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Corresponding Author: Mr. Wilson Ramirez,

Corresponding Author's Institution:

First Author: Wilson Ramirez, PhD

Order of Authors: Wilson Ramirez, PhD; Vitor Barbosa C. Souza; Eva Marin-Tordera; Sergio Sanchez

Abstract: The recently coined Internet of Things (IoT) paradigm leverages a large volume of heterogeneous network elements (NEs) demanding broad connectivity anywhere, anytime and anyhow, fueling the deployment of innovative Internet services, such as Cloud or Fog Computing, Data Center Networks (DCNs), Smart Cities or Smart Transportation. The proper deployment of these novel Internet services is imposing hard connectivity constraints, such as high transmission capacity, reliable communications, as well as an efficient control scheme capable of enabling an agile coordination of actions in large heterogeneous scenarios. In recent years, novel control schemes, such as the so-called Path Computation Element (PCE) has gained momentum in the network research community turning into real PCE implementations. Indeed, there is a wealth of studies assessing the PCE performance, clearly showing the potential benefits of decoupling routing control tasks from the forwarding nodes. Nevertheless, recognized the need for a control solution in IoT scenarios, there is no much published information analyzing PCE benefits in these IoT scenarios. In this paper, we provide an insight particularly demonstrating how the PCE may gracefully provide support to the service composition in an agile manner, handling the specific constraints and requirements found in IoT scenarios. To this end, we propose a novel PCE strategy referred to as Service-Oriented PCE (SPCE), which enables network-aware service composition.

Exploring Potential Implementations of PCE in IoT World

Wilson Ramirez [1], Vitor Barbosa C. Souza [2 1], Eva Marin-Tordera [1], Sergio Sanchez [1]

[1] *Universitat Politècnica de Catalunya, BarcelonaTech, Spain*

[2] *Universidade Federal de Viçosa, Brazil*

Abstract

The recently coined Internet of Things (IoT) paradigm leverages a large volume of heterogeneous network elements (NEs) demanding broad connectivity anywhere, anytime and anyhow, fueling the deployment of innovative Internet services, such as Cloud or Fog Computing, Data Center Networks (DCNs), Smart Cities or Smart Transportation. The proper deployment of these novel Internet services is imposing hard connectivity constraints, such as high transmission capacity, reliable communications, as well as an efficient control scheme capable of enabling an agile coordination of actions in large heterogeneous scenarios. In recent years, novel control schemes, such as the so-called Path Computation Element (PCE) has gained momentum in the network research community turning into real PCE implementations. Indeed, there is a wealth of studies assessing the PCE performance, clearly showing the potential benefits of decoupling routing control tasks from the forwarding nodes. Nevertheless, recognized the need for a control solution in IoT scenarios, there is no much published information analyzing PCE benefits in these IoT scenarios. In this paper, we provide an insight particularly demonstrating how the PCE may gracefully provide support to the service composition in an agile manner, handling the specific constraints and requirements found in IoT scenarios. To this end, we propose a novel PCE strategy referred to as Service-Oriented PCE (SPCE), which enables network-aware service composition.

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1. Introduction

Networking as a single word embracing many different concepts is nowadays experiencing a tremendous evolution. Part of this evolution is caused by new dedicated routing architectures, such as the so-called Path Computation Element (PCE) [1]. It has been largely demonstrated that conventional PCE–based schemes can substantially overcome the weaknesses related to path computation of distributed source-based routing strategies such as high signaling overhead, processing burden, among others.

Simultaneously to the evolution of routing strategies, the network is rapidly evolving towards a new scenario so-called the Internet of Things (IoT), mainly raising the benefits

Wilson Ramirez, Vitor Souza, Eva Marin-Tordera and Sergio Sanchez are with the Advanced Network Architectures Lab (CRAAX), Spain (emails: wramirez, vbarbosa, eva, sergio@ac.upc.edu).

and needs of a large and heterogeneous amount of Network Elements (NEs) demanding ubiquitous and seamless connectivity round the clock –hereinafter a NE does mention to end-devices such as a mobile node or a content-server. In addition, the advent of new Internet services, such as Cloud Computing, Data Center Networks (DCNs), Smart Cities or Smart Transportation, are also being positioned in an IoT scenario [2]. Different areas can benefit from the distinct services enabled by IoT, including health, security, education, industry, and welfare, among others [3].

IoT applications can benefit from the so-called service-oriented communication –also referred to as information or content oriented communications [4]. In a service-oriented communication model, the initiator of a communication provides an Identifier (ID) instead of a locator (LOC), i.e., an IPv4 address, as it is the case for current host-oriented communications. An ID might be mapped to one or more LOCs according to a set of parameters defined by the service layer. Once the set of LOCs are chosen, the network layer is in charge for assigning the network resources required to provide the demanded service. In this way, the process of identifying the possible provider(s) –service composition process– of the service and establishing connection to it (location/routing process) are decoupled.

Therefore, the concept of using IDs can be seen as shim layer between the service and the network layer, which decouples the service layer requirements from their deployment (assignment of resources) at the network layer. To clarify this idea, consider that in the current host-oriented communication model, any change related to a LOC motivated by mobility, address migration, etc, will substantially affect all services; hence, disrupting all established connections. However, when IDs are used, only the layer managing the ID is responsible to keep state of the LOCs. It is worth mentioning that the service-oriented communication stems in the fact that the initiator of a communication is solely interested in setting up a connection in order to provide some service. The relevant is the "What" ("the service to be provided") rather than the "Who" or the "Where" (the LOC of the node who has the service).

From a technological perspective, the decoupling of functionalities envisioned by the service-oriented communication paradigm enables long-term scalability. This is, the service layer focuses on the composition of the service, whereas the network layer solely focuses to provide enough bandwidth to set up the demanded services, as well as providing network features such as mobility and Traffic Engineering (TE).

In order to support the bandwidth requirements of IoT applications, network carriers are starting to adopt new transmission technologies, such as Flexible-Optical networks, which offer high transmission capacity with low power consumption [5]. Therefore, from the network backbone point of view, flexible-optical networks play a key role in an IoT scenario.

