# Towards the scalability of a Service-oriented PCE architecture for IoT scenarios

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*Abstract*— **Despite the increasing number of mobile heterogeneous network elements (NEs) interconnected through the Internet, all of them setting the foundations for an agile IoT development, many issues remain still unsolved. The scalability of the current host-oriented Internet model is one of these problems. In this paper, we present a novel service-oriented architecture dealing with the scalability problem leveraging the Path Computation Element (PCE) concept. PCE has already been proved as an efficient technology to decouple the control tasks from the forwarding nodes, what undoubtedly impacts on scalability growth. Given the importance of control solutions for IoT, we propose to enrich the current host-oriented PCE model to become a Service-oriented PCE (SPCE). Results obtained after running several evaluation tests shows that the proposed PCE-based solution may support a higher number of Network Elements (NEs).**

***Keywords***— ***Service-oriented PCE, Internet of Things, Scalability***

## I. INTRODUCTION

Recent advances on mobile devices technologies, such as processing power, storage, and energy capacity, among others, as well as the increasing amount of distinct sensors embedded in a single device, combined with new routing and addressing technologies, have contributed to the origin of the Internet of Things (IoT) concept. The potential advantages of the usage of traditional mobile devices (such as smartphones, tablets, etc.) but also those not initially designed to embed that functionality (such as vehicles, wearables, etc.) as mobile network elements (NEs) have been emphasized in several works in the literature [1], [2], [3]. For instance, service providers and/or city administrators might benefit from the existing high number of mobile devices (embedding sensing capacities) distributed along a city to collect data, hence diminishing the need for deploying new sensors in the city. Also, a community effect may rise enabling the data aggregation from different sources in order to build a service. Furthermore, NEs maintenance tasks are also distributed, since each NE owner is responsible for maintaining its own device.

Mobility as a concept is currently pervasive and, therefore, globally affecting not only network providers but also service providers. The main rationale under this assessment is that new services may be generated leveraging the anywhere, anyhow, anytime connectivity paradigm. An illustrative example notoriously relevant in the last decade refers to vehicular networks. The capacity to connect vehicles has driven the Intelligent Transportation System (ITS) paradigm, gathering an unforeseen set of functionalities and innovative services, driving new smart city management models, new traffic control strategies and even novel health assistance solutions. ITS is a clear example on how mobility and pervasive connectivity may come together fueling new extremely impacting services to the overall society. Surely, from the technical perspective ITS scenarios present inner characteristics which lead to a contrast among others wireless mobile network scenarios, such as the higher displacement velocity, which conducts to a high handover frequency on Wireless Local Area Networks (WLAN). It is worth mentioning that there are several contributions already addressing some of the specificities for these ITS scenarios, such as for example, mobility patterns in [4], [5] enabling easier and faster handover prediction.

At the edge side, the evolution of mobile devices (i.e. higher and much better processing capabilities, memory, storage, and connectivity) facilitates its utilization as Web Service providers (i.e., mobile hosting of web services) [2]. Nevertheless, we consider that in an IoT scenario a mobile NE uses its embedded sensors and actuators to provide data or actions to service providers which are responsible for orchestrating the services to be provided.

Unfortunately, mobility does not bring only advantages. Indeed, mobility makes the well-known limitations of the currently IP addressing architecture widely used in the current Internet, even worse. This assessment is particularly significant in an IoT scenario, due the large number of “things” demanding Internet connectivity. The so-called IP address depletion problem is related to the double functionality of IPv4 addresses in the current Internet host-oriented model. That is, an IP address acts both as a locator (LOC) in the network layer and as identifier (ID) in the application/service layer. Further, in this host-oriented communication model, the NEs mobility also introduces frequent communication interruptions [6].

Handling the addressing problem in IoT scenarios in a non-disruptive fashion, the ID/Locators Split Architectures (ILSA) [7] have been proposed. The main concept boils down to linking one “thing” to one ID, whereas its corresponding LOC address is changed and updated at the ILSA server according to the “thing” mobility. The mapping between the ID to the updated corresponding LOC is managed by the ILSA scheme.

