

1) Tussles on the trading model

The first main space for tussles is concerned with defining and evolving the trading model within the system. As providers and consumers join a SENSEI eco-system, their primary aim is to provide and/or invoke trade services. Given the very wide variety of business entities forming the potential communities (private individuals, corporations, governments, etc), there will be tussles to influence the approach of consumers and producers to learn of each other’s interest and offerings, which requires a rendezvous service function. Some will favour a very democratic and peer to peer approach, while others will prefer greater levels of control and hierarchy. Example outcomes to this tussle include public or restricted access service registries, fair or biased search engines, etc.

Consumer using the SENSEI system may require complex trade services, which can only be delivered if a number of atomic services from different providers are composed. This requires producers to fit into a larger and coherent value chain, leading to tussles for influencing the service creation and composition mechanisms used within the eco-system. Example outcomes of such tussles could be a centrally controlled composition framework, dictating data formats and composition models, or a distributed collaborative approach based on sets of community adopted semantics.

While some trade within a SENSEI system may be free, support for remuneration, or more generally value exchange, is also envisaged. Tussles will therefore ensue to define pricing and pricing models which suit the particular community. Example outcomes may be an auction or exchange pricing mechanism, and subscription or flat rate for the charging mechanism.

As soon as value exchange is exercised, the consumer’s interest in the precise nature and quality of the target service increases. The potential scrutiny which a service will undergo within the trading environment together with varying options to enable customer choice motivate the need for a separation of the rendezvous service mechanisms from the actual invocation of the service.

All trade services within the system may not be infinitely shared. For example, while a sensing service can be accessed by many consumers simultaneously, an actuation or processing service may require exclusive access (at least for a period of time). There are many approaches to resolving such conflicts, and the design and evolution of the resource arbitration function will therefore lead to another tussle. Example outcomes include role based pre-empting frameworks, compromise mechanisms, multicriteria ranking approaches, etc.

2) Tussles on the relational model

The second top level space for tussles is concerned with defining and evolving the relational model of the system. Given the breadth of independent parties interacting within the SENSEI eco-system (in terms of capability, influence, goals, values, etc), there will be many tussles to influence the way in which identity is managed within the system. More precisely, tussles to define the nature of identity (whether it resolves to role or precise entity), the degree to which identity within the system can be related to identity outside it (what level of privacy is provided, for example whether anonymity or pseudonymity can be allowed), and the confidence which can be placed in a stated identity (what type of trust model is in place).

Even with a common framework for identity management, a tussle appears between producers and consumers to arbitrate access to services. Consumers would typically like access to any services without restriction (law enforcement agencies may indeed mandate they should be able to access all services), while producers may desire to limit access to certain subsets of consumers only. This tussle will inform the approach to access control. Example outcomes may include discretionary, mandatory or role based access control, etc. It must be noted from the previous discussion that these tussles cannot be completely dissociated, as the access control approach will be influenced by the approach to identity management.

Relationships in the SENSEI system are not exclusively to be found within the service layer eco-system. The SENSEI framework does not necessarily provide all support functions itself, and is therefore required to establish relationships with 3rd party service providers. Additionally, the service layer is consumer of connectivity services provided by yet another set of business entities (referred to here as the connectivity providers). Finally, SENSEI eco-systems are envisaged to be implemented around pre-existing communities of interest, and therefore require means of relating to each other. This provides 3 further tussle spaces, explored below.

As the SENSEI framework uses 3rd party providers to deliver some of the functionality it is responsible for, it can do so with different relational models. The framework could provide a thin wrapper to the 3rd party service, so that the relationship is established end to end between the community member and the 3rd party provider. On the other hand, the framework could invoke the 3rd party service on behalf of the consumer, which breaks to end to end relationship into 2 independent parts. This variety of approaches will lead to a tussle between all parties involved. 3rd party service invocation should therefore be contained in a stand alone architectural functional block.

