



FOCAN: A Fog-supported smart city network architecture for management of applications in the Internet of Everything environments

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HIGHLIGHTS

- Present a generalized multi-tiered smart city architecture utilizes FC for devices.
- Develop an FC-supported resource allocation model to cover FNs/device components.
- Provide various types of communications between the components.
- Evaluate the performance of the solution for an FC platform on real datasets.

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ABSTRACT

Smart city vision brings emerging heterogeneous communication technologies such as Fog Computing (FC) together to substantially reduce the latency and energy consumption of Internet of Everything (IoE) devices running various applications. The key feature that distinguishes the FC paradigm for smart cities is that it spreads communication and computing resources over the wired/wireless access network (e.g., proximate access points and base stations) to provide resource augmentation (e.g., cyberforaging) for resource- and energy-limited wired/wireless (possibly mobile) things. Motivated by these considerations, this paper presents a Fog-supported smart city network architecture called Fog Computing Architecture Network (FOCAN), a multi-tier structure in which the applications are running on things that jointly compute, route, and communicate with one another through the smart city environment. FOCAN decreases latency and improves energy provisioning and the efficiency of services among things with different capabilities. In particular, three types of communications are defined between FOCAN devices – *interprimary*, *primary*, and *secondary* communication – to manage applications in a way that meets the quality of service standards for the Internet of Everything. One of the main advantages of the proposed architecture is that the devices can provide the services with low energy usage and in an efficient manner. Simulation results for a selected case study demonstrate the tremendous impact of the FOCAN energy-efficient solution on the communication performance of various types of things in smart cities.

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1. Introduction

The *smart city* concept arises from the idea of efficient use of city resources for enhancing citizens' quality of life [16], as

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the pace of urban living has recently accelerated. To achieve a better quality of life, improvement of services and infrastructure in cities must be taken into account. Thanks to the revolution in information and communication technology and the power of the Internet [24], infrastructures and public services are expected to be more interactive, more accessible, and more efficient as it moves towards the realization of smart cities. In this context, the emergence of the Internet of Things (IoT) paradigm strongly encourages utilization of the IoT's potential to support the smart city vision around the world. As a consequence, the smart city has emerged as one of the important IoT application drivers. Smart city

IoT systems promote the concept of interrelated physical objects (*things*) that are uniquely identified and distributed over broad physical areas covering an entire city. Recently, the IoT concept has taken an important step towards connecting four pillars –things, data, process, and even people –as the Internet of Everything (IoE). From one perspective, cities can be regarded as an aggregation of interconnected networks that make up the IoE. Hence, the IoE pillars play a significant role and work together toward the promise of our smart city vision for the future.

The IoE's generation of Big Data (BD) over a distributed environment has the potential to create data processing as well as data storage problems. One solution to address these problems is the utilization of Cloud Computing. However, some applications cannot work efficiently on the Cloud due to its inherent problems [7]. As an example, smart city applications like health monitoring and traffic monitoring cannot tolerate the delay and latency incurred when transferring a massive amount of data to the remote Cloud Computing center and then back to the application. For this purpose, the concept of *Fog Computing* (FC) recently appeared. FC extends Cloud services to the edge of the network, closer to the end user, which reduces data processing time and network traffic overhead [23].

The primary definition of FC was introduced by Cisco [2]. The most fundamental entity in FC, called a *Fog Node* (FN), facilitates the execution of IoT applications. Basically, FC can act as an interface layer between end users/end devices and distant Cloud data centers, with the aim of satisfying mobility support, locational awareness, geodistribution, and low latency requirements for IoT applications. Since the distance between FNs and end users also varies, this paper proposes a multi-tiered framework that does not need to transfer a vast amount of data to and from remote FNs.

It saves energy and reduces delays by avoiding transferring data or using storage resources that are too far away from the FNs by choosing FNs that are closer to the end users. Our framework also attempts to answer the following questions: What is the current state of the art in the field of smart city research, specifically, in smart city components and services? What are the main challenges that need to be addressed? This article aims to shed light on these issues and to define future research directions. Specifically, in this paper the services and components engaged in smart cities should adopt emerging technologies around the following pillars: (i) It presents a generalized multi-tiered smart city architecture that utilizes FC for each device; (ii) it develops an FC-supported resource allocation model to cover device-to-device (thing-to-thing or $t2t$), device-to-FN (thing-to-FN or $t2FN$), and FN-to-FN ($FN2FN$) components; and (iii) the paper includes various types of communications between the components and evaluates the performance of our solution on real datasets. In summary, the most important property that distinguishes this framework from other FC-supported frameworks is the utilization of resources closer to the end users based on their layer, beginning with $t2t$, then $t2FN$, and finally $FN2FN$.

The remainder of this paper is organized as follows. In Section 2, the most recent FC-based smart city applications and their benefits/drawbacks are studied. In Section 3, a high-level view of our smart city model is presented. Section 4 presents the FC-supported smart city architecture, its hierarchical layer definitions, and their relations to the FNs. Section 5 presents a smart city case study for the IoE-based architecture and the numerical results attained through extensive numerical tests on a simulated scheme for an FC platform (i.e., iFogSim), with details about the test setup and the formulas utilized. Section 6 describes recent issues and research directions for this problem. Finally, Section 7 concludes the paper and suggests new research directions.

