An Efficient Smart Metering Infrastructure in Fog Computing Environment

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ABSTRACT

With frequent increment in deployment of modern metering infrastructure, the amount of the data gathered increases in very impressive way. Incorporation of such large data needs wide-ranging transformation of the available metering infrastructure. The smart meter is considered as a key element of the smart grid. It provides social, economic and environmental advantages for numerous stakeholders. One of the primary factors that decide the success of smart meters is smart meter data analytics, which handles data acquisition, processing, transmission and interpretation that are beneficial to all stakeholdersSince, as the no. of smart meters increases to higher than hundreds of thousands, it would become increasingly clear that the state-of-the-art centralized information processing architecture will no longer be sustainable under such huge data explosion. In this short communication letter, we suggest an implantable data storage and- processing solution for enhancing the available smart meter infrastructure. The practicality of the suggested solution is validated on a proof-of-concept test bed.

Index Terms-- Fog Computing; Smart Gid; Smart Meter; Big Data and Advanced Metering Infrastructure (AMI).

I. INTRODUCTION

SMART Energy has been a significant conceptual paradigm for future energy utilization. Due to limited non-renewable energy resources present on Earth and also high costs of obtaining renewable energies (REs), how to make energy usage more effective and efficient is more demanding for future economic and social developments [1]. Smart grids (SGs) are power networks that can intelligently integrate the actions and behaviours of all stakeholders associated with it, for example, customers, generators and those that do both—for efficiently delivering economic, sustainable and secure electricity supplies. SGs faces some technological challenges, i.e. intermittency of RE generation that influences the quality of electricity; large scale networks of small distributed generation techniques, e.g., photovoltaic (PV) panels, wind and solar, batteries, plug-in hybrid electric vehicles (PHEVs), that creates high complexities. Another important issue is how to utilize advanced electronic and analytic technologies, information and communication technologies (ICTs), to improve efficiency and cost effectiveness of energy usage.

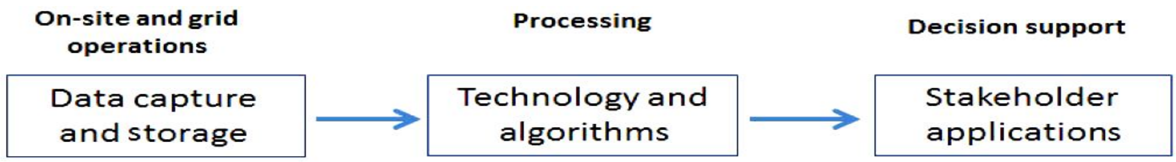

Figure. 1. Key components of electricity meter data intelligence.

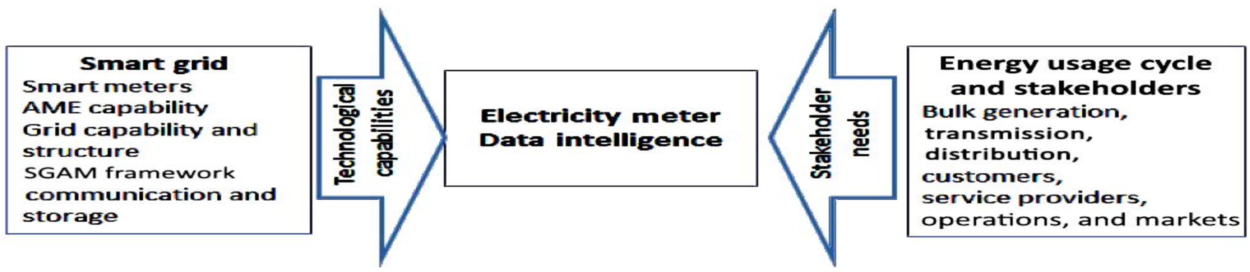

Figure 2. Environment for smart meter data intelligence.

In North America, the no. of smart meters installed has increased from 6% of households in 2008 to 89% in 2012, and by 2019, 30 million small and homes businesses will have smart meters [1]. For instance, Austin Energy in Texas has implemented 50,000 smart meters, and these smart meters forward data in each fifteen minutes to the data centre, which needs 200TB of storage capacity as well as important recovery redundancy. Also, it consumes more disk space to maintain as compared to just recording the information. If Austin energy moves from 15-minute to 5-minute interval data exchanging, their data storage requires will increase to 800TB [2]. Smart meters provide support to high sampling rate for data collection through a two way communication, whereas traditional electricity meters store data only once a month [3]. The massive volume of real-time data gathered by smart meters will support the grid operators obtain a better understanding of a highly dynamic and large-scale power system [4].

