Evaluation of WiMAX Technology in Smart Grid Communications

Ban A. Al-Omar[1], Taha Landolsi[2], and A. R. Al-Ali[2]
[1]Higher Colleges of Technology, Al-Ain Colleges, UAE
[2]Computer Science and Engineering Department, American University of Sharjah, UAE
Email: ban.alomar@hct.ac.ae; {tlandolsi, aali}@aus.edu

Abstract**—**This paper proposes a design of IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX) network to serve as a wireless communication platform for the smart grid. The grid traffic is classified into five priority classes. The traffic then is scheduled using three scheduling algorithms namely; Class-Based Weighted Fair (CB-WFQ), Class-Based Deficit Weighted Round-Robin (CB-DWRR) and class-based strict priority (CB-SPQ) scheduling. Simulation results show that no more than 450 smart grid devices should be used to satisfy the delay requirement of class 1 and class 2. The results also demonstrate that the CB-SPQ scheduling algorithm provides the best delay performance. As for class 3 applications, results show that in order to satisfy the latency requirements, the maximum number of smart grid devices that can be placed in a cell should not be more than 250. For this application class CB-WFQ outperforms the other scheduling algorithms. For class 4 applications, a cell can accommodate up to 450 smart grid devices, and CB-WFQ scheduling algorithm yields the smallest latency.

Index Terms**—**Smart grid, traffic classification, WiMAX, queuing systems, Quality of Service (QoS)

I. Introduction

The smart grid conceptual model was developed by the National Institute of Standards and Technology (NIST) in January 2010 [1]. The model divides the grid into three conceptual layers namely; physical, communications and information layers.

The physical layer consists of the energy and power stations such as generation, transmission, distribution and consumption. The information layer is a set of software packages that are responsible for the grid operation and control such as demand response, demand side management, outage management, distribution automation, and overhead transmission line monitoring and power consumption. The communication layer is the data transfer and exchange networks that link the above mentioned power subsystems with the information layers.

Among the three layers, the communication layer is evolving in a way that enables the grid to expand to a wider geographical area.

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This work was supported by the American University of Sharjah.
Corresponding author email: aali@aus.edu.
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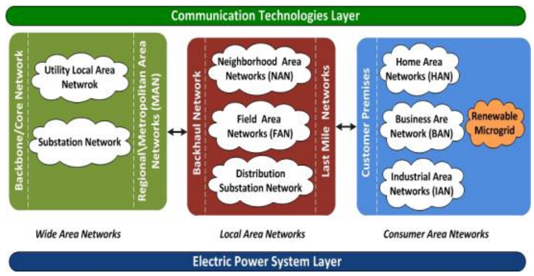

Fig. 1. End-to-End smart grid communications model

The proposed simplified end-to-end smart grid communications model in Fig. 1 shows that there are three major communications networks. These networks are Consumers Premises Networks (CPN), Distribution Substation Networks (DSN) and Wide Area Networks (WAN). Each of these networks has a unique set of functions and may utilize different technologies as discussed below:

- **Consumers Domain Networks (CDNs):** They have three sub-networks: Home Area Network (HAN), Business or Building Area Network (BAN) and Industrial Area Network (IAN). The CPN major functions are the transfer and the exchange of energy meter readings, power measurements parameters, demand side commands, smart appliances status to home gateway.
- **Distribution Domain Networks (DDNs):** They include four networks: Neighborhood Area Network (NAN), Field Area Networks (FAN), Last Mile Networks (LMNs), and Backhaul Networks (BHN). The functions of these networks are to transfer and exchange data and commands between various smart grid applications such the smart meter readings, demand-side management, advanced home energy management, accommodation of electric vehicles switches, reclosers, phase measurements, automated fault detection, workforce and distributed renewable energy resources.
- **Generation and Transmission Domain Networks (GTDNs):** They consist of four networks namely; substation LAN (SLAN), Control Center LAN (CCLAN) and Regional Networks (RNs). These networks transfer and exchange data and commands between the distribution domain networks, the zone substations Remote Terminal Units (RTUs), fault detections, wide Area situational awareness system

data, corporate data, transmissions and distribution automations, distribution management, on video conferencing, mobile voice and data, market and outsource service provides.

