Enabling SCI-FI: Service-oriented Context-aware and Intelligent Future Internet

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ABSTRACT
Internet is becoming a huge heterogeneous and dynamic network that is growing beyond its architectural limits. The scaling up of the number of communicating nodes and services is leading the Internet to an architectural crisis which in turn makes it difficult to provide services efficiently considering the requirements and context conditions of users. The Information-Centric Networking (ICN) approach proposes a network where the main paradigm is not an end-to-end communication between hosts, as in the current Internet. Instead, an increasing demand for efficient distribution of content has motivated the development of architectures that focus on information objects. ICN supports the proliferation of services and contents allowing seamless access to them. This work proposes a context-aware service negotiation protocol which will enable to find and compose services whilst meeting requesters' requirements and, consequently, maximizing the QoE of users. We also provide the main details of a first implementation of the proposed service-oriented solution (SCI-FI) and discuss the gathered results.

Categories and Subject Descriptors
C.2.1 [**Network Architecture and Design**]: Network communications, miscellaneous;

General Terms
Algorithms, Performance, Design, Experimentation, Verification.

Keywords
Service-oriented architecture, clean-slate, context-awareness signaling protocol, information-centric, validation, QoS/QoE.

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CFI'12, September 11–12, 2012, Seoul, Korea.
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1. INTRODUCTION
Given the fact that the Internet is growing in number of contents, services, users and devices, it is becoming an unmanageable heterogeneous and dynamic scenario where large amounts of information are exchanged among different stakeholders and services. The rigidity of the hierarchical TCP/IP stack and the persistence use of host-to-host oriented communications engender an Internet that lacks flexibility and scalability since the volume of exchanged information is on a gigantic increase.

Under these circumstances, one of the main limitations is the impossibility to intrinsically guarantee end-to-end Quality of Service (QoS) when offering a service. Consequently, this is a stumbling block in the evolution of Internet because it directly affects on users' Quality of Experience (QoE). A shift from current paradigm to service/content-centric communications should be the first stepping-stone on the road to overtake this flaw.

In the light of this situation, new communication approaches appeared based on paradigms such as Internet of Services (IoS) or Internet of Things (IoT). Thus, a generic Information-Centric Network (ICN) solution that sustains these new paradigms is needed, allowing seamless access to services and contents, should be at users' disposal to avoid the proliferation of specific and non-interoperable overlays. The corresponding network architectures to these approaches can leverage functionalities such as in-network storage or multiparty communication through replication and interaction models (e.g. publish-subscribe) to provide general platforms for communication services only available in dedicated systems such as peer-to-peer overlays and proprietary content-distribution networks.

Routing methods should be modified considering the type of information to be transmitted and the communication context, but network must also go beyond the current store and forward functionalities in order to satisfy the requirements demanded for the Future Internet (FI). By providing some clues on the semantics of the information that is to be transferred, the network can provide more advanced services than blindly moving bits and, thus, becoming more intelligent.

Hence, the creation of a flexible, dynamic and scalable system is essential, where services and contents can be added, searched and found in a natural manner. Architectures based on functional pieces that can be published and discovered by users (independently of the node/host/machine that offers it) are usually introduced in projects that revolve around ICN. However, our proposed framework (called SCI-FI) merges ICN and service-oriented concepts in order to create a system for service and content provisioning in an adapted manner whilst satisfying the specific requirements of a communication requester. In so doing, the QoE of users and an efficient usage of network resources can be maximized.

This approach mainly lays in Role-Based Architecture (RBA) [1] and Service-Oriented Architecture (SOA) [2] paradigms to respectively decompose and recompose network functionalities. Using a RBA-based methodology, protocol functionalities are divided into fine-granular services (e.g. retransmissions, error correction, etc.) and published and combined following the principles of SOA. In addition to this, the envisaged solution integrates discovery and routing functions whilst takes into account the requirements imposed by service requesters and context data.

2. RELATED WORK

The information-centric approach to the network of the future is being studied by a number of research projects, both in Europe - PSIRP (www.psirp.org), 4WARD (www.4ward-project.eu) or SAIL (www.sail-project.eu)- and in the US -CCNx (www.ccnx.org) or NDN (www.named-data.net)-. While they differ with respect to their specific architecture, they share some premises, goals and certain features. In general, the aim is to develop network architectures that are better suited for content distribution. Receivers requesting information objects drive communications. Senders make information objects available to receivers by publishing them. Our approach takes as a base the service-oriented architecture introduced in [3]. From a SOA point of view, the discovery of the services that have been published into the network is a fundamental process, since it is necessary to establish a feasible path to the resource.

