Federations of Connected Things for Delay-sensitive IoT Services in 5G Environments

I. Farris[1], A. Orsino[2], L. Militano[1], M. Nitti[3], G. Araniti[1], L. Atzori[3], A. Iera[1]
[1]University Mediterranea of Reggio Calabria, DIIES Department, Italy,
e-mail: {ivan.farris, leonardo.militano, araniti, antonio.iera}@unirc.it
[2]Tampere University of Technology, Finland, e-mail: antonino.orsino@tut.fi
[3]University of Cagliari, DIEE Department, Italy, e-mail: {michele.nitti, l.atzori}@diee.unica.it

***Abstract*—In this paper the MIFaaS (Mobile-IoT-Federation-as-a-Service) paradigm is proposed to support delay sensitive applications in the Internet of Things (IoT). This objective is reached by leveraging on the federation of distributed services and things at the infrastructure Edge and exploiting the real-world awareness and capabilities of IoT devices at the ground. MIFaaS enables value-added services by implementing the dynamic cooperation among private/public clouds of IoT objects with the purpose to *enhance the efficiency* in the provisioning of delay-constrained IoT services and *increase the number of successfully delivered IoT services*. The proposed paradigm is studied in a cellular environment based on standard Long Term Evolution (LTE). The simulative results we present demonstrate how the proposed federation solution of private/public IoT clouds outperforms alternative solutions with no federations and support of resources offered by the Cloud. Moreover, an analysis of the limitations and of the possible enhancements for cellular systems to support the proposed paradigm is drawn.**

I. Introduction

The Internet of Things (IoT) holds the promise to improve our lives by introducing innovative services conceived for a wide range of application domains. However, delay-sensitive IoT applications, such as sensing cognitive assistance, vehicular monitoring, and tactile Internet may suffer from latency issues related to the geographical distance between physical devices and IoT Cloud platforms hosted in remote data centers. The problem can be successfully tackled by exploiting the ubiquity of cellular systems and by adopting solutions like Mobile Edge Computing (MEC) paradigm [1] aiming to deploy micro-data centers at the edge of the Telco infrastructure. In this way, edge nodes may provide the required local computing and storage facilities to implement the intelligence needed by the surrounding devices and to improve the quality of services they offer to IoT applications. For this reason, MEC is considered one of the main pillar towards the next 5G cellular systems to support delay-sensitive applications.

In this paper we propose an enhanced *cooperative* paradigm among *cellular IoT objects*, according to which the eNodeB supports the orchestration and management of federations among private/public clouds of IoT objects identified as IoT Cloud Providers (ICPs). In particular an ICP is considered as a pool of both physical and virtualized IoT devices owned by the same public/private entity. This paradigm has first been introduced in [2] and identified as *MIFaaS (Mobile-IoT-Federation-as-a-Service)*. A broad set of advantages are introduced: i) enabling value-added services implemented through the federation of distributed IoT things and resources belonging to different owners (private users and public administrations); ii) cost savings by limiting the need to set up resource-hungry connections to the remote Cloud; iii) a better quality of experience, in terms of shorter latency in accessing services of interest; iv) an enlarged portfolio of available services to end-users well beyond those available if operating in a standalone manner. Compared to classic collaborative strategies in Mobile Cloud Computing (MCC) [3], where the single device can establish opportunistic cooperation by only exploiting its own resources, in MIFaaS *the federation process considers the pool of devices managed by each involved ICP as a whole* so to extend the opportunities of reciprocal support in heterogeneous IoT scenarios.

Objective of this paper is to investigate on how the federation of the so-called ICPs at the extreme edge of the network effectively supports delay-sensitive applications. More in particular, we will investigate on the MIFaaS adoption in a cellular IoT environment through a simulative analysis focusing on the suitability of standard LTE (Long Term Evolution) and its limitations in terms of efficiency in the radio spectrum resource utilization. A further contribution of this paper is to propose an integration of the core functionalities of MIFaaS in a cellular system and to analyze how the MIFaaS objectives can be achieved in the recently released ETSI MEC architecture [4]. The interest in this direction is motivated by the observation that, by 2025, cellular IoT (i.e., 2G, 3G, and 4G technologies used for IoT but not specifically optimized for IoT) and Low-Power Wide-Area (LPWA) modules will likely account for 7 billion units [5]. Moreover, next-to-come fifth generation (5G) cellular systems will be a strong boost for the actual IoT deployment [6].