In short, the important is “what” (ID) service is being requested, instead of “where” (LOC) the service is. In this way, the ILSA schemes replace the conventional host-oriented communication to the so-called service-oriented model.

As read above, while mobility is fueling new opportunities for all stakeholders, new challenges also arise. A crucial aspect refers to the control overhead required to handle the new services enabled by pervasive communications, what in fact impacts on the functionalities to be offered by the network. This set of functionalities, such as for example the deployment of an advanced addressing scheme like ILSA, requires control strategies, what are also introducing network overhead. To deal with this issue the scientific community is pushing for decoupling control and data plane functionalities, limiting the impact overhead they may have on the data plane. This paradigm known as Software Defined Networking (SDN) is a preliminary contribution to the idea of decoupling routing and control outside the router device, delegating it to a dedicated element referred to as the Path Computation Element (PCE) [8]. Thus, instead of a conventional source-based routing, the source element, called Path Computation Client (PCC), sends a Path Computation Request (PCReq) message to the PCE containing, at least, the source and destination node. Then, the PCE computes the best path(s) according to PCReq parameters and the Network State Information (NSI) stored in the Traffic Engineering Database (TED). Hence, the PCE sends a Path Computation Reply (PCRep) containing one or a set of computed paths to the destination node. The communication is done by means of the Path Computation Element Communication Protocol (PCEP).

Despite the advantages introduced by the PCE in terms of routing scalability, its main field is not mobile networks. Hence, although PCE may be a candidate for handling IoT mobile scenarios, the current protocol should be substantially extended. For example, PCE must be enriched to support proactive computation of new paths whenever the source or destination NEs change its connection to a distinct Aggregation Point (AP). Furthermore, the high dynamism and heterogeneity inherent to IoT, drive the NE selection and path computation to consider not only traditionally used network layer constraints, such as delay, jitter and throughput, but also service layer constraints, such as energy profile, device availability and processing resources.

In this paper, we show a network-aware service composition architecture leveraging state-of-the-art technologies, such as PCE and ILSA. In other words, we push for the adoption of the PCE concept to go beyond simple path computation along with an ILSA scheme to solve the reported issues on mobile routing.

The rest of this paper is organized as follows. In Section II, we briefly discuss some researches presenting distinct approaches to improve current Internet scalability and propose service composition based on network-aware architectures. Section III presents the contributions of this paper. Later, in Section IV, we show our first evaluation results in terms of service setup delay. And finally, in Section V, we conclude the paper and present future work.

## II. RELATED WORK

As stated in Section 1, the current addressing scheme is facing some limitations that are even more exacerbated in an IoT scenario. In fact, as the number of hosts goes up, the usage of IPv4 addressing is considered obsolete, hence driving the need for new mapping schemes to assume the role played today by DNS.

Some works in the literature propose modifications to classical DNS schemes in order to achieve larger efficiency when selecting servers. The algorithm proposed by [9] shows better results, when increasing the requests timeout, than the most widely used DNS –BIND (Berkeley Internet Name Domain)– in terms of delay, queries handled by second, and percentage of lost queries. However, this is not enough to handle the aggressive IoT scalability requirements.

In an IoT scenario supported by the current host-oriented communication model, the larger the number of IDs is, the larger the number of lookup retransmissions to obtain a particular service address will be. In [10], authors presented the observed latency on distinct DNS servers according to the number of referrals, and hit/miss for NS records in a local DNS cache. The referrals are responses to recursive queries which do not terminate the lookup. In other words, a referral occurs when a DNS server does not have the answer to a query and sends a response with one or more NS records indicating DNS servers which may contain the answer.

Other contributions, focusing on IoT scenarios, presented different approaches to select NEs in order to provide IoT services, highlighting the requirement of network-aware service composition in this scenario. In [11], authors compared the end-to-end delay when using single objective and joint-objective functions, considering a small number of IoT devices and treating Internet as a black-box used to any communication between two distinct access points.

