Enabling automatic composition of stream processing services through ontology-based standardization

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***Abstract*—Delivery of e-health services is the main subject of multiple research projects carried on among others by national institutions, international consortia both in industry and academia. The goal of on-going research is to develop an efficient, scalable, flexible and multipurpose networking platform allowing for delivery of personalized, composable and high quality e-health services for various types of healthcare applications. This paper describes the ComSS Platform, which aims to achieve this goal, and the SmartFit application built with the use of ComSS Platform. This paper also discusses encountered problems, which stand in the way of fully automated composition of e-Health services based on Internet of Things paradigm. Finally, this paper also proposes a preliminary metamodel for description of Internet of Things enabled devices' capabilities, interfaces, services and data streams. This metamodel is intended to support the process of automated composition of streaming services.**

I. Introduction

Growing popularity of e-Health applications creates a need for providing first-rate e-Health services. Semi-professional health state measurement devices are available for majority of the consumers [1]. There are many mobile sensors which acquire parameters like heart rate, ECG, EMG [2]. Various vendors offer different types of sensors. Polar is one to have launched wireless technology for monitoring real-time human performance in sports activities [3]. Their utilities support sport training to maximize human body performance by training intensity control and adaptation, to name a few. Such devices can inform users about estimated and/or predicted values of their training parameters such as burnt calories, expected speed, endurance, etc. There are also products which provide functions like generating personalized training plan. Suunto and Adidas tools provide software for training volume personalization which alows, among others, to adapt recommendations to the type of the user's activity [4] [5].

The problem is that there is no common standard for description and communication of such devices. This paper introduces the ComSS Platform for standardized description of streaming devices and the services they provide. The idea behind ComSS is to utilize this standard description augmented with ontology sematics to easily manage and automaticly compose streaming services. Section II introduces the Internet of Things sytems that are the backbone for the ComSS Platform solutions. Next, in section III the idea behind ComSS Platform itself is described in more detail, followed in section IV by an exemplary application in the form of SmartFit. Finally, section V provides some insight into the standardization of sources for sensory data.

II. Internet of Things Systems

Recently, a rapid increase of devices connected to the Internet can be observed. One of the interesting facts about this trend is that in many cases these devices are not computers or smartphones, but dedicated devices like sensors or machines, which can monitor and even interact with the environment. A large group of such devices are medical sensors, which are used for remote patient monitoring and diagnosis. Proper connection and use of such sensors may change life of patients who require continuous medical care and monitoring [6].

Such devices can send various data over Internet and communicate with each other. All concepts regarding the utilization of such devices and their capabilities are generally defined as a part of Internet of Things (IoT) paradigm [7] [8].

Internet of Things is one of the base concepts important for development of Next Generation Networks based on Internet. One of the key assumptions of IoT is that various devices, gathering and providing diverse data, can easily connect and collaborate and that behaviour should be achievable with the use of standard protocols used in the Internet. Despite this assumption, enabling connectivity between heterogeneous devices can be difficult because of differences in standards, protocols and data types required by different devices [9].

Also one of the requirements for IoT systems is their self-sufficiency and self-organization. This means that devices should be able to establish a communication link automatically, without the need of any additional configuration by human actors. An important requirement for IoT system is its independence and self-awareness. According to this requirement, user should benefit from the use of all his IoT enabled devices without the need for additional maintenance or configuration. Also, such system should automatically discover failures, malfunctions or changes in the environment, in order to be able to automatically reconfigure itself and preserve functionality offered to its user [10].

III. ComSS – Platform for Composition of Streaming Services

The main advantage of Service-Oriented Architecture (SOA) paradigm is that various applications can be built by composition of multiple stand-alone software modules (called atomic services) with precisely defined functionality. Such interconnection of atomic services is called a composite service and is able to provide a functionality which is not available by considering the functionaly of each atomic service it consists of [11] [12] [13]. Additionally, according to SOA paradigm, composite services can be adapted during run-time according to users' requirements [14]. This two basic features of SOA provide enormous flexibility to both, applications' developers and users. Standard SOA applications, however, are restricted only to atomic services operating in a request-response manner (called batch atomic services). This implies that it is not possible (or at least barely efficient) to compose applications requiring continuous transmission and processing of multiple data streams of various volume and content [15] [16].

