EHOPES: Data-centered Fog Platform for Smart Living

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***Abstract*—Nowadays, smart environments (e.g., smart home, smart city) are built heavily relying on Cloud computing for the coordination and collaboration among smart objects. Cloud is typically centralized but smart objects are ubiquitously distributed, thus, data transmission latency (i.e., end-to-end delay or response time) between Cloud and smart objects is a critical issue especially to the applications that have strict delay requirements. To address the concern, a new Fog computing paradigm is recently proposed by the industry, while the detailed Fog platform is yet to be developed. The key idea is to bring the computing power from the remote Cloud closer to the users, which further enables real-time interaction and location-based services. In particular, the local processing capability of Fog computing significantly scales down the data volume towards the Cloud, and it in turn has great impacts on the entire Internet. In this paper, a data-centered Fog platform is developed to support smart living together with dataflow analysis. Case studies are also conducted to validate and evaluate the proposed platform.**

Keywords—Cloud Computing, Fog Computing, Smart Living

I. INTRODUCTION

Smart living networks are developed with variety of devices and media, which include mobile phones, tablets, personal computers, TVs, wearable device, interactive message terminals, electronic appliance, etc. The booming of Internet of Things (IoT) / Internet of Everything (IoE) [1] makes communication and collaboration of intelligent home appliance possible and necessary. Smart energy, smart health, smart office, smart protection, smart entertainment and smart surroundings, namely EHOPES are fundamental elements in smart living. Network is the essential component of smart living which is composed of smart objects [2] and variety of processors. The smart objects include sensors, actuators, controllers and inter-connectors. The processors are used to control, communicate and monitor the smart objects in the network. Current smart living networks take advantage of Cloud computing [3] (hereinafter referred to as Cloud) and IoT/IoE, thereby offering a number of services such as smart home [4]. A cognitive gateway [4] is employed to link smart objects to the Cloud data center when external interactivity is required. In this paper we call it Cloud model.

However, there is significant deficiency in the current Cloud model. Firstly, the capability of local processing and storage on cognitive gateway is insufficient, which means it has to rely on Cloud for collaboration and storage. Secondly, the Quality of Service (QoS) is out of the control of cognitive gateway or Cloud during the data transmission over the Internet, leading to unpredictable delay and jitter that will severely affect data analytics. Thirdly, the transmission cost (time, money, etc.) between cognitive gateway and the Cloud data center makes those solutions less engaging.

Fog computing [5] (hereinafter referred to as Fog) is a newly proposed computing paradigm that offers certain local processing capability, which is able to address the above issues. In contrast to Cloud, Fog has 4 unique features [6] to greatly support smart living, which are:

- Low latency, i.e., Fog offers millisecond to sub second level latency, while it is in minutes- level in Cloud.
- Proximity, i.e., Fog adopts the decentralized model, which is closer to smart objects. Cloud adopts the centralized model.
- Real-time interaction, i.e., Fog computing offers quick even real-time interaction. Cloud is perfect at batch processing.
- Multi-tenancy, i.e., both Fog and Cloud support Multi-tenancy, but Fog performs better for applications that require low-latency.

Fog is a hierarchical network paradigm composed of two types of Fog nodes in terms of functionality, i.e., Fog Server (FS) and Fog Edge Node (FEN). An FS hosts a variety of management, collaboration, coordination services between Cloud and FENs. An FEN provides adjacent computing for ubiquitous and heterogeneous smart objects in terms of processing, storage and communication. Please refer to Section III for more details.

In this paper, we investigate smart living coverage to disclose EHOPES in terms of definition, involved devices and dataflow analysis. This investigation shows the necessity of local processing for majority of EHOPES data. Thus Fog is fit to EHOPES. Then we further investigate the Fog paradigm and its relation to Cloud. Next we investigate how Fog can be employed to support EHOPES. Based on the analysis of dataflow, we explore the variety of interplay of Fog nodes (more details in Section III.B) and Cloud. Following the work above, a case study and the evaluation have been conducted. This case study focuses on the actual latency in the two cases. Case 1 - Cloud is employed while case 2 - Fog is employed as the platform for EHOPES. A number of EHOPES applications (same amount of data) are conducted on the two platforms. The results demonstrate that Fog can significantly reduce latency in sharp contrast to Cloud. Lastly we conclude this paper and list a few of potential research directions.