2. Related work

Several works have been devoted to the relation between the IoT and smart cities. For instance, the Padova smart city project [25] introduces characteristics of the Urban IoT system as well as the services that are required to support and implement the smart city vision. The work of [6] shows that it is necessary to build smart city IoT applications that have distributed coordination schemes. Increasing attention is being devoted to integrating the IoT and Cloud computing in order to generate smart city applications and frameworks. The authors of [9] provide a Cloud-based framework to create a smart city through the capabilities of the IoT. Authors in [8] demonstrate the efficiency of analytic services over multi-tier FNs and the effectiveness of their QoS schemes. However FNs can largely improve the performance of smart city analytic services than cloud only model in terms of job blocking probability and service utility.

The aforementioned solutions discussed some drawbacks of utilizing Cloud Computing technology for smart city applications, which include latency, traffic congestion, lower throughput, and greater processing time. Some of these drawbacks, however, can be mitigated or even avoided by defining FC in such a way that it moves data processing towards the edge of the network, where data need to be quickly analyzed and decisions made. There is presently little existing work about FC platforms for smart city applications. Nevertheless, some related work in the remainder of this section will be discussed. Very recently, [3] designed an Open-Stack platform using FC, Stack4Things, to enable smart cities to meet scalability and low latency requirements. Also, the work [21] proposes a solution to utilize resource pooling, content storing, node locating and other related situations with Smart Collaborative Caching (SCC) scheme that is established by leveraging high-level Information-centric networking principles for IoT within fog computing paradigm. Authors in [12] introduced new architecture to collect, update, and process realtime and heterogeneous information from various sources. They validated their model by presenting map-based smart parking services, S^2 -Move, and tested the accuracy and efficiency of the Map Matching and Traffic monitoring algorithms in a smart city. A service-oriented FC architecture [5], the “Fog Data”, aims to reduce Cloud storage and delays in data transmission for telehealth applications by utilizing on-site data processing. To achieve this, the proposed model is designed in three tiers. First, raw data are gathered via wearable sensors and ambient services. Next, a Fog computer is responsible for preliminary data processing and filtering. Finally, a Cloud center conducts a secondary analysis of necessary data. The authors carried out validation of the Fog data for two case studies involving a speech disorder and an ECG. Several significant functionalities that ideal Fog computing platforms can support and some open challenges toward implementing them, to shed light on future research directions on realizing Fog computing for building sustainable smart cities [17]. Moreover, recently authors in [19] presented a software networking prototype played as infrastructure which provides computing resources for the Fog and core layer in the 5G network. They mutually address traffic offloading networking functions, and video streaming of various incoming traffics in a small smart city. Although their method and architecture are appealing, it did not support highly dynamic deployment scenarios and did not account the latency of the requests which are covered in FOCAN. In another work [13], authors present new robust green strategies for networking and computing of the things' traffics inside the cloud data centers. They aim to protect the response level against resource demand uncertainty while considering latency constraints on the service chains on the edge nodes. The major drawback of their solution is that they did not explicitly distinguish the edge node (i.e., FN) responsibilities and did not address the traffic management between the FNs. A working prototype [22] was constructed

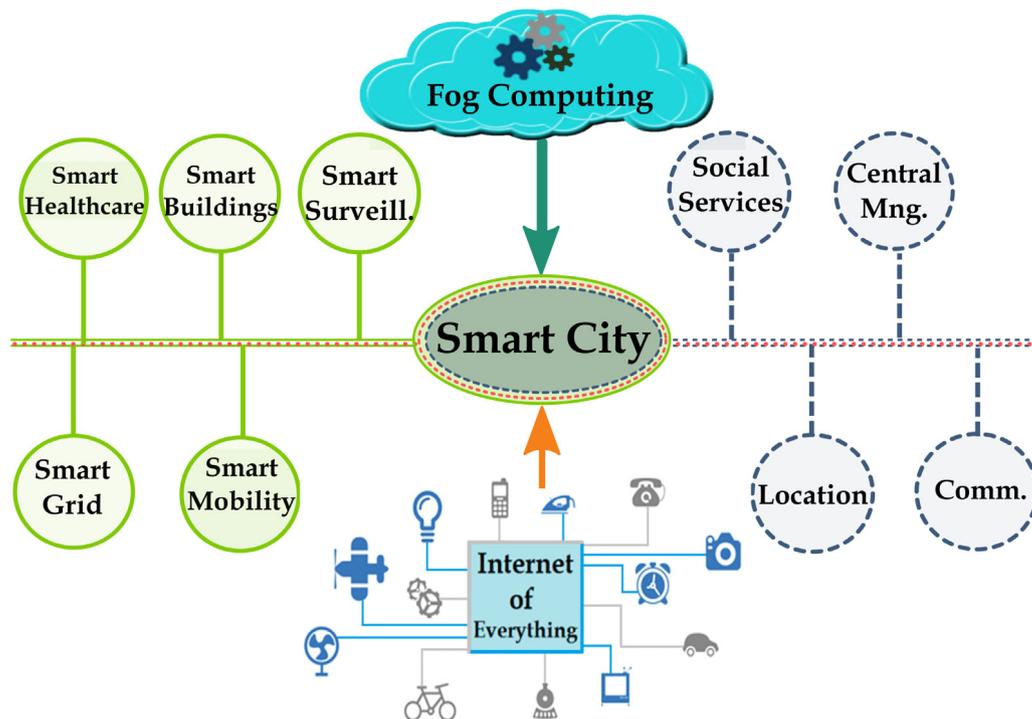


Fig. 1. High-level view of the smart city model. Comm:= Communication; Mng:= Management; Surveill:= Surveillance.

to experimentally evaluate event detection performance of the recognition of distinct events, demonstrating the feasibility of the system's city-wide implementation in the future.