An intelligent Service Discovery Protocol (SDP) is the key to find and compose different services in the network. SDPs have been widely investigated in the field of Pervasive Computing and Web Services. SDPs used in pervasive computing environments are more dynamic and heterogeneous. In [4] an in-depth analysis and comparison of several SDPs commonly used in pervasive computing appear. Some of them are INS, Ninja-SDS, DEAP-Space, Jini, UPnP, Rendezvous, Salutation and Bluetooth. However, a major problem of current SDPs is that networks with different properties require different discovery protocols. This yields to important interoperability problems. Moreover, Web Services are used at the top of the application level and aim towards service globalization in enterprise environments. Regarding service discovery, we can find three main discovery protocols standardized by OASIS: UDDI, ebXML and WS-Discovery [5]. UDDI is the most extended and mature one. The main drawback of WS approaches is that they focus on electronic commerce. Other works like [6] contemplate context-aware service discovery. On the other hand, other discovery systems focus on single hop (Bluetooth and DEEP Space) and multi-hop [7]. Our proposed negotiation protocol combines some of the techniques described above to discover services according to context data. At the same time, it permits to find a route that ensures the delivery of the requested service.

3. SCI-FI OVERVIEW

In order to create a system that can manage composition of network functionalities, SCI-FI defines three types of elements: Atomic Services (AS), Atomic Mechanisms (AM) and Composed Services (CS). ASs are the building blocks of the composition. A set of network functionalities (e.g. error control, framing, sequencing, etc.) is defined as a primary set of abstract self-contained composable functions. AMs are specific implementations for an AS. An AS can be implemented by different AMs (e.g. bit-oriented/byte-oriented framing, incremental/temporal sequencing, etc.). And CSs are more complex services that are built by a combination of coordinated ASs [8] [9].

However, before composing AS, a process of discovery over the network is previously needed. In the approach presented in this paper, all the process relies on the requester of the service, the Requester Node (RN). RN is the initiator of the communication, and is the responsible of discover the services which it is interested. Then it also selects the best combination and allocation of services through the intermediate nodes (IN) of the path from RN to the End Service Node (ESN).

3.1 Service Discovery Process

Service discovery is the process of identifying the nodes that can provide the desired end service, as well as the ASs that may be required in the nodes of the communication path ranging from the RN to the ESN. This phase is divided into three steps as well. In the first step, requester requirements are mapped out to a service request. Secondly, the nodes that receive the query evaluate if they are able to provide the service. Finally, context information is consulted to guarantee that the service can be provided under the required parameters (e.g. QoS).

Thus, an innovative negotiation protocol previously introduced in [10] is considered; for the sake of discover the services and capabilities of the nodes available in the network. Taking into account the requirements specified by the requester, this negotiation protocol (Figure 1) allows discovering a service into the network. It is flexible enough to work in ad-hoc sensor networks without infrastructure and larger scenarios with infrastructure support.

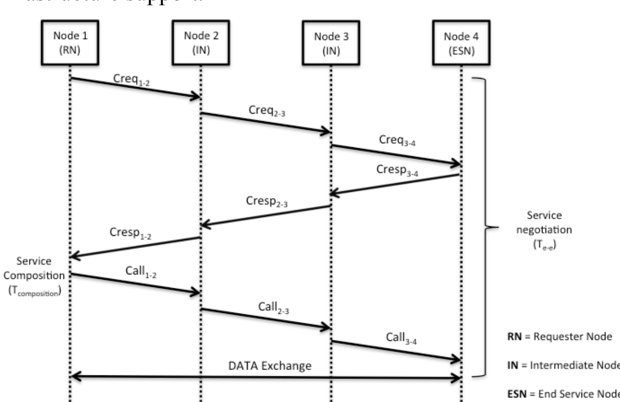


Figure 1 Negotiation Process

A first approach of the communication messages (request (*Creq*), response (*Cresp*), allocation (*Call*)) used for negotiating the service where previously defined by the authors in [9]. Considering the inclusion of service requirements in the request, a *Creq* message is proposed, where a list of QoS requirements, context parameters and AS attributes is requested. Optionally, the authors consider that effects and resources can be specified, respectively as desired high-level features for the communication and specific resources that complement the service request (e.g. a film provided by a video streaming service).

