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Smart Grid Communication Architecture Modeling for Heterogeneous Network Based Advanced Metering Infrastructure

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***Abstract*—**A smart grid is an emerging technology in the power delivery system which provides an intelligent, self-recovery and homeostatic grid in delivering power to the users. Smart grid communication network provides transmission capacity for information transformation within the connected nodes in the network, in favor of functional and operational needs. In the electric grids communication network delay is based on choosing the appropriate technology and the types of devices enforced. In distinction, the combination of IEEE 802.16 based WiMAX and IEEE 802.11 based WiFi technologies provides improved coverage and gives low delay performances to meet the smart grid needs. By incorporating this method in Wide Area Monitoring System (WAMS) and Advanced Metering Infrastructure (AMI) the performance of the smart grid will be considerably improved. This work deals with the implementation of WiMAX-WLAN integrated network architecture for WAMS and AMI in the smart grid.

***Keywords*—**WiMAX, WLAN, WAMS, Smart Grid, HetNet, AMI.

I. Introduction

THE evolution of electric distribution networks during the past century has introduced several challenges to the power grid in order to support reliable delivery of electricity in different deployment scenarios. Various domains of the electric network would need different kinds of communication systems, according to the information exchange requirements in each domain. Wireless communication network is capable to support QOS requirements of different service classes which are needed to transport the vast majority of traffic from diverse applications [1]. Two wireless network technologies are studied to support smart grid traffic, namely the Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX) standard [2].

The main characteristic of the WiMAX wide area network relies on the Orthogonal Frequency Division Multiple Access (OFDMA) which uses adaptive modulation codes (AMC) technique to support various applications QOS for the smart grid [3]. The communication network from the customer premises will be able to send local energy information to the energy service provider by supplying the server with various application requirements and their service QOS. The energy providers can use that information to supply the appropriate amount of energy in a sustainable manner to boost the electrical grid potency and to scale back the carbon footprint.

This paper is organized as follows: Section II describes the smart grid communication. Section III shows the proposed system. Section IV discusses the results of the simulations. Finally, Section V will provide the conclusion of this paper.

II. Smart Grid Communication

Smart grid is a communication network which stands between the application of information processing and digital data processing. The smart grid mitigates the challenges of current electric power supply system [4].

A. Smart Grid Technique

Nowadays, smart grid technologies are used in many applications like monitoring, substation automation, for the proper operation of electrical systems.

B. Sensing and Measurement

The main functions are to determine and prevent energy thefts, congestion control and monitor health and provide reliability to the grid. Various equipment used in smart grid are namely smart meters, meter reading equipment, WAMS and dynamic line rating.

C. Smart Meters

A smart grid replaces the manual meters with digital meters which monitor, record and report the readings periodically to data centers. AMI provides power from generating stations to the users in domestic and commercial applications [5]. The AMI devices installed in the consumer premises will be enabled according to the load profiles and the usage. The operational profile of the consumer devices depends on the consumption of energy and accordingly the AMI architecture will be implemented.

D. Smart Grid Framework

It contains a set of communication paths that need to be developed for the optimal behavior of the network. Fig. 1 shows the communication paths and the electric flows between the generation, transmission, distribution and control center.

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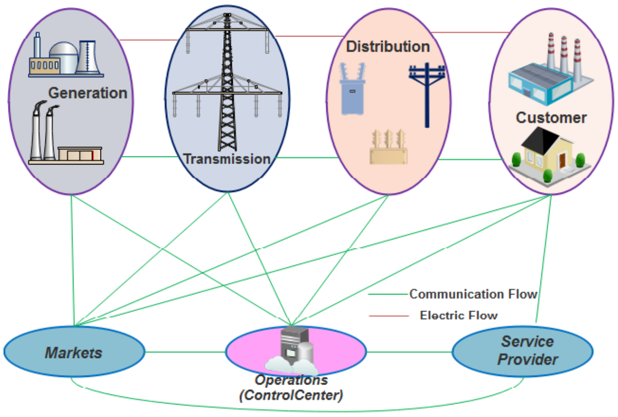

Fig. 1 Smart Grid Framework

According to the NIST model [5], a number of area networks have been proposed to support communications between devices, databases and controllers within a smart grid, because each domain has a different purpose, their devices use different applications that have different QOS requirements. Hence, the networks being chosen are Wide Area Networks (WAN) and Local Area networks (LAN) for the diverse network requirements [6]. Every domain has an intra-domain network that supports the communication across the devices of the specific domain. Also, secure communication channels should be created to transmit information across different domains.

