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Towards Internet of Services – SDN-enabled IMS Architecture for IoT Integration

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Abstract—The Internet of Things (IoT) paradigm is gaining tremendous popularity and the number of connected devices, or “things”, is continuously growing, aiming to transform our everyday life. In order to address the real needs of the end user, the capabilities of the individual “things” have to be combined and offered as “services”. The use of a local cloud of gateways that aggregate and analyze the data of different heterogeneous IoT devices and expose unified service oriented interfaces in support of machine-to-machine (M2M) applications has been presented in earlier works. This paper proposes a novel software-defined networking (SDN)-enabled IP Multimedia Subsystem (IMS) architecture that aims to facilitate the provision of IoT-based services over an all-IP telecom service provider’s network. The architecture combines the advantages of reduced network complexity and improved efficiency of network utilization that SDN brings with the standardized approach of service deployment and management over all-IP networks, offered by IMS.

Keywords—IoT, SDN, IMS, fog computing, BETaaS

I. INTRODUCTION

The concept of Internet of Things (IoT) incorporates the vision of ubiquitous virtual connectivity of billions of physical objects or “things” through a global network infrastructure with interoperable, self-configuring and scalable capabilities. “Things” might be part of various application domains and therefore are represented by different types of devices that have heterogeneous technical parameters and communication capabilities. This imposes various technical challenges in terms of adaptation, context awareness, device discovery and management, scalability, managing a large data volumes, privacy, and security.

The “Building the Environment for Things as a Service” (BETaaS) paradigm is the outcome of a successful research initiative [1] that leverages the concept of fog computing, and introduces the novel concept of ‘Things as a Service’ (TaaS) in support of machine-to-machine (M2M) applications. Fog computing [2] was introduced as a concept to cut down the amount of data that needs to be transported to the cloud and, thus, to reduce the processing burden of cloud systems, by implementing data processing, storage, analytics and networking closer to the network edge. BETaaS extended the fog computing paradigm by introducing a local cloud of M2M gateways that aggregate and analyze the data of different heterogeneous IoT devices and expose unified service oriented interfaces that can be used to access the things connected to the local cloud, thus introducing the concept of TaaS. This approach offers distinct benefits such as reduced network

complexity, reduced amount of transported data, generated by the things and homogeneous service oriented interfaces that can provide access to different types of devices that have heterogeneous technical parameters and communication capabilities. In order to fully exploit the benefits of the exposed IoT services, however, an efficient mechanism for service deployment, management and delivery to the end users is needed.

The current paper addresses the main challenges for IoT integration and proposes a novel Software Defined Networking (SDN)-enabled IP Multimedia Subsystem (IMS) architecture that aims to offer a possible solution. IMS is a technology that manages session establishment, management and termination via SIP (Session Initiation Protocol) protocol in order to enable service deployment over all-IP networks. IMS provides common IP interface that simplifies signaling and application development and facilitates handling of multiple sessions that might be used by different applications. Furthermore, IMS enables access control and billing handling, which allows consistent management of the different applications on the network [3, 4]. The benefits of introducing IMS to the IoT domain have already been examined by several research teams. In [5] a generic IMS framework for integration of IoT networks and cloud computing networks is described and the implementation issues of such integration are examined. A cloud-based implementation of the generic framework is later described in [6], where the core IMS components are virtualized into a resource pool and provided as Infrastructure as a Service (IaaS). The framework concept is further extended in [7], where a mechanism for object management and naming, based on IMS uniform resource identifiers (URI) is proposed. The paper introduced a naming delivery agent that utilized SIP ‘MESSAGE’ messages to assign specific URIs to the ‘things’. In [8] the integration of IoT devices into a SIP-IMS platform is considered in context of WLAN-3GPP networks. Different SIP message flows are designed to provide different IoT functions, such as registration, transmission of streaming data and notifications, based on query/report messages. Finally, in [9] a carrier class IoT service-oriented architecture that integrates IMS with wireless sensor networks (WSN) is prototyped. The architecture utilizes sensor web enablement (SWE) framework to tackle the heterogeneity of IoT devices, by introducing two main components – an enabler that introduces IoT services to the telecom operation platform, and a gateway that interconnects the enabler and the WSN. As a proof of concept the proposed design was implemented in an application scenario with 20 WSN nodes and the network load

was evaluated, showing that the introduction of the M2M gateway effectively reduces the generated data traffic.