Summarizing, the previous works reveal how the IoT and FC concepts can help realize the smart city vision and overcome the difficulties associated with remote Cloud data centers. However, none of these works show how they can choose and manage the available and appropriate resources through FNs to further reduce the delays and energy consumption caused by transferring data to far-away FNs. This problem is the main motivation for the multi-tiered framework that it proposes in Section 4.

3. Model overview

This section aims to provide an overview of the proposed model in Fig. 1. The main objective of the model is to show how smart city components and services can communicate with each other and FC. To this end, the smart city is comprised of several heterogeneous components that serve numerous requests coming from various devices in order to provide these devices with the ability to access different available technologies (e.g., 3G/4G-cellular, WiFi, ZigBee). The devices are connected via the Internet (labeled as the Internet of Everything; see the components at the bottom of Fig. 1). Without loss of generality, Fig. 1 presents a high-level view of the smart city. The devices in the smart city environment use different services (see the circular components in Fig. 1), such as smart mobility, a smart grid, smart surveillance, and so on. These services are used to meet some on-demand requirements that are served from communication devices (micro- and macro-cell objects).

4. Fog-supported smart city architecture

This section proposes an architecture for connecting the FNs and the IoE. In future smart cities, technologies will need to be applied in a distributed manner, covering each other in response to users' real-time demands, in order to provide low-latency and

high-performance computing for services. These activities will facilitate the residents' quality of life and improve the efficiency of services to meet their needs. Applying FC as a paradigm on top of IoE systems facilitates user services and enables low-latency, high-speed data processing. Motivated by this consideration, a multi-tiered communication architecture as shown in Fig. 2 is introduced, which provides an effective solution for hosting BD applications in the smart cities of the future. Specifically, the proposed architecture, FOCAN (Fog Computing Architecture Network), is comprised of two tiers: (i) the IoE tier, represented with the gray ellipse in the lower part of Fig. 2, is supported by several heterogeneous devices that are connected to each other and also to the FNs, for communication, and (ii) the FN tier, which covers the incoming traffic from the IoE tier and processes/transfers the data to decrease the latency that is required and thus satisfy the users' service demands. In the following subsections, the responsibility of each tier and also its relation to the other tier are described.

4.1. The IoE tier

In this tier, end users can apply any application, anytime, anywhere, and without limitations. In order to preserve the IoE's main function, it is essential to cluster the devices based on their locations. This helps manage the incoming traffic a way that minimizes overhead in terms of time, throughput, and energy consumption. It is possible to serve IoE applications with acceptable latency and throughput when the IoE navigates between heterogeneous hardware and software services if this tier is well integrated and processes IoE data in real time, which increases the proportion of workloads in data centers.

The things or devices that are the IoE-tier components (see the things inside the IOT tier in Fig. 2) use TCP/IP-based peer-to-peer (P2P) communication. They can communicate directly with each other via P2P communications when they are near to each other. Otherwise, when things are beyond the range of P2P communications (i.e., beyond the range of Bluetooth, ZigBee, or WiFi communications), they can utilize an FN.

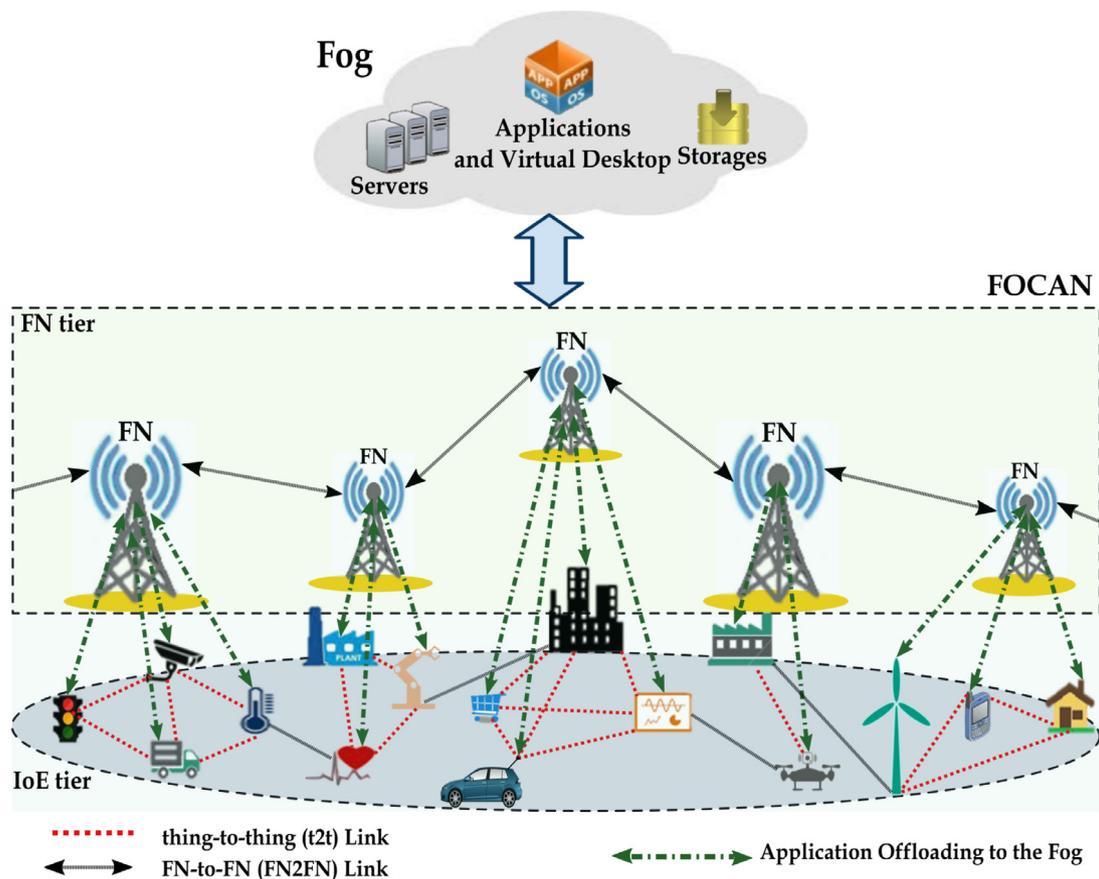


Fig. 2. Deployment of Fog-supported smart city architecture. FN:= Fog Node; FOCAN:= Fog Computing Architecture Network.

