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A Discussion on Context-Awareness to Better Support the IoT Cloud/Edge Continuum

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ABSTRACT This article debates on notions of context-awareness as a relevant asset of networking and computing architectures for an Internet of Things (IoT), in particular in regards to a smoother support of the the networking operation between Cloud and Edge. Specifically, the paper debates on notions of context-awareness and goes over different types of context-awareness indicators that are being applied to Edge selection algorithms, covering the approaches currently used, the role of the algorithms applied, their scope, and contemplated performance metrics. Lastly, the paper provides guidelines for future research in the context of Cloud-Edge and the application of context-awareness to assist in a higher degree of automation of the network and, as consequence, a better support of the Cloud to Edge continuum.

INDEX TERMS Context-awareness, Internet of Things (IoT), edge/fog computing.

I. INTRODUCTION

The daily routines of regular citizens integrate a wide variety of highly heterogeneous *Internet of Things (IoT)* systems. Such systems integrate simple sensors and actuators, networking devices, and more complex cyber-physical systems, such as smart sensors and mobile personal devices (e.g., smartphones) which further integrate a large number of sensing interfaces. For instance, in personal mobile devices, sensors such as accelerometer, GPS, microphone, or camera, bring in the possibility of exploiting new types of data coined as *smart data* or *small data*, derived from the track and trace process of different aspects of the routine of citizens, e.g., roaming habits; application usage; location preferences [1]–[3]. While such sensorial capability is giving rise to new types of data and services, it brings in additional computational and data exchange challenges. Firstly, the datasets are richer, even though data is fine-grained, and often polled more frequently, thus resulting in larger volumes of data to be analysed [4], [5]. Secondly, the IoT communication architectural models that are being applied to support such data transmission cannot cope with the properties of such traffic (e.g., high volumes of small data packets). This is both due to the increasingly larger number of devices being

interconnected to the Internet and to a higher heterogeneity of the hardware and software involved [6]. Thirdly, the processing of the richer and more complex data sets require support from computationally heavy Artificial Intelligence (AI) engines supported by the Cloud. While the Cloud helps in supporting the required data analytics complex computation, the more heterogeneous IoT scenarios available today are often not compatible with the delays derived from pushing all of the data processing and storage to the Cloud [7].

In the quest to assist smart data computation in IoT scenarios, related trends concern a decentralisation of Internet services and of networking functions across the so-called *Cloud to Edge continuum (Cloud-Edge)*. The Cloud-Edge continuum refers to a set of operations that are required to fulfil, in an automated way, user and application requirements, taking into consideration networking features. Today, the Cloud-Edge continuum relies already on context-awareness indicators, as shall be debated in section III and IV of the paper. However, this is limited, often tied to strict network guarantees, and such indicators are not sufficient, in our opinion, to sustain novel and more dynamic IoT environments, where the Edge is mobile, highly heterogeneous (e.g., an embedded device, a smart satellite).

Existing trends attempt to best serve mobility of devices and users; the need for data and user privacy; the larger volumes of sensitive data to be analysed, and the requirements

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to handle such data [8], [9]. This is giving rise to alternative ways to provide data exchange in IoT environments, as occurs with the paradigm of Edge/Fog computing [10]. Usually, such paradigms take into consideration task, service and resource offloading, to assist in a better resource management. However, to support better dynamic environments, it is necessary to consider how to best adjust the computational needs to the respective context and hence, it is relevant to revisit notions of *context-awareness*.

This is the motivation for this work. We believe that context-awareness can assist in a smoother transition of computational/storage/networking resources, from the Cloud to the Edges and vice-versa. To assist this debate, the paper contributions are three-fold: i) the paper provides a thorough review on work that focuses on context-awareness for IoT; ii) the paper contributes to the definition of context-awareness in IoT and debates on specific context-awareness indicators that can be considered to better support a smooth Cloud-Edge continuum; iii) the paper provides guidelines concerning the integration of context-awareness in Cloud-Edge IoT environments

The review provided in this article has been based on an extensive review of papers concerning context-awareness for IoT environments. This review has comprised an analysis of papers from 2011 until 2020, based on the paper keywords “context”, “context-awareness”, “Edge computing”, “behavior inference” and also focused on the area of “networking architectures”, areas of interest of the authors. The selection took into consideration the following aspects: i) the work has been described in peer-reviewed publications with a high Impact Factor; ii) most recent references have been preferred against older ones.

