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Performance Analysis of WLAN-WiMAX Smart Distribution Grid

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Abstract— **The smart grid requires the integration of intelligent electronic devices such as Automatic Metering Infrastructure (AMI) in the distribution side. This Automatic Metering Infrastructure needs wireless communication technology for relaying information from the energy meters to the control center. In this paper, a Smart Distribution Grid (SDG) using WLAN-WiMAX technology is proposed. The proposed architecture significantly improves the efficiency of the Smart Distribution Grid at reduced cost. The performance of this WLAN-WiMAX communication architecture is studied and parameters like delay, Signal-to-Noise Ratio(SNR), packet drop etc., have been obtained using discrete event simulation model based on OPNET.**

Keywords- WLAN, WiMAX and Smart Distribution Grid.

I. INTRODUCTION

The present power grid is one of the greatest engineering achievements of the twentieth century. But, it is more outdated leading to blackouts. Due to this transformation efforts are underway to make the current electrical grid into smart grid. The smart grid modernizes the present electric grid for the purpose of enabling bidirectional flows of information and electricity in order to provide consumer's information regarding on how, when, and how much electricity they use. It is self-healing in case of disturbances, such as physical and cyber-attacks and natural disasters. The smart grid infrastructure links and utilizes energy sources including renewable energy producers and mobile energy storages. The smart grid infrastructure provides better power quality and more efficient delivery of electricity[1]. These goals can be realized with a communication technology infrastructure that will gather, assemble, and synthesize data provided by smart meters, other intelligent electronic devices and information technology systems.

While there are many discussions and proposals on a suitable architecture for smart grid communication network is available, there is no detailed simulation evaluating the exact performance of WLAN-WiMAX technology. This work aims to fill this gap by presenting a multi-service network model for smart electric distribution systems. We consider both direct and aggregate network architectures and their respective features. We propose different direct and aggregation-based communication architectures and try to find out whether the WLAN-WiMAX technology can satisfy smart grid quality of service requirements, namely latency and reliability.

The rest of this paper is organized as follows. Section II gives an overview on WLAN-WiMAX standard features, surveys some of the current WLAN-WiMAX deployments in SDG. In Section III, our SDG system model architectures are presented. Comparison between these architectures through OPNET simulator is presented in Section IV, and concluding remarks are provided in Section V.

II. SMART DISTRIBUTION GRID ARCHITECTURE

The architectural overview of the smart grid is depicted in Fig. 1. The smart grid has a tiered architecture to supply energy to consumers. Energy starts from power generation plants and flows through transmission systems to distribution and finally to consumers. The smart grid integrates and coordinates various generation and production mechanisms. The transmission and distribution grid delivers the energy to the consumers [2].

This paper concentrates more on distribution part of the smart grid specifically the Home Area Network (HAN) and the Neighborhood Area Network (NAN). These networks are very essential for data communications between the utility and the end users. HANs are composed of three components: first, the smart in-house devices that provide demand side management such as energy efficiency management and demand response along with renewable energy sources; second, the smart meter that collects data from smart devices and invokes certain actions depending on the information it retrieves from the grid; and third, the HAN gateway, which refers to the function that links the HAN with the NAN. This gateway can also represent the physical device dedicated to performing this functionality. A NAN connects multiple HANs to local Access Points (AP) where transmission lines carry the data out toward the utility.

A smart distribution grid has some important characteristics, e.g., 1) it is integrated with distributed energy sources such as solar cells, wind turbines, or electric vehicles (EVs); 2) power flows do not necessarily follow a single direction from a generator to an end device; instead, the distributed energy source can send power directly to customers or even to power grid, which results in multidirectional power flows; 3) electric devices and power meters must be intelligent to enable dynamic power dispatching; 4) it provides dynamic pricing [3].