4.2. The FN tier

The Fog-supported smart city provides quality of service (QoS) guarantees to support services. Each FN is composed of a number of physical servers that are interconnected with a wired/wireless access network covering a limited area of radius $R_a(n)$ (i.e., the coverage area for the n th FN). The FNs function as small-sized virtualized networked data centers that enable the deployment of Fog services with various types of hardware, such as multicore processors, with fixed hardware resources that can be configured, connected by different network technologies (wired and wireless), and aggregated and abstracted to be viewed as a single logical entity. Each FN serves as a cluster of proximate things that pre-processes and analyzes the real-time data near to the users who are generating the data, facilitating collaboration and proximate social interactions between things (IoT devices), distributed and dynamically.

In addition, the FN provides entry points to a radio access network serving as a wireless communication network technique that is configured to be allotted a single destination (unicast) in the range of the communication. Protocols have been developed to support concurrent data transmissions of the same packet or message to multiple destinations, or data packet broadcasts to all destinations (within a given cell, served by a given service provider, etc.).

From the structural point of view, the FN platform can include a local database that can store applications that are not actively being used in its memory. It can use several retrieval policies to access the data in its buffer in order to decrease the processing time for IoT applications. As part of the Fog-supported smart city architecture, this layer is designed in a way that is capable of

implementing social IoT applications (SIoTs) – that is, FNs can optimize IoE deployment, improving latency, bandwidth, reliability, and security in IoE networks. To this end, FNs can communicate with each other to process data and transfer the required data to the other FNs.

4.3. Data communications on FOCAN

In SIoTs, the data transfer size is rapidly growing. This has led to a decrease in processing speed and the need to retrieve the data from storage and increase the network bandwidth. The data may be obtained from sensor devices, other things (IoT devices), the web, or local storage. The data undergo preprocessing (integrating, filtering, and cleaning) according to the rules that are used for data manipulation.

Instead of sending all data to the Cloud, an FN (an edge device) performs a preliminary analysis and sends an abstract of the metadata to the Cloud. In FOCAN, it considers SIoTs using FCs as an emerging paradigm to allow the splitting of real-time data processing [2] in such a way as to enable the mobility of the end users who are supporting the IoE applications. The FNs in the FN tier provide computing plus networking storage to support the application services for the connected things. Officially, the communications between the components in FOCAN in Fig. 2 are classified as:

- **Primary Communication/Interprimary Communications:** These are local wireless communications in which local devices (things) with processing and sensing capabilities –such as touch-screen devices, sensors, laptops, and computers –construct a local P2P inter-thing network to

Table 1
FOCAN communication characteristics.

	Primary	Interprimary	Secondary
Architecture	Centralized	Centralized	Distributed
QoS	High	High	Very high
Access medium	Fixed/wireless	Fixed/wireless	Fixed
Technologies	WiFi/3G/ 4G-LTE	WiFi/ Bluetooth/Zigbee	WiFi/3G/ 4G-LTE/5G
Mobility	Yes	Yes	No
Heterogeneity	Yes	Yes	Yes
Bandwidth	Medium	High	Low
Latency	Low	Very low	Low
Delay Jitter	Very low	Very low	Low
Stream applications	Yes	Yes	Yes
Pervasive applications	Yes	Yes	Yes
Storage	Yes	No	Yes
Protocols	CDMA/TDMA/FDMA/OFDM/GSM		

support the wireless communication. For example, WiFi provides primary communication with medium-distance coverage (green dashed lines in the IoE tier in Fig. 2), and Bluetooth and ZigBee provide interprimary communication, with short-distance coverages between things/devices (red dashed lines in the IoE tier in Fig. 2) guaranteeing the communication by TCP/IP connections.

- **Secondary Communications:** These are wired/wireless communication between two FNs ($FN2FN$) (see the FN tier in Fig. 2). It is obvious these should include end-to-end TCP/IP connections such as IEEE802.11/15 for wireless connections and Cat 5 or 6, or optic fiber, for wired connections.

The primary and interprimary communications are close enough to be supported by a local wireless connection, while the secondary communications are physically or geographically dispersed by more than the range of the local wireless connections. For $t2t$ communications, they have two types of communications: *direct* and *indirect*. Put simply, direct communications are like primary and interprimary communications, whereas indirect communications almost cover the secondary communications. Each FN can communicate with another FN using the direct hopping system. This helps the FOCAN reduce the transfer of data requested by the things between the FNs and thus avoid congestion and jitter and decrease the latency in the network. Furthermore, FNs support secondary types of communications. In a secondary communication, connections are configured to support one or more connections. FNs also guarantee multicasting, which is a transmission of data packets to a given group of destinations that can be performed in a number of ways within wireless communication systems.