The paper is organised as follows. Section II goes over related work, explaining the contributions of this article towards related literature. Section III describes background on IoT communication aspects, including notions for Edge/Fog computing. Section IV discusses the role of context-awareness for IoT and describes specific indicators that are being used to assist on a selection of the whereabouts to store and compute data. Section V specifically focuses on the integration of context-awareness into IoT Fog/Edge architectures, detailing existing areas of interest. Section VI concludes the paper, discussing findings and providing a set of guidelines for future research.

II. RELATED WORK

Several related work has focused on different categories of network communication challenges experienced in IoT scenarios. Specifically focusing on the domain of eHealth, Islam *et al.* describe on challenges existing in current IoT healthcare middleware [11]. Dimitrov *et al.* delve into issues concerning data mining, data storage, and data analysis [12] in IoT eHealth scenarios. Poon *et al.* focus on sensor communication [13]. Sensing and big data management have been debated by Hong *et al.* [14], and the identification of key components of an end-to-end IoT has been discussed by

Baker *et al.* [15]. This line of work identifies and highlights challenges that IoT faces in Smart Health environments, including security, privacy, usability, energy awareness. This line of work is relevant to our work, given that eHealth scenarios experience specific challenges, in particular concerning data privacy and data sensitivity, challenges which can be lowered if the underlying networking architectures assist in handling data locally, within trusted environments.

In the context of IoT for Smart Cities environments, where smart applications are used to collect and to exchange different types of data, Sholl *et al.* propose a Smart City architecture that harnesses the power of semantic technologies to allow machines and people to understand the relationships among data in a context-aware manner, and to extract knowledge [16]. Choi *et al.* propose a software architecture to assist efficient middleware deployment in Smart Cities, by relying on semantic technologies [17].

Context-awareness is also highly relevant to data mining and classification as, for instance, debated in the context of vehicular networks by Ruta *et al.* [18].

Chen *et al.* surveyed Edge computing resource-efficient offloading mechanisms [19]. Still in regards to Edge/Fog computation offloading, Wang and Tao [20] collected and investigated key issues, methods related to the offloading problem in Cloud to Edge environments.

Another category of related work focuses on the understanding and definition of context and context-awareness, which are central points in this review paper. Some authors [21] define context in association with parameters such as location, neighbour identity, time-based indicators such as visit duration, environmental characteristics such as season, temperature. Ryan *et al.* define context as the user’s location, environment, identity, and the time [22]. Dey *et al.* states that context is the user’s emotional state, focus of attention, location and orientation, date and time, objects and people in the user’s environment [23]. Schilit *et al.* argue that the only important aspects of context are user location, the user’s neighbours, and resources near the user [24]. They define context to be subject to the constantly changing execution environment and the environment is thus three-fold: computing environment, user environment and physical environment. Sofia *et al.* [25] define context indicators based on the network layers, derived from roaming patterns of users.

Our work differs from the described related work in that it debates on research that applied context-awareness to assist in automating the IoT Cloud-Edge operation, surveying the use of context data to improve network performance in Edge/Fog Computing for environments exhibiting variability, such as occurs today in IoT environments that involve Thing-to-Thing and People-to-Thing interactions.

III. IoT COMMUNICATION BACKGROUND

IoT environments can be broadly grouped into two categories, related with the specific requirements and expected benefits: *Consumer IoT (CIoT)* and *Industrial IoT (IIoT)* [26], [27]. Both IoT categories rely on computational architectures that

integrate four main functional blocks: data capture; data storage; data analysis; data exchange. However, the requirements on these different environments introduce different challenges.

IIoT [28], [29] focuses on how smart machines, networked sensors, people, and data analytics can improve aspects such as productivity, service efficiency. IIoT is applied to different vertical markets, e.g., Industrial Automation, Smart Cities, Smart Factory, Logistics. Moreover, specific IIoT markets include also Smart Health, Smart Energy, or People-at-Work markets.