The paper is organized as it follows. In Section II we introduce the related works and the research background. In Section III we define the proposed system for the ICPs federation in a cellular MEC environment by describing the procedures for the setup of ICP federations and the relevant communications over cellular networks. In Section IV a performance evaluation is provided, whereas conclusions are drawn in Section V.

978-1-4673-8999-0/17/$31.00 ©2017 IEEE

II. Research Background

The concept of federation among devices and systems has recently attracted a high interest within the IoT research communities. For instance, to promote interconnectivity among IoT platforms, the FIESTA-IoT project [7] focuses on federation, unification, and semantic interoperability across multiple IoT domains. However, solutions relying on the adoption of cloud infrastructures and services will unlikely be able to keep up with the expected scalability and network congestion issues in future IoT scenarios. Moreover, available solutions do not account for the strict requirements of current and future IoT delay-sensitive applications[1]. These issues may be addressed by augmenting the processing and storage capabilities of IoT devices through the exploitation of on-demand cloud computing resources close to the physical devices and the user. Similarly, to the purpose of reducing latency for time-critical services, the Fog computing [8] and Mobile Edge Computing (MEC) paradigms [1], along with the Cloudlet concept [9], have recently promoted the idea of relying on a middle tier between end-devices and the remote cloud, consisting of purpose-built servers, access points (APs) or base stations, to offer fast access to cloud services. The benefit of such an approach is the offloading of the network/cloud infrastructure [10], which is currently inadequate to sustain the growing demand for massive ICT services.

On the other hand, recent works focusing on MCC [3] have proposed infrastructure-less cooperative solutions to create local mobile clouds [11]. In particular, these solutions rely on a distributed cooperation to create collaborative computing platforms wherein devices share their resources. The idea of a resource coordinator elected among the mobile nodes is proposed in [12] to manage the matching between application requests and resources at the devices. In [13], the authors propose the refactoring of the Cloudlet in a controller so that nearby devices can be configured into a coordinated cloud computing service. However, the aforementioned papers do not consider the heterogeneity of IoT objects in terms of capabilities and resource constraints.

The proposed MIFaaS paradigm moves cooperation from the level of *single resources* to that of *groups of resources*, where each group is owned by a single entity, with the aim of increasing the performance in terms of satisfied local requests of resources. Additionally, MIFaaS exploits Fog Computing at the network edges to increase the reliability of the delivered services. In a previous work [2], we have introduced an initial idea of edge-assisted collaboration model for private IoT clouds and showed the improved performance when compared to alternative device-oriented approaches. In this paper we extend our previous research by considering *(i)* new policies for ICP federation, *(ii)* latency and mobility challenges *at the edge of a cellular IoT* system, and *(iii)* presenting an extensive simulation campaign of the MIFaaS paradigm in current cellular technologies. In particular, the analysis will be performed in an LTE (Long Term Evolution) enhanced with MEC features. This analysis would also offer insights in the benefits introduced by the MIFaaS paradigm in forthcoming fifth generation (5G) systems, which will exploit LTE as the baseline radio technology.

[1]Ericsson Research Blog, 5G Radio Access for Ultra-Reliable and Low-Latency Communications. Available at: https://www.ericsson.com/research-blog/5g/5g-radio-access-for-ultra-reliable-and-low-latency-communications/

A. LTE reference Cellular Systems

The efforts of academic, industrial, and standardization bodies are pushing towards the fulfillment of IoT requirements through the next-to-come fifth generation (5G) wireless systems [14], [15], [16]. The common objective is to design cellular IoT solutions, based on LTE, that meet the novel requirements and enhance the radio and core networks capability to work with simple, low cost devices [6]. Indeed cellular networks are promising candidates to allow effective internetworking of IoT devices, thanks to the benefits these offer in terms of enhanced coverage, high data rate, low latency, low cost per bit, high spectrum efficiency.