Table 1 presents the FOCAN communication characteristics. It is important to emphasize that the secondary communications are distributed all over the FOCAN, while the primary and interprimary communications are confined to the range of the FNs. The primary communications increase the QoS much better than the two other types of communications, due to the use of high-speed communications and low latency for the service processing. The mobility of things has an important influence on their communications, which can be handled with primary and interprimary communications. Moreover, FOCAN supports device and FN heterogeneity, and stream-type/pervasive applications and secondary communications, due to the use of FNs in these communications, have much less jitter compared to the other communication types.

Fig. 3 shows the FOCAN flow diagram. The Fog component in Fig. 2 comprises several servers, applications, and storage devices

(as shown in the uppermost Cloud-shaped component named “Fog” in Fig. 2). Therefore, it can be divided into *three* groups of blocks (see the dark blue, red, and green box components in Fig. 3). In the FOCAN architecture, each FN device covers a server in the Fog component. The FN block in Fig. 2 can be subdivided into primary and secondary communication types, as shown in the light green box under the FN main block. The primary and secondary communication blocks use wired/wireless communications for transferring data between the first and second tiers of FOCAN. In this framework, the servers (FNs) are allocated among several applications that can be dynamically shrunk or expanded based on the service’s requirements, real-time demands, and the available resources in the FN tier, which can be handled in a distributed way by the FNs. The FN communications can be classified into Local Communications (LCs) and External Communications (ECs). An LC is interpreted as a primary communication and an EC is interpreted as a secondary communication. Primary communications can be subtyped as the interprimary box, which expresses the $t2t$ relationships. To follow the flow of this type of communication, it initiates by authenticating and authorizing the applications that each thing needs to utilize (see the dashed-line control-flow decision between the Application box and the Load Application box in Fig. 3), over the congestion-aware safe communication link in the FOCAN IoE tier. Then they run the applications and save the processed applications in the FN’s storage using the dashed-line control link to the storage component in Fig. 3. This same process is conducted for the $tFNt$ communications. Furthermore, for the EC communication type linked to the secondary communication subblock, $FN2FN$, they need to find the proper destination FN from a source FN when one of the things covered by the source FN wants to communicate with a thing in the destination FN. Thus, they need to find the routing path (see the routing algorithm block in Fig. 3) by identifying the hops for transferring the required information between these two things. The first step here is to find a traversing path to identify the hops. It is assumed that the path from the source FN to the destination FN is labeled “1” and the return path is labeled “0”. After finding the routing path and the direction, if it is labeled “1”, the request is sent from the source node $FN(i)$ to the destination node. The steps 1 and 2 are activated and load the application into the FN buffer, traverse h hops to reach the destination $FN(i+h)$, and then execute steps 3 and 4, saving/registering the application in the storage of the destination FN. After that, step 5 occurs, and it leaves $FN(i+h)$ and returns to the source node $FN(i)$ (following label “0” in Fig. 3, which is connected to the “Routing Algorithm” box), and then repeats steps 6 to 9 from the “Routing Algorithm” box for the applications. Note that this will happen if an FN is communicating with another FN ($FN2FN$), so it is essential to use routing algorithms for the connection.

To understand how the FN buffer is processed, the time chart for the data packet scheduling technique between the source and destination FNs in Fig. 4, following [4] is presented. The [4] is modified in such a way that the application’s packets are transferred from the source FN to the destination FN. These packets include secondary communication tasks and primary communication tasks, distinguished in the figure by color. This time chart also adopts the Time-Division Multiple Access (TDMA) routing algorithm recently presented in [15] as a viable solution for $FN2FN$ communications. In accordance with the TDMA technique presented in [15], the time rounds of the packets and the overall TTL, T , for transferring a set of packets to the identified destination FN, $FN(i+h)$ are used. In the next section, a holistic case study and evaluation of the FOCAN with several cases are presented.

5. Performance evaluation and validation

In this section, real-time-based scenarios, which are heightened in smart cities are presented.