IIoT is expected to support both *Machine to Machine (M2M)* and *People-to-Machine* interaction, either for application monitoring, control, for instance, or as part of a self-organised system, with a distributed control which does not necessarily require human intervention. IIoT often implies higher data rates and larger data volumes. Moreover, applications are often mission and/or safety critical requiring strict and bounded guarantees, such as low delay, low jitter, or zero packet congestion.

CIoT concerns the use of IoT in aspects related to the daily living of people and aims at increasing usefulness of technology in such context. It involves scenarios focused on the interconnection of consumer and devices, as well as of anything involving the users' environments such as homes, offices, and cities [30]. Vertical markets of CIoT comprise, for instance, Smart Cities, Connected Mobility, Smart Health.

Personal IoT (PIoT) is a sub-category of CIoT focused on the application of smart systems based on personal devices, as well as based on sets of sensors and actuators applied to improve quality of living. The most popular form of PIoT concerns fitness solutions aiming to bring awareness and to improve physical health of users [11], [31]. Currently, these systems are more commonly used in the context of *Ambient Assisted Living (AAL)*. AAL encompasses technical systems to support people with special needs in their daily routine, e.g., elderly [32], temporarily disabled people, or anyone that needs supportive monitoring [33], [34].

A. SUPPORTING ASYNCHRONOUS AND MANY-TO-MANY COMMUNICATION

From a protocol perspective, the interconnection of IoT Things and applications, be it directly to a controller or to the Cloud-Edge, has been traditionally deployed by having sensors harvesting information and sending such information to a specific device/system, for instance, an IoT gateway, an IoT broker. Hence, initially the point-to-point communication model provided by TCP/IP was enough to support the requirements of IoT data exchange.

With the increase of IoT devices, as well as with the new software-based and open-source approaches being explored, IoT services are becoming more complex, thus introducing additional requirements. Firstly, several, if not most of the devices in IoT scenarios are mobile. Secondly, the integration of the different hardware and software solutions that compose IoT environments is often provided by third-parties. Thirdly,

IoT scenarios often accommodate hundreds or thousands of devices, often communicating across large distances.

To cope with these changes, data exchange in IoT needs to be supported by mechanisms capable of accommodating aspects such as mobility, security, large distances, intermittent connectivity. For this, it is necessary to support two main communication requirements: *asynchronous communication support*, and *many-to-many service distribution support*.

Internet communication protocols are therefore evolving, in the context of IoT, to support the 2 main mentioned requirements. For instance, the protocols that support IoT data exchange (IP-based messaging protocols) usually rely on a *broker-based* publish/subscribe communication model [27]. The broker is a mediating functional entity that handles data being exchanged between producers and consumers in an asynchronous way. First, consumers subscribe specific data interests. Then they get the matching information provided by producers [35]. Broker models create an abstraction layer as well, and can protect the identity of producers and subscribers. Nevertheless, they are still focused on reaching hosts (machines), and not really focused on the content.

The most recent evolution of publish/subscriber models is embodied in the *Information-centric Networking* publish-subscriber paradigm [36]. *Information-centric Network (ICN)* is a networking architectural paradigm that is focused on data reachability, instead of host reachability. In the context of IoT, ICN models seem to be promising as the network semantics that ICN automatically supports aspects such as consumer mobility [37], security, as well as address abstraction by design. There are today several ICN architectural proposals such as the *Data-Oriented Network Architecture (DONA)* [38]; the *Network of information (NET-INF)* [39]; the *Content-Centric Networking (CCN)* [40]; the *Named Data Network (NDN)* [36]. Out of these, the networking architecture most suitable for IoT is the NDN architecture [41].

The NDN architecture defines a simple and robust data-centric, pull-based and receiver-driven communication model based on the exchange of two packets types, *Interest* and *Data* packets. Interest packets are sent by consumers willing to express interest on specific content and contain hierarchical, global content names [42]. Data packets are sent by producers upon the reception of Interest packets, and carry chunks of signed data.