II. EHOPES Elements and Dataflow

In this section, we investigate the definition, devices and dataflow of EHOPES. Each EHOPES application brings up a sub network.

A. *Smart Energy*

We define smart energy (electricity, gas and water) [7, 8] in terms of energy generating [9, 10], energy consuming, energy delivery [11] and billing [12]. Smart energy refers to using IoT and networking technologies to dynamically distribute energy in order to maximizes energy as well as minimize their cost, which involves decision-making and action-taking subsystem.

In the smart energy network, metering devices push the usage data to and retrieved the billing information out from a number of energy providers intermittently. Residents are happy to know their energy consumption daily or weekly from variety of devices such as personal computers, tablets or mobiles. A local Fog Server (FS, refers to Section III.B) that helps to minimize energy costs will delight consumers by bringing timely benefits. For example, a program on FS can work out the cost for hot water supply through using different energy and take actions to minimize the cost. In smart energy sub network, dataflow mainly exists between energy provider (Cloud) and local decision-maker (FS).

B. *Smart Healthcare*

Smart healthcare system seeks to intervene early in maximizing health and well-being of a population. Smart healthcare devices refer to wearable Body Area Network (BAN) devices, healthcare apps, medical Robots, etc. They play an important role in terms of daily monitoring, data collection, Tele-diagnostic process and medical services. For example, BAN device provides live feedback on the wearer's health that helps to alert professionals and consumers to potential risks before they become serious.

In the above example, massive repetitive data such as heart monitor stream can be filtered in the Fog Edge Node (FEN, refers to Section III.B). A brief periodic report is stored on a FS and in Cloud as backup. Live data stream can be sent to professionals when Tele-diagnostic services are in action. In this case, majority of the dataflow exists between BAN devices and FEN. A small portion of data is transferred to FS and Cloud.

C. *Smart Office*

Smart office is about aspects of business processes that drive daily operations in the office on a basis of projects and scheduled work tasks that are regularly performed by office employees. This sub network communicates with various project management systems, databases and information systems that control a regular office work [13]. The hardware infrastructure includes laptops, printers, scanners, mobiles, etc.

Depending on its business type, dataflow varies significantly among home, Fog and Cloud. For example, a lawyer may conduct a professional legal practice [14] from home using technologies such as word processing and printers, Emails and billing software. A number of home-based lawyers may partner to become a medium or large syndicate to enforce their competency. In this case, a large portion of dataflow exists between FEN and Cloud.

D. *Smart Protection*

Smart protection focuses on physical security in terms of hazard recognition, invasion detection, alarm, surveillance, and protection robots for homes. The elements such as sensors, actuators, camera, and robots work jointly on protection project which aims to secure personnel and property from damage or harm (such as espionage, theft, terrorist attacks, etc.).

Massive data are processed at the proximity of properties. For example, an FEN stores videos for a certain period. The video can be removed or pushed to an FS if required. In case of hazard recognized, the FEN with consultancy of FS, can inform corresponding robotics to take actions. When external assistance is required, the FEN reports to Cloud with detailed information such as location and required services. Thus majority of dataflow exist between FEN and FS.

E. *Smart Entertainment*

Smart entertainment allows people to customize their amusement and relaxation at home with a family cinema on demand, gaming, Karaoke and so on.

As video streaming is at random and bursting, the dataflow heavily relies on the Cloud at the stage of initialization, which means the latency level may be minutes above in the beginning. FS can host a large amount of data prior to service to scale down the latency. In this sub network, the busted dataflow exist between FEN and Cloud.

F. *Smart Surroundings*

Smart surroundings involves making decisions and taking actions that are in the interests of protecting sustainable living conditions to support human life. Smart surroundings device include heaters, coolers, air-conditioners, lights, windows, doors, cleaners, hot water supplier, waste/recycle rubbish bin etc. Those devices may work independently or collaboratively with other devices within this sub network.

This sub network involves a number of sensors, actuators, controllers and robotics. Vast majority of the dataflow exist between the above smart objects and FEN.