This paper proposes a design of an IEEE 802.16 worldwide interoperability for microwave access (WiMAX) network to be used for smart grid communications. A simulation model is developed based on the smart grid applications requirements and the IEEE 802.16 WiMAX network parameters. Bandwidth, latency, priority, and some other Quality of Service (QoS) parameters are used to categorize the smart grid applications into five different priority classes. These classes are mapped with the Differentiated Service Code Points (DSCP), and WiMAX service flows such as real-time, non-real-time and best effort. Aggregated data are queued and scheduled using three different scheduling algorithms; namely Class-Based Weighted Fair Queuing (CB-WFQ), Class-Based Deficit Weighted Round-Robin (CB-DWRR), and Class-Based Strict Priority (CB-SPQ). The expected outcome is to find out which scheduling algorithm that suits best the smart grid applications.

The communication network allows the integration of all applicable components in the smart grid [2]. Furthermore, it allows appropriate communication scenarios among various stakeholders to better operate and manage the multiple components that build the smart grid at large. Simulation models are developed to evaluate the network performance based on pre-defined QoS requirements in order to explore the possible solutions for the grid.

The rest of the paper is organized as follows: Section II reviews a survey of the recent existing research activities in smart grid communications. The proposed smart grid applications traffic classification and the WiMAX communication network model will be presented in Section III. The proposed simulation algorithm is detailed in Section IV. Simulation results analysis and discussion are presented in Section V followed by the conclusion.

II. Recent Research Activities in Smart Grid Communications

The DDNs are smart grid networks with longer range than HANs. Several wired and wireless network technologies and communication protocols are used such as Power Liner Carriers (PLC), GSM/GPRS, DASH7, Satellites, WiMAX and Long Term Evolution (LTE) [3] –[8].

However, the capabilities of WiMAX standard may allow the implementation of different communication scenarios for the smart grid. WiMAX standard can serve as a backhaul or a point-to-multipoint access network. In addition, WiMAX can provide full end-to-end QoS that makes it a good alternative for smart grid communication networks [9]. So far, few researches have been carried out to investigate the performance of WiMAX networks for end-to-end smart grid applications, which is the main objective of this paper. WiMAX utilization in smart grid is still marked as on-going Research and some solutions are still under testing [3], [10]. Therefore, this paper proposes new a WiMAX design model. The model takes into consideration the smart grid applications latency, reliability and priority requirements as well as the network QoS.

Ongoing WiMAX researches in the smart grid have reported good simulation results. A simulation model for smart meter readings was conducted based on WiMAX network architecture [11]. The readings are non-real-time with time latency of 1-5 sec. The authors used one of the WiMAX service flows parameters namely; non-real-time Polling Service (nrtPS) and 2-5 km radius cells [11]. Results have showed that polling services are able to support and fulfill the needs of metering application. Even though this study is considered a milestone one and the pioneer, it is based on one smart grid application and one service flow.

A recent WiMAX smart grid last mile communication model (SGLM) was discussed in [12]. The model divided the last mile smart grid applications to three different priority classes namely; mission critical, real time and non-real time. It divided the applications into four latency classes very LOW (3 ms), followed by LOW (16 ms), MEDIUM (160 ms) and an unbounded HIGH latency class (greater than 160 ms) [3]. Using a discrete-event simulation, it was found that the lack of persistence of real-time flows was at very low bit rates. However, the authors concluded that the WiMAX Network is rich communication media for smart grid last mile traffic, but they will require engineering efforts.

Another WiMAX network simulation model was developed for the smart grid Wide Area Monitoring and Control (WAMC) application [13]. The proposed model utilized the real-time Polling Service (rtPS), Unsolicited Grant Service (UGS) and Best Effort (BE) scheduling algorithms to analyze the grid preference using the Phasor Measurement Units (PMUs) readings. It was found that the BE is the worst and rtPS is the best.

III. System Model

A. Proposed Smart Grid Applications Traffic Classification

In order to find the WiMAX optimum networks design for the smart grid data and commands exchange, the smart grid applications have been classified into five priority classes; class 1 being the highest priority and class 5 being the lowest priority. This classification is based on the bandwidth, latency and reliability requirements shown in Table I: Bandwidth range is from 9.6 kbps to 100’s of kilobytes and latency range can vary from 4 ms to several minutes.

For example, substation automation has the highest priority class; it is a mission critical control application that requires 15 to 200 ms latency and 96-56kbps bandwidth [14].