In addition to the evolution of optical transmission technologies, wireless technologies have experienced substantial enhancements with regard to transmission capacity, energy consumption, as well as processing capacity of wireless end-devices. Indeed, the advent of the so-called 5G wireless technologies has captured the attention of research community [6]. In light of this, network researches have devoted strong efforts with the aim of developing 5G tecnologies, looking forward for their deployment in an IoT.

Other constraints demanded by the IoT are related to mobility and TE features. These features are pushing for the demise of both conventional addressing (IPv4 based) and communication schemes. Indeed, there are several studies discussing the inability of current IPv4 addressing scheme to support an IoT[7]. This is mainly rooted in the fact that 1) IPv4 address space is running out, and; 2) the host-oriented model adopted by the current communication model offers limited support to mobility and TE features. As a result, new network paradigms such as ID/LOC Split Architectures (ILSA) have been proposed to address IPv4 limitations in a non disruptive manner. ILSA schemes aim to solve this limitation by replacing the host-oriented model of IPv4 addressing scheme and adopting, instead, a service-oriented communication model [8].

Since both flexible-optical networking and service-oriented communication are key ingredients of the IoT, it is intuitive that the performance of control schemes such as the PCE must be evaluated in such scenarios. Nevertheless, despite the advantages provided by PCE schemes, they are designed for the conventional a host-oriented communication model.

In this paper, we push for positioning the PCE concept into an IoT scenario. To this end, we introduce the novel concept of Service-Oriented PCE (SPCE), based on enriching the conventional PCE architecture with ILSA schemes.

Contrary to a conventional PCE, where the endpoints of a connection requested in a Path Computation Request (PCReq) are host/location dependent, i.e., host-oriented PCE, in the SPCE scenario, the endpoints are IDs. These IDs are service identifiers (hereinafter referred to as SID), which are first mapped to host IDs (hereinafter referred to as HID) of possible NEs providing the demanded service. Then, HIDs are mapped to the LOCs. In the proposed architecture, the ILSA scheme is the entity in charge of the mapping of SID, HID and LOCs.

The goal of the SPCE is to compute the optical lightpath required to provide a demanded service. As inputs the SPCE receives a source HID and a destination SID. To this end, the SPCE performs the following actions. 1) based on a given SID, obtain a set of destination HIDs capable of providing the demanded service with the minimum service layer cost; 2) for each HID, compute an optical lightpath (with source HID and destination HIDs as endpoints) with the minimum network layer cost; and, 3) select the optical lightpath with minimum cost considering the service layer cost of an HID and the network layer cost of its respective lightpath. Hereinafter, this last step is referred to as network-aware service composition, i.e., to orchestrate a service based on both service and network cost[1].

On one hand, by network layer cost we consider metrics such as available bandwidth, which is a common metric in optical networking. On the other hand, by service layer cost we consider metrics such as processing resources of energy availability, which are metrics that must be considered in scenarios with heterogeneous NEs such as the IoT [9, 10].

The rest of this paper is organized as follows. Sections II describes in a nutshell related works proposing network-aware routing architectures. Section III discuss the limitations of current network-aware service composition architectures for addressing the IoT requirements. Section IV elucidates the concept of service-oriented PCE, by describing its architecture and possible use-cases in IoT scenarios. This section also describes the path computation process of the SPCE. Finally, Section V provides the final conclusions and suggests avenues for future work.

[1] Other studies call this concept as cross-layer routing

2. Related Works

There are some contributions available in the literature proposing new routing architectures for IoT scenarios. Authors in [11] propose a general model for routing in an IoT scenario. This model is based on Desision Markov Process, which attempts to capture the cost of routing at different layers. However this study do not consider network architectures such as the PCE or ILSA.

Moreover, authors in [10] propose a similar network-aware service composition model as the proposed in this work. Nevertheless, their work solely considers wireless technologies as the main infrastructure of the IoT. Therefore, authors do not consider new optical transmission tecnologies. More related works can be found in [12, 9], where authors consider optical infrastructures as a key building block of IoT. However, these studies do not take into account novel network architectures such as the PCE or ILSA schemes. To the best of our knowledge, this is the first work addressing the collaboration between both ILSA and PCE schemes. We push for the ILSA scheme as the engine dealing and managing the state of NEs whereas we consider the PCE as the entity managing optical network connections

3. Towards an IoT scenario

In this section, we provide insights about the limitations of the current routing and addressing schemes which are preventing its deployment in the IoT scenario. Then, we discuss the new network paradigms proposed to deal with these limitations.

3.1. Limitation of current Network Architecture

The host-oriented communication model currently being used in the whole Internet is not suitable for an IoT scenario. One of the limitations is the well-known IPv4 depletion problem. The depletion problem is caused by the increasing amount of NEs demanding Internet connectivity as well as by the so-called double functionality problem [13]. This ever-increasing demand of Internet connectivity is highly impacting on the overall routing performance, including the Domain Name System (DNS) performance as well the deployment of new Internet applications [14].

The double functionality problem refers to the fact that IPv4 addresses are being used both as a locator (by the network layer) and as an identifier (by the service layer). To exemplify this problem consider that, when a NE changes its aggregation point, its locator (commonly a IPv4 address) will be re-assigned. This will have a substantial impact on all its established communications. This address re-assignation drives several negative effects on the network, such as i) significant degradation of the communication quality; ii) eventual connection disruptions, increasing the complexity for the deployment of mobility features, and; iii) occurrence of a non-negligible impact on resilience, mobility and TE features.

There is no doubt that the double functionality problem of current addressing schemes is more severe in an IoT scenario, where users are not statically (geographically) connected to Internet, rather they are demanding connectivity on the move (from anywhere, through anything and at anytime). Moreover, a clear example related to the current addressing scheme scalability can be easily illustrated and assessed by observing how end-users are using distinct, ever smaller and smarter NEs requiring new connectivity

Table 1: Requirements of IoT

NEs demanding internet connection >> 2^{32} (IPv4 addressing scheme size)
Smart NEs with enhanced capabilities
Network features: TE, green networking
New users roles: consumers + producers = prosumers
New network scenarios: Virtualized Data Centers, Smart Cities, Smart Transportation
Dynamic Set up/tear down connections in short-term basis
Proactive network reconfiguration
Mobility without communication disruption (Full Mobility)

demands. These connectivity demands make scalability to become a real problem considering that the IP-based addressing scheme deployed so far –mainly IPv4 with less than 2^{32} addresses—is not enough to support the huge addressing space envisioned for an IoT network scenario, see Table 1.