In this sense, this request can be propagated through the network in different ways, gathering the network knowledge and the capabilities of each node. Any node that receives a *Creq* will, by default, evaluate if it can provide the service and if it can deliver the service in the requirements demanded in the request. If the conditions could be achieved, the node answers with a *Cresp* that will be sent through the reverse path of the *Creq*. This methodology permits to face dynamic and frequent changes in the network and in the capabilities of the nodes. In the event the node may not be able to provide the ESN, it will propagate the request to its neighbors until the requested service is found.

The requester will receive 'N' response messages corresponding to 'N' candidate paths. Each of them contains the identifiers of the 'M' nodes that the path, with their capabilities, ASs and AMs.

And finally, once the RN has evaluated the composition possibilities, it sends an allocation message (*Call*) to all nodes through the path from RN to ESN. It specifies, by means of a set of 'M' workflows, which ASs and AMs must be executed in each of the 'M' nodes.

An important issue regarding scalability of this protocol is to limit the scope of the request, in order to not flood the entire network or propagate it indefinitely. Although the authors have not defined a specific solution, many approaches can be adopted depending on the kind of network. Time to Live (TTL) can be set in network without infrastructure or small-sized networks, while dedicated overlays with dedicated directory nodes could be used to perform the search in large-scale networks. A scalable solution providing inter-domain service discovery is a challenging issue, although this topic is out of the scope of this article.

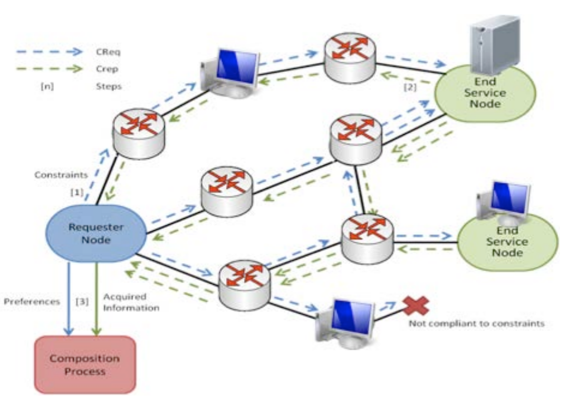


Figure 2 Discovery Process

3.2 Service Composition

Service composition process consists in a prioritized selection and combination of the end service and intermediate ASs among all the candidates found during the service discovery phase. This allows optimizing the network resources during connection setup by selecting those services which minimize the overall costs when providing a service. Service selection must take into account domain policies and effects that the usage of a service produces over the network (e.g. delay, congestion, cost, etc.).

In order to empower the requesters' control over the communication, the authors propose for this first version that the orchestration of services relies in the RN. The requester will always decide which services will be chosen according to the discovered ones.

First, the information discovered in the network is organized in a graph structure where nodes of the graph are the nodes of the network. This graph can be simplified as a tree of disjoint branches since each *Cresp* obtained from the discovery process can be mapped into a structure like the one shown in Figure 3.

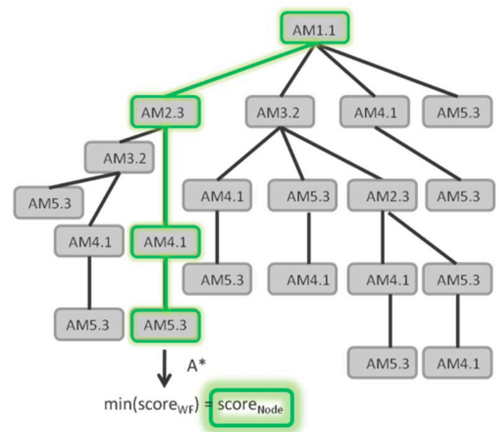


Figure 3 AS composition process

This work divides the composition process to create a CS into three phases: AM Scoring, AS Composition and Path Selection.

3.2.1 AM Scoring

In this phase, by means of scoring functions, the AM that implements each AS is selected. It takes into account different specific attributes related to the AS, for instance the QoS requirements and capabilities that they can provide and the priorities of the RN. A set of possible AMs is scored and the best one is selected for each AS. As the most generic function available in all the nodes, a weighting function to score the AMs is proposed. The weights of this function can be tuned depending on the preferences introduced by requesters. Therefore, it is possible to define trade-offs between different parameters such as the desired quality that should be provided, requirements or the price to pay for a service. However, specific scoring functions could be used for each AS in order to consider particular requirements as shown in [8], where a score metric for audiovisual contents is proposed.

