Enabling Internet of Things for Smart Homes Through Fog Computing

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Enabling Internet of Things for Smart Homes Through Fog Computing

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Abstract — **Smart grid is the process of applying ICT in order to optimize energy consumption and decrease energy loses. This paper presents a three tier Internet of Thing based hierarchical framework for the smart home, as a reflection to the present lack of intelligent solutions that do not fully use the advantages of Internet of Thing technologies. Our framework aims to extend the smart home to microgrid level, in order to integrate all renewable distributed energy sources from the microgrid and to achieve better energy optimization. As an extension to the traditional data processing, we define fog computing approach for smart home. Through simulation on real smart meter dataset, we showed that fog computing based on predictive filters can reduce the number of transmissions and minimize smart home network traffic.**

Keywords — **data reduction, Energy management, Internet of Things, smart home, smart grid, smart metering.**

I. Introduction

SMART grid has attracted increased attention in the last decade. By definition, smart grid is the process of applying ICT in order to optimize energy consumption and decrease energy loses. ICT can be applied in all parts of the grid, i.e. energy generation, transmission and distribution. In the last years, with the expansion of the IoT paradigm, the smart home became an integral part of the smart grid [1][2].

Currently, the main issue toward development of generic smart home solutions is the cost associated with integrating smart home devices. Leading companies in the world that are producing smart devices are working toward to achieve full interoperability that will ensure easy integration with the exiting Internet. It is expected that smart objects will invade the market in the next few years and will become vastly present in consumers households, which will impose the need for new and enriched services for smart home. For these reasons, the need for Internet of Things (IoT) based solutions will be inevitable.

In this paper, we propose an IoT-based hierarchical approach for the smart home. Our framework aims to extend the smart home to a microgrid, in order to achieve better energy optimization. We further compare state-of-the-art commercial smart home solutions and identify that they all work separately and do not fully use the advantages of IoT technologies. We define fog computing approach for smart home, and prove that fog computing can be suitable solution in terms of reducing network traffic. Through simulation on real dataset, we showed that fog computing can optimize smart home network and solve some of it challenges.

The rest of this paper is organized as follows. The next section provides details about our three-tier framework for smart grid encapsulating smart home. Section III gives an overview of the state-of-the-art commercial solutions for smart home. Section IV introduces fog computing as an approach for efficient data transmission inside the smart home. Finally, we conclude this paper in section V.

II. IoT-based Framework for Smart Grid

Sensor devices at consumers' homes are widely present and attached to the home appliances. Dozens of these smart devices are equipped with communication interfaces and come with mobile application used for remote controlling, like boiler, heater, air conditioner, etc. In example, an iPhone is equipped with different sensors, like accelerometer, microphone, proximity sensor, GPS and ambient light sensor. The smartphone equipped with communication interfaces like BT/BTLE [Bluetooth/Bluetooth Low Energy], Wi-Fi [Wireless Fidelity], NFC [Near Field Communication] or 3G services is one of the major ingredients which pushes IoT in Smart Home and Smart grid concepts. Smart phones can serve as processing units in smart home, as they can easily communicate with smart meters and other appliances. Therefore, they can collect data from the smart home and perform sophisticated algorithms for optimal load balancing, or even create task schedulers to achieve reduction in energy consumption.

There are many different frameworks for smart grid/smart home proposed in the literature. An in depth survey is available in [1]. In this section we are going to explain in detail our framework for smart grid based on Internet of Things as depicted in Fig. 1.