We consider an area covered by multiple LTE femtocells as the network edge nodes able to support the MIFaaS paradigm. The interested ICPs under coverage of a single femtocell are considered for the federation process. Whenever an object needs to communicate either to the remote cloud or to the local edge, as well as to interact with a federated ICP, a cellular link is activated by exploiting the allocated radio resources. The available radio spectrum is managed in terms of *Resource Blocks* (RBs) and, each RB corresponds to 12 consecutive and equally spaced sub-carriers in the *frequency domain* and lasts 0.5 ms in *time domain*. One RB is the smallest frequency resource, which can be assigned to a User Equipment (UE). The total number of available RBs depends on the system bandwidth configuration and can vary between 6 (1.4 MHz channel bandwidth) and 100 (20 MHz), however for a system configuration adopting femtocells (as the one considered in this paper) up to 25 RBs per femtocell is usually considered. A *Packet Scheduler* (PS) is implemented at the Medium Access Control (MAC) layer and is designed to efficiently handle the resource allocation in the time and frequency domains. The *Frequency Domain Packet Scheduler* (FDPS) performs the link adaptation procedures, assigning the RBs to each scheduled user and selecting the Modulation and Coding Scheme (MCS) for each assigned RB. The scheduling is based on the *Channel Quality Indicator* (CQI) feedback transmitted by each UE to the eNodeB and associated to the maximum supported MCS. Transmission parameters (i.e., MCSs) are adapted at every *CQI Feedback Cycle* (CFC), which can last one or several Transmission Time Intervals (TTIs), where one TTI is equal to 1 ms [17].

III. Federation Framework for cellular IoT Cloud Providers

We consider an ICP as a set of heterogeneous devices, either belonging to the same private user/company or deployed by a public authority/service provider forming a local cloud of resources. When the ICP owner registers the devices at the edge node, an ICP controller is created, which is in charge of managing resources and services of the corresponding ICP and, thus, has an aggregate vision of the status of the offered services and the available resources (e.g., computation, storage, and sensing).

A MIFaaS orchestrator has to manage federations of different ICPs on demand. Both the ICP controllers for each ICP and the MIFaaS orchestrator modules are software modules that can be executed in the edge node, which in this case is the femtocell owned by a Mobile Network Operator. We refer to the ETSI MEC documents [4] where the architecture for the Mobile Edge System of a Telco Infrastructure is defined. In particular, Mobile Edge Hosts (ME Hosts) contain the virtualization infrastructure which provides computing, storage, and network resources for the execution of user Mobile Edge Applications (ME Apps). The ICP controller can be considered as an ME App that an ICP can request to be activated. Furthermore, Mobile Edge Services (ME services) can be offered by the ME host itself, to provide additional functionalities to the ME Apps. The ETSI MEC document has specified some basic ME services, such as: (i) Radio Network Information, which exposes up-to-date network information to the ME Apps; (ii) Location, which offers location information of specific UEs currently served by the radio node associated with the ME host; (iii) Bandwidth Manager, which allows allocation of bandwidth to certain traffic routed to and from ME apps and the prioritization of specific traffic. In this context, we envisage the MIFaaS orchestrator to be introduced as a further additional ME service available to the ME apps, e.g., ICP controllers, to cooperate and obtain the desired IoT services. Based on these considerations the proposed solution is designed to be compliant with the next 5G cloud-native cellular network as sketched in Fig. 1.

