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Demand Side Management Using the Internet of Energy based on Fog and Cloud Computing

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***Abstract*— The smart grid, as a communication network, allows numerous connected devices such as sensors, relays and actuators to interact and cooperate with each other. An Internet-based solution for electricity that provides bidirectional flow of information and power is internet of energy (IoE) which is an extension of smart grid concept. A large number of connected devices and the huge amount of data generated by IoE and issues related to data transmission, process and storage, force IoE to be integrated by cloud computing. Furthermore, in order to enhance the performance and reduce the volume of transmitted data and process information in an acceptable time, fog computing is suggested as a layer between IoE layer and cloud layer. This layer is used as a local processing level that leads to reduction in data transmissions to the cloud. So, it can save energy consumption used by IoE devices to transmit data into cloud because of short-range communication technologies such as Bluetooth and Zigbee. In this paper, a smart gateway, which bridges fog domain and cloud, is introduced for scheduling devices/appliances by creating a priority queue which can perform demand side management dynamically. The queue is affected by not only the consumer importance but also the consumer policies and the status of energy resources.**

Keywords—Internet of Things; Internet of Energy; fog computing; cloud computing; microgrid; demand side management.

I. Introduction

The Internet of things (IoT) is considered as the next phase in the evolution of the Internet. Internet of Things has been identified as one of the emerging technologies in IT as noted in Gartner's IT Hype Cycle. It has been forecasted that IoT will take 5–10 years for market adoption [1]. IoT devices rapidly grow and are used in industries and various domains. IoT connects people, machines and devices to each other and to the internet and enables bidirectional information transmission and real-time decisions [2]. Two key factors which affect growth rate of IoT, are reduction in size and cost of IoT devices. IoT can play an essential role in applications related to private users such as smart homes, wearable tools, learning ad applications related to business users such as automation and industrial manufacturing, intelligent transportation, smart city, smart grid and e-health [3]. IoT has huge potentialities for developing new intelligent applications in nearly every field. The various applications can be grouped in three major domains: (A) industrial domain, (B) smart city domain, and (C) health well-being domain. Each domain is not isolated from the others but it is partially overlapped since some applications are shared. Fig. 1 shows the subdivision in the aforementioned domains and provides a non-exhaustive list of IoT applications for each of them [4]. Bob Metcalfe, inventor of Ethernet and expert in technology domain, says that: "over the past 63 years it has been tried to provide clean and cheap information for world by Internet; however in the next 63 years the need of world for cheap and clean energy should be fulfilled by Enernet" [5]. Enernet is the idea that we can learn from the history of the Internet "how to meet accelerating world needs for cheap and clean energy". Private industries and governments are accelerating the promotion of using innovations for smart grid applications. Some investments should be done in this domain to provide an agile platform for power generation and distribution in smart energy system that allow customers save money by scheduling the proper time for effective device usages [6].