How to store and process the large amount of data becomes a serious issue. When it comes to the huge data storage and processing area, the centralized data centre with relational database is a general choice. All the smart meter data are combined and processed in a central location by two-way communication channel.

More particularly, the legacy of smart meter infrastructure requires to be enhanced considerably, in terms of the following four significant aspects:

Inflexible for expansion: increasing the available database infrastructure is very complicated and time consuming. It is almost impossible to improve hardware performance by just enhancing the hardware, without incurring extra cost for the unit [5].

Inefficient: As there is no effective manner of processing raw data with the available centralized technique [6], it needs an effective information extraction method.

Unreliable: A single point of failure in the chain of operations may decrease the reliability of the entire power system and build the whole database unreliable. Such database contains important information for day-to-day system operations [7]. Furthermore, High-frequency metering data which are needed for effective network operations may reveal clients' private information [8].

High-cost: Some software companies (for example, Oracle) have been enquiring for new solutions to manage the growing amount of smart meter data. Since, they concentrate primarily on generating a brand new system, which can end up as a rather costly investment proposal.

As the no. of smart meters increases to higher than hundreds of thousands, it is rather intuitive that the current state-of-the-art centralized data processing architecture will no longer be sustainable under such large data explosion. Nowadays, a great amount of work ([5],[10]) concentrate on using cloud-based solution for data-driven analytics in smart grid to manage the data explosion problem. Since, there are many main drawbacks of cloud computing. For instance, cloud computing systems are internet-based and primarily based on the internet connectivity. Smart meters forward data package to the cloud each second, resulting in high need of communication bandwidth. Data privacy and security are also significant issues when the sensitive smart meter data is combined in a cloud.

To address these challenges, Fog Computing, an extended idea of cloud computing, offers more benefits on its reducing service delay and its dense geographical distribution. The small latency and proximity to end-users characteristics lead to the fog paradigm well placed for real time big data and real time analytics [11].

In this paper, we introduce an implantable fog computing like solution for improving the available smart meter infrastructure in a cost-effective, reliable and efficient way. We also validate the practicality of the suggested solution on a proof-of-concept tested, utilizing a cluster of low-cost minicomputers. The ideas of the introduced fog computing solution can be increased to some applications i.e. connected vehicles and cyber-physical systems.

II. FOG COMPUTING

Cloud computing is being considered as a primary factor for IoT, providing reliability, ubiquity, scalability and high-performance. Since, because of its communication implications as well as geographically centralized nature, cloud computing-based IoT is not appropriate for applications that need a very low and predictable latency, are fast mobile, are geographically distributed, or are large-scale distributed control systems [2]. Fog computing is a good technology introduced and developed by Cisco [3]. It complements the cloud computing services by exploring the computing paradigm to the network edge. Fog computing proposes an intermediate layer between the end nodes or the edge network and the conventional cloud computing layer. Transporting the computational intelligence geographically close to the end users will provide better or new services for location-aware, latency sensitive and geo-distributed applications which because of their characteristics are not feasible simply through cloud computing. The expected advantage is faster computation times for requests that need low latency. In addition to the need of low latency, fog computing is a promising technology to deal with big data produced from IoT-based systems with a large number of nodes distributed across a vast area.In opposite to the cloud computing, which is more centralized, Fog computing provides the applications and services with broadly distributed deployments. The Fog will be able to provide high quality streaming to mobile nodes, like moving vehicles. Fog computing is appropriate for applications with low latency requirements, gaming, video streaming, augmented reality, etc. Fogs play a significant role for smart communication. For many tasks, it is not possible for a gateway to perform alone in an effective way. The underlying networks and nodes are not always physical. Virtual sensor networks and virtual sensor nodes are also needed for different services. Similarly, pre-processing, temporary storage, data security and privacy, and such other tasks can be performed easily and more effectively in the availability of a smart network or Fog, positioned with the Smart Gateway. However, Fog is localized; it delivers low latency communication and more context awareness. Fog computing provides real-time delivery of data, particularly for delay sensitive and healthcare related services. It can do the pre-processing smart tasks and inform the cloud, before cloud could further adapt that data into improved services. With heterogeneous nodes, heterogeneous data would be gathered. Transcoding and Interoperability become an issue then. Fog plays a very important role in this matter. Fog and Smart Gateway based communication architecture is presented in figure 3.