According to the proposed paradigm, whenever an application running in a device generates a new task request, the ICP controller checks if the relevant ICP has enough resources to serve the request. If this request cannot be directly satisfied or the cost to serve the request is too high, then the ICP controller sends a collaboration request to the MIFaaS orchestrator of its ME host, which is responsible to take the decisions about the creation of federations based on the requests from all the ICP controllers running locally. The MIFaaS orchestrator checks the status of all the ICPs interested in a federation, and, based on the collected information, decides which resources among those available should resolve the task requests from the different ICPs over a given federation duration time (hereafter referred to as *federation period*). Then the list of supported tasks is created and sent to the LTE scheduler, which will schedule the requests so to meet the desired latency constraints over the overall federation period.

A. Federation management at the edge of the network

In a dynamic scenario with multiple ICPs under coverage of a single LTE femtocell, the proposed paradigm creates and orchestrates one or more federations of ICPs to maximize the number of executed tasks while meeting the desired Service Level Agreement (SLA) levels (in terms of latency). To this aim, the connected ICPs inform the orchestrator about the set of devices capabilities and the set of task requests. Based on this information, possible federations of ICPs are created after having efficiently mapped the service requests to the available resources. This requires an implementation of a task allocation solution at the orchestrator. We consider a simple algorithmic solution, based on a greedy approach to map as many task requests as possible to the resources of the involved ICPs, giving preference to those devices that guarantee the lowest latency for the requested service. In particular, the following steps are defined: i) the adopted task allocation algorithm checks among already allocated tasks if any of the corresponding allocated resources can be reused to also serve the new request (e.g., sensing services); ii) if service reuse is not possible then a suitable device for the service is searched by ordering the available nodes according to the expected latency and the number of currently served tasks; iii) the device with the lowest latency and number of executed tasks is selected to increase the probability of tasks meeting the SLAs and at the same time guarantee some load balancing; iv) the algorithm allocates the task to the corresponding ICP owning that device. Based on the task allocation, the ICP controllers update the resource availability status relevant to all their involved devices.

Accounting for the possible allocated services, the selection of the best configuration of federated ICPs can be naturally modelled as a coalition formation problem. In doing so, we define a non-transferable utility coalitional game where each player (i.e., an ICP) wishes to maximize the associated value in the coalition it belongs to. For each of the possible federations to form, we associate a single value that gives the measure of how preferred this is w.r.t. the other federations. Such a value is considered as the difference between the gain that the players obtain (the utility) in cooperation minus a cost term associated to the sharing of their resources. The utility term for any ICP is associated to the number of tasks being executed over the number of requested tasks, whereas the cost term is a measure of the amount of resources used to execute all

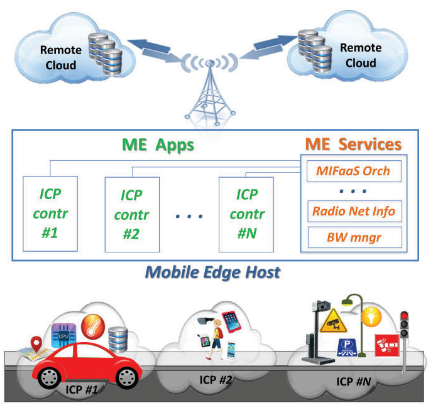
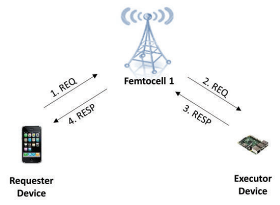


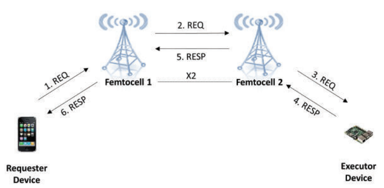
Fig. 1. MIFaaS framewok.

assigned tasks over the total amount of available resources at the ICP. In the sample results shown below, we equally weight the costs and the benefits in the utility, but other solutions may be considered to better account for the ICPs willingness to share their own resources. Once the utility is computed for every possible coalition, the MIFaaS orchestrator selects the best ICP federations to form, according to an iterative application of so-called *switch operations* that lead to a stable partition. In particular, it can be shown that the final partition is *Nash-stable* whereby no player (i.e., no ICP) has an incentive to move from its current coalition to join a different coalition or to not cooperate (please refer to [2] for details).