The smart grid applications are mapped along with the proposed classes based WiMAX Service Flows (SF) (Table I and the differentiated service code points Table II). The network has five different service flows that take into account whether the smart grid application requires Unsolicited Grant Service (UGS), extended real time Polling Service (ertPS), real time Polling Service (rtPS) non real-time Polling Service (nrtPS), or Best Effort (BE) [15].

In addition, each class has another major QoS metric called the Differentiated Service Code Point (DSCP). It is used to reserve the network resources based on priority traffic classes rather than individual service flows. The DiffServ classes are Expedited Forwarding (EF), Assured Forwarding (AF), Class Selector (CS) and default Diffserv [16].

TABLE I: SMART GRID APPLICATIONS QOS REQUIREMENTS [3]

Smart Grid Application	DSCP	Bandwidth (kbps)	Latency Traffic	Type
Substation Automation	67, 64	9.6 -56	15-200 ms	Periodic 15-60 minutes
WASA	55	600 - 1500	15-200 ms	Periodic/Random
Outage Management	43	56	2000 ms	Random
Distribution Automation	33	9.6 -100	100 ms -2 s	Periodic
DER		9.6 -56	100 ms -2 s	Random
Smart Meter	15	10-100 /meter 500 /concentrator	2000 ms	Random
Demand Response	31	14 - 100	500 ms-min	Continuous
DSM	11	14 – 100	500 ms-min	Occasional
Assets Management		56	2000 ms	Random

For the smart grid applications, at the network point of entry, the DSCP is calculated for each application [17]. A mapping between the DiffServ classes and WiMAX service classes is performed based on the QoS characteristics such as delay, jitter and packet loss tolerance. Table II shows the mapping between Diffserv classes and WiMAX service classes.

TABLE II: MAPPING BETWEEN DIFFSERV AND SERVICE FLOWS

WiMAX MAC Services	Diffserv Class
UGS	EF
rtPS	AF2 , AF3
ertPS	AF4
nrtPS	AF1
BE	Default

The smart grid applications are classified and assigned to three WiMAX service classes, i.e. rtPS, nrtPS and BE. Based on this classification and the mapping between the DiffServ and WiMAX service classes shown in Table II, new tailored DSCP implementation is proposed for supporting smart grid applications.

For example, the smart meter application data is divided into periodic and non-periodic traffic (mission critical). The DSCP is used to distinguish between these traffics by assigning relative priority weight for each. In this example, the DSCP relative priority weights are 15 and 31 for the periodic and the non-periodic traffic, respectively.

B. Proposed WiMAX Network Topology

After classifying the smart grid applications based on the QoS requirements, A WiMAX network architecture is proposed. In this topology, each application has a dedicated bidirectional connection to the command and dispatch center i.e.it is a point to multipoint topology. This topology is useful for suburban and rural areas where the average number of smart meters is about 800/km^2 and 10/km^2, respectively. In addition, there is no need for that number of distributed transformers. It is expected that this design will serve more consumers per WiMAX cell because the aggregation and the service of data as well as the commands take place at a single point, i.e. the command and dispatch center. Fig. 2 shows the proposed network.

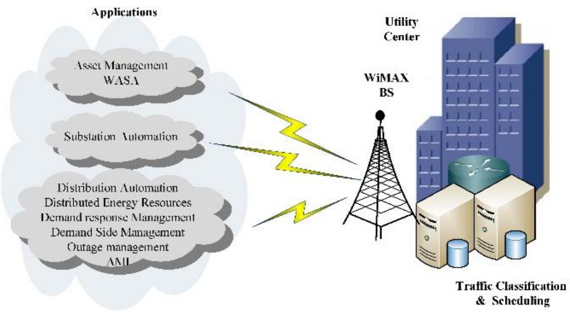

Fig. 2. WiMAX traffic generated from smart grid applications is forwarded to the utility center.

C. Scheduling Techniques

Each device has local scheduling mechanism where the generated traffic is locally queued based on the traffic service flows. Then, the local queues contents are forwarded to the base station uplink scheduler for further processing [18]. Based on the QoS parameters, the base station uplink scheduler determines the transmission period and the burst profile for every connection [19].

This paper proposes three different uplink scheduling algorithms namely; CB-WFQ, CB-DWRR and CB-SPQ.