Another limitation of current network architectures is related to the distributed control schemes that are commonly used in today‘s networks, e.g., Automatically Switched Optical Network (ASON) or Generalized Multi-Protocol Label Switching (GMPLS). Even though both ASON and GMPLS provide acceptance performance in current network scenarios, their performance might be suboptimal in IoT scenarios such as DCNs [15]. This is mainly because routing strategies based on distributed control planes exhibit low performance under highly dynamic large scenarios due to signaling overhead imposed by distributed control schemes and the high processing burden added to the Network Elements (NEs) [16].

3.2. New network paradigms

In the following lines we describe two novel network architectures which are considered key building blocks of the IoTs.

3.2.1. ILSA paradigm

There are two main network approaches in order to deal with the issues of current routing and addressing scheme: 1) Clean-slate approaches, that is, solutions decoupled from the traditional OSI layered structure (for example adopting a service-communication model), and; 2) Non-disruptive approaches, that is, solutions which are "friendly" to the current layered structure (but still offering service-oriented communication capabilities), such as ILSA schemes. Both approaches have become the target for numerous research efforts in the recent years. Nevertheless, network carriers seem reluctant to adopt clean slate architectures mainly due to the migration task difficulty, and the potential disruption on provided services possibly promoted by this migration [17].

As a result, ILSA schemes have increasingly gained momentum in network research. The adoption of ILSA schemes may be justified given their proficiency in dealing with both the double functionality problem and the depletion of IPv4 addresses. ILSA schemes deal with these two issues by assigning an independent set of addresses for identification and location functions respectively. Thus, the service layer relies on the use of Identifiers

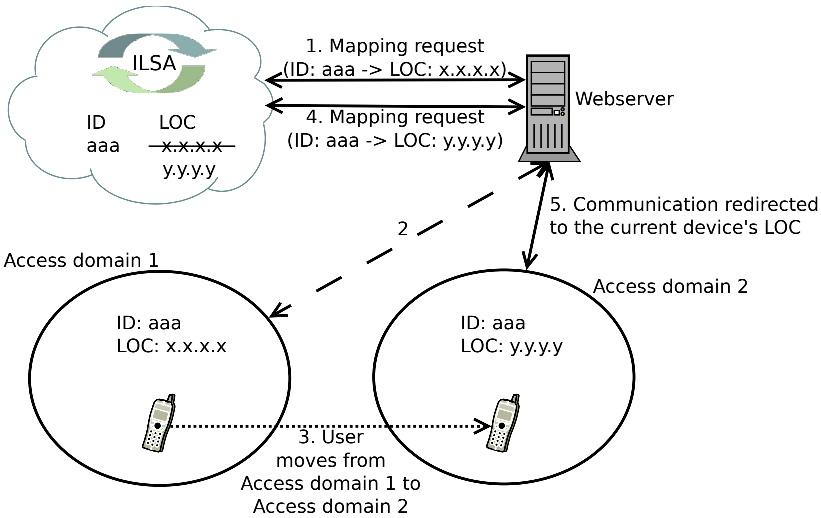

Figure 1: ILSA scheme operation.

(IDs) to support end-to-end connectivity, whereas in the network layer, routing functions are enabled by the use of Locators (LOCs).

To illustrate the basic operation of an ILSA scheme consider the scenario shown in Fig. 1. Whenever an end-user NE moves to a different access point, a new network address (LOC) is assigned to it. However, the NE's identifier (ID) does not change such as it occurs in current host-oriented communications, where an IP address is used for both the service and network layer. As a result, the communication established between the Webserver and the ID "aaa" is not affected by the reassignment of Locators (LOC x.x.x.x to y.y.y.y). It happens because, by means of an ILSA scheme, it is possible to map the NE ID to the current LOC.

3.2.2. PCE paradigm

On the other hand, another network paradigm that is gaining momentum in recent years is the so-called PCE. The main goal of the PCE is to face the limitations of current distributed control schemes such as GMPLS and ASON. In a PCE scenario, path computations actions are decoupled from the NEs, hence, this functionality is embedded on the PCE.

Despite of the advantages provided by the PCE in terms of scalability, path computation time as well as complexity, its performance might be degraded in IoT scenarios. This is due to several reasons, such as mobility or resilience features as well as the inaccurate network state information caused by the aggregation imposed in these scenarios. To illustrate these negative effects, consider the scenario shown in Fig. 2a, where a lightpath A-E-B is computed by the conventional PCE and then it is set-up by the Path Computation Client (PCC) in order to establish a video service. This video content is acquired from the NE Server and it is provided to the NEs within access domain 1. It is worth mentioning that we consider that the PCC is a Network Management System (NMS) with PCE Communication Protocol (PCEP) features as well as communication with control plane technologies such as Openflow [18]. Indeed, the lightpath A-E-B is successfully established. However, the traffic sent along this lightpath will be affected in case of a failure affecting optical node B. Moreover, the Network State Information (NSI) available in the Traffic Engineering Database (TED) will reflect that optical node B is still part of the network topology. This inaccuracy related to the NSI of optical node B will continue to be reflected on the TED until the updating messages related to topology changes are sent to the PCE. When this occurs, the NSI available in the TED will become accurate. It is worth mentioning that inaccurate NSI occurs also in mobile scenarios. To illustrate this, consider the scenario shown in Fig. 2b. The NE *s* is requesting a service from NE *d*. From the service layer perspective, the service identifier (www.mobilealsa.es/bus1) is directly mapped to a locator, LOC B. From the network layer perspective, this service demands the set-up of lightpath A-E-B using λ_1. In the case that node *d* changes its optical aggregation point to optical node E, the lightpath A-E-B will become useless for providing the demanded service, see Fig. 2c. Therefore, this lightpath must be torn-down and a new lightpath A-E-D must be set-up. However, this will only occur when the PCC knows about the new locator assigned to node *d*. In a conventional Internet scenario, the PCC knows about this LOC change by means of the DNS.