It is worth observing that the service provisioning in a device clearly requires a not negligible activation time for delay-sensitive applications. Therefore, we assume that the involved devices initially setup the relevant service instance and the task requesting ICP can send multiple requests (e.g., the application requires either execution of offloaded micro-services or sensing sample every x ms). In this way, the requesting ICP can receive fast responses from the cooperating ICPs during the federation period. Concerning the communication among the devices and the corresponding ICPs, we assume that data exchange between federated ICPs goes through the edge node so that interoperability is guaranteed by implementing appropriate syntactical and semantic translations. Clearly, in case of mobility of the ICPs it might be required that different edge nodes should communicate to transfer the task requests/responses among collaborating ICPs. As sketched in Fig. 2, in the LTE setting we considered for this paper, the communication between two adjacent femtocells is easily supported also in case of mobility through communications over the X2 interface. Clearly, the communications involving the forwarding over the X2 interface between the two ME hosts (i.e., the femtocells) will introduce some delay in the service delivery.



(a) Single femtocell



(b) Inter-femtocell communications

Fig. 2. Communication between femtocells for MIFaaS paradigm.

IV. Performance Assessment

The performance analysis in this Section illustrates the benefits introduced by MIFaaS in terms of *percentage of served tasks* w.r.t. alternative non cooperative solutions. The analysis, conducted by using the Matlab tool, addresses the impact of the number of ICPs, their mobility, the radio resources available in the LTE system, and the length of the federation period. Moreover, in the last part of the analysis, we will discuss the limitations related to the use of the LTE technology and the extent to which innovative paradigms (e.g., NB-IoT) in forthcoming 5G systems may be of interest for the MIFaaS paradigm. We consider six types of applications: computation offloading, data storage, and four different sensing services (e.g., video streaming, warning messages, temperature, and sensing for wearable devices); more details about the task configuration and parameters are provided in Table I. For the network deployment, we consider a grid topology of edge nodes (i.e., deployed in an area of [500,500] m), equi-spatially distributed with an inter-site distance of 100m. The edge nodes are interconnected through X2 LTE channels and are represented by LTE femtocells. All the interested ICPs under coverage of the same edge node are considered for the federation process, whereas federations involving ICPs under different edge nodes are not allowed. The mobility of the ICPs is implemented by considering the Levy Flight mobility model with an alpha parameter equal to $\alpha = 1$. The main simulation parameter settings are summarized in Table II.

In order to show the effectiveness of the cooperation-based MIFaaS solution in an LTE system, four different approaches are compared:

No cooperation – (No Fed): in this case, no cooperation is implemented, i.e., each ICP operates as a stand-alone entity, relying only on its own resources.

No cooperation – (No Fed+Cloud+Edge): in this case, the single ICPs are working as stand-alone entities without forming cooperative federations, but they can exploit the available remote Cloud and constrained edge nodes resources. In particular, the Cloud can especially offer support for delay-tolerant tasks since the RTT to remote data center typically is not negligible.

Cooperation-based MIFaaS – (Fed): this solution refers to the proposed federation of ICPs paradigm.

Cooperation-based MIFaaS – (Fed+Cloud+Edge): this solution refers to the proposed federation of ICPs paradigm, with additional computation and storage resources provided by the traditional remote Cloud and by the edge node.

In Fig. 3 we compare the three solutions by varying the number of ICPs between 4 and 24 (with federation time equal to 30 s), and by considering different federation periods between 5 and 30 seconds (with number of ICPs equal to 24). Regarding the radio resources, we consider an LTE bandwidth configuration equal to 1.4 MHz. As we can observe in Fig. 3(a), the percentage of successfully allocated tasks with the *MIFaaS* solutions (i.e., *Fed* and *Fed+Cloud+Edge*) overcomes other approaches. In particular, when varying the number