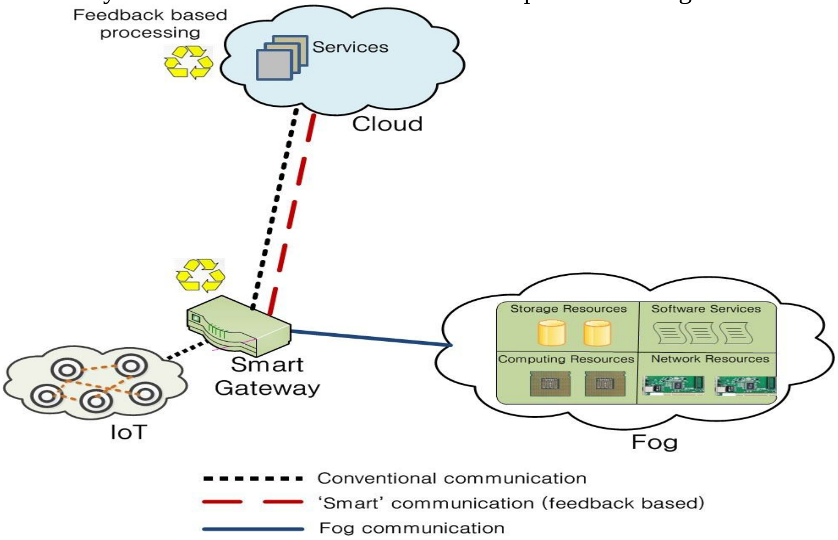

Figure 3. Smart Gateway with Fog computing/Smart network

III. SMART-METERING ENVIRONMENT

To explain the smart meter data intelligence components, it is essential to understand the environment in which they exist.

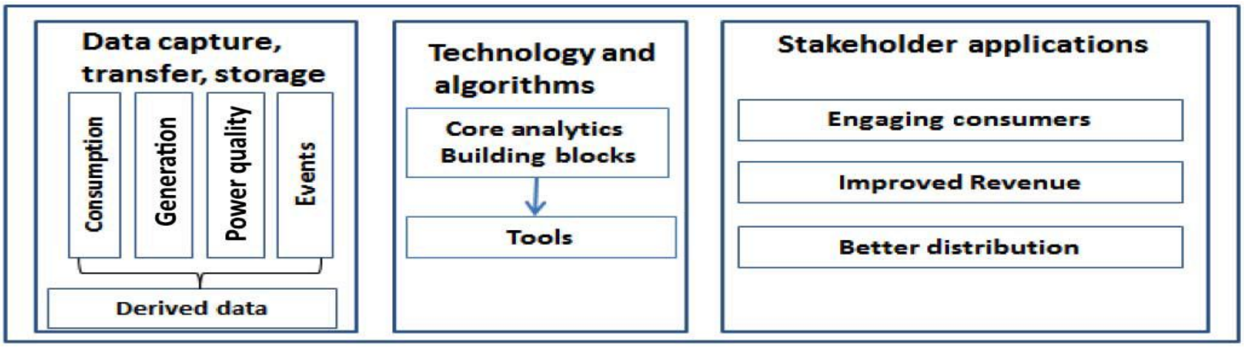

Fig. 4. Smart meter data intelligence framework.

A. Smart Meters

Initially, the term "smart meter" means the functionality of calculating the electricity utilized and/or generated and the capability to remotely control the supply and cut-off when it is required. It was known as AMR that used one-way communication. With the time the AMR ability was enhanced into short term interval (hourly or less) data capture, on-demand reads and associating into and reading other commodities.

B. Smart-Metering Process

Even though, there are smart meters of different design and technology, there is a common entire process for data collection, communication, and analysis which leads to decision support. This process, in fact, could be considered as part of the activation and SG functioning. The smart meter collects data locally and transfers through a local area network (LAN) to a data collection point. In terms of the data processing, some data processing could be done at the local collection points, but in most of the cases, the data are transmitted to the utilities' central collection centre through a wide area network (WAN). The data gathered at the utility are utilized for a no. of business objectives, i.e. billing, profiling, network and service monitoring, prediction and planning.

IV. DATA FOR METERING INTELLIGENCE

In the past, a smart-metering framework has been introduced, but it only viewed at consumer characterization and not holistic view of the entire smart-metering process and environment [4]. The introduced framework is extended and improved in. this section and shown in Fig. 4 consisting of two primary components.

1) The top part shows the modern smart-metering scenario: the data aspects, stakeholder requirement-based applications, and technology tools and algorithms that try to support the application requirement from the existed or derived data. Modern technologies and algorithms are depicted as core analytics building blocks that are accomplished by using different tools.

2) The lower part shows new needs that have arisen because of reasons, i.e. technological advancements, competition, change in human behaviour and needs, and better-informed consumers.