As leading enablers of all aspects of the service layer functions, the connectivity providers have a strong influence on the performance of the overall system. The complex interactions envisaged in the system (for example composed trade services) will require service layer entities to agree on the underlying service they should invoke, including who should be charged for it and how the service should be parameterised. This leads to tussles among the parties.
involved to define the nature of connectivity services and the way they are offered, motivating a connectivity service management function within the SENSEI system. Connectivity providers may be reluctant to provide additional support for the specific needs of the service enablers in the SENSEI eco-system. In such cases additional support mechanisms may have to be deployed on top by the SENSEI community. Other connectivity providers may see this as an opportunity to update existing technology with mechanisms to cater for the specific needs to gain a competitive advantage over another or may be simply forced to adapt their technology to deal with the strains caused by SENSEI eco-systems.

Finally, as SENSEI systems are implemented around disjoint or overlapping communities, trade services from one system may be required in another. It is envisaged that SENSEI systems should be able to peer, in order to deliver this capability. This however introduces a tussle between systems, as community members may favour joining larger communities if service access through peering is not transparent to them, while SENSEI framework providers will be keen to retain and grow their own community. This tussle will drive the approach to the peering mechanisms, and in particular the level of cost to the consumer (financial, delay, complexity, etc) associated with invoking services from peer systems.

3) Resulting architectural artefacts

In the previous sections, we have analysed tussles which are likely to appear during the lifetime of the SENSEI systems. From these, we have identified functional boundaries, which will allow each tussle to take place within an architectural functional block. In this section, we briefly summarise in pictorial form the functions which we have identified as containing the major tussles. This is shown in Figure 5.

![Figure 5: Architectural artefacts](image)

It must be noted that this view does not aim to be a complete functional breakdown for the architecture. Other functions are likely to be required to deliver the full system. The figure does however capture functional blocks, which should be kept separate.

B. Important Interfaces at Tussle Boundaries

Designing the architecture to separate out the tussles, to enable run-time choice of mechanisms for a particular realization of a SENSEI eco-system can certainly contribute to the constructive evolution of the system. However it is not the only aspect influencing its potential success. Carefully designed open interfaces also play an important role in making an architecture evolvable, as they enable effective replacement of modular parts of the system with alternative technological solutions, driven by tussles and technological advance, and at the same time fostering competition. Of particular importance are interfaces at tussle boundaries, as they need to take into consideration the interest of multiple actors that may be involved in the tussle [7]. The design of these interfaces must recognize that the diverse set of possible actors (ranging from private non technical users to large-scale corporations and governments), taking one or more roles in the system, require different level of expressiveness and different forms of (explicit) choice. Furthermore these interfaces need to facilitate the exchange of adequate value flows between the actors, providing an incentive for the provision of varied and differentiated services.

In the remainder of the section we will focus on two primary interfaces: the interfaces between the SENSEI eco-system and the connectivity providers, and then between peering SENSEI eco-systems. Interfaces between functions internal to the SENSEI eco-system are also important, but require a full functional architectural breakdown which is beyond the scope of the paper.

1) Interfaces towards connectivity providers

As in the current Internet, the fundamental service of a Future Internet will be the interconnection of networks and endpoints. Such connectivity services will be enabled by connectivity providers, taken up by a diverse set of actors similar to today’s ISPs and mobile network operators. The services and respective mechanisms in the SENSEI eco-system will rely on the provided connectivity substrate to enable the envisioned global market place for real world context and interaction.

Naturally there will be tussles among the providers of connectivity services and the providers of other roles that constitute the SENSEI eco-system. The fact that multiple such connectivity providers may jointly provide the underlying connectivity substrate of an eco-system complicates the tussles even further. The interface between the SENSEI eco-system and the connectivity providers should accommodate the varying interest of the different parties. Depending on the nature of traded services within a SENSEI eco-systems and the service mechanisms used for supporting the trade, different types of services may be required from the underlying connectivity substrate. An interface should thus enable the SENSEI eco-systems the choice of underlying connectivity service characteristics. This may be either in terms of types of service, if service differentiation is supported by the connectivity provider or go even further to allow the run-time choice of a connectivity providers that fulfil the required service characteristics for an adequate value. An interface could even go as far as to allow a SENSEI eco-system to dynamically select the chain of connectivity providers that inter-connect its services [8], obviously assuming that respective service mechanisms among the connectivity providers are in place. Such choice would foster the competition among connectivity providers and encourage development of solutions to efficiently deal with the required traffic characteristics of SENSEI eco-system. Additionally, an
interface also has to explicitly support adequate value flows towards the connectivity provider, in order to provide adequate incentive for the provision of differentiated service offerings. The interface must allow consumers to make the decisions based on service characteristics and cost, within and between providers.