B. THE ROLE OF EDGE/FOG COMPUTING

Fog Computing [10], also known as Edge computing [43], extends the Cloud Computing paradigm to the "Edges" of the network, bringing in new opportunities to explore applications and services. By assisting the placement of storage and data processing closer to the data sources, Edge Computing brings in benefits in terms of latency and energy consumption [44]–[48], for instance.

In this article Fog and Edge are used indistinctly, as we consider the most recent evolution of Edge, where the Edge is elastic in terms of whereabouts or even system composition

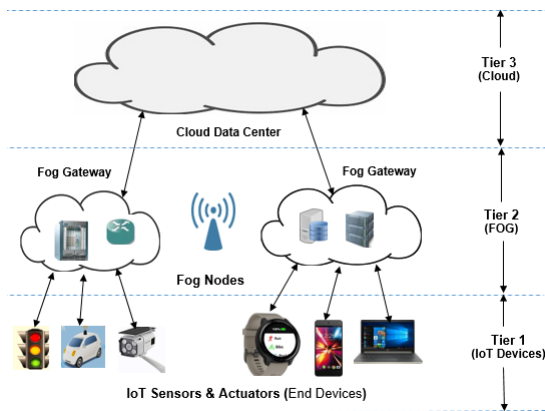


FIGURE 1. Fog/Cloud computing Architecture.

(e.g., an Edge can be a smart sensor, a satellite, a smartphone, or an eNodeB) [49]. However, other views provide a stricter perspective on Edge computing, derived from a telecommunications perspective. This is the case, for instance, of the Mobile Edge Computing (MEC) architecture, where the Edge is still within the control of the operator and consists of a specific computational unit, working in isolation or being complementary to the Cloud. While in Fog computing, the notion of Edge is more elastic, covering, for instance, field-level and end-user devices (e.g., smartphones, smart sensors) [50].

For IoT, and due to aspects such as security (e.g., the need to have in-plant security and resilient communication in IIoT scenarios), large distances, as well as large sets of frequent data lead to an insufficiency of the Cloud to satisfy the *Quality of Service (QoS)* requirements (e.g., low latency) of different IoT applications. Fog computing aims to overcome some limitations of Cloud-centric IoT-models by taking advantage of Edge network resources [51].

Fog/Edge network architectures integrate mechanisms to better distribute data computation and data storage across a specific infrastructure. Figure 1 illustrates such a networking architecture, where Layers represent Tier levels.

Tier 1 integrates IoT *field-level* devices, such as sensors and actuators. These are data sources, devices that capture and distribute data to other Tier devices, same Tier, or next Tier level. **Tier 2** (FOG) integrates IoT devices coined as *Fog nodes* [52]. IoT hubs and gateways that gather data and process information fall into this category. The Tier 2 level includes also devices such as routers and *Access Points (AP)*. Fog nodes are arranged in a hierarchical way and communication is only possible between a parent-child pair in the hierarchy. Given that these devices are in the edges of the network, often located in Customer Premises, Fog nodes often have limited resources. **Tier 3** (CLOUD) devices often have a significantly higher amount of resources. These are, for instance, virtual machines in data centers.

IV. CONTEXT-AWARENESS IN IoT

Context-aware computing has been used over the last decade in desktop applications, Web applications, mobile computing,

and pervasive/ubiquitous computing. Context-aware computing is a computing paradigm in which applications can discover and take advantage of context information such as user location, time of day, neighbouring users and devices, user activity [53]. Context is “*any information that can be used to characterise the situation of an entity. An entity can be a person, place, or object that is considered relevant to the interaction between a user and an application*” [54].

Hence, there is a significant difference between context information and raw data sent by IoT devices. Raw data concerns unprocessed data that is directly retrieved from data sources. Context information is generated by processing raw sensor data. Such data is validated, checked for consistency, and often annotated with meta-data [55]. For instance, GPS sensor readings can be considered as raw sensor data. Once it represents a geographical location, it becomes context.