ComSS Platform is a software solution which naturally exploits and extends SOA paradigm to the domain of IoT and applications requiring data streams' transmission and processing. Key assumptions behind the ComSS Platform are:

- there are multiple data stream processing services registered and available in a distributed environment (e.g., cloud),
- services can be dedicated to domain-specific applications (e.g., ECG signal analysis) or general (e.g., signal noise filtering or cryptography),
- all services are encapsulated in ComSS framework allowing the services to communicate with each other and to be managed and controlled by standard SOA protocols (e.g., SOAP or REST),
- all services are semantically described in terms of delivered functional and non-functional properties.

Fulfilment of above assumptions in connection with the automatic semantic composition and execution of composite services, allows for rapid development, deployment and delivery of personalized composite streaming services (see Fig. 1) such as remote monitoring and decision support for patients suffering from diabetes (red arrows in Fig. 1) or remote training support for athletes (green arrows in Fig. 1).

In addition such an approach allows for reusability of already developed and deployed atomic streaming services in various scenarios and in different composite streaming services. As an example consider an athlete who suffers from diabetes. This athlete would probably use both composite services (red and green) simultaneously. With little effort one could add to the platform a new dedicated service which models the influence of physical effort on the glucose level and with use of existing atomic services prepare a new composite streaming service dedicated to monitoring and support of diabetics during workout. Main advantages of the proposed approach include, but are not limited to:

- full compatibility with SOA standards and technologies,
- rapid development of new applications by composition of existing (deployed and/or stored in repositories) atomic streaming services,
- easy deployment of new streams' processing services,

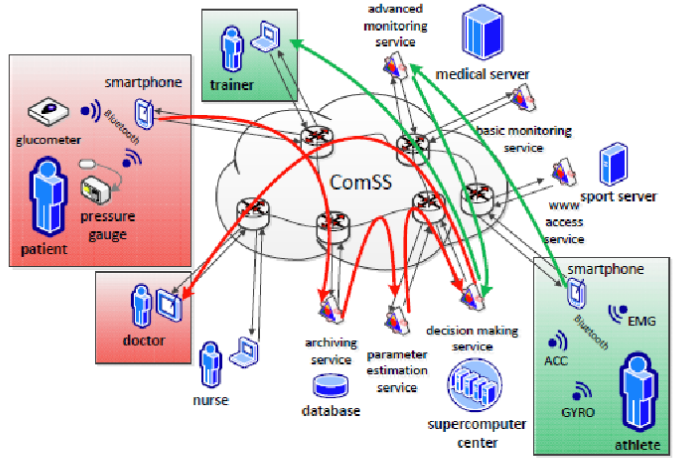

Fig. 1. ComSS Platform overview. Two different composite streaming services i) remote monitoring and therapy support for diabetics (red arrows) and ii) remote training support for an athlete (green arrows).

- semantic composition of services with use of functional and non-functional services' description,
- automatic workflow negotiation between atomic streaming services interconnected in composite streaming service (including data formats, codecs, quality of service, etc.),
- anywhere & anytime access to platform components and services through web-based interfaces,
- data transmission technique independent – both wireless and land-line.

The list of main ComSS Platform components includes:

- web-based graphical user interface with access to services' repositories for manual development of composite services,
- ComSS famework & API for easy streaming services development and deployment,
- state-of-the-art composition and execution engines,
- data streams' processing services repositories:
  - domain specific analytical and processing services (e.g., time series comparison, classification, prediction or estimation, decision support),
  - domain independent generic services (e.g., streams' compression, streams' and data formats' translation, cryptography, streams' merging, multiplication and division, etc.).

IV. Exemplary application – SmartFit

SmartFit is an application for remote monitoring and decision making support concerning human physical activity. SmartFit consists of three basic parts:

1) Mobile part including mobile phone, mobile application and sensors for data acquisition.
2) Web part including web graphical user interface for stationary users.

3) Distributed services for real-time data processing and decision making support.

SmartFit can be used in a wide range of physical activity applications starting from supporting of amateur sport activities (e.g., maintaining of runners heart rate within predefined range) ending on supporting a professional trainer during technical trainings (e.g., technical evaluation of arm movement of a tennis player) [17] [18] [19]. Such a flexibility of SmartFit system is achieved by using solution and concepts of the Future Internet, i.e., Internet of Things, services and media, in conjunction with emerging network architectures aware of: required quality of service, transferred content and the context of communication itself [20]. SmartFit utilizes the assumption that in the Internet of the future there are available multiple data processing services and all devices (e.g., mobiles, sensors, cameras, servers) can be interconnected with each other. This allows to build flexible and self-adaptive applications personalized for each individual user.