Moreover, the work presented in [12] proposed a three-layer QoS scheduling model which is suitable only for offline routing. In [13], an online routing model is presented but it does not consider wireless scenarios with high dynamism as IoT.

Thus, the ongoing work introduced in this paper intends to propose a novel network-aware service composition architecture for IoT which, unlike previous works, enables online routing in IoT, dealing with issues like scalability, dynamism and heterogeneity. The main component of this architecture is the proposed Service-oriented PCE (SPCE), whose main architectural characteristics along with the main concepts deployed to achieve scalability in IoT scenarios are introduced in next Section.

## III. SERVICE-ORIENTED PCE CONCEPT

The inherent deployment of thousands of NEs in IoT scenarios, such as smart cities or vehicular networks turns IoT routing as well as IoT service composition into large distributed problems. Moreover, the heterogeneity and dynamism perceived on IoT scenarios is adding even more complexity in the way NEs must be managed. Aligned to the current trend in decoupling control tasks to a centralized entity, we propose to extend PCE to accommodate the particular needs of IoT in the NEs selection (for service composition) and the routing.The PCE is already established as an architectural solution to detach path computation actions from the network routers.

Extending PCE to support IoT constraints however, is not a minor task. This complexity is mainly added by the fact that while in traditional routing source nodes only queries a path between two clearly defined endpoints (the hosts), in an IoT scenario, the service provider, when composing a new service, is not worried about the edge nodes but on different real-time information from the network. Hence, in practice, the service provider does not know what the NEs located in the destination domain area are, nor the availability of the existing devices in terms of application/service layer resources (e.g., processing, storage and energy availability), and, even how to connect to each one of the mobile NEs (i.e. what is the best path). To cope with these issues, we propose using an extension of PCE enriched with ILSA, hereon referred to as a Service-oriented PCE (SPCE).

## *A. Architecture*

In the proposed architecture, the PCC located at the edge domain of the user triggering the query, contacts the SPCE in order to get the service requested by the final user. To that end, the PCC sends a PCReq to the SPCE asking for the best path to the optimal NEs with capacities to provide the requested service. The SPCE makes use of the network state information (NSI) and an ILSA scheme to select the best NEs and also the best path between the PCC and each NE. As a network-aware service composition architecture, the SPCE must select the best NEs considering both network layer and service layer constraints. In the proposed architecture, the SPCE is responsible for enabling the service orchestration by the PCC, whist the PCC is in charge of processing the data received from each NE in order to deliver the service requested by the final user.

An overview of the SPCE architecture is illustrated in Fig. 1, including the sequential steps on the overall process. Thus, step 1 represents the PCReq sent to the SPCE by the PCC located at access domain 3 (i.e., the domain of the final user requesting the service); step 2 represents the communication between SPCE and ILSA (to find out where best NEs are); step 3 represents the PCRep containing the computed optimal paths to the selected NEs and; step 4 (red-dashed line) represents the establishment of a lightpath between LOC C and LOC B (assuming that the selected NEs are located in access domain 2).

Special attention must be devoted to step 2 in the process above. In order to cope with the NEs mobility, the SPCE relies on an ILSA scheme to get the current LOC of an ID. Nevertheless, the described scenario requires a more daring approach for the ILSA mapping paradigm. Since the PCC does not know beforehand what the specific NEs it will connect are, the PCReq message requests just for a service, identified by a Service ID (SID) and a set of message parameters. Thus, based on NSI stored by the SPCE, it selects one or a set of Host IDs (HIDs) able to satisfy the request. Finally, the SPCE, by means of an ILSA server, maps each selected HID to its respective LOC. This three-tier ILSA paradigm is illustrated by Fig. 2.