3.2.2 AS Composition

Depending on the composition of a service, provided QoS may vary. For instance, a reliable service can be provided by means of acknowledgment, error detection and retransmission functions, or by applying forward error correction.. Depending on the requested priorities, the composer mechanism would select those that are best suited to satisfy them.

Note that the RN generates the corresponding WFs by composing the services per each node in the path (RN, INs and ESN). Thus, the RN creates a tree graph (Figure 2) with all discovered services of each node. Our solution evaluates first the different dependencies at each hop and the input and output attributes among ASs. Therefore it concatenates those that could be executed within a node in order to assess that the communication goal can be satisfied. Thereafter, the best branch of services is selected, the CS is generated for each node and specified in a WF. Our implementation of the service composer component applies A* algorithm [11] for searching the best solution taking into account the nodes with best scoring.

3.2.3 Path Selection

In this paper, paths are considered as sequences of nodes different ASs, from the RN to the ESN, and are capable of reaching the demanded end service. If a cost restriction is specified by the RN, it would be necessary to discard as soon as possible those paths with a higher cost than the demanded one.

When each node is scored, the path is selected using graph theory search strategies to evaluate the most cost-effective path (Figure 4). Moreover, depending on the preferences of the requester, the selected path can be the one that offers the best trade-off between different parameters. For instance, selection could be done according to the lowest delay path, lowest cost per transmitted bit, or one considering a trade-off between both criteria by means of a weighted scoring function.

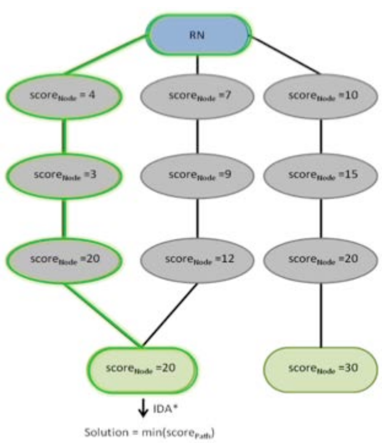


Figure 4 Negotiation Process

4. A TARGETED SCENARIO: ENABLING ADAPTED MULTIMEDIA COMMUNICATIONS USING SCI-FI

The goal of SCI-FI is to enable FI communications that permit to meet QoS/QoE requirements whilst satisfying user expectations. Service and content adaptation is a fundamental issue for multimedia communications, especially when it comes to distribution of audiovisual contents in heterogeneous and dynamic networks due to the strong requirements they present in terms of bandwidth, delay, losses, device capabilities, etc. Moreover, audiovisual contents are expected to be consumed anywhere, anytime and anyhow. Specifically, it is expected that by 2013, the sum of all forms of video (TV, VoD, Internet video and P2P) will exceed 90% of global consumer IP traffic [12]. For this reason, providing seamless multimedia communications in the FI is and will be a challenging issue that needs to be addressed.

Imagine a domestic user (U1) who wants to watch an online audiovisual content, e.g. a movie (M), from the sofa using a mobile device. In so doing, U1 accesses the network using a tablet device. At home, U1 uses WLAN 802.11g technology to access to the media server containing the desired movie through the Internet. U1 is subscribed to an xDSL Line. Finally, regarding U1 device capabilities, his device supports MPEG4 and MPEG2 video codecs.

When performing the lookup of the desired movie, it can be provided by two different streaming services which are available: service1 (S1) and service2 (S2). We assume that these services are placed in different End Service Nodes (ESN): N1 and N2. These are the candidate service providers for U1 as they can offer the specific service that the user is asking for. Each service in the network is represented by a specific service interface that allows them to be discovered and invoked. For the sake of clarity in this use case, we will assume that each node knows which services (ASs and corresponding AMs) can offer. Thus, each node has a local repository with the locally published information.

In an initial proof of concept implementation, a scenario without infrastructure support is considered. We considered this elementary but constrained scenario in order to test SCI-FI without external support to store and maintain information (external repository like a DNS). Nevertheless, in future work, an approach with a distributed global directory will be undertaken.