TABLE 1: EHOPES DATAFLOW ANALYSIS

EHOPES Service	Dataflow Characteristics	Requirement on Fog Edge Node		
		Processing	Storage	Communication
Energy Network	FEN pushes data to Cloud. FS retrieves billing information from Cloud. FS makes decisions and FEN take actions.	Medium	Small	Medium
Healthcare Network	FEN filters repetitive data. Brief report is sent to FS, also to Cloud as backup. Live data stream occasionally exists between FEN and Cloud.	Large	Small	Medium
Office Network	Heavily relying on Cloud, dataflow varies from business to another.	Large	Small	Large
Protection Network	Dataflow mainly exists between FEN, FS and robotics.	Medium	Medium	Medium
Entertainment Network	During the initialization stage, burst dataflow mainly exists between FEN and Cloud. Afterwards, FS can host a large amount of data. (Cloud to FS)	Medium	Large	Large
Surroundings Network	Dataflow mainly exists within in this network.	Large	Medium	Small

Next, we summarize the dataflow characteristics of EHOPES in Table 1. We further divide the computing into processing, storage and communication. Accordingly, we investigate EHOPES network data requirement on FEN and presented in this table.

Through the analysis above, we recognize that majority of EHOPES data can be processed at the proximity to data source. In contrasting to Cloud, Fog brings more benefits in terms of low latency, proximity, real-time response and multi-tenancy with diminished latency. Local processing on incoming dataflow from numerous smart objects not only scales down the latency thus improving quality of experience, but also notably attenuates the traffic on the Internet. As a result, Fog has outstanding impact on the entire Internet infrastructure.

III. FOG PLATFORM FOR EHOPES

In this section, after outlining state of the art for Fog computing and its relations with smart objects and Cloud, we explore the required Fog elements in order to support EHOPES applications. The roles of FEN, FS and Foglet are explored.

A. *State of the Art*

The term "Fog computing" was initially proposed from industry. Cisco, HP and IBM collectively contributed to its motivation, paradigm and high-level architecture [5, 6, 15]. Due to its proximity to smart objects, Fog is able to offer appealing features such as mobility support, location-awareness, minimum latency and multi-tenancy. It provides ubiquitous connectivity for heterogeneous smart objects and allows them to directly access, control and manage resources on Fog nodes (refers to Section III.B). Those resources include CPU, memory, network, environment, energy, hypervisors, OSes, service containers, server instance, security etc. [16, 17]. Fog serves both wired and wireless devices as Cloud does, however, it is much closer to users. In general, Cloud is good at centrally batch processing while Fog is targeted to offer distributed local processing with minimized and predictable latency.

Instead of replacing Cloud, Fog is complementary to Cloud by providing real-time interaction between distributed smart objects and centralized server farm. On the other hand, Cloud backs up Fog for its unlimited computing power and storage.

TABLE 2: USER'S PERSPECTIVE TO CLOUD AND FOG

Evaluation Metrics	User's Perspective to	
	Cloud	Fog
Distance to the provider	Remote from	Adjacent to
Service Reachability	Relying on Internet access	Relying on local network infrastructure
Variety of Information	Unlimited	Limited from FEN.
Latency	Minutes to yearly [6]	Milliseconds to second [6]
Cost	High	Low
Deployment Speed	Slow	Fast
Network Requirement of Device	High, i.e., the Internet access capability is mandatory.	Low, i.e., the Internet access capability is not necessarily required.

Furthermore, Fog is also excellent in resilience and robustness. Fog users (smart objects, Apps, people etc.) do not necessarily rely on the Internet accessibility any more. FS is still working even disconnected from the Internet[18]. Table 2 reviews user's perspective towards Cloud and Fog. Next, we investigate Fog elements in terms of hardware and middleware.

B. *Fog Node (hardware)*

As smart objects are heterogeneous in nature, Fog has to support both high and low power level devices. We further elaborate Fog node into two categories, that is, Fog Edge Node (FEN) and Fog Server (FS).

- Fog Edge Node (FEN)

An FEN is adjacent to smart objects, aiming to provide Fog edge computing in terms of processing, storage and communication. As an endpoint of Fog, FEN provides variety of wired and wireless access methods to empower immediate communication with smart objects. Repetitive data collected from smart objects are filtered. Decision-making and action-taking emerge immediately to provide real-time interaction. It has sufficient processing, storage and communication power to run instances of Foglet (refers to Section III.C), through which FEN collaborates with other Fog nodes.