III. Proposed System

In IEEE 2030 standard, HetNet architecture has been framed for AMI communication in smart grid [7]. As admitted in the standard, metering data management system (MDMS) is the data collector which collects the data periodically from the smart meters. It communicates with the smart meters through NAN and WAN as shown in Fig. 3. The NAN serves as a data aggregation point for WAN, that gains information from group of smart meters. The collected information is conveyed to the MDMS over WAN.

For this study, the NAN and WAN are imitated as WLAN and WIMAX respectively. The dual-mode WLAN\WIMAX router is the vital organizer for this architecture. In the IP layer the router executes protocol shaping as shown in Fig. 3. Since the WLAN and WIMAX are physically separated, so the smart meters need to communicate with the WWR only, which forbids the alteration in WLAN and WIMAX base station [8].

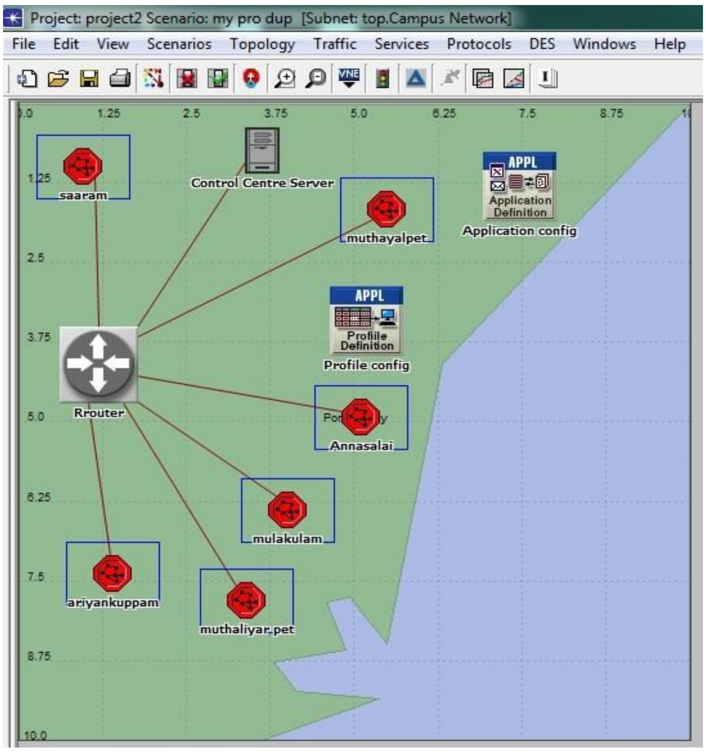

Fig. 2 Placement of Subnets in a Smart Grid Communication Network

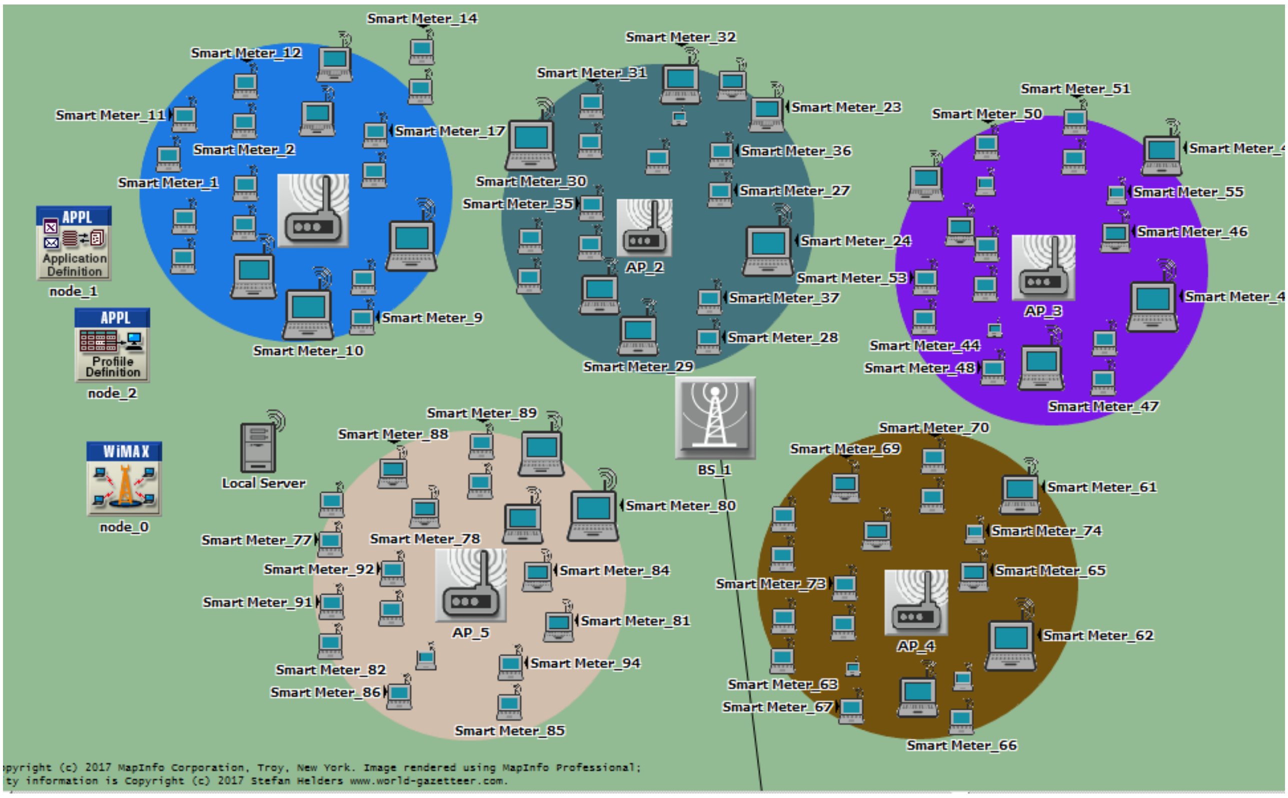

Fig. 3 Heterogeneous Architecture in Smart Grid

IV. Results and Discussion

This section analyses the performance of smart grid network using multiple applications and presents traffic model for multiple smart grid applications namely, metering data, demand side management, automation and sensor readings. These are the main traffic resources included in the smart grid communication network model to analyze its performance. Also, this section presents a simulation model used to incorporate the new applications, including the distribution and application models and the appropriate heterogeneous network parameters [9].

The smart grid is employed with different simulation parameters and their results help to conclude the analysis of coverage area, the range of users which can be included for a specific dimension. Fig. 2 shows the placement of subnets in the sub urban area. These subnets consist of multiples of randomly placed smart meters. All the subnets are connected to the ethernet2_slip8_gateway_42 router, which interconnects the subnets to the server which is located in the distribution station. The node model explains how the nodes are distributed within the service network coverage area of a smart grid.