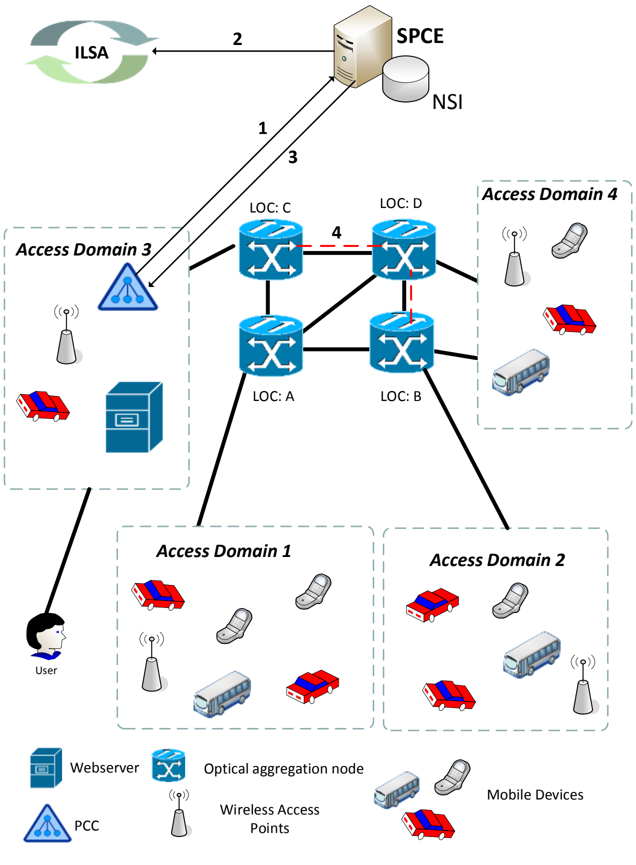

Fig. 1. SPCE architecture overview.

From a functional architecture description, SPCE is built on top of the components shown in Fig. 3, all as a whole setting the required extension of PCE to provide a Service-Oriented PCE. The interaction among SPCE components is as follows: the PCC should make use of an extension of the PCEP to send a PCReq to the PCEP Module (PCEPM). As shown in step 1, PCEPM receives the PCReq requesting for a service (SID) containing network layer and application/service layer requirements. In step 2, the request is transmitted to the Service

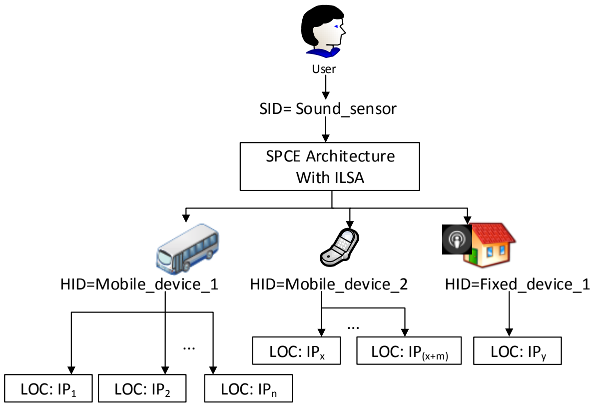

Fig. 2. Three-tier ILSA paradigm.

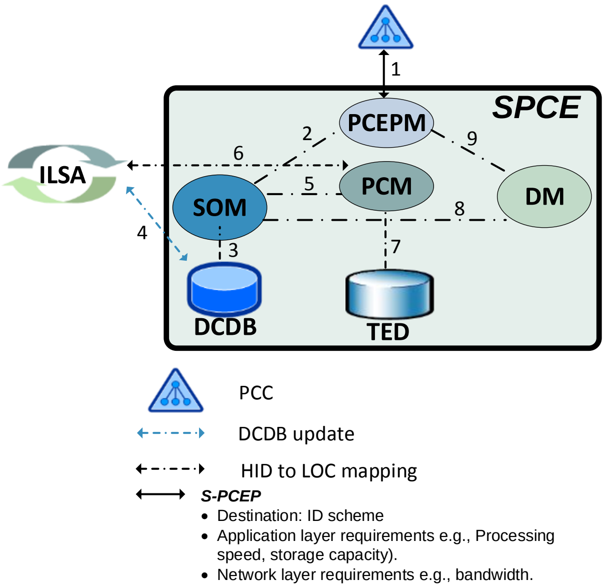

Fig. 3. SPCE architecture.