FENs can be mobile phones, set-top boxes, access points, edge routers or switches (even some smart sensors) located at one-hop proximity of FS. FENs have enough computing power to accommodate immediate operation for smart objects and instances of Foglet, thereby extending the large computing power further to smart object level.

An FEN is capable of creating, receiving, transmitting information over a dedicated Fog communication channel. It has certain capability of self-configuration, routing, security and QoS. In brief, FEN focuses on local processing of incoming and outgoing IoT dataflows. Generally, FEN varies significantly in terms of its capability of processing, storage and communication. According to EHOPES data characteristics (refer to Table-1), different FEN can be deployed for each sub-network.

- Fog Server (FS)

Different from FEN that focuses on the interplay among smart objects, another type of Fog node is FS which focuses on the interplay between FEN and Cloud data centers. An FS refers to both underlying hardware and running instances of required software capable of accepting request and responding to FENs. It hosts predefined applications and stores a large amount of information to support local FENs. It associates with Cloud when required in order to take the advantage offered by Cloud. FS can work both independently and jointly without/with the support of Cloud [18].

As Fog varies in size, functionality and surroundings, one or more FSes can be deployed in one Fog. Some FS provides large storage to host data and applications, some FS provides advanced routing and switching for FENs, and others provide services such as configuration, QoS, security and more. Ideally, FS can be remotely accessed from external networks for management and other operations, which include but not limit to application-deployment, data offloading, network configuration, optimization and billing.

To offer one-hop proximity to FEN, the distributions of FS are well organized to provide a seamless coverage of FENs. An individual or combination of permanent, seasonal and /or drone-style [19] FSes may work respectively or collaboratively to support variety of FENs in an established community. FSes are facilitated with high-speed uplink to the Internet, so once requested, it can quickly pull and push large amount of data to support local FENs. When necessary, FS can organize some of its redundant resources (processing, storage and more) and lease to an FEN for on-demand services or burst traffic (such as tele-diagnosis and entertainment program watching).

An FS (physically or virtually) can be advanced routers, switches, robotics and servers with large capabilities of processing, storage and communication. It supports state-of-the-art of routing protocols such as segment routing [20], Layer-7 switching, security implementation such as IEEE 802.1x and IPv6 features such as Anycast.

It is worthy noticing that, as long as a device is able to run Foglet, it can serve as an FEN. For instance, a smart phone can work as a FEN once Foglet is in place in entertainment. This phone may still have resource available for other Fog or non-Fog applications. The device could be run as an FEN, but such operation is not preemptive. Sometimes an FS and an FEN may be interchangeable. One device may be an FEN and an FS simultaneously.

C. *Foglet (middleware)*

Foglet is reasonably small agent software that can be easily and smoothly employed by Fog nodes. Foglet helps smart object to enjoy dynamic, dependable and scalable Fog services. These Fog services include network management and hosted applications. Foglet is capable of bearing the orchestration functionality and performance requirements. It can be running on any Fog nodes when required or on-request. It can be used to monitor the health (physical machine and service deployed on it) and control resources (VMs, service instance, etc.), negotiate to establish, maintain and tear down sessions between Fog nodes and Fog abstraction APIs [6].

As a middle-ware, Foglet must offer a cross-platform capability and allow smart objects to take advantage of fruitful Fog services without knowing any infrastructure of Fog. An FEN can utilize Foglet to detect Fog resources (such as CPU, memory, bandwidth, real-time throughput, etc.) and proactively select the best path to deliver data units. Fog nodes also use Foglets to collaborate interactively to liaise and organize related resource to offer customizable service based on SLA.

In summary, smart objects are linked to an FEN to form a sub-network. An FEN runs Foglet to collaborate with other FEN and FS. Some FENs may need to talk to Cloud occasionally while the others need not to. Fig.1 illustrates the interplay between smart objects, FEN, FS and Cloud.