The path loss model considered for the heterogeneous network based AMI simulation is SUI model. The basic path loss expression of the SUI model with correction factors is presented as [10] & [11]:

$$PL = A + 10\gamma \log_{10}\left(\frac{d}{d_0}\right) + F_c + F_a + S_c,\ for\ d > d_0 \quad (1)$$

where, d is the distance between BS and receiving antenna (m). d_0 is the reference distance 1000 m. F_c is the frequency correction factor for frequency above 2 GHz. F_a is the correction factor for receiving antenna height (m). S_c is the correction factor for shadowing (dB) and γ is the path loss exponent. The other parameters are defined as

$$A = 20\log_{10}\left(\frac{4\Pi d_0}{\lambda}\right) \quad (2)$$

where, λ is the wavelength (m). These nodes are distributed in the simulation environment to represent a typical neighborhood area network where smart meters are placed within the service area. The simulation model used in a single cell network with a radius of 2 km or 5 km for urban and suburban radio coverage area is used as presented in Fig. 3. The nodes are distributed randomly within the network area. This scenario provides a typical distribution of an average city. The application traffic generated parameters are shown in Table I.

TABLE I
PARAMETERS OF APPLICATIONS IN SMART GRID

APPLICATION	DISTRIBUTION	SIMULATED VALUE
Metering	Exponential	60 min
Automation	Uniform	15min to 45 min
Sensor	Uniform	1 min to 10 min
Smart Meters	Uniform	60 min

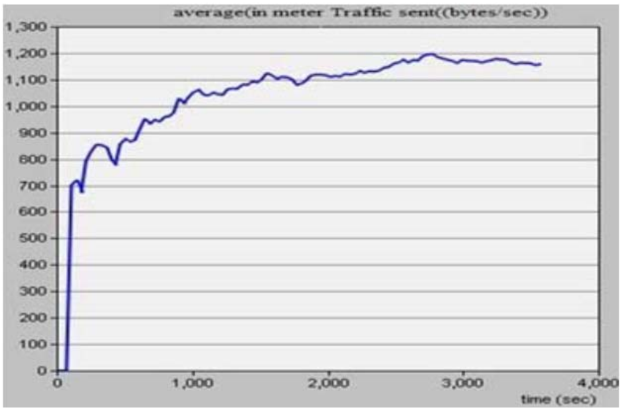

Fig. 4 Average WiMAX Throughput of Single Smart Meter

Fig. 4 shows the data gathered by the smart meters performing various applications with path loss and random distribution is presented in a 3 km cell. The values accounted are overall average throughput and WiMAX delay of single - smart meter as shown in Fig. 4.

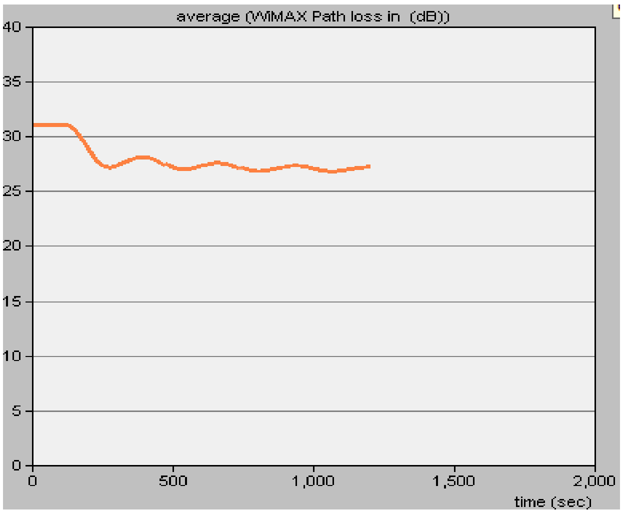

Fig. 5 Average path loss in dB

The average path loss for the proposed heterogeneous based AMI network for the WiMAX environment is shown in Fig. 5.

The average throughput value is approximately 24000 bps. With the fixed AP delays, there is an increase in the shorter reporting intervals in the presented WiMAX network. This is due to the effect of shorter reporting intervals. A lot of smart meters are targeted within the APs that will increase the bandwidth demand for every collective data burst. Even with identical polling delay, BS requires extra frames for bandwidth allocation. Due to this, both the data transmission delay and overall WiMAX delay increases as illustrated in Fig. 5.