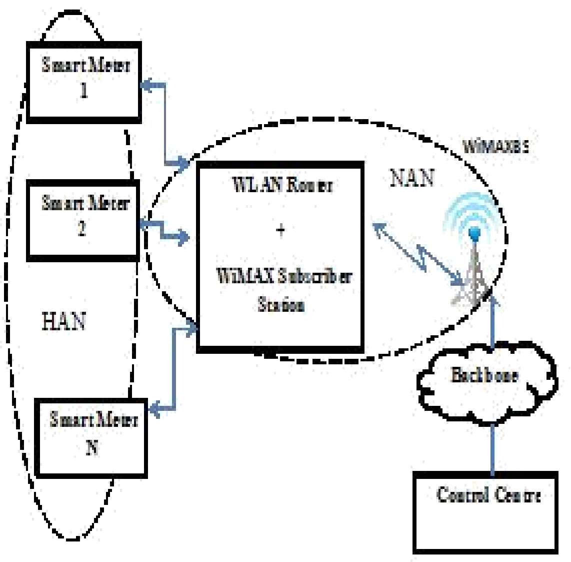

Fig. 1 WLAN-WiMAX Hetnet architecture

In our proposed architecture, we are considering the AMI infrastructure through WLAN-WiMAX by which the cost and efficiency of the smart grid can be significantly improved.

A. HAN Communication Mechanisms

The AMI is the key element in smart grid HANs. The AMI measures, collects and forwards the data to the power grid through the supporting information architecture. For this to be possible Wireless LAN and WiMAX are promising candidates.

Wireless LAN 802.11 is a set of standards developed for wireless local area networks (WLANs). It specifies an interface between a wireless device and a base station (access point) or between two wireless devices (peer-to-peer). On one hand, it can be declared that the WLAN (802.11) technology may be a feasible solution in a HAN. As a result, all smart devices should be equipped with an embedded WLAN adapter [4]. Those devices would directly communicate with a WLAN home gateway that could also be a WLAN enabled smart meter. WLAN, with its open standards, high throughput, strong home market penetration, good economics, and relatively secure communication, is a suitable choice in a HAN.

B. NAN Communication Mechanisms

The next intermediate tier in the communication architecture of smart grid is NAN. This type of network provides two-way communication between the WLAN/WiMAX router and the base station. Its infrastructure is critical since it connects multiple HANs and gathers energy consumption information from customer premises to the control center. A NAN enables monitoring and control of power distribution network to enhance the power delivery.

The Smart Grid Working Group emphasis WiMAX technology for smart grid network. WiMAX is a wireless communication standard which was released within 802.16 series standard with the objective to achieve worldwide interoperability for microwave access. WiMAX provides links between a base station and a home gateway. The cost associated with the deployment of a WiMAX network is low compared with other wireless standards. It operates in (2.3, 2.5 and 3.5 GHz) in licensed spectrum and operates in 5.8 GHz in unlicensed spectrum. It provides data rate upto 70 Mbps and coverage area of 50 Km. WiMAX can be implemented in various topologies such as point-to-point, point-to-multipoint or hybrid for the data transfer from the meters to the utility.The specific advantage of hybrid network is that it uses both licensed and unlicensed band which increase the spectrum efficiency of the system without changing the interference margin.

The Smart Grid Working Group acts as a major point for utility interests in WiMAX as a technology for smart grid networks [5]. Thus, it promotes WiMAX as a core communication technology for NANs. Furthermore, WiMAX is a broadband wireless last mile technology that can support smart grid distribution. As a result, WiMAX can be implemented between a base station and the home gateway. The smart meter would collect smart devices data and then forward them to the home gateway, which has the interoperability property to comprehend WiMAX communication. The home gateway is in fact a subscriber station (SS) in the HAN. The SS would collect the data from the smart meter and send it to the NAN through a WiMAX dedicated connection. To complete the data transfer toward the utility, point-to-point, point-to-multipoint, or hybrid (multihop relay) WiMAX topologies can be implemented. WiMAX, with its high throughput, significant smart grid standardization and working groups, backhaul media for Wi-Fi or ZigBee in-premises devices, and interoperability features, is very applicable as a NAN communication technology.

Utilities are deploying smart meters in the AMI network to collect measurement datas from residential and commercial meters such as (energy, voltage, power etc.,). AMI also provides utilities with data related to meter reading, outages, restoration operation. The coverage area of a wireless network are mostly limited due to noise, fading, multipath propagation condition in an AMI application. Since the meters are present in a fixed location they may remain under poor coverage area. This problem can be overcome by denser deployment of base stations. However it increase interference thereby deteriorating the propagation environment. Deployment of IEEE802.16 based WiMAX relays is another solution to overcome this problem, but it also increase latency and interferances. If we use both IEEE 802.11based WLAN and IEEE 802.16 based WiMAX networks in the AMI environment it significantly improves the coverage area, transmission latency and interference[6].