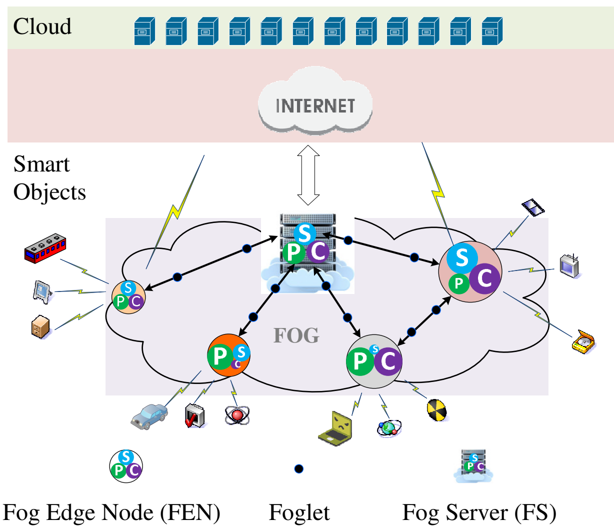

Fig. 1: Interplay between IoT, Fog and Cloud

IV. CASE STUDY AND EVALUATION

Some EHOPES applications are run on Cloud and Fog in order to compare their latency performance for the same amount of smart living data.

A. *The Scenario*

We first present data volume in the given scenario followed by the network topology when either Cloud or Fog is employed.

At impairment BAN user's home, Tom is enjoying his smart living services. His BAN sensors generate an average of 8900 bps amount of data by monitoring his vital signs [21]. We assume that his healthcare Apps and medical robots generate a similar amount of data respectively. The total throughput is about 3,375 bytes per second. The security camera resolution is CIF (704x480) level, which generates about 34,290 bps per camera. There are six cameras implemented, altogether generating 25,938 bytes per second [22]. He usually watches TV for four hours each day at home for entertainment. The throughput is about 500 kilobytes per second [23]. Meanwhile, he works as an editor for eight hours each day, five days per week. The average throughput is then about 125 kilobytes per second. The above scenario involves typical EHOPES applications such as smart healthcare, protection, entertainment and office, whose throughputs are summarized as follows:

TABLE 3: DATA VOLUME IN THE SCENARIO

Application	Throughput (byte/second)
Smart healthcare	3,375
Smart office	125,000
Smart protection	25,713
Smart entertainment	500,000
Total	654,088

Case 1: Cloud computing model

In this case, the data are required to store in a centralized Cloud as shown in Fig. 2. According to Akamai 2014 rankings, the average download data rate is 6.9Mbps in Australia [24]. Hence, we assume Tom has this speed with the latency between the Cognitive Gateway and Cloud about 250ms.

Fig. 2: Cloud Model Diagram

Case 2: Fog computing model

In this case, the data are only required to store in the local Fog, as shown in Fig. 3. He has a 1Gbps link between his FEN and FS. All his FENs share this bandwidth.

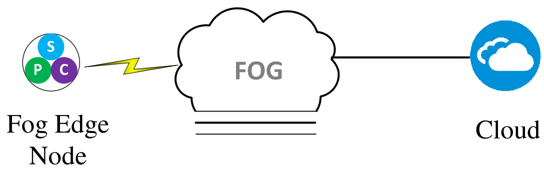

Fig. 3: Fog Model Diagram

B. *The Simulation*

The simulation is carried out in the OPNET Modeler 14.5. Cloud and Fog scenario has been setup respectively. For the Cloud model, we use an IP-32 Cloud to simulate the Internet (refer to Fig. 3), a PPP client to simulate the Cognitive Gateway and a PPP server to simulate the Cloud server that hosts those services required in Section IV.A. DS-3 PPP links are used to facilitate the connections. The DS-3 PPP link between Cognitive Gateway and Cloud is fine tuned to 6.9Mbps. For the Fog model, we use four Ethernet nodes to act as FENs, an Ethernet server to act as an FS that hosts required service (refer to Fig. 4).

High load email is used to simulate smart healthcare traffic. To match the traffic volume, we run 42 folds of this application in this simulation. Heavy database query (5 folds) is used to simulate smart security traffic. Image browsing (62folds) is used to simulate smart entertainment traffic. Heavy load file transferring (297folds) is used for smart office traffic. The above setting generates the required traffic volume as listed in Table 4.

TABLE 4: DATA VOLUME IN THE SIMULATION

Application	Simulating Application	Average Throughput (byte/second)
Smart healthcare	High load Email	2,800
Smart Office	File Transfer	85,000
Smart protection	Database Query	28,000
Smart entertainment	Image browsing	530,000
Total		645,800

C. *Simulation Results*

The latency (response time) has been collected for each application. The following are those collected values in a weekly basis.