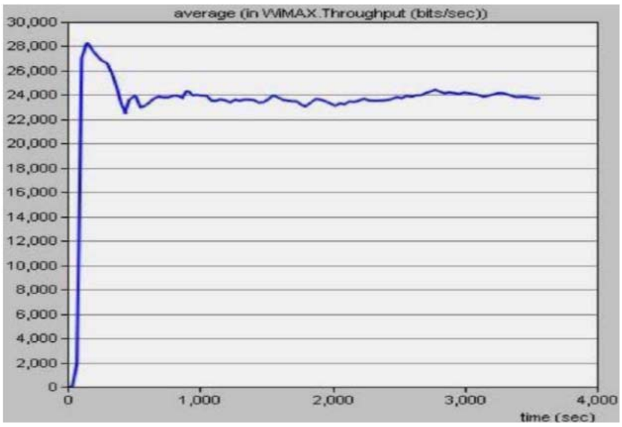

Fig. 6 Average WiMAX Throughput of Single Smart Meter

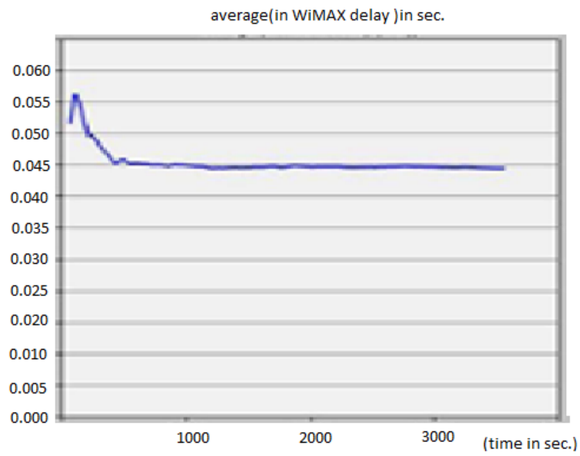

Fig. 7 Average WiMAX delay of Single smart meter

In Fig. 7 a delay average of 0.044 seconds is experienced when smart meters send packets to the WLAN access points. The number of admitted users is close to 100% for most of the scenarios as shown in Fig. 7. For larger cells, the number of admitted users is lower, particularly for BSS 4, 5 and 6. For the random distribution all cell sizes supported 100% of users. In the case of the circular distribution where all the users are located at the same distance, the admission failure is due to the shadowing fading; also it shows the relation between time and number of admitted users. In this case, the value is 800 bps, 300 bps more than the actual consign value. This is because the BS assigns extra bandwidth to nrtPS and rtPS for polling purposes, and avoids traffic starvation due to the usage of data bandwidth during polling.

In the secondary simulations the amount of users is increased up to 540 per cell by fixing the IPT values as 4 seconds. The final simulation is run in a 5 km cell with pathloss and random distribution. The UDP transmission mechanism helps to increase the transmission power to 2 w and also the IPT value increases up to 300 seconds by increasing the amount of users as 1500 simultaneously.