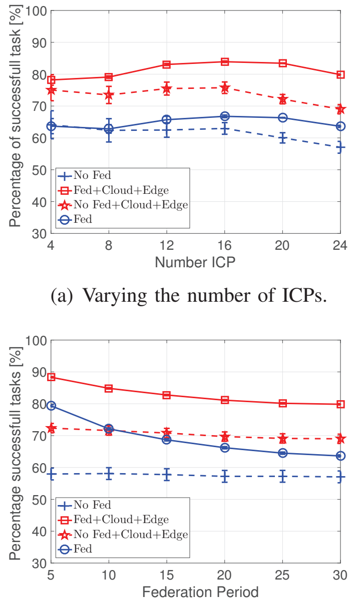
TABLE I
TASK CONFIGURATION PARAMETERS

ID TASK	TASK TYPE	LATENCY THR	PCK SIZE REQUEST	PCK SIZE RESPONSE	TIME INTERVAL	RESOURCE REQS	EXECUTION TIME
1	Computation (video processing)	[30,60,100] ms	[200,250,600] Kbits	[200,250,600] Kbits	100 ms	[2, 4, 6] MFLOPS	25 ms
2	Storage (video download)	[30,60,100] ms	0.1 Kbits	[200,250,600] Kbits	100 ms	[10, 30, 50] MBs	1 ms
3	Sensing (video streaming)	10 ms	0.1 Kbits	80 Kbits	10 ms	Available Sensor	1 ms
4	Sensing (warning messages)	25 ms	0.1 Kbits	25 Kbits	25 ms	Available Sensor	1 ms
5	Sensing (temperature)	50 ms	0.1 Kbits	0.5 kbits	50 ms	Available Sensor	1 ms
6	Sensing (wearable eHealth)	50 ms	0.1 Kbits	0.5 kbits	50 ms	Available Sensor	1 ms

TABLE II
MAIN SIMULATION PARAMETERS

Parameter	Value
Number of task requests per ICP	3
Sensing units per task request	[1-10]
Computation capacity per device	[1-10] MFLOPS
Storage resource units per device	[10-100] MBs
Sensing resource units per device	[0-1]
Computation capacity of Cloud	Unlimited
Storage resource units of Cloud	Unlimited
Computation capacity of Edge node	10 MFLOPS
Storage resource units of Edge node	100 MBs
Number of ICPs	[4-24]
Number of devices per ICP	3
Mobility pattern ICP	Levy Flights ($\alpha = 1$)
Round Trip Time Remote Cloud	80 ms
Round Trip Time X2 inter-edge link	10 ms
Edge coverage radius	100 m
LTE Bandwidth	[1.4-10] MHz
Simulation runs	100

of ICPs, for the *Fed* and *Fed+Cloud+Edge* solutions, the percentage of successfully executed tasks is about 65% and 85% (see Fig. 3(a)), whereas *No Fed+Cloud+Edge* and *No Fed* solutions reach about 57% and 70% when the number of ICPs increases. Noteworthy, with the *No Fed+Cloud+Edge* approach, the remote cloud can only provide limited support, since the majority of the requested tasks has strict time constraints, as well as the local edge nodes due to their small-scale resource availability. In Fig. 3(b), we also analyze the impact of the federation period on the performance of *MIFaaS*-based solutions to meet the latency requirements. The motivation to investigate on this is that the possible transition of mobile ICPs from an edge node to another during the federation period increases the experienced service latency due to inter-edge communications. The achieved results show that the percentage of tasks with unsatisfied latency SLA decreases linearly with the federation period. Nevertheless, the *MIFaaS*-based solutions are able to satisfy the latency requirements for a range that varies from 90% to 80% (i.e., *Fed+Cloud+Edge*) and from 80% to 65% (i.e., *Fed*) of the tasks. On the contrary, the percentage of successful tasks varies from 75% to 70% for *No Fed+Cloud+Edge* and from 65% to 57% in case of *No Fed* solutions.



(a) Varying the number of ICPs.

(b) Varying the federation period.

Fig. 3. Percentage of successful tasks.