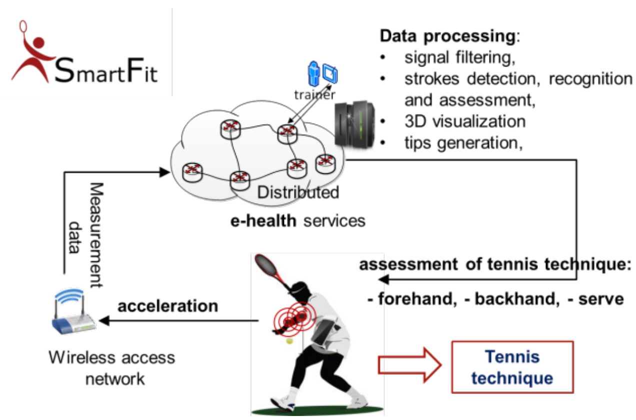

Fig. 2. Technical training of a tennis player with SmartFit.

Exemplary SmartFit scenario consists of monitoring and decision making support for a technical training for various sport disciplines (e.g., tennis, golf, table tennis). For each discipline a personalized applications is built with use of resources of the SmartFit system. Vital and kinetic data acquired by sensors are transmitted to appropriate data processing services, and then, results of technical evaluation are send back to the training person. In the tennis scenario players' technique is evaluated basing on data from accelerometers and gyroscopes placed on player's body. The correctness of movements is analyzed by comparison to signals acquired from a professional trainer. Additionally, player's movements are visualized and recommendations concerning the improvement of players technique are generated automatically.

SmartFit can be utilized for monitoring and decision making support in a wide range of human physical activities, both amateur and professional. These application include among others:

- learning and perfecting technique in various sport disciplines (e.g., tennis, golf, speedway) – see Fig. 2.,
- long-term training protocol planning for endurance and fitness improvement,
- short-term endurance and fitness training planning,

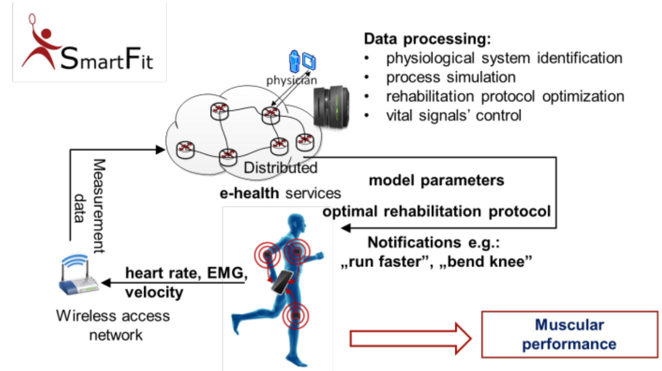

Fig. 3. Rehabilitation with SmartFit

- on-line adaptation of training plan according to current training results,
- assessment and prediction of human endurance and fitness,
- rehabilitation of physical disorders (e.g., assessment of correctness and repeatability of exercises according to predefined pattern) – see Fig. 3.

Designed as a flexible solution, SmartFit can support various data processing and analysis scenarios. In addition, the executed scenario can be dynamically changed depending on the state of monitored person, the state of available sensors and the availability of computational and communication resources. The key feature of the system is to adapt to dynamic changes in order to continuously provide reliable services, which comply with user's functional and non-functional requirements. To achieve this flexibility, SmartFit utilizes the ComSS Platform to execute its scenarios.

To summarize, we can distinguish the following features of SmartFit:

- anywhere and anytime services' availability,
- on-demand services' composition according to user's needs (flexibility) services' personalization (user awareness),
- automatic adaptation to changing environment and user's requirements (context and content awareness),
- innovative decision support services based on state-of-the-art models, algorithms and methods,
- quality of service (QoS) and quality of experience (QoE) assurance.

V. Standardization of Sources for Sensory Data

In the area of sensory data collection the number of devices and protocols for data transfer is overwhelming [21]. Despite the fact that general IoT concepts are founded on assumption of simple and robust connectivity between devices, most of manufacturers provide their own standards for data transfer, use their own formats for data description and do not provide machine-readable descriptions of the type of content that can be retrieved from their devices. Due to this situation enabling interoperability between different devices requires users to use devices provided by one manufacturer or to use dedicated solutions for data translation for each connection between different IoT devices if such solutions are available. This means that currently creation of advanced solution based on devices delivered by different manufacturers would require a IT specialists who can configure each of the connections between devices, yet still, due to proprietary solutions used by manufacturers, configuration of such connections can be virtually impossible.