- **CB-WFQ:** The smart grid applications have multi-classes traffic applications which make it a good candidate to utilize a scheduling algorithm such as CB-WFQ that is used in multi-class traffic environment. CB-WFQ is used mainly to enhance fairness by giving lower priority queues the opportunity to transmit packets even if higher priority classes are not empty [20].

One of the major processes of the CB-WFQ scheme is a weight assignment to each class queue. This process specifies the decided bandwidth ratio that will be dedicated to the queues. The weights are assigned to reflect the relative priority and QoS requirements for each traffic class. Based on the bandwidth ratio, the CB-WFQ scheduler examines the traffic classes' queues and forwards the selected packet to the output link accordingly.

- **CB-SPQ:** This queuing algorithm transmits the highest priority packets first. Once the higher priority queue is empty, the next priority queue packets are transmitted.

This feature is most suitable for the smart grid applications that require the fastest response time. In this context, the wide area situational awareness and substation automation application requires 15–200 ms response time compared with the 2000 ms response time in the smart meter application.

- **CB-DWRR:** CB-DWRR visits non-empty queues and determines the number of bytes of the packet at the head of the queue. The variable deficit counter is incremented by the value quantum. When the size of the packet is larger than the variable deficit counter, the system scheduler skips the queue and moves on to serve the next queue.

If the size of the packet at the head of the queue is less than or equal to the variable deficit counter, then the variable deficit counter is reduced by the number of bytes in the packet, and the packet is transmitted on the output port.

The scheduler continues to de-queue packets and decrement the variable deficit counter by the size of the transmitted packet until either the size of the packet at the head of the queue is larger than the variable Deficit Counter, or the queue is empty. If the queue is empty, the value of the Deficit Counter is set to zero. When this occurs, the scheduler moves on to serve the next non-empty queue [21]. Fig. 3 shows the queuing model of each network node [22], [23].

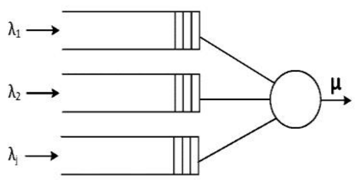

Fig. 3. Queuing model of each network node in the proposed architecture [22], [23].

D. Queuing Model

This study proposes a single server multiple queue system scheduled with different schemes, i.e. CB-WFQ, CB-DWRR and CB-SPQ. The scheduling schemes are used for bandwidth scheduling. Five separate queues Q_j with exponentially distributed inter-arrival times ($1/\lambda_j$) and service rate μ_j where j is the traffic class, is used to host five classes of traffic. The queues have finite capacities L_j and follow a First-In First-Out (FIFO) queuing approach.

The arrival rate λ_j of each queue can be further broken down to $\lambda_{(i,a)}$ probabilities, which one represents the arrival probability for i-priority packets generated from smart grid application a, where $a = 1 \cdots k$ and k is the number of applications that belongs to the same priority class. It holds that:

$$\lambda_j = \sum_{a=1}^{k} \lambda(i,a) \tag{1}$$

Each priority queue Q_j is assigned a weight, which specifies the bandwidth ratio that will be dedicated to that particular queue. The weights of the classes are determined according to their QoS requirements.

$$w_j = \frac{BW_j^{req}}{\sum_{j=1}^{p} BW_j^{req}} \tag{2}$$

where, BW_j^{req} is the bandwidth required for each traffic class in bit per second, p is the number of traffic classes, i.e. five .

In WiMAX standard, time frames are divided into a constant number of time slots S with same time-slot duration (5 milliseconds). Therefore, priority queues Q_j are allocated a number of time slots according to their weights.

$$S_j = S w_j \tag{3}$$

where S is the total number of slots and S_j is the allocated number of slots for class j .

To calculate the end-to-end delay for processing a complete smart grid application request, let $D_{(i,n)}$denotes the delay of the packet i at the nth hop of the network [24]–[26].