Recognized the limitations of the PCE, there is no doubt that novel solutions are required to overcome them. Fortunately, the collaboration between an ILSA and a PCE scheme may yield high performance in IoT scenarios. As an example, consider the scenario depicted in Fig. 3 showing an optical network where a PCC requests to the service-aware PCE (SPCE) a path computation, as shown in step 1. However, contrary to conventional PCE schemes, the source node is attached to an ID, specifically a HID, rather than a LOC, and the destination of the service request is a SID. For instance, a requested service computation might have a destination with ID "VideoServer". This ID might correspond to each NE identified with an HID capable of providing the requested service (identified with a SID scheme); in the case of Fig. 3, is HID "Server". In order to map the HID "Server" to a LOC, the PCE makes use of an ILSA scheme, see step 2. Once the LOCs are obtained, the PCE computes the best path to the access domain where "Server" is, that is domain 2, according to request requirements, which are service-dependent (e.g., bandwidth, delay),and send a Path Computation Reply (PCRep), as shown in step 3. Finally, in step 4, the optical lightpath is established.

By attaching the destination of a path computation to an ID, the network resources allocated to a path can change on the fly according to the LOC that best map the service requirements. To put this into context, consider that, in case of failure affecting optical node B, the service-aware PCE might compute a new path in an agile manner. This is because the destination of the computed path is reflected on the TED as it is attached to ID "Server". This ID can be mapped to a new LOC, such as LOC C, i.e., the decoupling of ID/LOCs provides an abstraction layer. Unfortunately, in conventional PCE scenarios, the failure in optical node B will impact strongly on all paths with node B as a destination since the information stored in the TED would be inaccurate, i.e., reflecting that network resources are allocated to the failed optical node, which is no longer available.

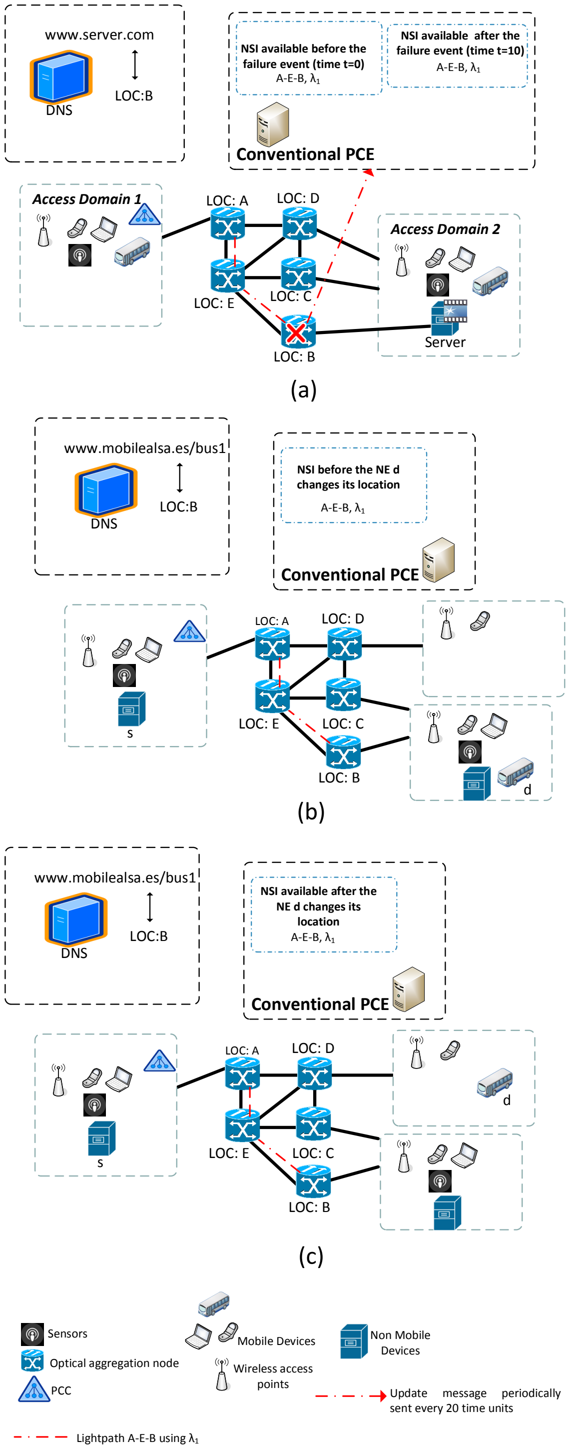

Figure 2: Conventional PCE in a mobile scenario.