IoT environments comprise a large number of devices and large volumes of data to be transmitted and processed. Understanding how to use and how to process that data to generate relevant knowledge is therefore dependent on the type of context of services, users, as well as networking architectures. Hence, context-awareness plays a critical role in assisting decisions in terms of what data needs to be processed, where that data should be processed, and when.

In regards to IoT environments, context-awareness is being applied to improve different computational aspects, as summarised in Table 1. The table categorizes related work first by area of application, explaining the purpose (column 2), and where the related work applies such improvements (column 3). The context-awareness indicators used are presented in column 4, while the applicability domain (vertical market) is provided in column 5. The related literature is placed in column 6.

A first area of related work (row 1) applies context-awareness to authentication and control in untrusted environments. Context-aware access control mechanisms are being used to provide system access, using the user personal data context and not personal data.

A second area of related work (row 2) concerns the application of context-awareness for resource management and orchestration. Such line of work focuses on improving the overall computational and networking performance by exploring context-awareness to reduce energy consumption; reduce overall latency; message overload. Context-awareness is relevant to assist in deciding when and where to process data, thus contributing to latency reduction, for instance [69], [79].

In regards to forwarding/routing applications (row 3), one example of the work being pursued is to take into consideration, at a network level, the context that surrounds users and that can assist in better defining opportunities for data transmission over time, and space, i.e., context-awareness at the network layers [25]. Context-awareness can also assist in a better distribution of in-network caching; more efficient naming aggregation, as well as in a more efficient data transmission in the context of large-scale scenarios [68], [92].

TABLE 1. Context-awareness application in IoT computational and networking Architectures.

Area	Purpose	Where	Indicators	Domain	References
Authentication and Control	To facilitate secure authentication and control of IoT devices in untrusted environments	End-user, Edge, Cloud	Physical context (light, temperature, noise); computing context (app usage, touch patterns), User context (roaming patterns, neighbor cluster, location, etc.)	PIoT, SmartHome, SmartHealth, Automation	[20], [56]–[65]
Resource management and orchestration	To improve the overall IoT computational platform and services providing control based on context	Edge, Cloud	Device usage and resources, time, location, user behavior	SmartHome, SmartCities	[66]–[74]
Forwarding/routing	To introduce context-awareness to the network layers in order to provide better chances to forward, in particular in highly heterogeneous scenarios	End-user, Edge, Cloud	Location, roaming data, accelerometer, speed, device usage (e.g., battery)	Opportunistic IoT environments, SmartCities, PIoT	[25], [75]–[78]
Offloading	To assist in deciding where to store data and to compute	Edge, Cloud	Location, battery, latency and other network measurement indicators	Smart Logistics, SmartCities, SmartMobility	[71], [79]–[82]
Semantic interoperability	To assist in a smoother operation in large-scale heterogeneous environments	Edge	Application delay requirements, request history, service/user similarity	Smart Logistics, SmartCities, SmartMobility	[83]–[88]
Multi-layer interoperability	To provide IoT interoperable ecosystems by using context-awareness in a bottom-up approach	Edge, Cloud	Users, device usage, environmental indicators	Data discovery, management and communication	[87]–[91]

Another category of work focuses on applying context-awareness to offloading (row 4), i.e., to decide where to store data, and also where to compute such data. For this purpose, parameters such as location, residual energy of the device are being applied.

A fifth category of related work focuses on semantic interoperability aspects, including related work that has been delving on improving data sharing on upper layers via semantic modelling. Once the information can be collected from a range of sources and some information must be explicitly supplied by users, context-awareness can be applied to identify the relationships level between people, the ownership of devices and communication channels providing a seamless approach to the interconnection of devices and their data exchange, by providing automated support to the interconnection of, for instance, different data models derived from different applicability domains (row 5). In this context, indicators derived from the application layer (such as delay requirements), or even similarity between used services is being applied to assist in an automated interconnection.

The last row (row 6) covers work related with multi-layer interoperability. This work focuses on discovery, management and high-level communication of IoT devices in heterogeneous IoT platforms, defining, for instance, component-based methods for middleware interoperability.