V. KEY CHALLENGES AND FUTURE OF SMART METERING

To get real advantages of analytic outcomes, it is necessary to achieve consumer's acceptance and support for smart meters. A primary need for such acceptance is process transparency, which is currently being approached by government regulators as well as utilities [6]. The availability of visual displays and easy to understand information is also an important requirement. Building smart meter data and analytic outcomes available on mobile devices and on the web will make such information more easily available and also updates communicated to consumers in near real time [7]. Hence, Smart meter analytics will proceed to evolve; making demands on the current knowledge and technology existed.

V.CLOUD AND FOG COMPUTING IN ADVANCED METERING INFRASTRUCTURE (AMI)

For the suggested fog computing i.e. data storage-and processing solution, smart meters are aggregated to make a cluster. Every smart meter behaves as a Data node and one of the Data nodes acts as the Master node, which maintains the file system. Master node records the metadata that have file name and storage location information. To manage privacy, the metadata is recorded only in readable form through a particular decoding program. Also, Data nodes (such as smart meters) as the end-users can also arrive the cluster if the Master node allowed. At each fixed time interval, data retrieved by the smart meter will be duplicated and divided into small chunks (e.g., 64MB) and then disseminated to the Data nodes inside the cluster.

Each smart meter will record a portion of the duplicated data chunks as back-up of its neighbour's data, as a precautionary measure in case of the hardware failures. In summation, the Master node will seamlessly monitor the connection status of the Data nodes to assure whole system reliability. As the nodes are not needed to share any storage space with one other, extra nodes can be easily plugged-and-played as the data repository increases.

Fog computing is a paradigm that increases Cloud computing and services to the network edge, as shown in Fig 5. In the suggested AMI framework, every Smart Grid component (for example distributed renewable energy generator, smart building and smart home) is associated to smart meter (i.e., Fog device). These Fog devices are interlinked with one other and connected to the Cloud. As smart meter is implemented at the smart grid network edge, the Fog computing offers location awareness, low latency, location and enhances quality-of-services (QoS) for real time and streaming applications [13].

This cluster contains 15 Data nodes, which can interact with one other. Every Cubieboard is a Data node and can also present a smart meter. Furthermore, we utilize a PC to function as the Master node to monitor this cluster. In the available case study, we preload all the raw data in a particular data format in every Data node, which can manage the smart meter data privacy. All the data can be maintained only by a Hadoop MySQL-like language – Hive. Here, we model the process of the grid operator to determine the abnormal frequency data seen by these "smart meters". Firstly, we generate a table through the Master node, and then we load the frequency data monitored by the smart meter in the particular form into this table. Also, the table will be packaged, cut and dispersed to Data nodes spontaneously. Then, we utilize Hive for searching this table and determining the abnormal frequency data to prevent power outage or examine the root cause of the accident after a blackout. During the searching procedure, we plug in and out a specific node respectively to mimic real-world scenarios in power system operations.