A. Baseline LTE limitations in heterogeneous IoT scenarios

A wide range of tasks for IoT applications are characterized by small amounts of data to be exchanged. This may be in contrast with the objective of an efficient management of the available LTE radio spectrum, which is a key challenge in current and future 5G systems. In particular, current LTE cellular networks are not optimized for applications that only transmit small amounts of data with strict requirements in terms of latency. Furthermore, the existing cellular standards do not support power saving capabilities, which makes these standards unsuitable for inexpensive devices that require battery lives of several years.

To better highlight the limitations of the LTE technology for heterogeneous IoT scenarios with an avalanche of potential “connected things”, in Fig. 4 we investigate the LTE transport block utilization ratio for four different LTE bandwidth

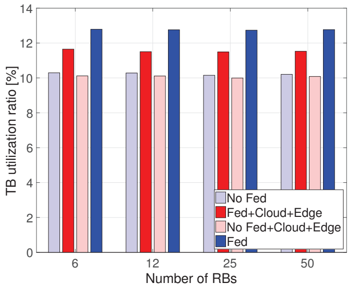


Fig. 4. Transport block utilization by varying the number of RBs.

configurations, i.e., 1.4, 3, 5, and 10 MHz. Although the *MIFaaS*-based approaches outperform the other solutions by reaching a transport block utilization around 12%, this is still representative of an inefficient use of the available radio spectrum regardless the amount of available radio resources. Therefore, there is a strong need for new approaches and radio technologies able to accomplish not only the high number of transmissions typical of an IoT MEC environment, but also to provide the desired latency requirements with an efficient management of the radio spectrum. Along this direction, the 3rd Generation Partnership Project (3GPP) started the standardization process in its LTE Release 13 of a new radio technology thought to accomplish discontinuous (and not) transmissions driven by the fast proliferation of low-end and high-end IoT devices over the cellular radio spectrum. This new radio access technology, known under the name of Narrowband IoT (NB-IoT) technology [18] is expected to connect more devices w.r.t. the current LTE radio technology and to efficiently support IoT applications in next-generation 5G networks, with challenging requirements in terms of latency and battery life. Among its benefits, NB-IoT will provide enhanced support of massive number of low throughput devices, low delay sensitivity, ultra-low device cost, low device power consumption, and optimized network architecture. It also offers deployment flexibility allowing an operator to introduce NB-IoT by using a small portion of its existing available spectrum. Further, NB-IoT is optimized for applications that need to deliver small amounts of data over long periods of time and, since it operates in licensed spectrum, it is secure, reliable, and provides guaranteed quality of service.

V. Conclusion and Future Works

In this paper we introduced Mobile-IoT-Federation-as-a-Service (MIFaaS), a paradigm designed to enable dynamic cooperation among private/public local clouds of IoT devices at the edge of the cellular infrastructure. The performance evaluation showed how the proposed federation of ICPs enhances the number of solved tasks meeting the latency constraints for the requested services w.r.t. alternative solutions where cooperation is not implemented. The presented results also show the low efficiency in using the available radio resources within LTE system to serve IoT service requests. To face this issue, in our future research activities we will focus the attention on the adoption of novel cellular IoT solutions, such as Narrowband IoT (NB-IoT), which are driving the development of next-generation 5G networks. As further future works, we plan to investigate the definition of suitable ICP federation policies based on several criteria to optimize the cooperation at the edge of the network, such as: (i) the ability to predict the mobility pattern of the ICPs; (ii) evaluation of the *power consumption* associated to each task; (iii) ensure *trusted interactions* among ICPs to build a reliable system.

References

[1] Y. C. Hu, M. Patel, D. Sabella, N. Sprecher, and V. Young, "Mobile Edge Computing A Key Technology Towards 5G," *ETSI White Paper*, vol. 11, 2015.

[2] I. Farris, L. Militano, M. Nitti, L. Atzori, and A. Iera, "MIFaaS: A Mobile-IoT-Federation-as-a-Service Model for dynamic cooperation of IoT Cloud Providers," *Future Generation Computer Systems*, vol. 70, pp. 126 – 137, 2017.