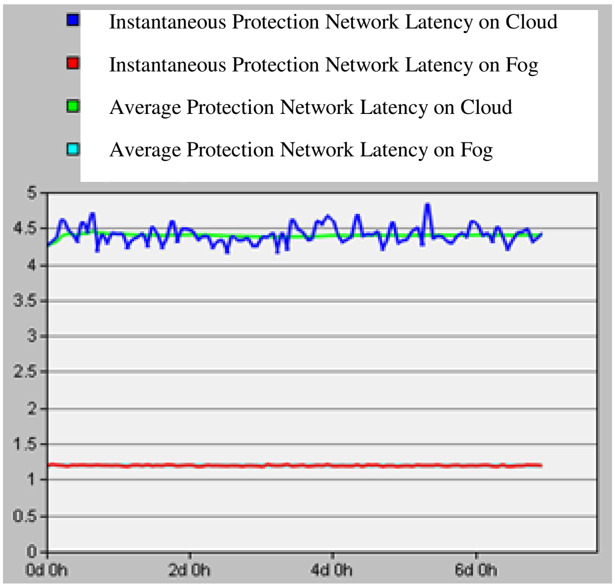

Fig. 4: Latency Curve Comparison

Fig. 4 shows Instantaneous and average response time for smart protection network. The blue curve shows this application occurring at that moment in Cloud while the red one shows as in Fog. The green curve shows the average response time in Cloud. The cyan curve shows average value in Fog. From the figure, the average delay is 4.4 seconds in Cloud. In sharp contrast, the average delay is about 1.2 seconds on Fog platform. This result shows that the latency drops 73% on average when Fog is employed. Regarding two Instantaneous response times, the blue one is a jiggling curve, which implies the latency is unstable in Cloud. While Fog is employed, the latency is relatively stable as shown in a red flat line. Thus the latency on Fog is easier to be predicted.

We can see a significant latency dropping from Cloud to Fog for the same amount of data. The table below outlines all the results from the data we have collected.

TABLE 5: EHOPES LATENCY VALUE ON CLOUD AND FOG

Response Time / Application	Cloud	Fog
	Average(s)	*Average(s)*
Smart Health	2.8	0.8
Smart Security	4.4	1.2
Smart Entertainment	1.9	0.6
Smart Office	2.8	0.7

V. CONCLUSION

This paper investigates Fog computing as a platform for a smart living concept, namely, EHOPES. Because of Fog's proximity to the users, it improves the efficiency and quality of user experience in supporting smart living. As Fog architecture has not been clearly defined, we suggest the required Fog elements such as FEN, FS and Foglet from IoT user's perspective. Various aspects of FEN and FS in terms of processing, storage and communication are considered for EHOPES. Two use cases are proposed to show the effectiveness of reducing the latency for the same amount of data on Fog compared to Cloud. Although this paper focuses on Fog platform for smart living, the framework is ready to be generally applied to other IoT applications wherever Fog is employed. As Fog is merely in its infancy stage, lots of work are still required to be done, e.g., workload mobility between Cloud and Fog, Fog routing and switching, Fog deployment, Fog security and QoS, interplay between smart object, Fog node and Cloud as well as Data storage (pull and push).

REFERENCES

[1] D. Evans, "The internet of things: How the next evolution of the internet is changing everything," *CISCO white paper,*, 2011.

[2] G. Kortuem, F. Kawsar, D. Fitton, and V. Sundramoorthy, "Smart objects as building blocks for the internet of things," *Internet Computing, IEEE,* vol. 14, pp. 44-51, 2010.

[3] M. Armbrust, A. Fox, R. Griffith, A. D. Joseph, R. Katz, A. Konwinski, *et al.*, "A view of cloud computing," *Communications of the ACM,* vol. 53, pp. 50-58, 2010.

[4] Z. Yan, Y. Rong, X. Shengli, Y. Wenqing, X. Yang, and M. Guizani, "Home M2M networks: Architectures, standards, and QoS improvement," *Communications Magazine, IEEE,* vol. 49, pp. 44-52, 2011.

[5] F. Bonomi, R. Milito, J. Zhu, and S. Addepalli, "Fog computing and its role in the internet of things," presented at the Proceedings of the first edition of the MCC workshop on Mobile cloud computing, Helsinki, Finland, 2012.