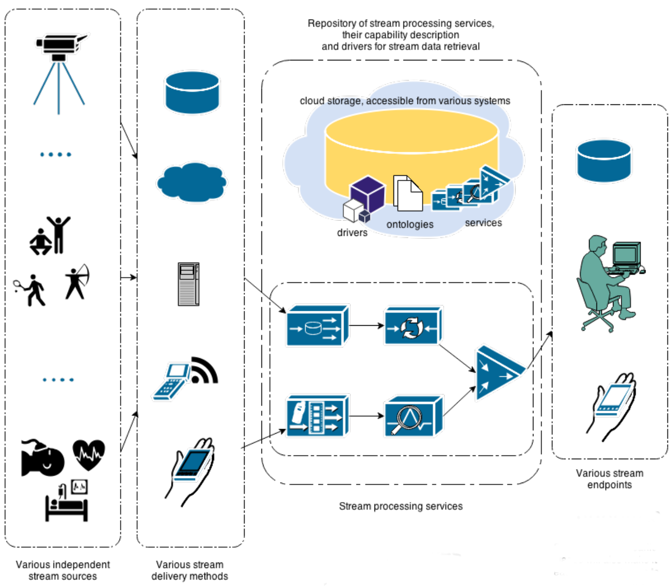

Fig. 4. Typical IoT data flow.

Also, the volume of data that sensors can deliver is immense and unique to this domain. Processing and analysis of such data can be beneficial in numerous applications, from remote medical diagnosis of patients, athlete training monitoring or vehicle monitoring to even large scale crisis management systems [22]. However, due to this large volume of data, manual analysis and even manual configuration of analysis system for processing data gathered from IoT devices can be troublesome. At the same time this process could have been relatively easy to implement if IoT devices could have been automatically composed and configured in order to enable their interoperability and connectivity.

The greatest barrier for this automation is the lack of standards that would decrease the complexity of dealing with sensory data, that is to:

- easily connect to any device (automatically find a proper driver if it exists) and retrieve its data,
- have a standard way to represent various kinds of data (data type, data format and communication protocol), so that one could easily find services that can operate on it based on its content and not its type, format, protocol etc.,
- have a standard way to represent the content of the data stream – to understand exactly what kind of information is being transferred, thanks to a common vocabulary (or mapping of manufacturer vocabulary to a standardized vocabulary).

To make this automated connectivity and composability possible, each manufacturer, abiding a new standard, should describe its devices' capabilities, especially the data these devices generate:

- how the data is generated and transferred: data types, formats, protocols for communication,
- what is the meaning of data: semantic description of data transferred, preferably, using a common vocabulary for a given domain (e.g., medical domain),
- grounding of the semantic meaning in the data structures: description of data packets/frames, but also the notion of data correlation in the stream (time correlation, common described object etc.).

On the other hand, we need a common standard for data representation, which would:

- present and allow for the transfer of data in a standardized manner,
- need a repository of adapters from manufacturers' standards to a common standard, have a standardized notion of time,
- allow for grouping of devices that describe a common object (e.g., a person being monitored) and easier stream integration (based on object and time),
- transfer the meaning behind data (e.g., Acceleration) grounded in its standardized format, allowing for easy manipulation on this data by a variety of services, that could be searched automatically (based on the content, type or both).

Lastly, a standard for services that can operate on a stream of data, that can describe services' capabilities and data type requirements. This should be a specialized standard based on already existing standards dedicated for semantic description (like OWL-S) but simplified for the needs of this specific domain.

As a result of our initial analysis of the described problem a draft of metamodel (Fig. 5) for describing devices' capabilities and data streams have been prepared in UML.

In our model we specify the IoT device and its capabilities as well as services provided by this device and autonomous services that only process data. This description is used by IT specialist to create a virtual entity which describes devices and services and is grounded in physical IoT devices and software components. In many cases a virtual IoT device provides a set of services for stream data processing. A service is described by its address, human-readable description and ontology-based definition of its functionality and class. Each streaming data service can have multiple configuration interfaces and streaming interfaces.