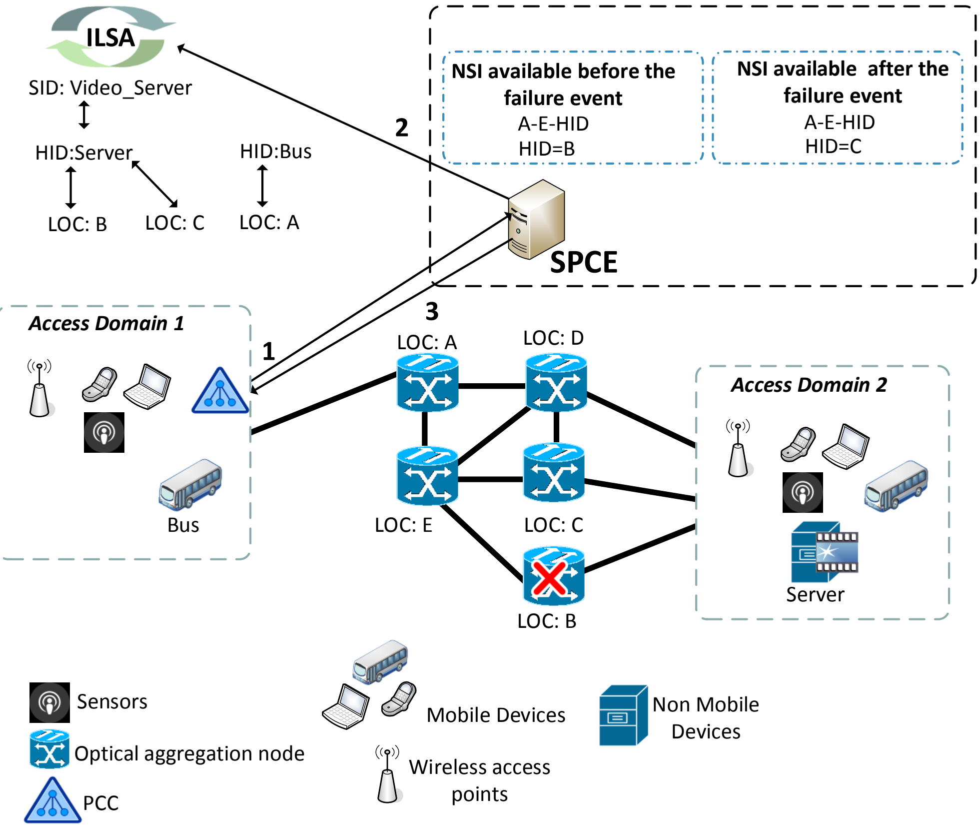

Figure 3: Collaboration between ILSA and PCE.

4. Service-Oriented PCE Architecture

The pendulum has swung from host-oriented to service-oriented communication models due to the advent of new network paradigms, such as IoT and ILSA schemes. In this section, we discuss in detail how the PCE scheme may ease path computation actions in a service-oriented architecture. Furthermore, we provide use-cases of the proposed architecture, namely SPCE.

4.1. ILSA Model

A PCReq from a PCC in the SPCE architecture can request as endpoint a specific type of service, for instance SID may be Video_Server, Temperature_Sensor, Sound_Sensor, etc. The PCReq may contain more than one SID, in case that the final service is the composition of different services; and of course, this request to the SPCE should also include some service layer parameters, such as energy availability, storage resources, mobility profile or city area in the case of sensors. This is one of the main differences and contributions of this paper to the new service oriented architecture: the request endpoint is a service (or services) instead of a specific host.

After receiving the PCReq, the SPCE architecture maps these SIDs to HIDs of possible NEs providing these services. In the example depicted by Fig. 4, the SID=Sound_Sensor is mapped to three different devices, two of them mobile devices and the third a fixed microphone installed in a building, i.e., HIDs=Mobile_device_1, Mobile_device_2 and Fixed_device_1.

Finally, the HIDs are mapped to LOCs by using an ILSA scheme. The SPCE will select the most suitable LOCs (which correspond to the specific NEs required to provide the demanded service) based on a two-layer graph, which is based on the following: 1) the service layer cost, e.g., energy availability, storage capacity, total free memory; 2) the network layer cost, e.g., available optical bandwidth or link delay. The SPCE architecture considers both, mobile and fixed devices. In the case of mobile devices, a single device (characterized by its HID) can be located in different positions due to its mobility. For instance, the device can frequently change its access point, which might result in a change of aggregation point at the optical layer. In this mobile scenario the SPCE architecture should be able to provide different LOCs according to different sevice layer parameters for these devices depending on the actual location of the device or also according to other requirements. In the example of Fig. 4, the Mobile_device_1 could be in n different locations (LOCs=$\mathrm{IP}_1, \ldots, \mathrm{IP}_n$) and the Mobile_device_2 could be in m different locations (LOCs=$\mathrm{IP}_x, \ldots, \mathrm{IP}_{x+m}$), whereas the Fixed_device_1 (which is a microphone in a city building) has associated only the LOC IP_y. As it is mentioned, the SPCE will select for each device the more suitable LOC, for instance, if Mobile_device_1 is located in the IP address IP_2, the SPCE will provide the LOC= IP_2.

4.2. Architectural Approach for the SPCE

In this section, we describe an overview of the SPCE architecture. In addition, in Table 2, we list the set of symbols used in this paper.

We envisioned an IoT scenario (see Fig. 5a) where the access layer is based on mobile as well as fixed network technologies. Each access domain is formed by a wealth of heterogeneous NEs that are enabling new utilization of their generated big data [19]. On the other hand, the network core is based on optical flexible technologies, where each

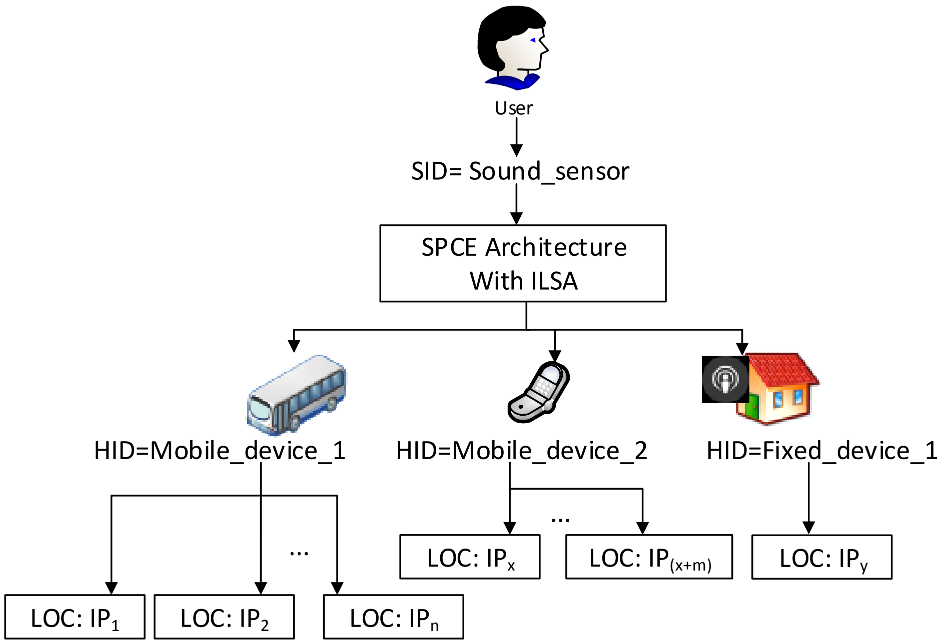

Figure 4: Service-Oriented PCE ID mapping.