In this paper, we share some of our studies on a WLAN-WiMAX Hetnet architecture for smart meter communications in the smart grid architecture. The architecture and interworking of the WLAN-WiMAX Hetnet that has been adopted for this study has been described. Based on the basic numerical analysis, the Hetnet architecture can provide significantly improved coverage than that of a standalone WiMAX network by bringing connectivity closer to the devices. Using discrete event simulation models based on the OPNET simulation package, we examine the and performance of the Hetnet architecture and benchmark the results against a standalone WiMAX network[7].

The rest of the paper is organized as follows. Section II describes the architecture and interworking of the Hetnet for AMI communications. In section III, the proposed WLAN-WiMAX smart grid architecture has been discussed. The performance of WLAN-WiMAX network is presented in section IV. Finally, section V concludes the paper and provides direction for future works.

III. WIMAX-WLAN SMART GRID ARCHITECTURE

The IEEE 2030 standard for smart grid has outlined heterogeneous communication architecture for AMI communications. Based on the standards a smart meter can communicate with the control center by a point to point connection from the wide area network or through the Neighborhood Area Network (NAN) as shown in figure1. The information sent from the various smart meters are aggregated by a data aggregation point (DAP) present in the NAN. All the WLAN routers in the NAN will send the aggregated data to the control center through the WAN. In this proposed architecture we assume that WLAN and WiMAX networks will serve the NAN and WAN respectively[8].

The WiMAX/WLAN router (WWR) performs protocol adaptation in the IP layer and provides internetworking between the NAN and WAN devices. The advantage of such networking is that the networks are physically separated and the meters need to interact with the corresponding WWR only. The AMI communication traffic in this study is assumed to be scheduled meter interval reads, where a utility obtains interval usage information from smart meters in 15-minute intervals. Smart meters are separated into five groups. Each group sends out their consumption packets to control center through the base station in assigned time periods. The size of consumption packet is chosen as 128 bytes. All meters must report their consumption in 15-minute intervals. In practice, each meter sends out its packets at a random time. For simplicity in interpreting the result, this study assumes that all smart meters in each group sends all packets at the same time, at two minute apart for each group only [9].

IV. PERFORMANCE EVALUATION

To evaluate the performance of smart grid network, the WLAN-WiMAX Hetnet scenario was developed with different number of user distributions. The first scenario is developed with two WLAN-WiMAX networks connected to single WiMAX BS each with five numbers of WLAN users and one WiMAX user as shown in figure2. The second and third scenario is developed with 10 and 20 users each respectively.

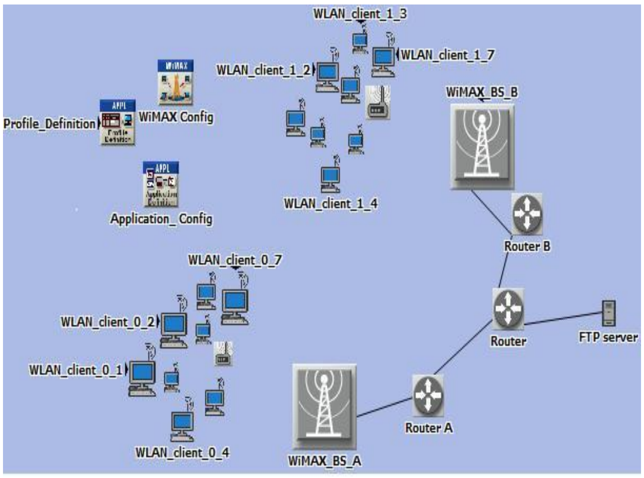

Fig. 2

The application service that has been considered is FTP service. Table I presents the basic simulation parameters of WLAN and WiMAX. The simulation results of Signal-to-noise (SNR), packet drop and delay are discussed below.