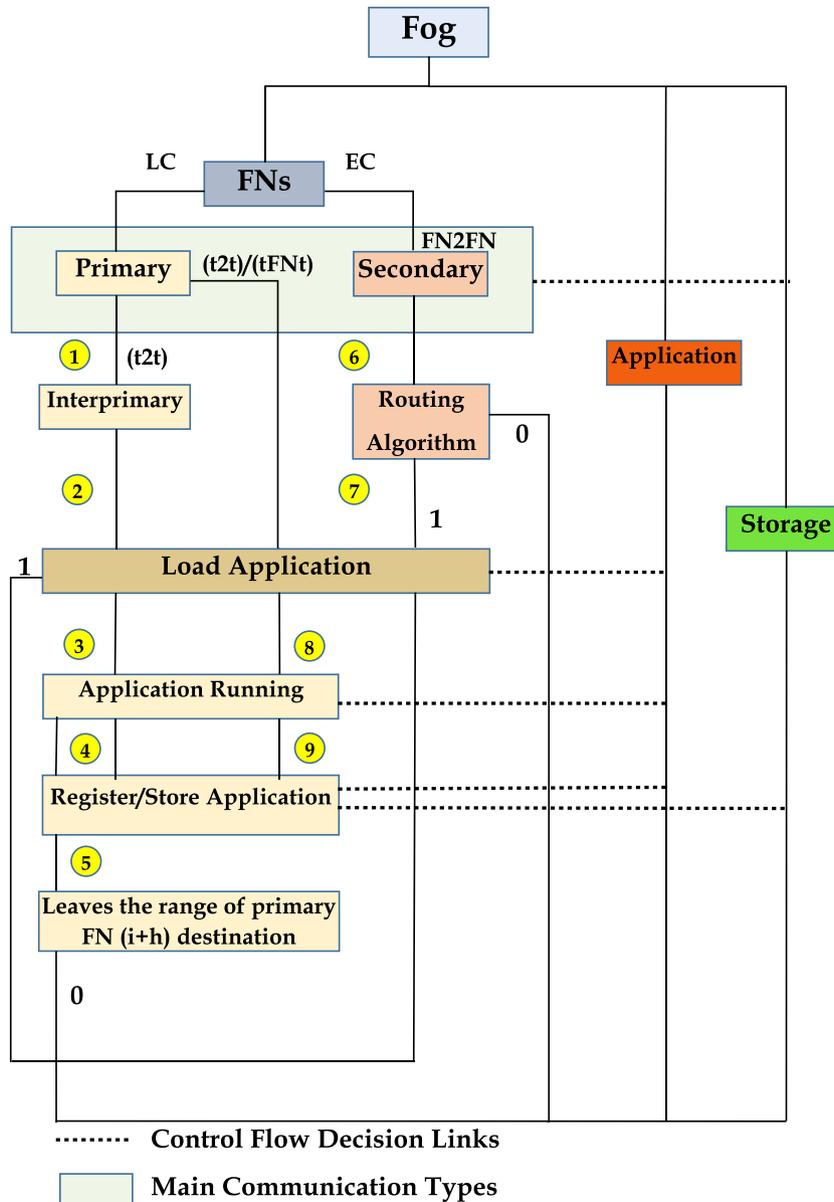


Fig. 3. FOCAN model diagram. EC:= External Communication; LC:= Local Communication. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

5.1. Simulation setup

To evaluate and compare the performances of the FOCAN platform, some numerical simulations are conducted. The experiments for our proposed platform are implemented on an iFogSim simulator, which provides real-time scenarios for Fog-based networks in a smart city [7]. In addition, it used the same network setting as [15]. Here, the incoming traffic, called tasks, refers to the web-based application demands of two types of resources (CPU and intra-/inter-network) that are needed for executing the I/O traffic on the things in the smart city.

The static FNs are deployed in the city based on physical proximity (e.g., 10 m, 30 m, 3 ft) [7]; each FN serves a spatial cluster of the corresponding radius value, acting as a service point for the things currently in the served cluster. The FN comprises a heterogeneous multicore server that can simultaneously run multiple instructions time on AMD, a Phenom II X6 1090T BE 6-core x86 architecture processor, equipped with 3.2 GHz and 6 GB of RAM for each core. These settings have great gains in processor performance by virtue of increasing the operating frequency, which

allows higher performance at lower energy. A wired Giga Ethernet switch connects the FNs, and each FN has primary and secondary communications. Each FN consumes electric power to process the incoming traffic. The tasks are performed on the FM cores at the processing frequency 10 Mb/s with a maximum rate of 2.5 Gb/s. It is assumed that the tasks are uniformly allocated to each core. In order to evaluate the CPU and network power cost for each FN, the CPU and network power formulas of [18] are used and set the maximum and idle CPU power at 195 and 105 watts, respectively. Also, the delays are fixed for $t2t$, $tFNt$, and $FN2FN$ communications at 2, 4, and 6 ms, respectively [7]. In addition, the configuration's average round trip time for the wireless and wired communication are set at 0.5 ms and 10 ms, respectively [15,18]. The simulations are carried out for a period of 1000 s.

5.2. Simulation results

The FOCAN is validated in terms of the average overall energy consumption (average of the CPU and network costs) per