[6] F. Bonomi, R. Milito, P. Natarajan, and J. Zhu, "Fog Computing: A Platform for Internet of Things and Analytics," in *Big Data and Internet of Things: A Roadmap for Smart Environments*, ed: Springer, 2014, pp. 169-186.

[7] G. Holmes. *Smart Energy System.* Available: http://mams.rmit.edu.au/rh9as052ftqz.pdf. Accessed on 1/5/2015.

[8] C. Reinisch, M. J. Kofler, F. Iglesias, and W. Kastner, "Thinkhome energy efficiency in future smart homes," *EURASIP Journal on Embedded Systems,* vol. 2011.

[9] M. Schulz and M. Sundaresan, "Smart sensor system for structural condition monitoring of wind turbines," *Springfield, VA: National Renewable Energy Laboratory,* 2006.

[10] M. Liserre, T. Sauter, and J. Y. Hung, "Future energy systems: Integrating renewable energy sources into the smart power grid through industrial electronics," *IEEE Industrial Electronics Magazine,* pp. 18-37, 2010.

[11] Y. Strengers, *Smart energy technologies in everyday life: smart Utopia?*: Palgrave Macmillan, 2013.

[12] P. Wang, J. Huang, Y. Ding, P. Loh, and L. Goel, "Demand side load management of smart grids using intelligent trading/metering/billing system," in *PowerTech, 2011 IEEE Trondheim*, 2011, pp. 1-6.

[13] O. Akribopoulos, D. Amaxilatis, V. Georgitzikis, M. Logaras, V. Keramidas, K. Kontodimas*, et al.*, "Making P-Space Smart: Integrating IoT Technologies in a Multi-office Environment," in *Mobile Wireless Middleware, Operating Systems, and Applications*, ed: Springer, 2013, pp. 31-44.

[14] S. Mark.. *PRACTISING IN A VIRTUAL WO* [Without Prejudice]. Available: http://www.olsc.nsw.gov.au/agdbasev7wr/olsc/documents/pdf/wp_issue51_august2010.pdf, Accessed on 17/5/2015

[15] L. M. Vaquero and L. Rodero-Merino, "Finding your way in the fog: Towards a comprehensive definition of fog computing," *ACM SIGCOMM Computer Communication Review,* vol. 44, pp. 27-32, 2014.

[16] B. Nunes, M. Mendonca, X. Nguyen, K. Obraczka, and T. Turletti, "A survey of software-defined networking: Past, present, and future of programmable networks," 2014.

[17] J. Zhang, Y. Zhao, H. Yang, Y. Ji, H. Li, Y. Lin*, et al.*, "First demonstration of enhanced software defined networking (eSDN) over elastic grid (eGrid) optical networks for data center service migration," in *National Fiber Optic Engineers Conference*, 2013.

[18] *From the Cloud to the Fog.* Available: https://techradar.cisco.com/trends/Fog-Computing. Accessed on 1/5/2015.

[19] X. Li, D. Guo, H. Yin, and G. Wei, "Drone-assisted public safety wireless broadband network," in *Wireless Communications and Networking Conference Workshops (WCNCW), 2015 IEEE*, 2015, pp. 323-328.

[20] S. Bidkar, A. Gumaste, and A. Somani, "A scalable framework for segment routing in service provider networks: The omnipresent Ethernet approach," in *High Performance Switching and Routing (HPSR), 2014 IEEE 15th International Conference on*, 2014, pp. 76-83.

[21] D. Bragg, M. Yun, H. Bragg, and H.-A. Choi, "Intelligent Transmission of Patient Sensor Data in Wireless Hospital Networks," in *AMIA Annual Symposium Proceedings*, 2012, pp. 1139-1140.

[22] *NVR Storage Calculator for Network IP Security Cameras*. Available: http://www.supercircuits.com/resources/tools/security-nvr-storage-calculator. Accessed on 13/07/2015.

[23] *How Much Bandwidth Do You Need for Streaming Video?* Available: http://www.soundandvision.com/content/how-much-bandwidth-do-you-need-streaming-video. Accessed on 13/07/2015.

[24] *List of countries by Internet connection speeds*. Available: https://en.wikipedia.org/wiki/List_of_countries_by_Internet_connection_speeds, Accessed on 13/07/2015.