Historical Data shows that a large part of energy has been generated from fossil fuels (in 2011, 82%) [7]. The widespread use of fossil fuels has damaging and undesirable environmental impacts such as global warming caused by CO_2 emissions from them [8]. Also, there is another political challenge, energy insecurity which denotes that most imported oil comes from politically volatile regions [9]. So, a sustainable approach to face this problem is to replace fossil fuels by renewable energy resources [10]. Therefore, there is an increasing pervasive focus on renewable energy systems to replace fossil fuels and how to meet future demand for electricity. The International Energy Agency in [11] says that the share of renewable energy in global power generation will rise up to 26% by 2020. Using renewable energy resources such as solar and wind generation for homes and buildings presents a new challenge for balancing energy on the power grid because they do not supply constant power and have stochastic behavior over the time [6],[12]-[13]. There are some challenges regarding the wide spread adoption of renewable energy such as ability to store and control the wide variety of different energy resources which typically require complex control of diverse and distributed energy sources and storage to meet demand [9]. Smart grid is an intelligent distributed infrastructure that manages energy needs in a sustainable, reliable and economic manner with the help of reliable high-speed communication networks for monitoring and control [14]-[15].Convergence of smart grid and IoT is called Internet of Energy (IoE) and can be seen as an extension of the smart grid concept [16]. The goal of IoE is to provide a robust system for energy exchange between prosumers. Distributed and intermittent energy production and storage needs to be monitored and controlled intelligently via Internet. IoE will allow energy exchange between a wide variety of sources and loads, including renewable energy sources, distributed energy storage, plug-in electric vehicles, domestic and industrial prosumers, etc. To overcome increasing complexity and enormous amount of data that generated by a large number of devices such as smart meters, sensors, actuators and relays, which has to be stored, processed, and accessed, the powerful processing resources are required which can be provide by cloud computing. The combination of cloud computing and IoT for creating IoE platform can enable ubiquitous sensing services and allow the sensing data to be stored and used intelligently for smart monitoring and powerful processing of sensing data streams. However, increasing the number of IoE devices leads to an increase in response time and latency in cloud computing which causes deviations from the time requirements for some delay-sensitive devices and applications [17]. To conquer these challenges, the fog computing has been suggested in [18]. Fog computing pulls the cloud computing to the edge of the network and allows data to be preprocessed whenever latency limitation is required [19] and leads to an increase in interoperability, scalability, consistency and better connectivity between smart devices [17]. The most important features of Fog area which can be mentioned are: low latency and location awareness, wide-spread geographical distribution, mobility, very large number of nodes, predominant role of wireless access, strong presence of streaming and real-time applications and heterogeneity [19]. IoT faces some challenges such as stringent latency requirements, network bandwidth constraints, resource-constrained devices, cyber-physical systems that connected to IoT, uninterrupted services with intermittent connectivity to the cloud, new security challenges, keeping security credentials and software up to date on a large number of devices, protecting resource-constrained devices, assessing the security status of large distributed systems in a trustworthy manner and responding to security compromises without causing intolerable disruptions which cannot be satisfied by cloud computing. Fog is a computing and networking architecture that distributes computing, control, storages and networking functions closer to end-user devices [20]. Thus, this paper elaborates on presenting an effective platform for IoE based on combining two technologies: cloud computing and fog computing.

Fig. 1. List of IoT applications

The paper is organized as follow: in section II, the fog computing is presented. Then, the fog computing application for smart grid is discussed in section III. Finally, section IV draws the conclusions.

II. Fog Computing

Fog computing can be seen as a layer between the underlying network and the cloud computing. Indeed, Fog computing extends the cloud computing to where the things are [21]. These devices, are called fog nodes. Fog computing is a platform, which provides computation, storage, and networking capabilities between the end devices and traditional cloud computing. Since number of connected devices are increasing, traditional cloud computing is not designed for the volume, variety, and velocity of data that the IoT devices generate. Analysis of big data generated by IoT devices, mostly must be real-time or near real-time. In order to attain this, data transmission, data storage and data processing must be performed in very short time intervals. Analyzing and storing IoT big data on devices which are physically close to the things, minimizes the latency. By this way, network traffic toward the core network can be reduced and real-time processing can be achieved. Also fog computing speeds up the sharpness and the response to events by analyzing data/event near to where it is generated [21]. Other motivating aspects for fog computing emersion are: geographical distribution, very large number of nodes, mobility, real-time interactions, heterogeneity, interoperability and location awareness [19]. Main advantages of fog computing are interoperability, cognition, efficiency, agility and latency reduction [20]. Compared to cloud computing, there are some superiorities in using fog computing such as: edge location, location awareness, and low latency, geographical distribution, large-scale sensor networks to monitor the environment, very large number of nodes, support for mobility, real-time interactions, heterogeneity, interoperability and federation, support for on-line analytic and interplay with the cloud [19]. These advantages can be met by following three parallel approaches:

- A considerable amount of data can be stored at or near the end-user (instead of storing whole data in remote data centers).
- A considerable amount of computing and control actions can be performed at or near the end-user (instead of doing all in remote data centers).
- A considerable amount of communication and networking can be carried out at or near the end-user (instead of routing all network traffic through the backbone networks).

Therefore, fog computing increases the overall performance of IoT applications as it performs a substantial part of high- level services inside the local resources and near the end-users rather than in the cloud. Of course, it cannot totally replace the cloud computing. It is obvious that, fog and cloud complement each other to build an adaptable and scalable platform for IoT. Fig 2. Presents architecture supporting IoT platform based on cloud and fog computing. In this architecture model, fog nodes do as following:

- Receive data/events from IoT heterogeneous devices in real-time using any protocol,
- Run IoT applications for real-time control, monitoring and analytics, with minimum response time,
- Provide temporary storage,
- Forward periodic data summaries to the cloud.