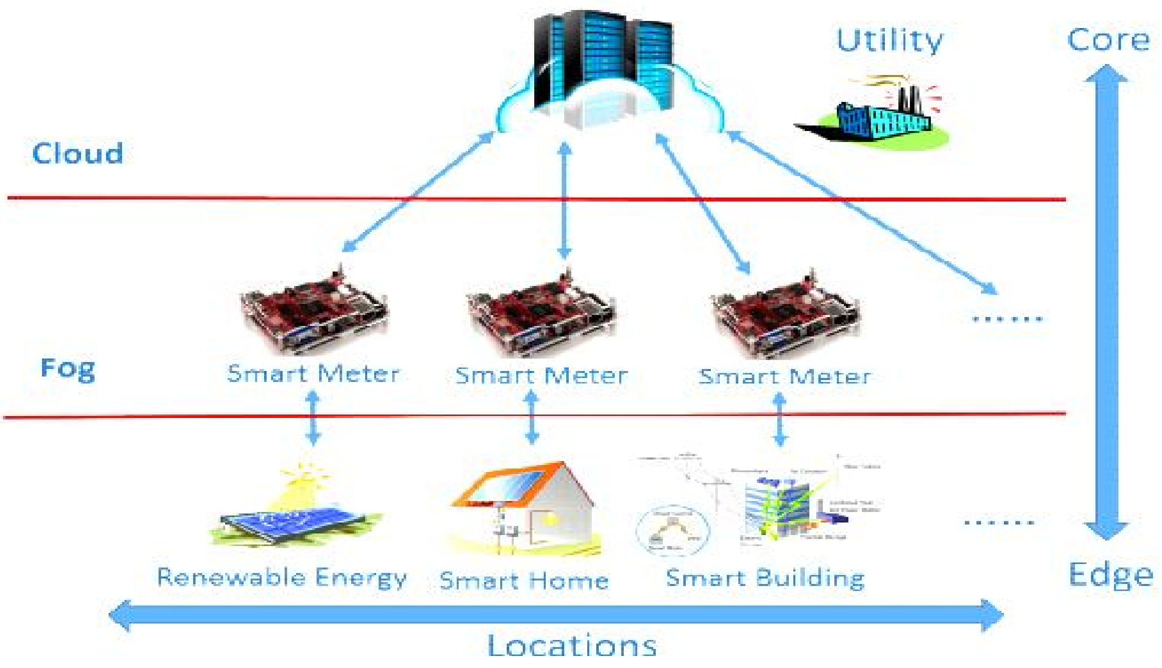

Figure 5. Cloud and Fog Computing in Advanced Metering Infrastructure (AMI)

Plug-and-Play: The distributed data cluster utilizing fog computing can automatically maintain addition or deletion of any Data node without reconfiguring the whole operation system.
Efficient: The self-loop processing method is based primarily on parallel computation, which is specifically effective for huge volume of data. **Fig 6** represents the comparison between average processing times by the centralized (Ubuntu server, 3.6GHZ, 8GB memory) and fog computing-like (aCluster of low-cost distributed Data nodes) methods. The superiority of the distributed solution stands out obviously when we increase the data size from 39.4MB to 10GB. The intelligent and fast processing capability of huge volumes of data will provide smart grid operations [11].

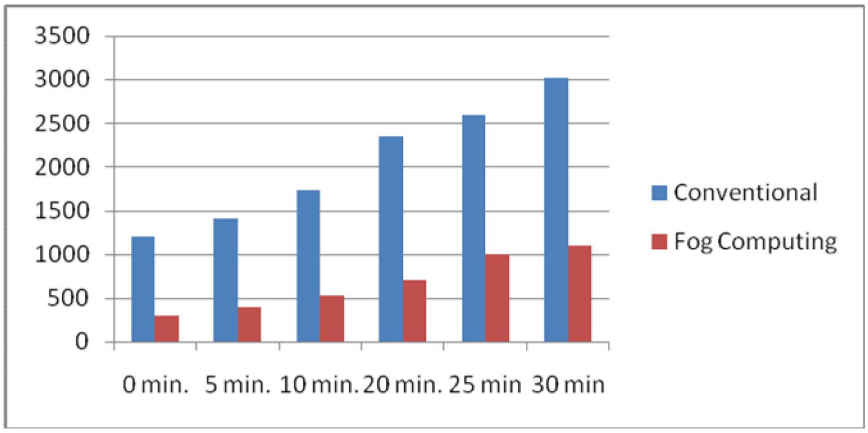

Figure 6. A Comparison on average data processing time

Robust: Even after shutting down many Data nodes during the experiment, the whole data is still writable and readable any time. During the turn-off transient, the entire system is still in stable operation. Therefore, if any of the Data nodes is broken, unlike the centralized system with backup storage, it require not be repaired or substituted immediately, which further decreases the soft cost linked with the available smart meter infrastructure. The low-cost hardware supports both wireless and wired communication, involving Wi-Fi, network cable and Bluetooth, etc. Our tested is based on the wired communication. However that split data in every smart meter is unreadable, the different communication techniques will not lower the system security level.
Low-cost: When facing big data exposition, under today's centralized architecture, the cost of the relational database involved in the software purchase with its license and the maintenance cost of the database centre keeps increasing all

the time [12]. Moreover, the writers in [13] explained that it is costly and difficult to expand the available data centres. Our suggested fog computing-like framework is capable to offer a cost-efficient alternative to the costly centralized data centre, in terms of portability and low-cost hardware. The available and developing advanced metering infrastructure can be easily explored and tailored to adopt the suggested fog computing-like solution.

IV. CONCLUSION

This paper introduces a fog computing-like solution for the available smart meter infrastructure. The suggested solution can be easily incorporated into the available smart meter infrastructure, at a little additional capital cost. In our future research, our objective would be to completely integrate the sensor, data processing, data storage devices and distributed controllers into a single smart meter. A user-friendly graphic user interface will be developed to visualize and archive the gathered data and process commands and extra information. In summation, we will customize the Map Reduce methods in Hadoop infrastructure to fulfil the particular application needs. As explained earlier, the fog computing solution for AMI has some strength. Since, it is worth to describe that it is still a long way to move the idea of fog computing to the real-world AMI at scale

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