Orchestration Module (SOM), which will communicate with the Device-Context Database (DCDB) to get information about the available NEs, step 3, and hence choosing the HIDs to be selected (using information on the DCDB updated through ILSA, step 4). Once the set of best HIDs are selected, the SOM sends the information about these HIDs to the Path Computation Module (PCM), step 5, which is in charge of selecting, according to network constraints, the best paths from the source node (PCC) to each selected destination (HIDs). To complete that task, the PCM must communicate with the ILSA scheme, step 6, in order to map each HID to its respective LOC and, then, in step 7, the PCM, communicates with the TED to get an updated NSI and compute the paths. The computed paths are sent back to the SOM, so the SOM can forward to the Decision Module (DM), step 8, a set of tuples each containing the respective destination HID, a set of network layer and service layer constraints, and the path to the LOCs of the HIDs where the source HID is the PCC. The DM is in charge of selecting the best combination of paths according to the received PCReq (step 9) and sending it to the PCEPM. Finally, the PCEPM sends the PCRep to the PCC.

### B. *Service Provisioning Specifications*

In this section we present a path computation model with a clear focus on the service setup delay in order to compare the scalability of the proposed scheme. In order to illustrate the main differences we propose a comparison between delays conducted by the SPCE setup and the host- oriented PCE computation model using DNS for mapping.

In order to calculate the delay in an IoT scenario, we consider a generic service demanding to communicate with a high number of distributed IDs. The service setup delay may be considered as the accumulative aggregation of individual delays as follows: (a) send request from PCC to SPCE; (b) mapping SID to HIDs; (c) mapping HIDs to LOCs; (d) compute paths to each LOC; (e) send the reply from SPCE to PCC; and (f) establish each path according to the reply received by the PCC. It is worth mentioning that despite the fact that (a) and (e) delays may vary slightly due to eventual PCEP modifications required by the new paradigm, we assume the difference as negligible. Delay (f) depends only on the peers establishing the connection and the use of PCE or SPCE is not relevant to the communication establishment although the use of an ILSA scheme may have a high impact on communications maintenance. However, the delays expressed in (d) are different between host-oriented PCE and SPCE due the amount of NEs used for service orchestration in SPCE, resulting in several path computation actions increasing the ILSA delay in this phase.

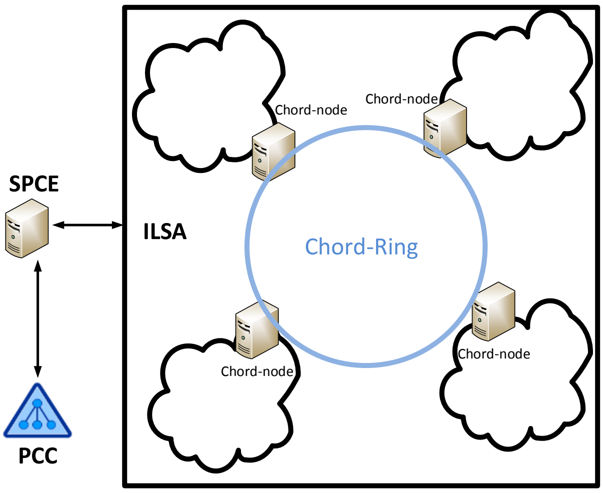

Fig. 4. Chord-ring topology used by ILSA.

A significant difference in comparing delays generated by both systems falls into the mapping phase. Indeed, in the proposed SPCE architecture, the mapping phase, i.e., (b) and (c), is much different from the classical host-oriented PCE, which is concerned just on mapping one single specific ID to one specific address. In this paper we particularly focus on delay in (c), i.e., HID to LOC mapping, in order to compare the mapping delay used by the proposed architecture against the current internet architecture based on DNS. The final objective is to show the scalability of the proposed model in terms of latency.

It is kept for future work, to elaborate more on steps (b) – SID to HID mapping– according to the adopted mapping algorithm, and phase (d) –path computation– according to the number of NEs selected by the algorithm.