2) Interfaces between SENSEI eco-systems

Another important design choice is to make interactions among different SENSEI eco-systems explicit via an open but well defined service interface. Providers and consumers sharing a common goal and purpose may organize themselves into different communities forming distinct SENSEI eco-systems. Each of these SENSEI eco-systems may have agreed upon a set of different mechanisms and protocol solutions to govern its internal operation tailored to its needs (potentially as part of an ongoing tussle or through mutual consent of the parties). While sharing their services in isolation within their community, there could be significant benefit for different SENSEI eco-systems to cooperate with each other by tapping into each other’s services and resources.

Such a peering interface between SENSEI eco-systems enable wider choice for both consumers and producers of a SENSEI eco-system, however requires careful design as it needs to preserve the interest of the communities at both ends. In nature the peering interface is similar to the inter-domain interfaces of connectivity providers, requiring explicit choice, e.g. via policy enforcement and value exchange. The interface would also need to recognise the heterogeneity of the SENSEI eco-systems at different levels, ranging from the policies to the mechanism they may deploy, by making the inherent heterogeneity explicit at the system boundaries. Supporting such architectural pluralism has been argued for already between connectivity providers [8], and is even more justifiable due to the expected heterogeneous nature of SENSEI eco-systems.

V. CONCLUSIONS

This paper has provided an initial exploration of the design space for an architecture suitable for enabling a global market place for real world information and interaction in the Future Internet. Different architectural options exist, mainly varying in the level of support and control they provide for the trade among producers and consumers. Any system which is jointly implemented by a large number of stakeholder will be subject to tensions and pressures as they attempt to influence it’s design to suit their own agenda. In order to survive such evolution, the underlying architecture needs to provide a framework consisting of a set of well defined functions, but can’t be so restrictive as to dictate a single model of interaction and a corresponding specific set of mechanism between the entities involved. While providing initial guidance it should be flexible enough to allow different actors in the eco-system to agree to a specific set of mechanism to realise their preferred mode of trade and accommodate changes to parts of the system that may occur due to run-time tussles between the parties. The best way to ensure this can happen is to design the architecture to isolate potential tussles, so that they can be played out in a self contained manner without challenging the coherence of the overall architecture. After identification and analysis of important tussle spaces between the actors, a number of functional boundaries have been identified, which allow an isolation of these tussles. The resulting functional blocks provide an initial decomposition of the architecture into self contained elements not subject to overlapping tussles. While not aiming at defining a complete set of functions, we believe that the identified set will be essential for an architecture to accommodate the inevitable and desirable evolution of their implementations. Important interfaces at tussles boundaries have also been discussed, which should support value exchange in either direction and make choice and heterogeneity explicit. The work presented in this paper describes one approach of deriving architectural artefacts which, while not providing a full functional breakdown, does uncover fundamental design constraints. It adds a unique perspective to the architecture design process contributing an understanding of the architectural requirements for a system enabling a global market place for real world sensing and actuation.

ACKNOWLEDGEMENT

This paper is based on ongoing work undertaken in the context of the SENSEI project, ‘Integrating the Physical with the Digital World of the Network of the Future’ (www.sensei-project.eu). SENSEI is a Large Scale Collaborative Project supported by the European 7th Framework Programme, contract number: 215923. The authors would like to acknowledge the contributions of their colleagues from the SENSEI Consortium. It should be noted that the views expressed in this paper are those of the authors, and may not reflect the view of the consortium as a whole.

REFERENCES