$$D_{(i,n)} = D_{(n)} + D_{Q(i,n)} + D_{S(i,n)} + D_{R(i,n)} \tag{4}$$

$$D_{(n)} = d_p + d_g + d_t + \mu \tag{5}$$

$D_{Q(i,n)}$ is the queuing delay and can be calculated by the following equation:

$$D_{Q(i,n)} = T_{(a,n)} - T_{(d,n)} \tag{6}$$

where $T_{(a,n)}$ and $T_{(d,n)}$ respectively are the arrival and departure time of the i^{th} packet at the n^{th} hop of the network. $D_{S(i,n)}$ is the scheduling delay, which is defined as the time interval from the end of sending a corresponding bandwidth request message to the time when the corresponding BS grant becomes the first one in the BS grants shared buffer. $D_{R(i,n)}$ is the reservation delay, which is defined as the time interval from the packet arrival at the smart grid device to the start of sending a corresponding bandwidth request message to the BS. d_p is the processing time, which is the time a BS or smart grid device spends processing a packet; this includes error checking time, reading the packet header time and time for finding the link to the next hop. d_t is the transmission time which is defined as the time becomes the first one in the BS grants buffer to the start of the successful transmission of the corresponding packet in the UL sub-frame [26]. μ is the transmission time of a data packet. d_g is the propagation delay which is the time that it takes a signal to propagate through the communication media from a hop to the next hop. It can be calculated using the following equation where L is the distance between hop and the next hop and s_g is the propagation speed

$$d_g = {}^{L}/_{s_g} \tag{7}$$

IV. Simulation

The simulation algorithm is developed to measure the round trip time delay for each smart grid application. Smart grid applications classification and their requirements were summarized Table I. In order to find the network architecture that satisfies the applications requirements, a software program was developed.

The program inputs are the data and commands, hereafter information, from the smart grid applications that spread throughout the power network. While the information is propagating within the smart grid communication networks, the proposed algorithm performs several processes to calculate the round trip time latency.

A. *Description of Simulation*

As mentioned in Section II, WiMAX network architecture was proposed. Simulation models for the architecture were implemented using OPNET [27]–[29].

The simulation parameters, traffic models, and performance metrics are specified in Table III and Table IV.

TABLE III: PROFILES PARAMETERS

Profiles	Operation Mode	Start Time	Duration
Substation Profile	Random	30-300 ms	One cycle
Distribution Profile			
Utility Profile			
Distributed Resource Profile			
Smart Meter Profile	Simultaneous		

TABLE IV: APPLICATIONS PARAMETERS

Smart Grid Application	Inter-arrival Time	Distribution	Protocol	File Size
WASA	5 sec	Exponential	FTP over TCP	UL=1500 DL= 512 (bytes)
Outage management	5 mn	Exponential		
Distribution automation	1 sec	Exponential		
Distributed energy resources	5 mn	Exponential		
Energy consumption reading	15 mn	Periodic		
Demand response	30 mn	Exponential		
Demand side management	30 mn	Exponential		
Asset management	1 sec	Exponential		
Substation automation	1 sec	Exponential		

B. *Assumptions*

The smart grid nodes physical locations are assumed to be randomly distributed over a 5-15 km cell radius.

The TDD (Time Division Duplexing) is used to divide the transmission time frame into uplink (UL) and downlink (DL) sub-frames. The TDD is used because in smart grid networks, uplink traffic generated from smart grid nodes dominates a majority of the time. This creates asymmetric downlink/uplink traffic environment. Being able to adopt TDD enables the adjustment of the downlink/uplink ratio in the favor of the uplink traffic. Average packet size is assumed to be 1500 bytes for all applications.

C. *Profiles Parameters*

In order to simulate the WiMAX proposed design, the smart grid applications must be profiled. Each application must be profiled in term of operation mode, start time, duration and repeatability. The nine applications have been profiled based on their functionally. Five different profiles are defined; substation, distribute, utility, distributed resources and smart meter profiles. Each application may have a unique profile or share more than one profile with other applications.

Table IV shows the five different profiles and their related parameters. For example, outage management application has all the five profiles. On the other hand, distributed automation has one profile

D. *Applications Profiling and Parameters*

Depends on the smart grid application, a profile may have different inter- arrival rate and distribution but all share the same communication protocol and uplink and downlink file size. For example, the distributed Resource Profile has five different intern-arrival rates and two different distributions. On the other hand, substation automation application has one profile, one inter-arrival time, one communication protocol and file size. Table IV shows the nine smart grid applications along with their related profiles, inter-arrival times, distributions, communication protocol and file size.

E. *WiMAX Network Setup*

The WiMAX network configuration that are specified to satisfy the proposed smart grid applications data and commends transfer and exchange are shown in Table IV.

V. Results and Analysis

To validate the proposed five different priority classes, a simulation program for each class is developed and run utilizing the base station scheduling algorithms namely; CB-WFQ, CB-DWRR and CB-SPQ. The applications of class 1 are mapped with rtPS WiMAX service flow. As mentioned in the previous chapters, delay requirement for this class is 200 ms.