The current paper proposes an architecture for the provision of IoT-based services over an all-IP telecom service provider's networks, while facilitating the development and implementation of innovative networking solutions. We take the IoT IMS integration a step further by introducing SDN-based virtualization of the IMS core elements as a solution to meet the challenges of increased traffic and network complexity. SDN is defined by the Open Network Foundation as a technology where "network control is decoupled from forwarding and is directly programmable".

Previously related work, proposed an implementation of various software modules that can exert dynamic control on the network functions, for support of the network expansion and innovation and for more efficient utilization of network resources [10]. One of the main advantages of SDN is believed to be its capability to route efficiently the traffic flows, thus facilitating the support of quality of service (QoS) differentiation. In [11], an SDN and IMS converged infrastructure is presented, which incorporates an OpenFlow controller that communicates with IMS application servers via RESTful application programmable interfaces (APIs). This allows application-based QoS classification and data flow routing. OpenFlow integration within IMS is also proposed in [12], where a research SDN IMS testbed is designed.

The rest of the paper is organized as follows: Section II summarizes the challenges for IoT integration within the existing network infrastructures and outlines how the novel design tackles these issues. Section III gives a short overview of the enabling functionalities for the exposure of IoT-based services. Furthermore, a deeper inside on the mechanisms for SDN IMS convergence is proposed. Section IV describes the component and features of the proposed architecture. Finally, Section V concludes the paper and outlines the direction of the future research.

II. CHALLENGES FOR IOT INTEGRATION

ITU define IoT as "a global infrastructure for the information society enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving, interoperable information and communication technologies." In order for this futuristic vision to become reality, however, a range of technological challenges are yet to be overcome. Some of the main enabling technologies and the corresponding research issues have been discussed in [13] and [14] and briefly summarized below. The proposed technologies to address these issues are also outlined.

Architecture – an open architecture that will enable interoperability and of a large number of heterogeneous devices and distributes resources is needed. Moving the intelligence at the edge of the network is identified as a possible approach to address these issues. The current paper proposes an architecture that combines two novel technologies, SDN and IMS, which offer access to an agnostic environment for the creation, deployment and management of converged telecommunications services. Furthermore, the design integrates the M2M development and execution

platform – BETaaS – which tackles the heterogeneity of IoT devices and leverages the concept of fog computing to bring some of the intelligence to the edge of the network.

Identification – creating a digital identity of the 'things', defined by a digital name and the relationships between things in the digital domain is vital for realizing the IoT vision. The identities should be globally unique, offer significant consistency and enclose the multiple existing identifiers, such as identifiers, assigned by the manufacturer and network IPv6 addresses. A possible solution, proposed in [7] and adopted in the current design, is the utilization of IMS/SIP uniform resource identifiers (URI).

Communication Technologies – the utilized communication technologies should allow efficient communication between things, between things and human users, between things and the Internet. Furthermore, access to distributed units for data collection, data mining and information processing should be provided. In the proposed architecture, the powerful capabilities for session management of IMS, combined with the SDN techniques for flow control provide an efficient communication environment for the creation and deployment of IoT services.

Network Technologies – should provide ubiquity of access of almost anything, anywhere, offering scalability and reliable identification and tracking of the various objects in the IoT domain. The implementation of IPv6 over SDN, combined with IMS URIs, can bring the required scalability and consistency of identification of the expected huge number of interconnected IoT objects.

Service Discovery – automated discovery and mapping mechanisms will be essential for the efficient network and communication management and the utilization of the IoT resources. The discovery mechanisms need to be dynamically adaptable and continuously evolving to accommodate changing topologies or changing user needs. The IMS service discovery mechanisms, integrated by the Service Capability Interaction Manager (SCIM), might offer an efficient solution for service composition and service interaction.

Data and Signal Processing – the expected massive number of interconnected devices will generate huge amounts of data traffic. In order to utilize efficiently these resources, different mechanisms for edge processing, filtering and aggregation, semantic interoperability, data sharing and collaboration, QoS and streaming processing are needed. The concept of fog computing, realized by BETaaS local cloud, offers implementation of such capabilities closer to the network edge.

Network Management – the huge number of devices and the increasing complexity of communication networks predetermine the need of improved resource allocation techniques, which incorporate traffic and congestion management and resource reservation for time-critical and life-critical data flows. SDN concentrates the network intelligence in software-based central controllers, provides more efficient control, customizability and adaptability.