TABLE I
SIMULATION PARAMETERS OF WLAN AND WIMAX

PARAMETERS	WLAN	WiMAX
Operation mode	802.11a	802.16e
Data rate	11Mbps,	100Mbps
	24Mbps	
Maximum	0.05dB	0.5dB
transmission power		
Physical	Direct	
characteristics	sequence,	OFDM
	OFDM	
Range	100m	50 kms

A. Delay performance

The performance of delay for three different types of users distribution is shown below for simulated Hetnet scenario. The increase in delay with the increase in number of users for both WLAN and WiMAX networks is shown in Fig. 3 and Fig. 4 .

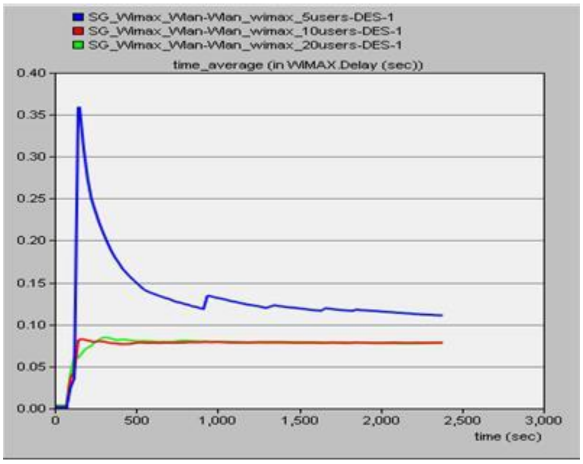

Fig. 3. WiMAX delay in Hetnet scenario

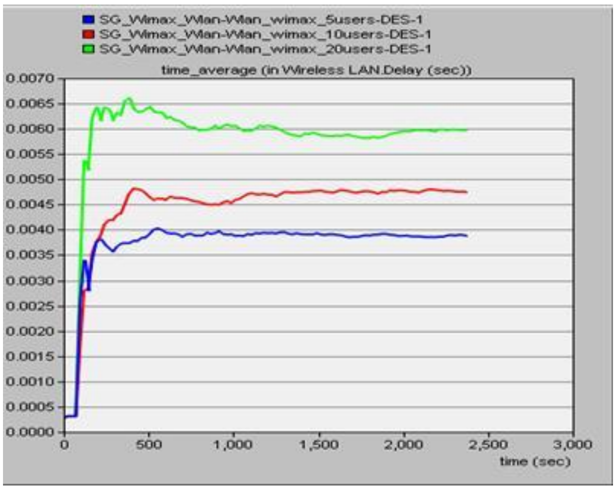

Fig. 4 WLAN delay in Hetnet scenario

This is due to the same start time of message transmission and also the scheduling service should be fast enough to serve the BW request on time. Fig. 5 shows the delay performance of two scenarios in which physical channel characteristics and data rate are changed from direct sequence with 11 Mbps to OFDM with 24 Mbps respectively.

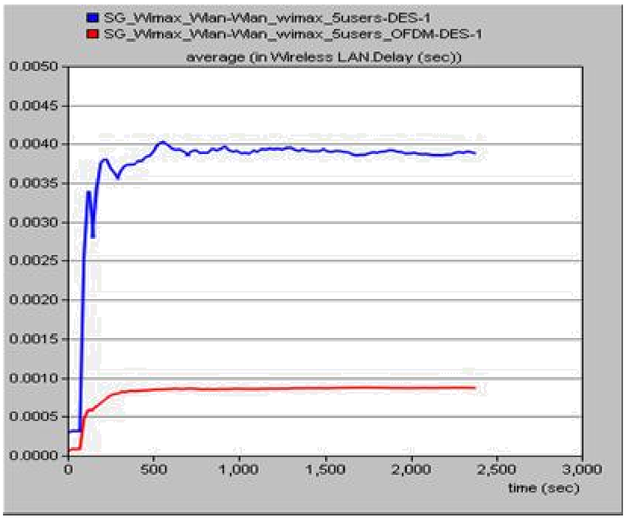

Fig. 5. WLAN delay in Hetnet scenario

When network bandwidth is high, network throughput, and network utilization are high, while on the other hand, propagation delay of the network is decreased. The result shows that OFDM offers better delay performance when compared to that of direct sequence.