A. First tier (Smart home)

All household devices, equipped with interfaces for wireless communication, represent home Wireless Sensor Network (WSN). Each home has WSN, and the sensed data are collected in a central station (sink) that is represented with the home sink. Home sink can be a smart meter or any other device that can perform data storage

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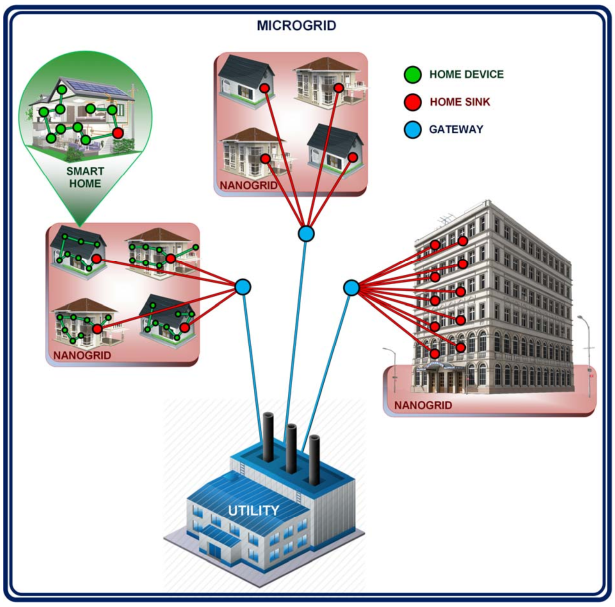

Fig. 1. Three-tier smart grid framework

and local processing (PC, tablet or smartphone). Each node of the network (home device) can accomplish advanced computational and communicational operations. Mesh is the most suitable choice for network topology due to presence of obstacles in the home, like walls, furniture, etc.

B. Second tier (Nanogrid)

On the next tier, all home sinks from the building can communicate with each other and exchange information. Here, the network topology can be both cluster-based or mesh, depending of the residential complex. In case of smart building, the mesh topology is more suitable, as smart meters cannot always send its data directly to the gateway (residential sink) due to obstacles in the building. If there are detached houses in the smart residential complex, then star topology or cluster topology is more appropriate solution, which can be accomplished using WiFi.

C. Third tier (Microgrid)

The gateways of all residential buildings communicate with the utility (through GPRS, 3G or optical fiber). This can be realized using cloud computing, as a state-of-the-art paradigm that is already commonly accepted for such problems. The typical information that can be exchanged between the gateway and the utility are: price of the electricity, current and future consumption of the microgrid, current and future production of the distributed production sources associated with the microgrid, etc. A utility is defined in a local context, e.g. distributed energy sources, like residential solar panel, residential wind turbine, etc.

III. State-of-the-art Smart Home Systems

There are a lot of commercial smart home systems on the market today [3]. Moreover, the terms “Home automation” and “Smart home technology” are still used interchangeable, although they should be differentiated.

TABLE I. Comparison of state-of-the-art smart home systems [4]

	Control4	Homeseer	Frontpoint	ADT Pulse	Savant	Vivint
Lighting	yes	yes	yes	yes	yes	yes
Heating/air conditioning	yes	yes	yes	yes	yes	yes
Smartphone connection	yes	yes	yes	yes	only for Apple	yes
Voice recognition software	no	yes	no	no	no	no
Fully customizable	yes	yes	no	no	no	no
Cost/price	1K-50K $	>500$	low	>100$	high	very high
Time to setup/easy to install	up to 2 days	hard, a lot of hard-wiring	easy	not trans-parent	Profess-ional installa-tion	Profess-ional installa-tion

In Table I we have compared some of the biggest players on the market regarding their functionalities, their advantages and disadvantages.

Unfortunately, these applications are designed for the first tier of the framework and none of them tend to integrate the devices on the second (neighboring) tier. This is not without a reason. Although technology is present for almost one decade now, smart home systems are still very costly solutions and can be afforded only by wealthy and upper-middle class people. Neighborhoods can be integrated only if all households have already installed such systems, which will be hardly possible. The cost of these systems is mainly due to their luck of interoperability. As a result, many smart home companies and devices have come and gone over the past few decades, as have many wireless standards.

It is expected that new leaders in this sector will be the companies that are major producers of electronic appliances. They have already installed communication interfaces in their gadgets, so it would be easier for them to achieve machine-to-machine communication for lower price. This should lead to dominance of companies like Samsung or LG, that have already launch their free mobile applications that can be used to remotely control the household.