Security, Trust and Privacy – the high penetration of the interconnected devices that will expose even more information about our environment, habits and needs will pose new security and privacy problems in terms of confidentiality, authenticity and integrity of data. Efficient mechanisms that

prevent unauthorized identification and tracking will be of primary importance. The BETaaS platform implements security mechanisms that monitor the environment and retrieve and impose security policies in order to prevent malicious behavior or unauthorized access. Additionally, the IMS framework provides the means for user authentication and IPsec association with the IMS terminal.

Standardization – in order to ensure high degree of interoperability between a large number of heterogeneous devices and systems the definition and use of standard interfaces and data models is needed. IMS technology specifications are defined by 3GPP's Services and System Aspects group. Regarding SDN, the Open Networking Foundation is responsible for the technology's promotion, adoption and open standards development.

III. ENABLERS OF IOT-BASED SERVICES

A. M2M development and execution platform: BETaaS

BETaaS is an M2M development and execution platform based on a distributed runtime environment made of a so-called local cloud of nodes that allows accessing things connected to the platform regardless of their access technology and location. It creates a horizontal runtime platform. Its distributed architecture also allows for the computation (i.e. M2M application) to run in close proximity to the physical thing, which is a crucial enabler for the M2M applications that require fresh information from the physical thing [1].

The BETaaS high level architecture consists of three main layers: Adaptation, TaaS (Things as a Service), and Service, which is shown in the left hand side of Fig. 1. This structure guarantees the proper level of abstraction to the applications at the top and the flexibility in integrating different M2M systems at the bottom. At the bottom layer, BETaaS integrates heterogeneous M2M systems at the physical layer into a unified M2M system thanks to the Adaptation layer. The adaptation layer allows plugins to be dynamically added and deployed into the platform to accommodate different M2M systems, e.g. ETSI M2M, CoAP, and even some proprietary systems, within the platform. The plugins provide interfaces to the higher layer components and convert the request from the later into their respective M2M systems. On top of the adaptation layer, the TaaS layer provides an abstract and uniform description of the underlying M2M systems regardless of the technology, communication protocol, and physical location. The TaaS paradigm defines a service for each thing connected to the platform; a thing service is created to represent the basic service(s) that can be exposed to the applications in a content-centric manner. the TaaS layer is implemented in a distributed fashion to cooperatively share resources among gateways. This approach allows for the application to transparently access thing services irrespective of the gateway that provides the physical thing connection. On top of the TaaS layer, the Service layer is designed to define the platform interface to the external applications. In general, the Service layer exposes all of the available thing services in the platform as basic services allowing the applications to interact with the things connected to the platform. In addition to the basic services, this layer also allows for the dynamic deployment of a so-called extended service, from a third party

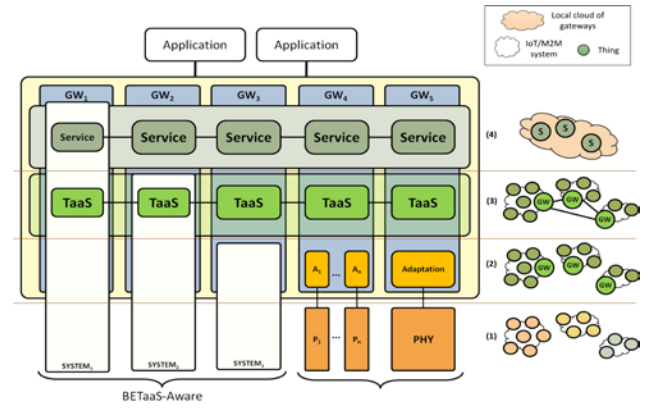


Fig. 1. BETaaS high level architecture

[1], which opens the opportunity to establish a marketplace of extended services that can be installed on demand by users [18].

B. SDN-based IMS implementation

IMS is identified in [4] as the enabling technology for the creation of a service environment over disparate all-IP networks and a step towards the Service Oriented Architecture (SOA). It provides a mechanism for session management of services, such as video conferencing and voice over IP, and open APIs for third-party access and web services integration. Furthermore, it aims to ensure relevant QoS parameters for different classes of services and to enforce the service level agreements (SLAs). In these aspects, the SDN-enabled implementation of the IMS core can be particularly beneficial, because of the powerful capabilities of adapting the network flow to the bandwidth and traffic changes and the management of virtualized resources. Such implementation will provide a synergic environment for the development and the deployment of innovative services.