In a similar fashion, the cloud platform is responsible for:

- Aggregating data summaries from many fog nodes,
- Analyzing IoT data and data from other sources to gain business insight,
- Sending new application rules to the fog nodes based on these insights [21].

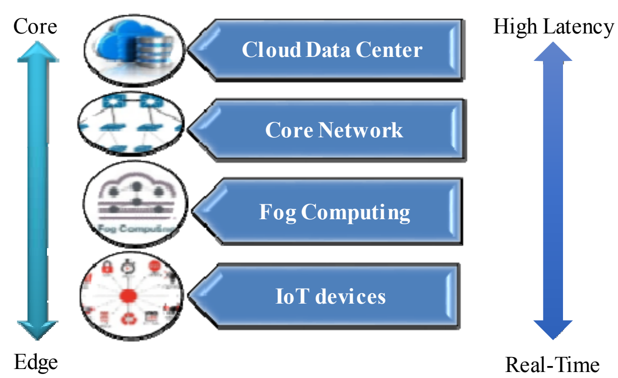

Fig. 2. Architecture supporting IoT platform based on cloud and fog computing

If IoT devices equipped with access network technologies such as 3G/4G/5G LTE, they would connect to internet directly. Otherwise, a smart gateway is required. Since some of the IoT devices are power-constrained, they use short-range wireless technologies such as Zigbee, BLE, IEEE 802.15.4 and Z-Wave to connect to gateway. IoT gateway can have two different approaches. First, it makes a simple connection between IoT devices and Internet. Second, it allows performing multiple operations (such as data refinement, filtering, trimming, and security measures) locally through fog computing and then to send important updates and necessary data to the cloud for synchronization [2]. Thus, real- time processing, low latency, bandwidth saving and traffic reduction are met.

III. Proposed Model

As mentioned previously, a smart grid is a smart energy hub which includes a variety of devices, including smart meters, smart appliances, renewable energy resources, etc. [22]. It can intelligently integrate the behaviors and actions of all users connected to it; including generators, consumers and prosumers, in order to efficiently deliver sustainable, economic and secure electricity supplies. It uses digital communications technology to detect and react to local changes in application. In addition, it enables demand side management through the integration of smart meters, smart appliances and consumers' loads, micro-generation units, energy storage options (electric vehicles) and by providing customers with information related to energy usage and prices. It is anticipated that customers will be provided with information and motivations to modify their consumption pattern to conquer some of the constraints in the power system. It also incorporates and comforts all renewable energy sources, distributed generation, residential micro-generation, and storage options [23].

Demand-side management is done by reducing the overall load on an electricity network. In fact, there are numerous connected devices to interact and cooperate with each other. The load shedding or load reduction is one of the demand side management approaches which is used in network scheduling and management phases. In traditional networks, the load shedding program is determined as the priority of loads based on some predefined factors. In fact, this priority may be changed during different time intervals. However, in grid environment there are some uncertain parameters such as renewable energy resources which behave randomly during time. Therefore, it can affect the load shedding program in a way that the load decrement is changed according to the status of renewable energies in addition to the status of peak-load in the utility. In a microgrid with high penetration of renewable energy resources and local loads, the load shedding is determined mainly based on the priority of the loads and renewable energy status which can be changed dynamically. Hence, there are numerous data that should be transmitted and processed. However, to overcome increasing complexity and enormous amount of data generated by a large number of devices such as smart meters, sensors, actuators and relays, which has to be stored, processed, and accessed, the powerful processing resources are required which can be provide by cloud computing. The combination of cloud computing and IoT for creating IoE platform can enable ubiquitous sensing services, allowing the sensing data to be stored and used intelligently for smart monitoring and powerful processing of sensing data streams. At a same time, increasing the number of IoE devices leads to an increase in response time and latency in cloud computing, which causes deviations from the time requirements for some delay sensitive devices and applications. To conquer the cloud computing issues, the fog computing is suggested. The fog computing pulls the cloud computing to the edge of network and allows data to be preprocessed whenever latency limitation is required and leads to increase in interoperability, scalability, consistence and connection between smart devices. In a bulk electrical network, the fog computing can be done on the local sub-networks, which are called microgrids. A microgrid is a small-scale local power grid that can operate independently or in connection with the utility grid, which constitutes of power resources, generation and loads and definable boundaries. Microgrid applications require real-time processing which can be carried out in the fog domain. Hence, data transmission rate into cloud,