To access the online movie content, U1 sends a *Creq* message to its neighbors. This message is propagated hop by hop (node by node). Each node evaluates if it is able to provide the requested End Service that has been asked by U1 or can provide the basic connectivity services under the desired conditions. That is, in this case, the QoS parameters (available bandwidth, delay and packet loss rate) that the U1 requires.

S1 an S2 can be reached through paths P1 and P2 respectively. In this scenario, it could happen that S1 or S2 would not be able to be reached because the INs in the path (P1, P2) between the RN (U1) and the ESNs (N1, N2) make the path unsuitable for the communication as they introduce too much delay (per link accumulative QoS parameter). In this case, no communication would be established through the corresponding path.

At this point, each node containing S1 and S2 answers with a *Cresp message* that goes back to the requester through the reverse path, that is, the path established for the demanded communication.

After this stages are successfully accomplished, the requester node (N1) evaluates each received *Cresp* message gathered from each path to the candidate ESNs. This is achieved by applying a service composition algorithm like the one proposed in section 3.2. In this specific use case, U1 can select S1 if he wants a service offered with the lowest delay. However, S2 is the best service available considering a trade-off between delay, energy consumption (it uses a less demanding codec) and overall audiovisual quality. Finally, U1 decides to select S2 because it meets his visualization preferences and makes a better use of the life of the battery in comparison with the previously tracked down services. The final decision is made considering the particularities of each AS and AM, for instance, the MPEG-2 video codec, which is the video codec (AM) available in S2, requires less computational resources..

Once services are selected for each node and WFs are created as an output of the service composition process, U1 sends a *Call* through the chosen path.

As explained in this paper, it must be noticed that the discovery process includes an intelligent routing process to the ESN. The integrated discovery and routing process is done on a per-hop basis during the establishment of the end-to-end path between the RN and the ESN. Thanks to this process, the routing is undertaken considering the context characteristics of the network and services to find the best possible path between the communicating entities.

The presented use case considers an homogeneous network with INs that perform the same functions and implement the same ASs. However, typically, the network is composed of heterogeneous networked nodes with different capabilities and different available services. Thanks to the composition and allocation processes we can specify which services should be allocated and executed at each node in order to obtain the best possible communication according to the user requirements. Consequently, a node with WiFi interface and wired interface (e.g. copper providing xDSL access) will be able to use different services depending on the features (context) of the interface being used to send data in the selected path. An example would be to use TCP-like congestion control functionalities in the wired interface whilst avoiding them in the WiFi interface in order to improve the throughput of data transferences when loss effect is present. This can be achieved by means of using an approach based on RBA decomposition of functionalities and SOA-based composition of them. In addition, compositions will take into account the specific context where the communication is established, allowing differentiating between segments of the network and placing services when and where needed improving the overall performance of the communication and avoiding unnecessary redundancy of functionalitites.

5. DEPLOYING SCI-FI

Regarding the generated code for the SCI-FI prototype, we migrated from the original modules specified in [10], developed in a System-on-Chip CC2430 from Texas Instruments platform. Moreover, code was adapted to run in a Linux-based desktop PC to test the proposed solution in a larger and more complex network with more nodes. Finally, we extended it with the following new modules: Service composition & allocation, Search service engine and Constraint-Based Routing (CBR) [13]. The whole development requires a total memory space of 1.5MB. Regarding hardware and software configurations we used an Intel Pentium 4 540@3.2 GHz (1MB L2 Cache, FSB 800MHz) with 512 MB RAM PCs to implement each node. Each PC used Ubuntu 11.04 (32bits) as operating system. In this testbed a total number of 8 nodes were used (1 RN, 3 ESN, 4 IN). All nodes were directly connected using several network interfaces configured in full-duplex 100Mb/s Ethernet mode.