B. Performance of SNR

The SNR values for three different types of users distribution is shown below for simulated Hetnet scenario. Fig. 6 shows the decrement of SNR value for increased number of users.

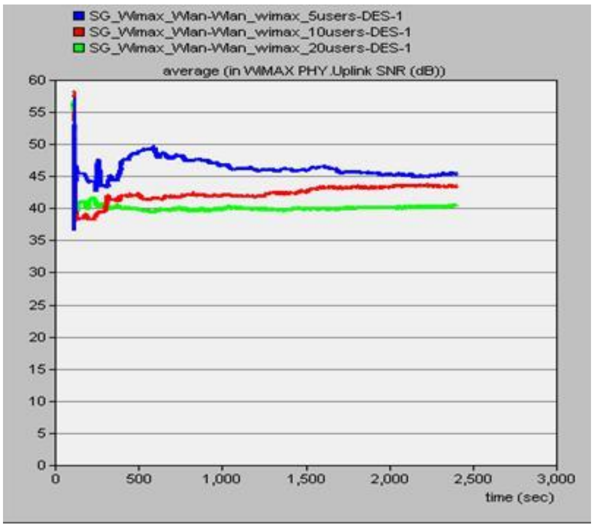

Fig. 6. WLAN delay for different physical characteristics

Fig. 7 shows that OFDM holds poor SNR ratio when compared to that of direct sequence channel.

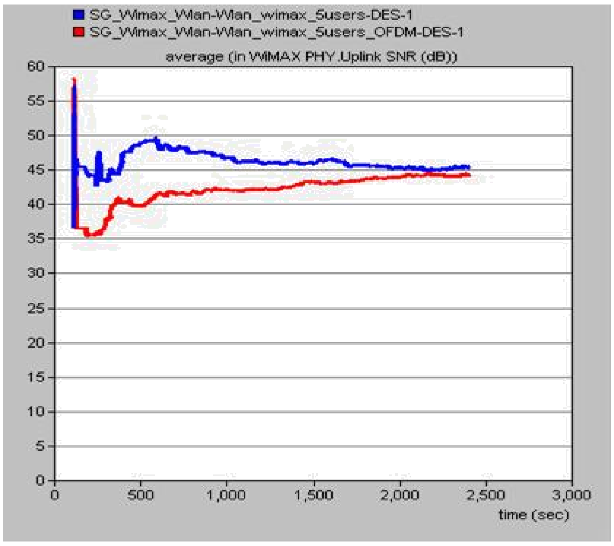

Fig. 7

C. Packet Delivery

Packet delivery ratio gives the ratio of the number of delivered data packet to the destination. This illustrates the level of delivered data to the destination. Fig. 8 shows that increase in number of users results in losses of packets delivered due to the buffer overflow.

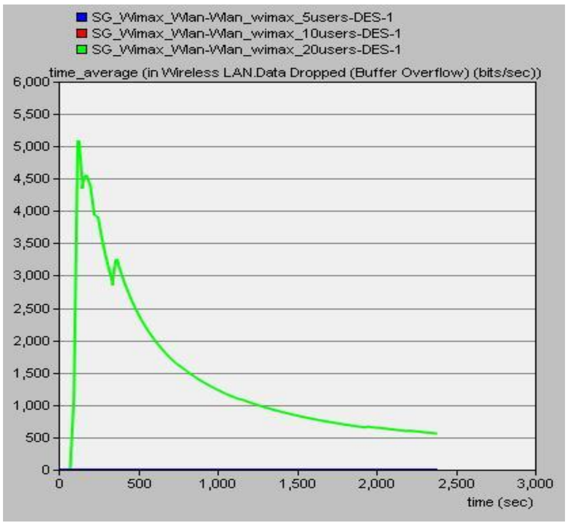

Fig. 8

V. CONCLUSION

The design of Smart Grid communication systems is an emerging research area. This work is an introduction to the WLAN-WiMAX communication network to provide communication channels for the smart grid applications. The paper presented the performance of different variables in WLAN-WiMAX grid applications. Results show that WLAN-WiMAX services are able to support and fulfill the needs of metering application. The simulations carried out in this paper has can be used to analyze larger scale smart meter networks based on this research.

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