Samsung Smart Home Application [5] enables users to easily connect with various Samsung home devices including refrigerators, washing machines, air conditioners, ovens, vacuum cleaners, room air conditioners, system air conditioners, air purifiers, lighting and more through smart phones and wearable devices. Users can connect mobile devices such as Galaxy Smartphones, Gears, and GearFits to smart home devices, and remotely access smart home services including status check, device control and customer support.

Of course, Samsung offers more reliable smart home solutions at greater prices. The SmartThings app offers a complete home monitoring and security solution that allows customers to get instant alerts if there's unwanted entry, smoke, leaks, or other unexpected activity. By adding a compatible camera, customers can also get accompanying video clips that capture footage of these events.

Google Nest [6] is another serious player ever since they launched their smart thermostat in 2011.

IV. Fog Computing for IoT Smart Home

Each device from the IoT framework can consume huge amount of energy if its communication is not optimized. Having in mind that for smart objects local computation is cheaper operation than communication, the effort should be shift toward developing lightweight algorithms for local data processing. Reducing the number of transmissions is also very important in order to avoid latency issues and saturation of the wireless channels, especially if using Z-Wave communication protocol [7].

For these reasons, different data reduction techniques should be employed. For example, if data are not needed in real time, data compression (like delta compression) can be used. In case of temperature regulation which is associated with smart home (heater, cooler), the device measurements are needed in real-time, thus compression is not appropriate solution.

A. Dual prediction scheme

Different filters have been proposed for real-time sensor data prediction, most of them based on adaptive filtering techniques. The prediction method is performed on each device and on the sink node, so predictions are made simultaneously at both sides. If sensed value differs significantly from predicted value (the difference is above a predefined threshold Emax), the IoT device should send the measurement to the sink node. Otherwise, the predicted value is considered as "reliable" and is used to feed the filter for future predictions. This paradigm is known as "dual prediction scheme", and was firstly introduced in [8], and later expanded in [9][10]. The detailed description of each of the modes is as follows:

1) Initialization mode:

The measuring IoT device keeps sending the data to the sink without making predictions. A certain amount of data must be collected in the beginning, so a proper estimation of the filter parameters can be made. Both the device and the sink compute the same value for the parameters.

After the initialization phase, both device and sink will continue to execute the predictive algorithm and device will be switching between the following two modes.

2) Normal mode:

Both the IoT device and the sink simultaneously execute the predictive algorithm and make a prediction for the following reading by using the last M readings and accordingly update the filter weights. If no a-priori knowledge is present, the initial weights should be zero.

The IoT device will stay in normal mode (collecting data and reporting it to the sink) as long as the prediction error is greater than the maximum error budget Emax. When the error drops below Emax for M consecutive iterations, then the IoT device switches to stand-alone mode i.e., stops reporting the readings and consequently stops updating the weights.

3) Stand-alone mode:

In this mode, the IoT device still collects data and

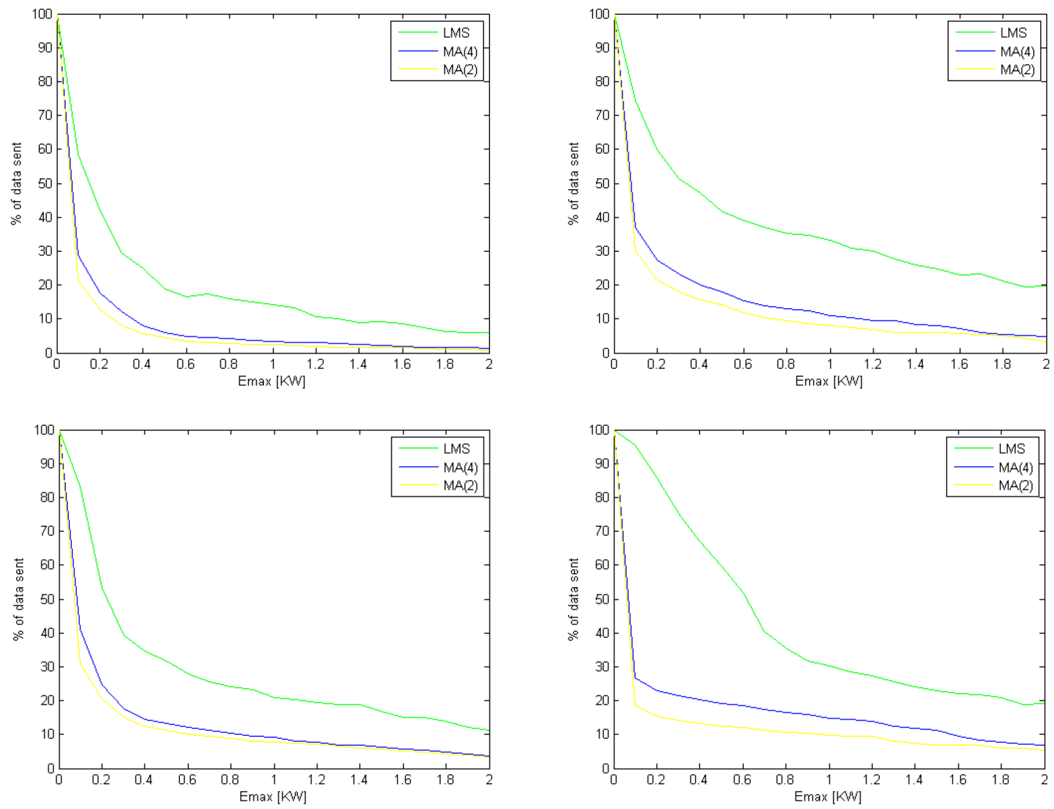

Fig. 2. Comparison of different filters for smart meter data prediction

makes predictions, but if the prediction error is below Emax, instead of using the measurements u[n], it feeds the filter with the prediction y[n], discards the real reading u[n] and does not send it to the sink. This enables both instances of the filter to be consistent and no update of the weights is needed (the error is zero) thus reducing the computational overhead.

If the prediction error exceeds Emax the IoT device switches to normal mode and reports the reading. When the IoT device is in this mode, the filter instance at the sink side uses only the predicted readings as an approximation of the real value.

B. Evaluation of Fog computing approach

In this paper, we evaluated three time-series forecasting methods i.e. one based on Least Mean Square (LMS) and two based on moving average (MA) models of second and fourth order.

The prediction can be performed on the first two tiers of the IoT-based framework. On the first tier, inside the smart home, the predictive filters are performed simultaneously at both the smart home appliance and at the smart meter. Smart meter should run separates filters for each smart home appliance, with the same parameters as the filters on the smart home appliance side. On the second tier, both smart meters and gateways aim to predict the overall household energy consumption. As smart meters always have the up-to-date information, by using predictive filter on the gateway side, there is no need to resend the current consumption unless it is above a predefined threshold.

The evaluation was done on real measurements from electricity usage, collected on minute-level from more than 400 anonymous homes [11]. We run the simulations for 20 different error margins Emax (ranging from 0.1KW to 2KW). We evaluated four different buildings chosen at random, with the aim to investigate whether the efficiency of the proposed solution is sensitive to the household characteristics. Fig. 2 presents the results and shows that using predictive techniques, number of transmissions could be reduced up to 95%, while maintaining desired data precision. These reduction levels are achieved regardless of the household characteristics. From the results, it can be concluded that MA(2) performs best and is very suitable for data prediction on second tier. Choosing the most suitable predictive filter is application specific. Therefore, we advise future developers of fog based IoT applications to experimentally confirm the best solution.

V. CONCLUSION

This paper presents a three tier IoT-based hierarchical framework for the smart home, as a reflection to the present lack of intelligent solutions that do not fully use the advantages of IoT technologies. Our framework aims to extend the smart home to microgrid level, in order to integrate all renewable distributed energy sources from the microgrid and to achieve better energy optimization. As an extension to the traditional data processing, we define fog computing approach for smart home, and prove that fog computing can be suitable solution in terms of reducing network traffic. Through simulation on real dataset, we showed that fog computing based on predictive filters can reduce the number of transmissions and minimize smart home network energy consumption.

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