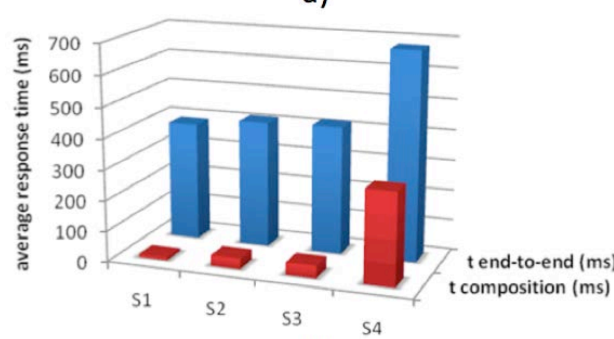
6. EVALUATION

We measured two significant parameters to see the behavior of the SCI-FI prototype. Firstly, the time required to establish a communication (Te-e) and, secondly, the resource consumption of the process. Concretely, different communication requests, asking for different requirements and network functionalities were tested. Different requirements imply different service compositions with different number of ASs and different AMs. In practice, these goal effects are associated to different ASs or combinations of them. For instance, reliability can be provided by sequencing and Forward Error Correcting services or by combining Sequencing, Acknowledgements and Retransmissions. Additionally, each AS can be implemented by different AMs. As an example, imagine we have an *encoding* goal which can be provided by *video_coding* ASs. Each AS can be then provided by AMs like MPEG-2 or H.264/AVC.

Regarding performance parameters, in Figure 5a we show,the average CPU and RAM total consumption during the process of negotiation. The time required for negotiating the desired communication (Te-e) in each scenario is shown in Figure 5b. Concretely, we show the results obtained for the longest path (P4) of our testbed.

Node Type	CPU	RAM
Requester Node (RN)	13%	340KB
Intermediate Node (IN)	5%	180KB
End Service Node (ESN)	9%	250KB

a)



b)

Figure 5 a) Testbed performance results and b) Testbed measured times

The most representative value is the time required for negotiating the services that will be used (Te-e) and the most influential parameter is the composition time needed to decide which services to use (Tcomposition). Composition can be a very demanding process if full flexibility and the best possible decisions are to be achieved. Mostly, its value depends on the number of goals to successfully target and the number of ASs and AMs that each node implements and has available. As specified in section 2.2, the proposed composition algorithm must calculate all the possible combinations between ASs in order to select the most appropriate for the required communication according to user preferences and context conditions. The more services, the more combinations will be calculated. However, in future work, some techniques for improving this process will be studied. Even though, once a composition is performed, the resulting workflow of services could be stored for future reuse so as to avoid calculating again all the combinations of services. This would ease the process of service selection and composition in situations where high composition time is required (e.g. network level services).

7. CONCLUSIONS AND FUTURE WORK

Internet is becoming a huge heterogeneous and dynamic network that is growing beyond its architectural limits. The scaling up of the number of communicating nodes and services is leading the Internet to an architectural crisis which in turn makes it difficult to provide services efficiently considering the requirements and context conditions of users. Consequently, the FI design should address the shortcomings of current TCP/IP-based Internet architecture based on end-to-end principles.

The ICN approach proposes a network where the main paradigm is not an end-to-end communication between hosts, as in the current Internet. Instead, an increasing demand for highly scalable and efficient distribution of content has motivated the development of architectures that focus on information objects, their properties, and receiver interest to achieve efficient and reliable distribution of them. Concretely, the SOA paradigm offers fundamental design principles that can guide the FI development towards a more flexible and scalable Internet architecture based on functional pieces called services that can be combined according to requesters' needs. This work takes as a base a service-oriented architecture that focuses on services combination and adaptation to context conditions by means of two main processes: service discovery and service composition. These processes are necessary to enable adapted FI service provisioning, satisfying the specific requirements demanded by requesters and, additionally, maximizing the QoE and making an efficient usage of resources. To achieve this, one important feature of this solution is that routing functions are integrated into a semantic service discovery protocol that evaluates context conditions hop-by-hop when communications are requested. In addition, we also propose a service negotiation protocol which would enable us to find and compose services to meet requesters' requirements in an efficient manner. This guarantees the demanded QoS whilst providing appropriate QoE.

As the research community contemplates new architecture designs for the FI, models and implementations for assessing its development viability are especially needed. In this paper, we provide the main details of a first implementation of the proposed service-oriented solution and discuss the gathered preliminary results. These results establish the grounds on which the proposed architecture will undeniably enable a more flexible, scalable and dynamic FI.

8. ACKNOWLEDGMENTS

This work was supported by the TARIFA project of the i2CAT Foundation, by the Spanish Government (MICINN) under research grant TIN2010-20136-C03, EURO-NF and the VISIONAIR FP7 Project. The authors would like to thank all participants from the i2CAT Foundation for their help and support. Thanks to the GTM group from Universitat Ramon Llull and the BAMPLA and WSN groups both from Universitat Politecnica de Catalunya with a special mention to Josep Paradells and Xavier Sanchez-Loro.

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