Several open source implementations of the IMS core have been proposed. Two of the notable examples include the OpenIMS [15] and the Project Clearwater [16]. Project Clearwater proposes a cloud-oriented design that claims to be extremely suitable for deployment in network functions virtualization (NFV) environments. It is based entirely on open source components and supports all standardized interfaces related to the IMS core. The OpenIMS, on the other hand, offers an open source implementation IMS Call Session Control Functions (CSCFs) and a lightweight Home Subscriber Server (HSS). It does not target carrier grade deployments, but rather aims to accelerate the IMS development and adoption. It has served as the basis of the SDN-based OSIMS open source IMS experimentation platform [11].

IV. PROPOSED ARCHITECTURE

The proposed architecture leverages the TaaS concept, defined by the BETaaS paradigm, in order to facilitate the provision of IoT-based services over an all-IP telecom service provider's network. The main purpose of the design, described in the current paper, is to offer not only an open environment for the development and deployment of innovative user-centered services, but also an architecture that targets provider

related issues, such as improved resource utilization, simplified network management, billing and access approval for the provided services. In order to address the aforementioned requirements and to tackle the various IoT-related technological challenges, described in Section II, the proposed design combines the advantages of two novel technologies - SDN and IMS - which both focus on making the network infrastructure horizontal and on the service exposure to third parties. The architecture design, shown in Fig.2, follows a layered approach distinguishing between an access layer, a transport layer, a control layer and an application layer. The current paper focuses mainly on the SDN and IMS integration, service creation, deployment and management and therefore the access and transport layers' functionalities will only be briefly mentioned.

A. Access Layer

IMS provides a standardized framework for service creation and deployment over all-IP networks, independent of the access technology, supporting mobile, wireless and wireline telecommunication environments. From the IoT device perspective, the BETaaS Adaptation Layer (described in Section III) integrates heterogeneous M2M systems at the physical layer into a unified M2M system, thus addressing the challenge of interoperability between the existing IoT technologies.

B. Transport Layer

SDN decouples the control plane and the data plane and concentrates the data forwarding decisions into a centralized software controller. A common standardized protocol that defines the communication between the control and the data forwarding plane is the OpenFlow. In the current architecture, the transport layer directly corresponds to the SDN's data forwarding plane, which consists of OpenFlow switches. Each OpenFlow switch contains one or more flow tables and an abstraction layer that communicates with the controller.

C. Control Layer

In the SDN scenario the data forwarding decisions and higher level control functions are performed by a logically centralized software controller. The network configuration is performed on a simplified network abstraction and the data flow configurations are communicated to the data forwarding devices via the OpenFlow protocol. The control plane is implemented using the SDN Network Operating System (NOS) and a set of software modules that perform the various network control functions. The NOS exposes the open APIs (northbound APIs) to allow for the development of various applications that can interact with the network and provide an improved network management. In such a scenario, the IMS core elements can be implemented as software modules that communicate with the NOS via the northbound open APIs. Several possible open source IMS solutions were mentioned in Section III. The core IMS components functions are described below.

The IMS Call Session Control Function (CSCF) server – provides the registration of the endpoints, routing of the SIP signaling messages and QoS. We distinguish the following:

- *Serving CSCF* – this is the central session control entity for the endpoint devices; it maintains the session state; stores the public user identity and the contact address of each subscriber of the network and retrieves the user profiles from the Home Subscribe Server.
- *Proxy CSCF* – this is the IMS entry point for the devices; it forwards the SIP messages to the user's home S-CSCF; provides the user authentication, the device control interworking security; and provides the QoS management, based on policy rules. The policy-based QoS control mechanism is implemented by two main entities – the Policy Decision Point (PDP) and the Policy Enforcement Point (PEP) [17]. The PDP is the logical entity that stores and retrieves the predefined policy rules and performs policy decisions, based on static or dynamic information from the network. In the current architecture, the PDP is implemented by the policy and charging rule function (PCRF) IMS component. PEP is responsible for enforcing the policies by communicating with the corresponding network elements. In the current scenario, the PEP entity is implemented by the policy and charging enforcement function (PCEF) that communicates with the SDN controller's NOS via the exposed northbound APIs.
- *Interrogating CSCF* – it maintains the session state; forwards the SIP request to the correct S-CSCF; retrieves the information regarding the correct S-CSCF from the HSS or assigns an S-CSCF if information is not available.