#### 1) *Service provisioning with SPCE*

As described in the previous section, in this paper we focus on the HID to LOC mapping and want to analyze delays obtained in this step for SPCE and conventional host-oriented PCE systems. To this end, a model for the delay evaluation must be generated, what needs for a concrete detail on how the mapping is performed.. As described in [6], some distinct approaches try to address the ID to LOC mapping in ILSA schemes, each one with pros and cons. Among them, schemes

TABLE I. REQUIRED NUMBER OF CHORD-NODES

| | | **Storage capacity of Chord-nodes** | | |
|---|---|---|---|---|
| **Number of HIDs** | | ***65536*** | ***262144*** | ***1048576*** |
| | ***30000*** | 25 | 7 | 2 |
| | ***40000*** | 30 | 8 | 2 |
| | ***50000*** | 35 | 9 | 3 |
| | ***60000*** | 40 | 10 | 3 |
| | ***70000*** | 44 | 11 | 3 |
| | ***80000*** | 49 | 13 | 4 |
| | ***90000*** | 54 | 14 | 4 |
| | ***100000*** | 59 | 15 | 4 |
| | ***110000*** | 64 | 16 | 4 |
| | ***120000*** | 69 | 18 | 5 |

based on DHT (Distributed Hash Table) seem to be the most appealing for the IoT scenario we are considering, which needs a high scalability.

Thus, whereas one of the most used DHT-based schemes is Chord [14], which provides logarithmic lookup time and requires a logarithmic amount of memory per node [15], the ILSA mapping scheme proposed for SPCE is Chord-based. Fig. 4 illustrates the interaction of the SPCE with the ILSA Chord-ring topology. The usage of the envisioned Chord-based mapping system results in the following expression to determine the delay:

$$D_{ILSA} = \text{Routing Path Length} * \text{Virtual Links Delay} \qquad (1)$$

where $D_{ILSA}$ is the delay for the NE selection based on an ILSA scheme; Routing Path Length is the number of hops in the Chord-ring required to reach the destination Chord-node (i.e., the Chord-node which contains the LOC of the HID being mapped); and the Virtual Links Delay is the average delay of each virtual link which composes the Chord-ring.

It is obvious that the average routing path length varies according to the number of Chord-nodes required to compose the Chord-ring. Thus, the Chord-ring size is a function which considers the average storage capacity of each Chord-node in bytes (SC), the total number of HIDs (N_HIDs), and the size of each entry of the mapping system, used to map a HID to a LOC (SEntry), as shown in the following equation:

$$N_{chord\_nodes} \geq N\_HIDs * SEntry / SC \qquad (2)$$

where $N_{chord\_nodes}$ is the minimum number of chord nodes needed to create the Chord-ring.

According to [14], the average routing path length for a DHT-based mapping system, arranged as ring, such Chord, can be described as:

$$\text{Routing Path Length} = ½ \log_2 (N_{chord\_nodes}) \qquad (3)$$

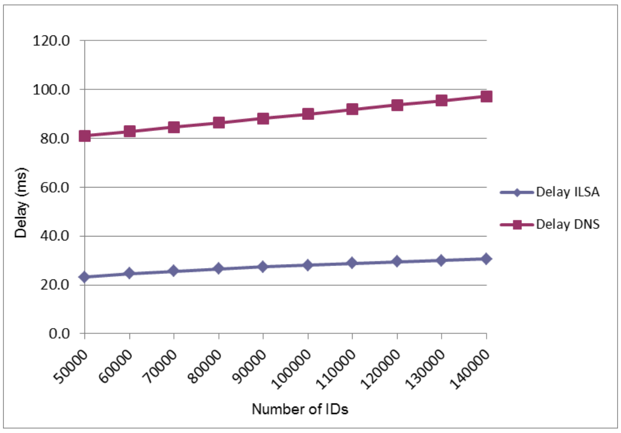

Fig. 5. Delay variation vs. number of IDs comparison between ILSA and DNS mapping schemes.