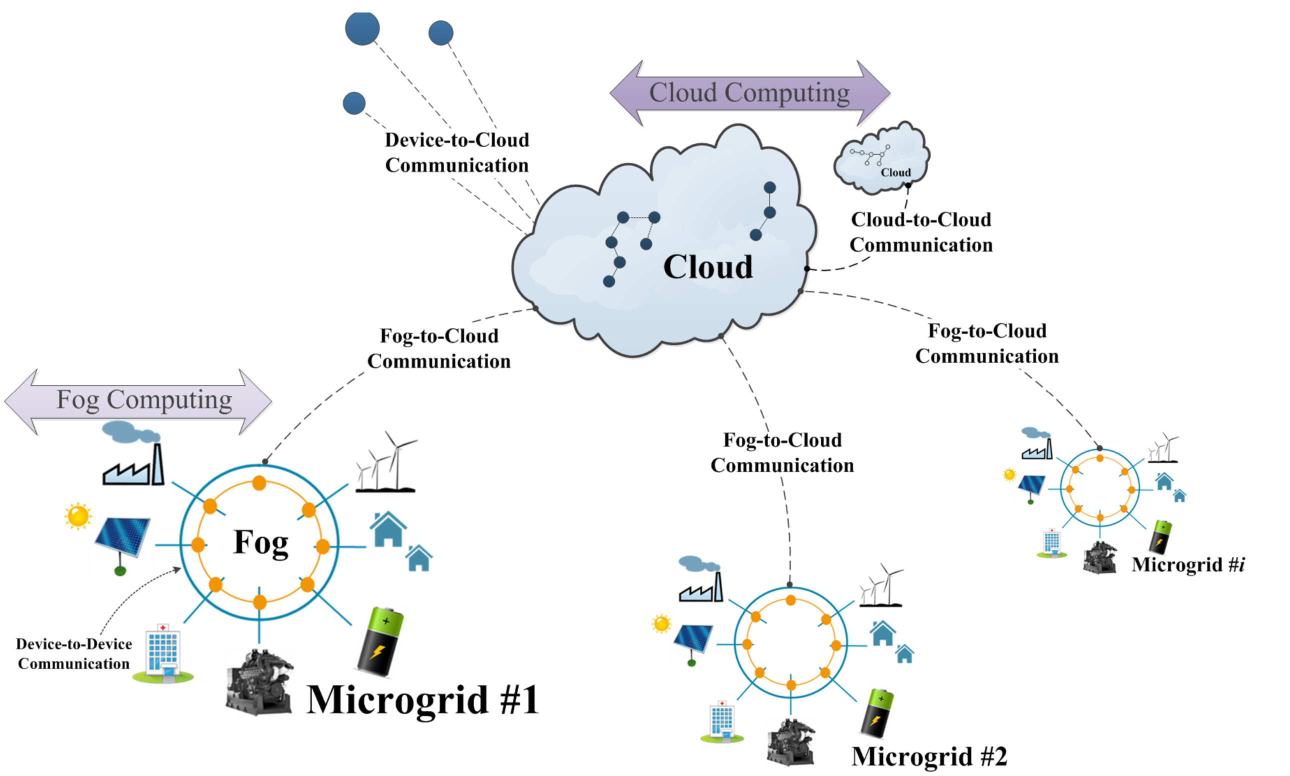

Fig. 3. Micro-grid considered as a fog domain

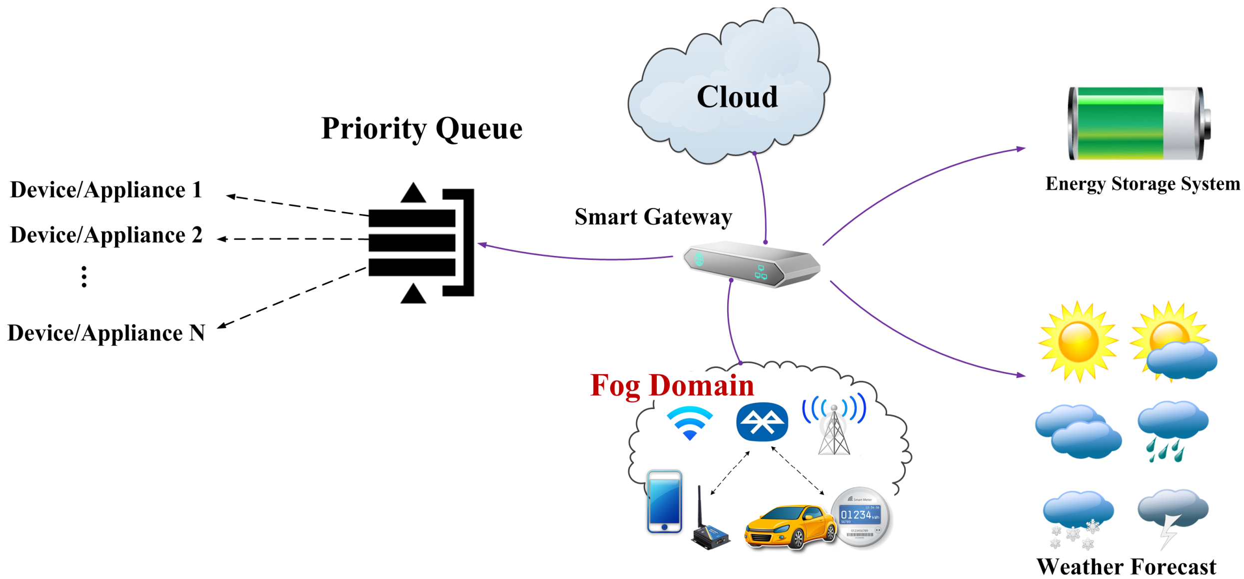

Fig. 4. Smart gateway: pointo of conection between the fog and other components

communication latency, traffic and bandwidth consumption are decreased.Since, in the proposed model it is tried to have the lowest data transmission from fog to cloud through core network, hence security and privacy are almost provided. As Fig. 3 shows, each microgrid considered as a fog domain and microgrid elements can communicate peer to peer to each other as well as to IoT gateway. In fact, smart gateway as shown in Fig. 4, bridges the fog and the cloud. Gateway as a fog node has computing, storage and networking capabilities. Moreover, two key components, local battery status and local weather forecasting, are connected to the gateway. As it can be seen in Fig. 4, there is a queue for microgrid which determined the priority of loads. The priority in queue can be changed dynamically based on the price and consumer's