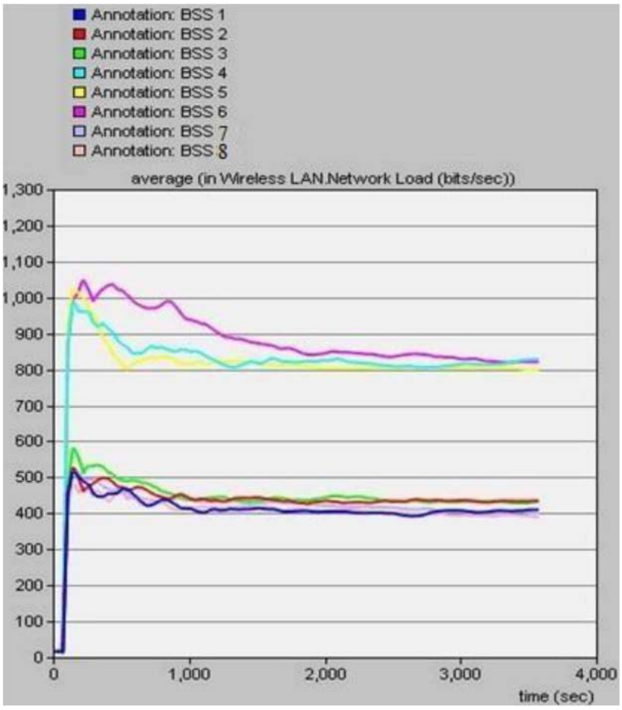

Fig. 8 Overall WLAN Network Load

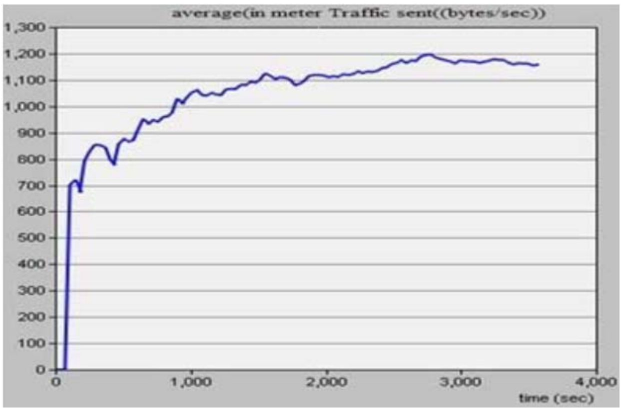

Fig. 9 Average Smart Meter Reading Sent

The smart meter reading traffic simulation model is illustrated in Figs. 9 and 10. The application model defines two versions of the smart meter reading. First, a File Transfer Protocol (FTP) based application is implemented with a packet size of 10 Kbytes through a DL confirmation message of 512 bytes from the server. A broadcast message to all users is sent from the server transmitting information about the network status. This message is 1.1 kbytes size. Second traffic model represents a single User Datagram Protocol (UDP) based application that is used to send the metering information in a 1 Kbyte file. In this case, no DL confirmation is implemented. The Message packet size has been changed along the different simulation scenarios to fulfill the application requirements. The traffic sent and received by the smart meters were varied in time due to polling and contention interval delay variations.

The packet sizes presented in this section are introductory values to provide information about connectivity, network entry and delay, and not full capacity analysis.

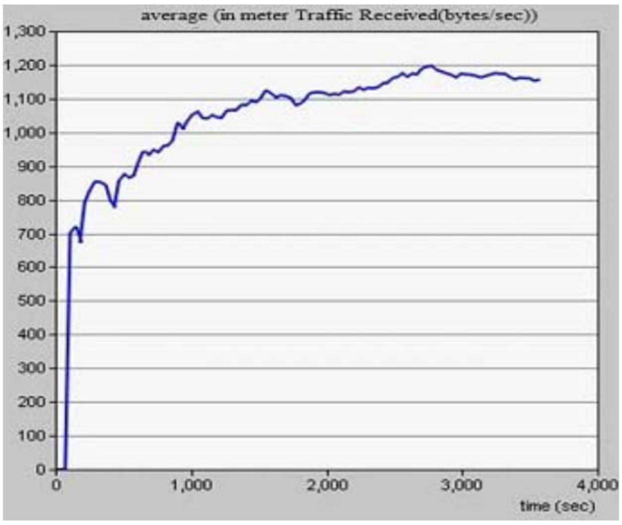

Fig. 10 Average smart meter reading received

V. Conclusion

The performances of the heterogeneous network in a rural AMI system are analyzed. In AMI the HetNet design promotes the results with the help of three applications. The AMI network reinforces a good variety of traffic generators with numerous QOS necessities using HetNet architecture. Whereas WiMAX has associate point to point quality of service framework, the WLAN gives restricted quality of service support at the MAC layer of IEEE802.11e standard. So, one amongst the foremost necessary challenges for the HetNet architecture is to keep up the point to point quality of service for every traffic category that is the amount of quality of service values among each sub network, that improves the coverage area and conjointly the number of smart meters. The future work incorporates improving the quality of services, by supporting various applications and traffic within a limited radio resource environment under different conditions of smart grid (normal, faulty and self-healing) for the WLAN\WiMAX Het Net architecture.

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