### 2) *Host-oriented PCE*

As mentioned, our focus in this work is to show the scalability of the proposed model in terms of latency, especially in relation with the mapping delay. As a host-oriented architecture, we assume the traditional PCE makes use of DNS servers in order to map the destination ID to an IP address.

Nevertheless, the DNS mapping time depends on many different configurations on the servers, including its location, number of supported entries, TTL of each DNS record type (e.g., A, NS, and PTX), server load, number of retransmissions, the algorithm used for caching and its efficiency on hits/miss, etc. Thus, because of the high number of variables, many works assessing DNS servers limit their analysis only to observations of real values contained in the log files of the evaluated servers (e.g., [9], [10]). Hence, instead of computing the DNS delay through mathematical models, we used values provided by these state-of-the-art contributions.

## IV. EVALUATION

In this section we present preliminary results of service setup time according to the time model explained in Section 3. We compare the results of the SPCE proposed architecture and the host-oriented PCE, with DNS mapping.

To achieve the presented results, we adopted as parameter the value of 10ms for the average Delay of the Virtual Links. The minimum numbers of Chord-nodes to compose the Chord-ring according to the number of HIDs and the average Chords-nodes storage capacity were obtained by using Equation 2 and are presented in Table 1. All presented results were generated considering HIDs with 20 bytes and LOCs with 12 bytes, i.e., 32 bytes for each entry.

Fig. 5 shows a comparison of the delay obtained to map one single ID (HID in SPCE) into a LOC (address in DNS-based) for the time model presented for the SPCE vs the values observed in [9] and [10], which consider the use of DNS servers in order to request a path to only one destination node.. We show in the x axis the overall amount of potential ID and as expected the larger this number is the larger the time consuming the mapping will be.

On one hand, we are aware that future works must consider not only one NE in order to enable service orchestration, and the mapping of distinct IDs will introduce an extra delay. Also, the path computation in an IoT scenario may result in a substantial increase of the SPCE path computation time, in comparison with the host-oriented PCE with less NEs. On the other hand, the results shown both in Table 1 and Fig. 5 illustrate a very small scenario with a low number of IDs in order to enable the comparison with presented DNS results. For instance, the Chord-nodes storage capacity of the results in Fig. 5 is only 65536 bytes.

To compare these results of SPCE with the traditional host-oriented PCE using DNS, we need to take into account the described characteristics of IoT as dynamicity and the high number of nodes. Thus, because of these characteristics, we assume that to resolve a DNS lookup in this scenario the number of referrals would be increased. According to values observed in real DNS servers by [10], 40% of lookups with one referral are resolved in more than 100ms and, when using two or more referrals, more than 95% of lookups have latency longer than 100ms and 50% have latency longer than 1000ms.

The presented values show that the use of ILSA may be a good alternative to the DNS based schemes when developing networks with a high number of IDs, such as IoT. For instance, [10] states that NS records tend to have a TTL much larger than A records. It is also claimed by [16] that the use of TTL value 0 for A records have a limited impact on traffic load when using DNS on mobile networks, but in IoT, with a large number of mobile nodes and a high mobility rate, such as in vehicular networks, this may not be true.

## V. CONCLUSION

This ongoing work proposes the use of mobile network elements (NEs), such as smartphones and vehicles to enable service composition in IoT. The architecture makes use of two distinct networks concepts to enable routing and addressing in such networks. In this paper we show the advantages of the proposed ILSA scheme in terms of latency scalability issues to enable a Service-oriented PCE.

The conducted evaluations compare the results obtained by the described model against real values observed in DNS servers' logs. The results can be considered good since it showed delays less than 100ms when selecting NEs among a total amount of $10^{21}$ IDs. On the other hand, the values observed in real servers with small amount of IDs, resulted in 40% of the lookups with latency higher than 100ms when using one referral. When the number of referrals is increased to 2 or more, 50% of lookups have latency longer than 1000ms.

In future works we must consider also the path computation time for host-oriented and service-oriented architecture. Furthermore, it is important to define a NE selection algorithm in order to compute the SID to HIDs mapping time in the proposed architecture.

## ACKNOWLEDGMENT

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