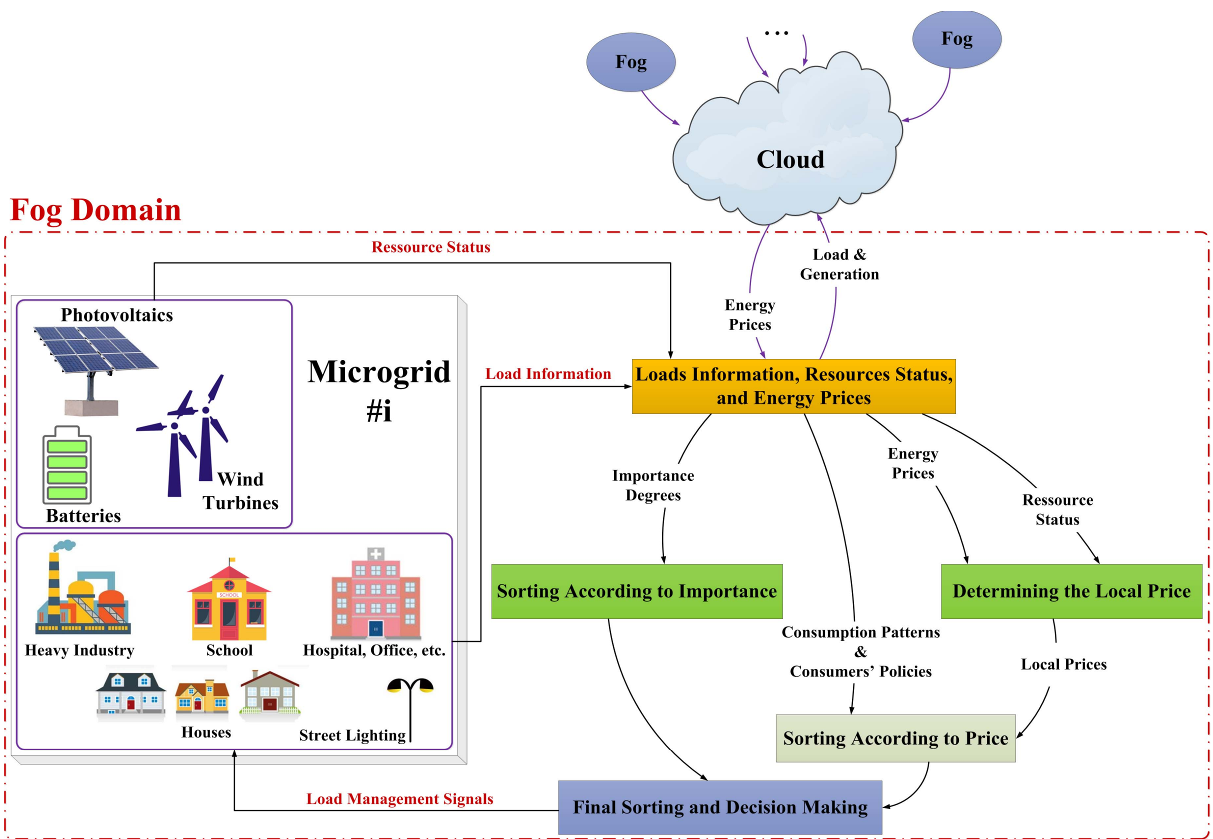

Fig. 5. Queue sorting flowchart in a fog domain

policies and importance. In addition, the status of renewable energies, which is predicted by weather forecast unit, can affect the priority in the queue and the amount of load shedding. Let's consider a scenario in a typical microgrid and in a peak-load situation where a priority queue can be made in gateway and scheduling can be done accordingly. In this case, gateway sends "off" or "reduce load" signals to lowest priority devices/ appliances. Therefore, due to local decision about load control, consumer's consumption turns economic. The queue sorting flowchart in fog domain is shown in Fig. 5. The load information, resources status and network price are the input data. The load information includes importance degree, consumption pattern and purchase policy of all loads. The purchase policy is defined according to local price by consumers. The local price is determined based on network price and the status of resources; e.g., in case of high price in network, if the renewable resources in microgrid can produce more, then the local price can be less than the network price. There are some important loads which should not be curtailed even in peak situation. Therefore, they will be at the beginning of the queue. The other loads approximately have the same importance degree which they can be curtailed. These loads would be sorted according to their purchase policies which are based on the price. These policies are announced by consumers to the gateway in each fog domain and they can be changed dynamically. Finally, the queue is sorted based on importance degrees and purchase policies momentary.

IV. Conclusion

Load shedding or load reduction is one of the demand side management approaches which is used in network scheduling. In traditional networks, the load shedding program is determined as the priority of loads based on some predefined factors. In fact, this priority may be changed during time intervals. However, real grid environment there are some uncertain parameters such as renewable energy resources that have stochastic behavior during time. Therefore, it can affect the load shedding program in a way that the load decrement is changed according to the status of renewable energies in addition to the status of peak-load in the utility. In a microgrid, with high penetration of renewable energy resources and local loads, the load shedding is determined based on the priority of the loads and renewable energy status which can be changed dynamically. Hence, there are numerous data that should be transmitted and processed. In order to handle this multiplicity, the Internet can be used in electricity grid to monitor and control distributed loads. A large number of connected devices and the huge amount of data generated by IoT and issues related to transmit, process and storing it, force IoT to be integrated by cloud computing. Furthermore, in order to increase performance and reduce the volume of transmitted data and process data in acceptable time, fog computing is suggested as a layer between IoT layer and cloud layer.

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