Table 2: SPCE architecture symbols

Symbol	**Meaning**
LOC	Host current Locator
HID_d	Host Identifier, where d is a NE registered at the ILSA scheme.
SID	Service Identifier.
$L_{s'd'}$	Optical lightpath where s' and d' are the locators of a source and destination NE respectively.
$m^{HID,d}$	Service layer parameters.

optical node is the aggregation point of an access domain. We assume that connectivity to each access domain is already established. Therefore, our goal solely consists to establish connectivity between the aggregation points of each access domain.

Moreover, the goal of the PCC is to delivery agile service orchestration. For this purpose, the PCC acts as service provider and relies on the SPCE features in order to achieve: 1) the Identification of the nodes providing the requested service, and; 2) establish physical connectivity to the aggregation point of each wireless node.

On the other hand, the SPCE goal is two-fold: 1) identifying the host IDs of the NEs offering the requested service with the minimum cost; and once the host identifiers are obtained and are mapped to their respective LOCs; 2) to compute path (based on the obtained LOCs) with the minimum blocking probability as well as low optical resources consumption. The rationale behind this two-fold goal is driven by aim of enabling network-aware service composition. It is intuitive that this novel path computation strategy imposes changeling requirements to the conventional PCE architecture.

A detailed view of the SPCE architecture is illustrated in Fig. 5b. The building blocks of the SPCE architecture as well as the steps followed by the communication among its modules are the following.

• **An extension of the PCE Communication Protocol referred to as (S-PCEP):** This PCEP extension supports both ID based endpoints as well as service layer requirements in addition to optical network layer requirements.

• **PCEP Module (PCEPM):** This module receives and sends PCReq and a PCRep respectively (see step 1 on Fig. 5b). It receives a PCReq in the form ($\mathrm{HID_s}$, SID), that is, the endpoint of the request is a required service, SID, and it sends a PCRep with one or a set of computed lightpaths.

• **Service Orchestrator Module (SOM):** The SOM is responsible for the destination HID lookup process (step 2), i.e., based on a given SID selecting the HID of the NEs offering the requested service with the minimum cost (from the service layer perspective). To this end, the SOM uses state information available on the Device Context Database (DCDB) (step 3). Once the ID lookup process is done, the SOM communicates with an ILSA scheme in order to obtain the LOC associated to each HID selected. In addition, the SOM receives updates related to SIDs from the ILSA scheme. Based on these SID updates it proactively performs HID lookup process in case that lightpaths reconfiguration is needed (step 4).

• **Device Context Database (DCDB):** The DCDB stores state information that is not generated by the Traffic-Engineering Routing Protocols. This information is the one which will be used by the SOM for the HID lookup process according to service layer requirements such as energy availability, storage resources or mobility profile. To illustrate an example of the service layer requirements let's consider the mobility profile metric. If a mobile NE X sharing specific sensors has been detected at the same place every workday between 8:00AM and 10:00PM for the last weeks, the SPCE can make some assumptions considering that the NE's sensors have a high probability of being available during that period on the next workday. Therefore, from the service layer perspective, the NE X is optimal for services that require real time environment information. Otherwise, constantly moving NEs only provide environment information during the (short) time period they are within a domain [20].

• **Path Computation Module (PCM):** The PCM performs path computation actions based on HID endpoints, specifically as the source node an HID specified in the

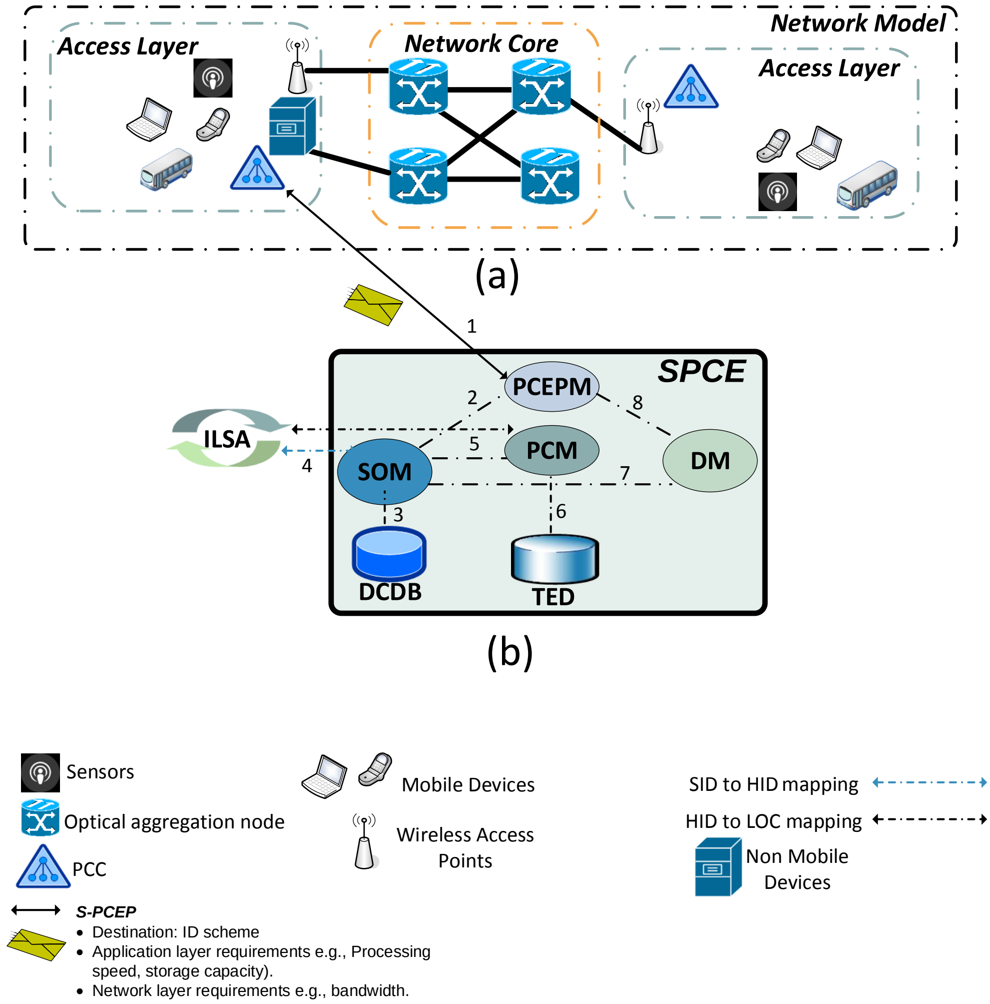

Figure 5: a) SPCE network model; b) SPCE architecture.