The Home Subscribe Server (HSS) - manages the subscriber database for the home network; grants or restricts access to the users, based on their subscriber information; and communicates with the S-CSCF.

D. Application Layer

The IMS control layer utilizes several interfaces to communicate with the service layer, which offer the capability of providing applications implemented by heterogeneous resources and application servers (AS). The ASs are the entities that host and execute the services provided by the IMS. These communicate with the S-CSCF using SIP in order to realize service the session control. These also communicate with the HSS via DIAMETER in order to retrieve or update the subscriber's profile information. The SIP ASs are the most common type of application servers used in IMS scenarios. They support SIP-based applications and respond to requests with SIP messages in order to enable the further processing of the user requests at the S-CSPF. The SIP applications might include the presence service or sessions involving multimedia elements such as voice, video, chat, gaming, etc. The proposed here architecture focuses on enabling the integration with third-party services, and particularly web services and the IoT-based services exposed by BETaaS local clouds. Such integration is enabled by the Open Service Access Gateway (OSA-GW) and the Open Service Access/Parlay Application Server (OSA/Parlay AS) components. The main purpose of these components is to allow for the integration of the underlying network assets with the third party services. This would allow for the network providers to employ a superior service access control and the QoS differentiation, which will result in an

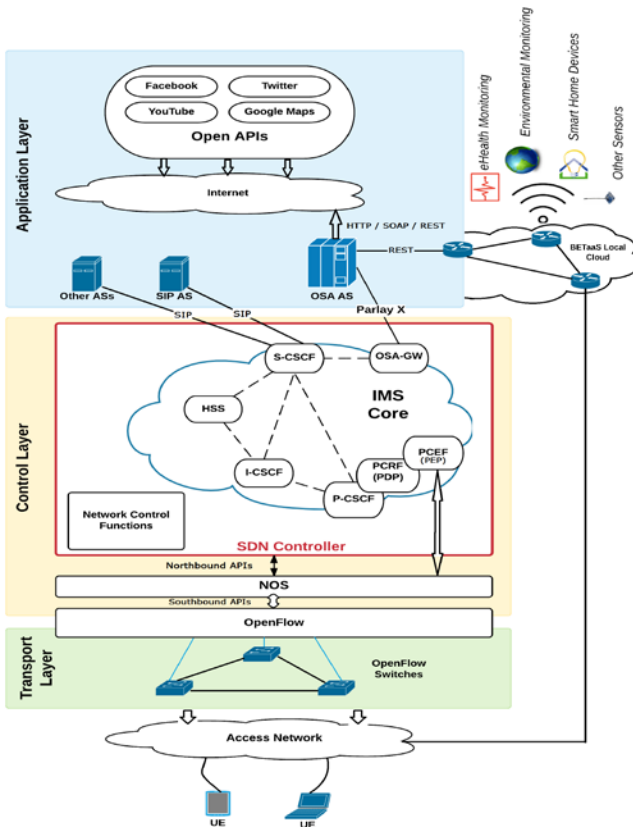


Fig. 2. SDN-based IMS architecture for IoT integration.

enhanced security and reliability of the provided services and improved quality of experience for the end-user. A set of standard web service APIs – Parlay – has been developed by The Parlay Group in collaboration with ETSI and 3GPP to allow such interoperability. The OSA/Parlay AS main purpose is to host a variety of applications that can access standard web services (via HTTP/SOAP/REST) and IoT-based services exposed by BETaaS (via REST APIs) and can communicate with the underlying network assets (via Parlay X interfaces). The OSA-GW is the session mediation gateway that defines the control flow of the established service sessions and implements the Parlay APIs and SIP protocol mapping mechanism.

V. CONCLUSION

The paper proposed a conceptual design that integrates the BETaaS M2M development and execution platform and an SDN-based IMS architecture in order to provide an open environment for the development and the provisioning of IoT services. The required technologies and the corresponding challenges for the service deployment in such a scenario were outlined and the main functional components to address these issues are described. The proposed architecture is the foundation for the planned future research on inter-cloud communication mechanisms and QoS classification and management in SOAs.

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