Configuration interface uses a standard request-response communication pattern and uses SOAP (Simple Object Access Protocol) or REST (Representational State Transfer) for data transfer. Configuration interface is described by its endpoint address, definitions of input and output data types and a description of configuration it offers. This interface is intended

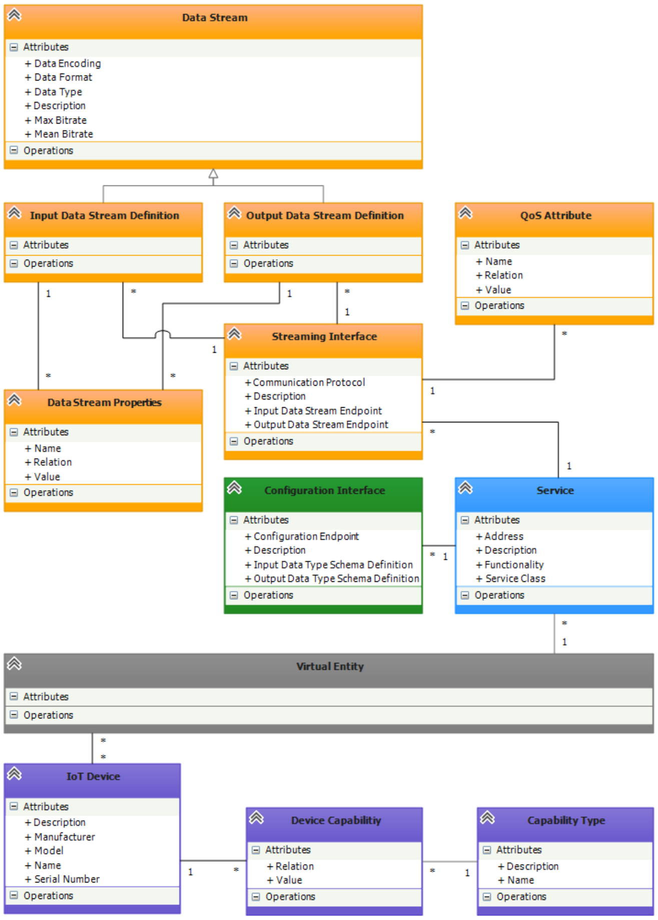

Fig. 5. Metamodel for IoT-based streaming service description.

to be used for initial configuration of streaming interface offered by the service.

Streaming interface is described by communication protocol, input and output data stream endpoint and description of its capabilities. This description can be used for automated protocol negotiations to select proper streaming interface offered by service in order to ensure connectivity with other services [23]. Streaming service is also described by Quality of Service attributes (e.g., latency, reliability) which are specified by name, relation (lower than, equal, higher than) and value. Each streaming interface is also defined by its input and output data stream. Proper definition of data streams is crucial for enabling proper interoperability between streaming services. Hence, their properties in our model are defined with the use of domain specific ontology, which will enable composition of services on the basis of semantic description of their functionality (described in service definition) and description of their input and output data. The properties described by concepts from ontology are: data encoding, data format and data type. This properties are followed by the description of data stream and its max and mean bitrate. In additional to this properties describing the connectivity attributes, presented meta-model also introduces Data Stream Properties, which can be used for semantic description of the data send in the data stream in its state.

As it was mentioned the proposed metamodel is preliminary, but initial implementation and experiments have proven that it can support automated composition of streaming services. However, this metamodel is still being evaluated and it will be developed further on the basis of future works and experiments.

VI. Conclusion

Internet of Things paradigm and data stream processing is rapidly gaining popularity due to consequent increase in number of IoT enabled devices and their capabilities. This creates new opportunities for development of data processing and analysis methods, which will be a welcome amenity for various applications which can benefit from the use of IoT devices. This can be especially important for e-Health domain, where such solutions can be used in remote patient monitoring and diagnostics.

The greatest barrier which inhibits the development of such solutions is the lack of standards which could enable simple and robust connectivity and composability of IoT devices and data streams they generate. Hence, the main task for today is the development of proper standards which will provide the required level of connectivity and composability.

In order to address this problem some initial research works have been conducted, which were described in this article. Presented works are mainly focused on analysis of the problem of IoT devices connectivity and composability on the basis of two scenarios implemented with the use of ComSS Platform. On the basis of this analysis a preliminary metamodel for semantic description of IoT devices and services capabilities, interfaces and data streams was developed. The proposed metamodel uses ontology-based semantic description connected with grounding in concrete data types.

Despite preliminary nature of presented results, they will be a base for our future works and development of ComSS Platform, which will support connectivity and composability of IoT devices and data stream processing. The main goal of our work is to provide a system where even a non-technical user can do anything, that his IoT devices are capable in collaboration.

Further works will focus on development of proposed metamodel, development of methods for automated composition of services offered by IoT devices with consideration of user's non-functional requirements and on building prototypes of devices working accordingly to guidelines specified in this paper.

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