S-PCEP message, as endpoint the HID computed by the SOM. The PCM communicates with the ILSA scheme to obtain the mapping of the HID to LOC in order to perform path computation actions (step 5). To this end, the PCM uses the NSI available in the TED (step 6). In addition, the PCM receives updates related to HIDs from the ILSA scheme. Based on these ID/LOC updates it recomputes optical lightpaths.

• **TED:** Similar to the conventional PCE architecture, the TED is responsible for storing the NSI.

• **Decision Module (DM):** The DM receives as input from the SOM a set of tuples in the form ($\{HID_d$, $m^{HID,d}\}$, $l_{s,d}$) (step 7). Each tuple is formed by a destination HID with its service layer parameters and an optical lightpath computed by the PCM. This optical lightpath has the Locator of HID_d as a destination and, as source, the locator of HID_s. Based on the given set of tuples the DM selects the minimum cost lightpath considering both service and optical layer cost (step 8).

4.3. SPCE use-cases

In the following lines, we illustrate by means of two use-cases how the SPCE might fit in a service-oriented communication model. In the first use-case we show how, in a mobile cloud scenario, the SPCE can proactively react to traffic conditions [21]. For instance, consider the scenario shown in Fig. 6, where each transportation vehicle may request Video Capture (VC) functions from other vehicles. These VC functions are processed by the cloud servers in order to get a holistic view of the entire road intersection. For instance, the PCC in cloud infrastructure requests a path computation with SID:ALSA_Buses (step 1). This SID selection is done because the PCC is interested to get live VC from busses belonging to the company named ALSA. To this end, communication with the SPCE is triggered and, then, the SPCE communicates with the ILSA scheme to obtain both HID and LOCs (step 2). Thus, optical lightpath B-E-D is computed and sent to the PCC for its set-up (step 3). However, since the providers of VC functions are not fixed, the vehicle identified with HID:ALSA1 changes its access domain to Access Domain 1. This will trigger the proactive provision of a new lightpath as it is shown in Fig. 6b. Notice that once the HID:ALSA1 is registered in Access Domain 1, in the ILSA scheme its LOC is changed to a new LOC (LOC A) (step 1). The ILSA scheme informs the SPCE of this LOC change (step 2). Then, the SPCE recomputes a new lightpath to HID:ALSA1 using LOC A as a destination. As a result, optical lightpath B-E-A is computed and sent to the PCC (step 3).

Another use-case of SPCE in IoT scenarios is related to the establisment of multicast connections, i.e., set-up more than one lightpath. In IoT, multicast-connection are driven by the need to access information from several NEs in order to build (compose) a service. In light of this, consider the scenario where the goal of the PCC is to compose a service called as Image Recognition service which makes use of cameras embedded on mobile NEs. This Image Recognition service is based on obtaining image content and process it in order to identify certain graphical content [22, 23]. Current approaches, such as the usage of fixed cameras or even the deployment of mobile cameras are expensive, besides being more difficult to solve the coverage problem in Wireless Sensor Networks (WSN), especially in Video-based Wireless Sensor Networks (VWSN) [24]. The second use-case, illustrated by Fig. 7, describes more details about the architecture behavior. In this example, a user located between two access points (AP1 and AP2) requests to a PCC (located in Acess Domain 3 and, thus, connected to LOC C) the provisioning of a service