[3] N. Fernando, S. W. Loke, and W. Rahayu, "Mobile Cloud Computing: A Survey," *Future Generation Computer Systems*, vol. 29, no. 1, 2013.

[4] "Mobile Edge Computing (MEC): Framework and Reference Architecture," ETSI GS MEC 003 V1.1.1, Tech. Rep., 2016.

[5] "LTE evolution for IoT connectivity white paper," *Nokia white paper*, 2016. [Online]. Available: http://resources.alcatel-lucent.com/asset/200178

[6] L. Militano, G. Araniti, M. Condoluci, I. Farris, and A. Iera, "Device-to-Device Communications for 5G Internet of Things," *EAI Endorsed Transactions on Internet of Things*, vol. 15, no. 1, 10 2015.

[7] A. Gyrard, C. Bonnet, K. Boudaoud, and M. Serrano, "Assisting IoT Projects and Developers in Designing Interoperable Semantic Web of Things Applications," in *2015 IEEE International Conference on Data Science and Data Intensive Systems*, Dec 2015, pp. 659–666.

[8] F. Bonomi, R. Milito, J. Zhu, and S. Addepalli, "Fog computing and its role in the internet of things," in *Proceedings of the first edition of the MCC workshop on Mobile cloud computing*. ACM, 2012, pp. 13–16.

[9] U. Shaukat, E. Ahmed, Z. Anwar, and F. Xia, "Cloudlet Architectures, Applications, and Open Challenges to Deployment in Local Area Wireless Networks," in *Journal of Network and Computer Applications*. Elsevier, 2015.

[10] I. Farris, R. Girau, L. Militano, M. Nitti, L. Atzori, A. Iera, and G. Morabito, "Social Virtual Objects in the Edge Cloud," *IEEE Cloud Computing*, vol. 2, no. 6, pp. 20–28, 2015.

[11] C. Shi, V. Lakafosis, M. H. Ammar, and E. W. Zegura, "Serendipity: enabling remote computing among intermittently connected mobile devices," in *Proceedings of the 13-th ACM international symposium on Mobile Ad Hoc Networking and Computing*. ACM, 2012, pp. 145–154.

[12] T. Nishio, R. Shinkuma, T. Takahashi, and N. B. Mandayam, "Service-oriented heterogeneous resource sharing for optimizing service latency in mobile cloud," in *Proceedings of the first international workshop on Mobile cloud computing & networking*. ACM, 2013, pp. 19–26.

[13] K. Habak, M. Ammar, K. A. Harras, and E. Zegura, "FemtoClouds: Leveraging Mobile Devices to Provide Cloud Service at the Edge," in *IEEE Cloud*, 2015.

[14] A. Gupta and R. K. Jha, "A survey of 5G network: architecture and emerging technologies," *Access, IEEE*, vol. 3, pp. 1206–1232, 2015.

[15] J. Sachs, N. Beijar, P. Elmdahl, J. Melen, F. Militano, and P. Salmela, "Capillary networks - a smart way to get things connected," vol. 8, pp. 1–8, 2014.

[16] S. Andreev, O. Galinina, A. Pyattaev, M. Gerasimenko, T. Tirronen, J. Torsner, J. Sachs, M. Dohler, and Y. Koucheryavy, "Understanding the IoT connectivity landscape: a contemporary M2M radio technology roadmap," *Communications Magazine, IEEE*, vol. 53, no. 9, 2015.

[17] 3GPP, "TS 36.300, Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN), Rel. 11," Tech. Rep., Sep. 2012.

[18] Y.-P. E. Wang, X. Lin, A. Adhikary, A. Grövlen, Y. Sui, Y. Blankenship, J. Bergman, and H. S. Razaghi, "A Primer on 3GPP Narrowband Internet of Things (NB-IoT)," *arXiv preprint arXiv:1606.04171*, 2016.