V. CONTEXT-AWARENESS AND SELECTION ALGORITHMS

Edge selection algorithms provide a smoother operation in Cloud-Edge environments, in particular when considering services and applications that might require very short response times, or applications that might produce a large quantity of data to be processed. Sending such data to the Cloud may result in large delays, or excessive energy consumption by the network devices, for instance.

An example of technological solutions that require adaptation on the go are *Mobile Pervasive Augmented Reality (MPARS)* [93]. As stated by Pascoal *et al.*, context-awareness derived from the surrounding environment, as well as from the user's habits, and computational preferences can assist a better aggregation and placement of data. This also assists in extending the reach of computational and networking architectures, considering Edges that are mobile and resource constrained.

Current Edge placement algorithms are often focused on aspects such as latency and energy improvement, as summarised in Table 2, which summarises Edge selection algorithms, categorizing them by context information considered (column 2), scope (column 3), as well as performance metrics relied by the algorithm (column 4).

Wattenhofer and Zollinger [94] propose XTC (1), a topology control algorithm to select the nearest Edge in ad-hoc wireless networks. The algorithm has three steps: 1- Neighbour ordering; 2- neighbour order exchange, and 3- Edge selection. It also has the advantage of not requiring full knowledge of the topology, or prior status on the node whereabouts. It therefore applies heuristics that take into consideration the direct neighborhood of the node, at different instant in times.

Sumit *et al.*, propose an *Edge selection algorithm for AR applications* (2) [95]. Their algorithm takes into consideration both application requirements and traffic load. The algorithm scans the state of neighboring edges to find a “best” Edge which can serve the user within a specified latency threshold.

An *Energy Saving via Opportunistic Routing algorithm* (3) is proposed by Luo *et al.* [96]. This algorithm is applied in wireless networks and has two steps to select nodes: 1-selects a set of nodes with higher centrality; and

TABLE 2. Edge selection Algorithms.

Nr.	Algorithm	Context	Scope	Metrics
1	XTC [94]	Neighbor ordering, neighbor order exchange, Edge selection (no need for node location or global topology knowledge)	Network control algorithm for ad-hoc environments, node selection	Latency
2	AR Edge Selection [95]	Application requirements and traffic load	Edge Selection	Latency threshold
3	Opportunistic Routing (ENS_OR) [96]	Distance to sink and residual energy on both neighboring nodes	Opportunistic relaying algorithm, node selection	Distance to sink and residual energy
4	RNST [97]	Node location via trilateration	Wireless indoor location, node selection	relative direct distance radio range
5	Latency Bounded Minimum Influential Node Selection [98]	Diffusion, influential nodes impact on the speed of diffusion	Node Selection	Propagation speed of influential nodes
6	Computation and networking load node selection [99]	Application requirements node resources link quality resources	Node Selection	Node and link availability
7	Branch-and-bound algorithm [80]	Computational overhead	Joint node selection and resource allocation	Computation overhead threshold
8	Threshold based policy [100]	Network policies	Edge/Cloud selection	Delay threshold
9	ThriftyEdge [19]	Task resource usage	Resource-efficient computation Node selection	Latency, minimum node usage (e.g., CPU, memory)
10	Edge Selected MPA [101]	Topology, neighborhood status	Edge Selection	Channel quality and proximity

2- considers the status provided by other nodes it encounters. In terms of indicators, it considers the node's distance to the data sink, and the residual energy on both the parent and successor nodes.

The *RNST* algorithm (4) [97] was developed to support mobile nodes for indoor wireless networks. It provides node location via trilateration, considering four steps: 1- A mobile node broadcasts a location message to its neighboring reference nodes, then the reference nodes return a confirmed location message; 2- The mobile node calculates the distances between each pair of nodes and judges if any of the three reference nodes can form almost equilateral triangle; 3- Compute the estimated locations of the mobile node using each of the possible equilateral triangles; 4- The mobile node calculates the average location value.

A *Latency-bounded Minimum Influential Node Selection Algorithm* (5), proposed by Zou *et al.* [98], provides a selection of the most influential nodes on a (social) network, where most influential relates with the speed of diffusion, and not with connectivity. The algorithm steps are: 1- find a 1-hop dominating set for the rest of the nodes that are INACTIVE 2- the vertices that could be influenced by the 1-hop Latency-Bounded Minimum Influential Node Selection in Social Networks.