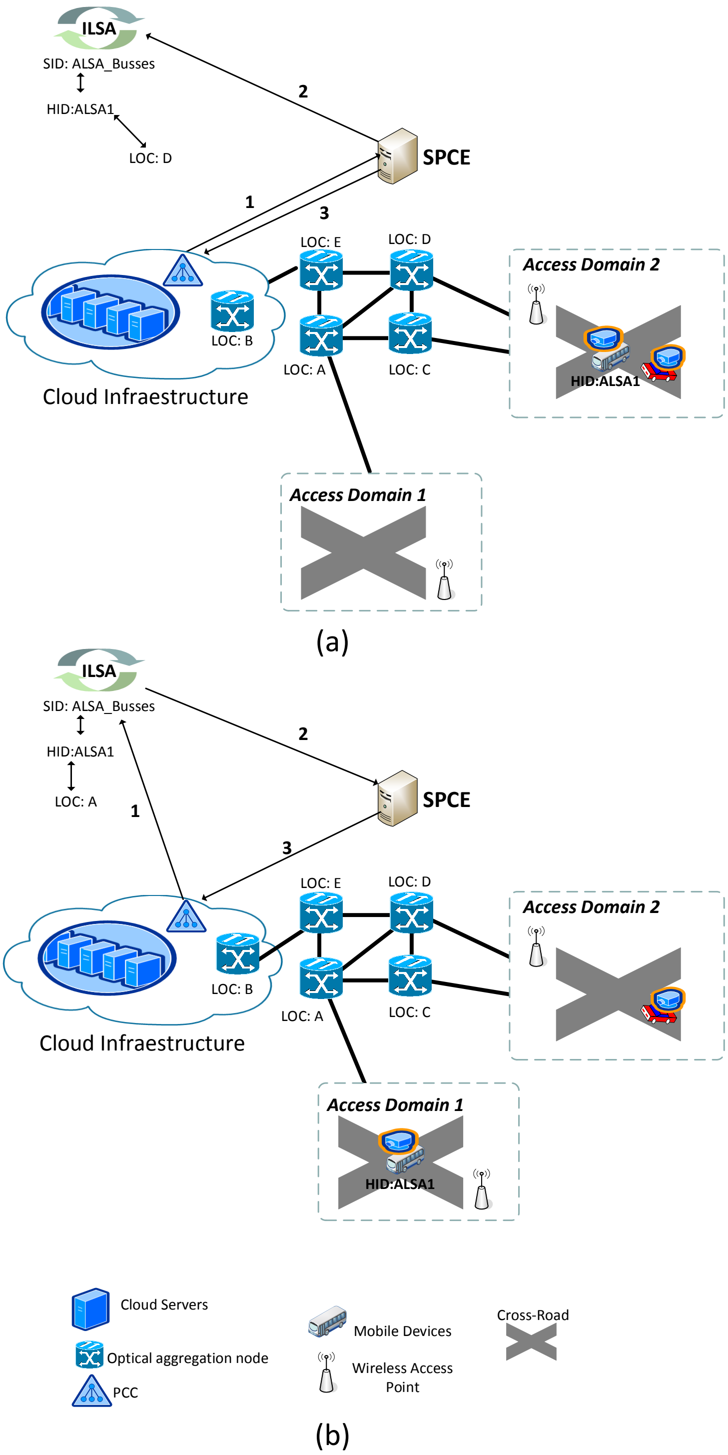

Figure 6: SPCE usage in a cloud computing scenario.

which is able to identify his/her lost dog using mobile cameras near his/her position. The PCC provides the requested service by collecting data provided by distributed NEs and processing them before sending a reply to the final user. The following steps describe how the PCC collects the data required in this use-case.

1. The PCC sends a path computation request with SID:CAM_NearUser to the SPCE. The service parameters received by the PCC are used to determine his/her positioning.
2. When a SPCE receives the request, it maps the SID:CAM_NearUser to a set of HID's (HID:CAR_13, HID:CAR_20 and HID:PHONE_5) which are capable of providing the requested service based on their context. Once the destination NEs are selected, the SPCE maps their LOC by means of an ILSA scheme. Thus, HID:CAR_13, HID:CAR_20 and HID:PHONE_5 are respectively mapped to LOC:A, LOC:B and LOC:A. Then, the PCEP uses the NSI available in the TED to compute the path to each selected NE.
3. The PCRep containing the computed optical lightpath as well as the NEs addresses are sent to the PCC.
4. The PCC establishes the optical lightpaths C-A and C-D-B, enabling the PCC to connect to the selected devices according to the routing information received from the SPCE.

5. Conclusions

The increasing number of end-user mobile devices combined with the advances on their hardware capabilities, including processing power, memory and energy availability, increasing number of sensors, among others, plus the network infrastructure advances providing ubiquitous connectivity, are contributing in leveraging the development of the so-called Internet of Things (IoT). In this paper we propose a novel network architecture referred to as Service-oriented Path Computation Element (SPCE). The SPCE leverages ID/LOC Split Architectures (ILSA) features in order to provide: 1) network-aware service composition,and 2) deal with the inaccuracy added by mobility features, which are common in IoT scenarios. This concept is based on the establishment of network connectivity based on both service and network parameters. As a future line of work, we will focus on modeling path computation assigment strategy of the proposed architecture.

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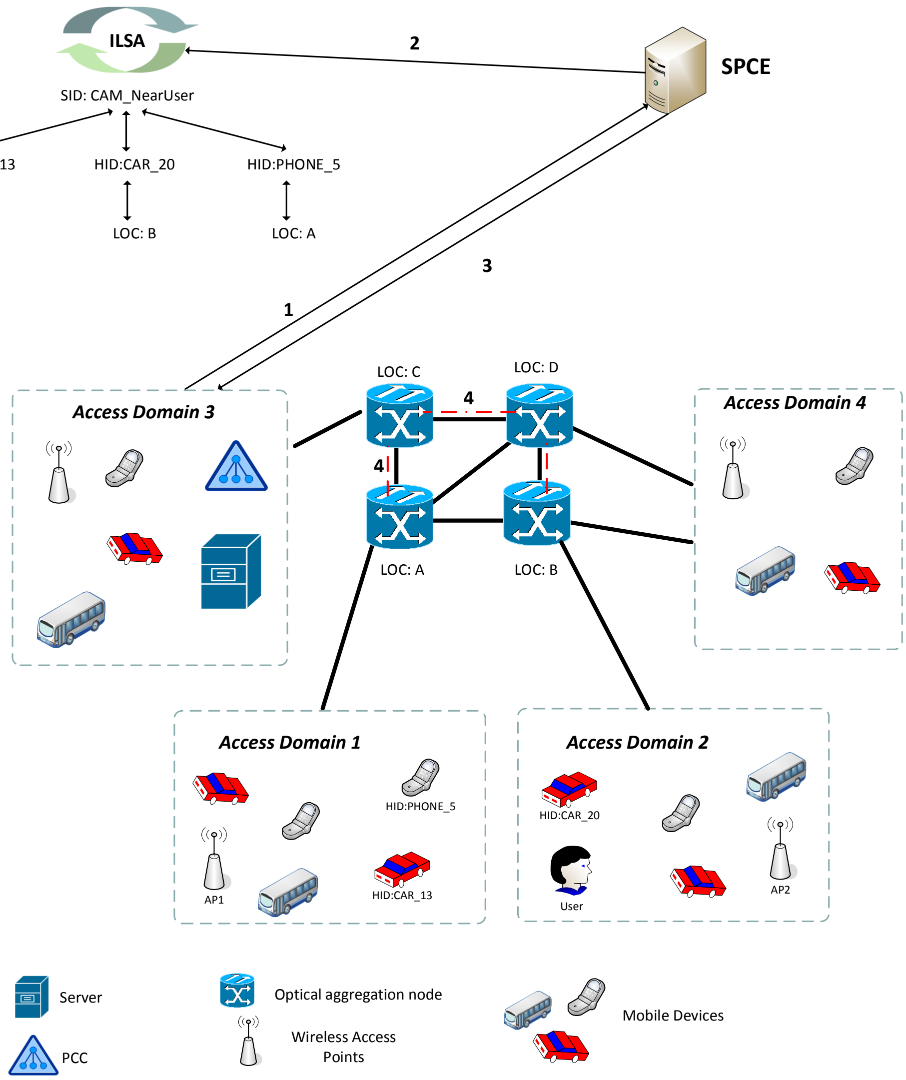

Figure 7: SPCE usage to enable service composition.

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