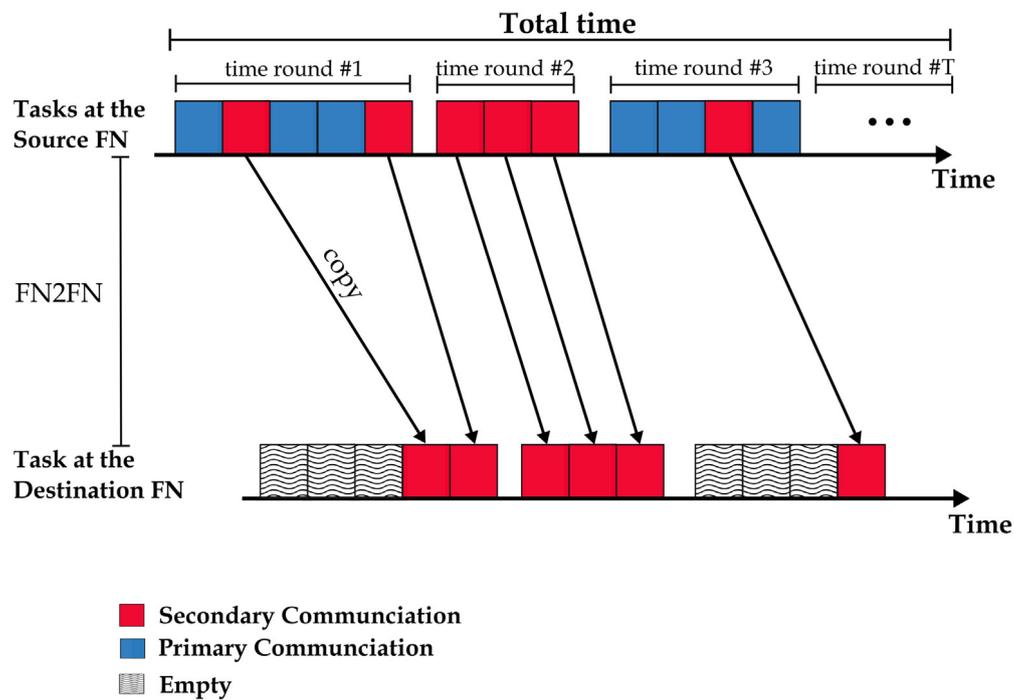


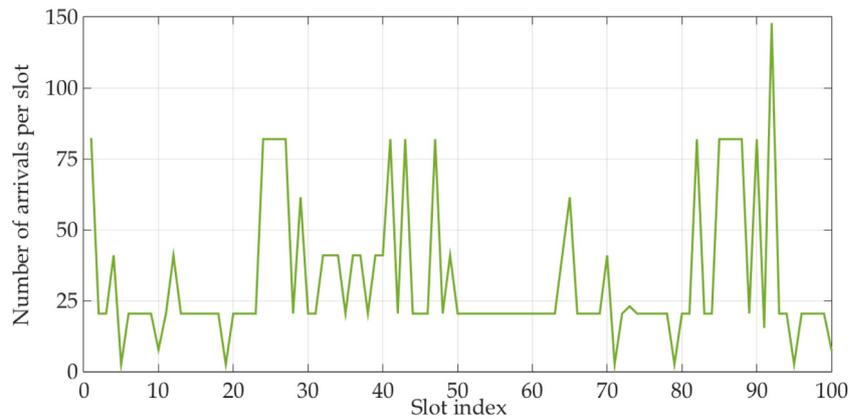
Fig. 4. Time chart for the secondary communications between FNs.

processing time by comparing the FOCAN and the D2D in [10] in terms of various communication costs (see Fig. 5). It runs our proposed solution and evaluated the resulting average total consumed power for each FN under a web-based application (i.e., MSN Messenger input arrival) and results are shown in Fig. 5a; this is a normalized traffic trace that reports the I/O real-workload traffic flow to the different types of communications. Note that the FNs can be integrated or distributed all over the model presented in Fig. 2. The power performance of the proposed FOCAN multi-tired scheduling and resource allocation is numerically tested and compared against Modified Best Fit Decreasing (MBFD) [1] and Maximum Density Consolidation (MDC) [11] under different configurations of communication rates. This is done by considering various connection scenarios under real-world workload traces reported in Fig. 5a. Fig. 5b, reports the obtained average power consumptions of various communications rates (i.e., Fast Ethernet (-F) and Giga Ethernet (-G)) under different things. Interestingly, since in FOCAN each FN in each round of processing, by design, is looking for finding the minimum requested power by instantiating the scheduled containers [14], the corresponding average power consumptions decrease for increasing the things and quickly approach to a minimum value that does not change when things are further increased (see the lowest plot of Fig. 5b). The numerical results in Fig. 6a for the FOCAN framework report the average energy and time per round; the underlying t_{2t} , t_{2FN} , and $FN2FN$ wired/wireless links are simulated which carried out the types of communication activities. For comparison purposes, a D2D platform is simulated that works, according to [10], uses IEEE802.11b with single-hop D2D links FOR t_{2t} connections, with the traffic flows transported by all simulated TCP/IP connections. Fig. 6a shows that the FOCAN platform is more power efficient than the D2D platform; with the corresponding average per-connection power, the D2D connections increase the power consumption because it is affected by the fading and path loss and the average number of TCP time-out events and packet retransmissions, which is confirmed in Fig. 6a. Finally, Fig. 6b shows the average power consumption for an evaluation of the interprimary, primary, and secondary communications. This performance trend is confirmed

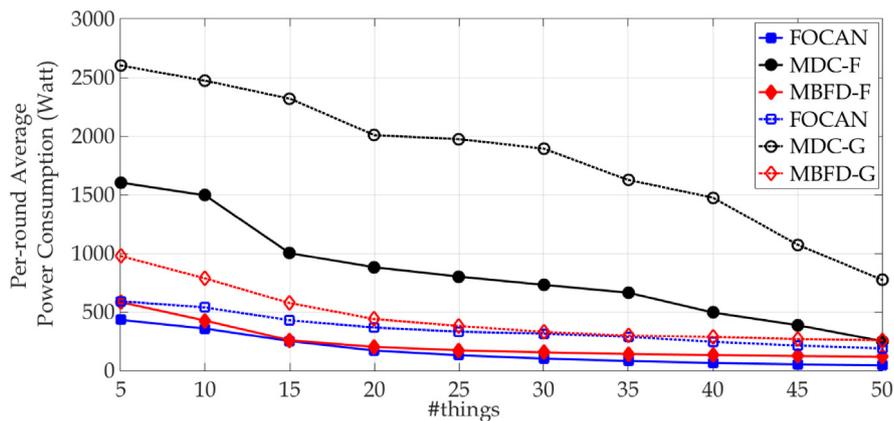
by the bar plots of Figs. 6a and 6b, that open, in turn, the doors to three additional considerations. First, the FOCAN framework is more energy efficient than the benchmark D2D one, and the measured per-connection average power gaps are around 17%, 22%, and 25% at Inter-Primary, Primary, and Secondary FOCAN device types, respectively (see Fig. 6a). Second, the increment of the power consumed by the FOCAN solution is almost entirely induced by the corresponding increment of the average number of clone migrations and FNs' connections between the IoT devices in the smart city. This last, in turn, is induced by the increment of the underlying t_{2t} and t_{2FN} wired/wireless connections (see Fig. 6b). Third, in Fig. 6b, average power consumption increases for increasing the level of connections (i.e., from t_{2t} to $FN2FN$); and, (ii) average power consumption increases for increasing values of the available FNs and the increment rate depends on the adopted intra-Fog communication technology reported in Fig. 4. Overall, the reported comparative performance results confirm the (aforementioned) expectation about the improved delay and power efficiency of the proposed FOCAN framework of Fig. 2.