A computation and networking load node selection algorithm (6) [99] is one of the first works, to our knowledge, that realises the need to meet, in an integrated way, both application and networking requirements. It relies on node resources such as CPU, and link resources, and considers as selection metrics node availability derived from a node and link QoS perspective.

The *branch-and-bound algorithm* (7) [80] proposed by Pham *et al.* addresses both node selection and

resource allocation. It is a Divide and conquer algorithm that uses computation overhead to select a node.

Zhao *et al.* provide a threshold-based policy mechanism (8) [100] which finds an optimal local node to run delay-tolerant applications in mobile Cloud computing, designing a scheduling scheme to realize the cooperation between the local Cloud and the Internet Cloud.

Xu Chen *et al.* introduce *ThriftyEdge* (9) [19], a resource-efficient IoT task offloading algorithm. The authors rely on a hybrid approach to exploit the hierarchical resources across local nodes, nearby helper nodes, and the Edge-Cloud in proximity. They propose a topology-sorting-based task graph partition algorithm in order to reduce the Edge resource occupancy (usage).

Yudan Wang and Ling Qiu propose *MPA (ES-MPA)* (10) [101], a low complexity Edge discovery and selection approach to better support the massive connectivity of cellular IoT.

Summarising, most of the existing algorithms that provide support for node selection usually consider a minor set of network or node requirements, e.g., latency, residual energy. Less common is the attempt to combine application/task and network requirements. Moreover, out of the analysis performed, we did not find algorithms that took into consideration behavior inference (node, link, service, and user), for instance.

VI. CONCLUSION AND GUIDELINES FOR FUTURE RESEARCH

This article reviews work concerning the relevancy of integrating context-awareness to improve the IoT data exchange across Edge and Cloud, in particular regarding the needs

of IoT services and applications. The paper provides an overview on the needs of different IoT environments and revises proposals which consider context-awareness indicators to provide operational improvements, e.g., latency reduction, lower energy consumption. The review shows that the role of context-awareness in IoT environments is acknowledged, but that its integration to support more dynamic IoT environments is still limited, often being defined simply as location to assist traffic locality, or node resources, as described in section IV. As also debated in section IV, there are several opportunities to improve the Edge-Cloud continuum, by considering different levels of context-awareness indicators, derived from application requirements and from networking requirements, and also derived from the behaviour learning of inference of user activities and habits (e.g., roaming patterns; preferred network locations). It is therefore relevant to consider some of the findings, to derive guidelines for future research. A summary of such guidelines is:

- IoT applications are becoming more and more distributed across the Cloud and Edge, as addressed in section III-B. Edge selection mechanisms (cf. section V) consider a limited integration of context-awareness. Other indicators which may better support more dynamic environments (e.g., indicators derived from mobility patterns) can be considered, thus being a relevant area of future work.
- The support of many-to-many asynchronous communication is today based on publish/subscribe models, as described in section III-A, is relevant to better support the needs of IoT data exchange. It provides the opportunity to scale better in comparison to the traditional client/server communication models, through parallel operation, message caching, tree-based or network-based routing. In addition to the IP-based messaging protocols commonly used in IoT environments, it is relevant to further delve on the relevancy of paradigms such as ICN, and focus on the integration of ICN architectures, such as NDN, into IoT. A relevant research area, which has been initiated but still requires much more exploration be it in terms of performance measurement or in terms of network architectures evolution is the applicability of ICN paradigms into IoT environments.
- Variable and heterogeneous IoT scenarios, such as the ones embodied in PloT, will benefit from bringing data processing closer to the end-user, as discussed in section V. Context-awareness therefore plays a relevant role, be it in terms of better defining traffic and computational locality, or to assist in a more automated behavior of IoT networking architectures, end-to-end.
- To promote feedback in close-to-realtime, context-awareness can assist the network in making decisions that improve the network operation and, as consequence, can also improve data processing.

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