6. Open issues and challenges

Academic research has developed a wide variety of techniques and technologies to capture, curate, analyze, and visualize BD. An integrated system includes network infrastructure services, education information services, and learning services. The leading benefit is that new knowledge is obtained and higher-order thinking skills are facilitated when each student generates a unique data track where data can be inserted, processed, and analyzed [20]. Today, more and more classrooms are becoming “open” through voice-, video-, and text-based collaboration, and teachers have a wide range of multimodal resources to enhance their teaching. In the field of computer science, the challenge is to develop different forms of innovative education that can be adjusted for large numbers of students around the world, engage students with different interests, and that can carry out a new curriculum that shows the fundamental changes in computing technology [20]. It also needs to support the integration and collaboration of different



(a) Normalized sampled trace of an I/O traffic flow from an enterprise data center, using Messenger.



(b) Per-communication and per-round average power consumption.

Fig. 5. The simulation results for FOCAN for various communication rates.

governments to improve business decisions through BD analytics. To achieve this, governments need to publish new policies for handling data that specify owners' and producers' restrictions. This legislation will be useful for managing the quality of the data and processing the real-time analytics of huge streaming data volumes. Also, the new legislation can help in developing a massively scalable scheme for enabling the visualization of information from thousands of real-time sources, encompassing application development built on Hoop, stream computing, and data warehousing.

7. Conclusion and future directions

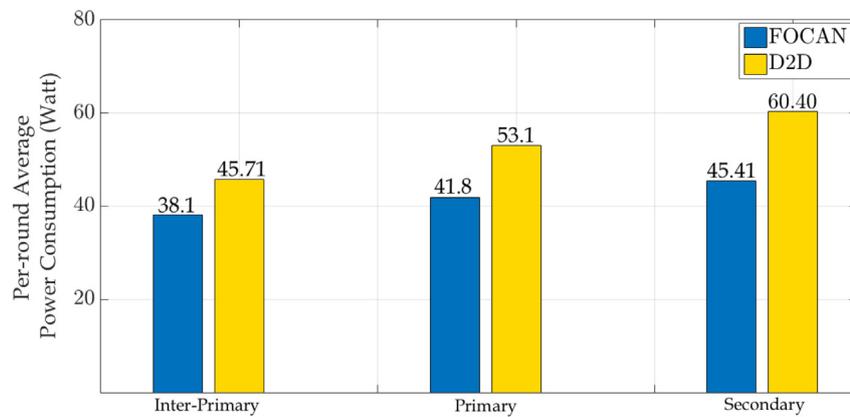
Considering the thousands of smart city applications that are running on numerous things, as well as the emergence of FC to cover such applications by running at the edge of the Internet to meet the requirements of scalability, energy awareness, and low latency, a framework called FOCAN is designed for managing things' applications. FOCAN can be classified as a computation- and communication-efficient structure and scalable routing algorithm that minimizes the average power consumption of FNs. Noteworthy features of the developed FOCAN include: (i) it minimizes the energy consumed by the overall FOCAN platform for computing, intra-Fog communication, and wired/wireless transmission over thing-aware TCP/IP connections; (ii) it subsumes the IoE device communications over FNs under three categories: interprimary, primary, and secondary, to arrange traffic and manage tasks across the FNs, and (iii) the flow diagram for the systems' incoming tasks and suggested routing algorithms shows how the data can be transferred to the corresponding things to guarantee the Fog

applications. A quantitative analysis demonstrates that FOCAN allows effective management of small areas within an urban region; hence, it provides scalable energy-aware Fog-supported application management.

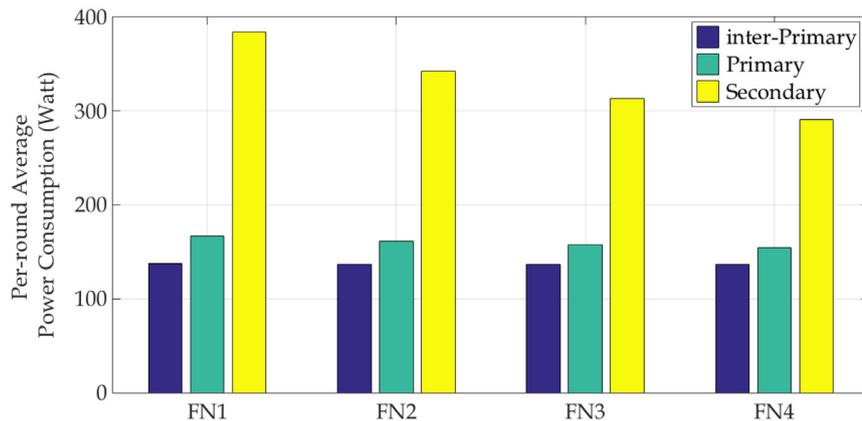
This work can be extended in several directions of potential interest. For example, it can be extended to cover 5G management in light of the huge number of things that use stream applications, e.g., online video chatting, or sets of things that are playing online games with other sets in other regions of the city. To do this, it is needed to add real-time data processing solutions together with using mobile edge computing techniques to make robust frameworks.

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(a) Per-communication and per-round average power consumption for D2D under the settings in [21].



(b) FNs' average total power consumption for the Messenger data.

Fig. 6. The simulation results for FOCAN compared with the D2D approach in [10].

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