The simulation is run with 50 smart grid devices; the result showed that the three scheduling algorithms satisfied the class delay requirements. With 100 incremental steps, the simulation was repeated.

The network performance started to deteriorate as the number of devices increases. It was found that the

CB-DWRR does not satisfy the class applications latency once the devices number exceeded 150 devices, moreover, the CB-WFQ failed after he devices number reached more devices. Once the number devices reached 450, the three scheduling algorithms are not any more stratifying the time latency.

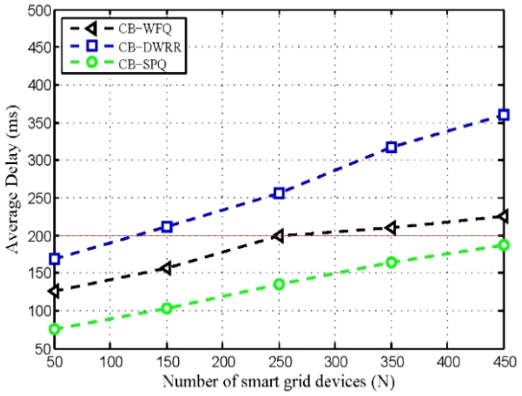

Fig. 4. Class 1 end-to-end delay under different queuing disciplines

Fig. 4 shows that the maximum value of the average delay experienced by class 1 rtPS connections. Therefore, we claim the following:

Claim 1: For class 1 applications, it is recommended that no more than 450 smart grid devices should be used to satisfy the latency requirement and the CB-SPQ scheduling algorithm is the best.

It is worth mentioning that the average delay starts to increase as the number of smart grid devices increase. This increase will generate larger uplink map (UL-MAP) size to accommodate more numbers of the burst Information Elements (IEs). Therefore, the connected smart grid devices have to wait more time to extract the uplink grant in formation and leads to higher delay. For the reader reference, class 1 traffic that is assigned for critical-mission applications such as substation automation, wide area situational awareness and outage management.

Class 2 traffic is generated from high priority applications such as distribution automation, distributed energy resources and storage energy. Following the same simulation pattern that was used in class 1, the result showed that the CB-SPQ scheduler is giving the best delay performance for class 2 traffic. This is due to the reason that packets generated from these applications are mapped to rtPS connections.

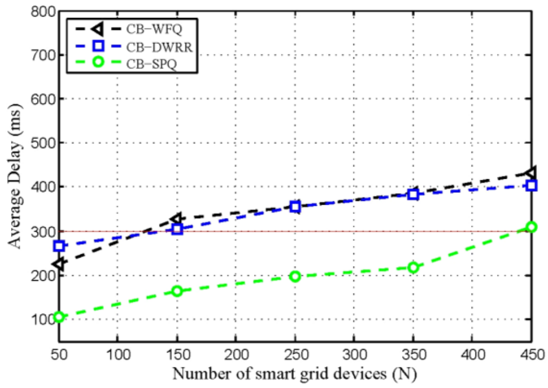

Fig. 5. Class 2 end-to-end delay under different queuing disciplines

The CB-SPQ scheduler serves the highest priority traffic (rtPS) at first, and then it tries to serve the lower level of priority traffic. Thus, class 2 traffic is affected by the low priority traffic flows from class 3, class 4 and class 5. It can also be noticed that the CB-WFQ scheduler acts indistinguishably to the CB-DWRR scheduler, but it has more variation in distributing the bandwidth among the traffic types.

Fig. 5 shows that the maximum value of the average delay experienced by class 2 rtPS connections.

Therefore, we claim the following: Claim 2: For class 2 applications it is recommended that no more than 450 smart grid devices should be used to satisfy the latency requirement and the CB-SPQ scheduling algorithm is the best.

Fig. 6 shows the simulation results for class 3 traffic. This traffic is generated from the smart meters. It includes interval data reads, meter remote disconnect / reconnect requests and critical peak pricing alerts. It is noticed that the number of smart grid devices, smart meters, in this class, that can be served dropped to 250.

To serve more than 250 meters, the delay exceeds the 2 sec time delay limit. From the result shown in Fig. 6, the CB-WFQ is the most suitable scheduling algorithm that satisfied class 3 traffic. The CB-DWRR and CB-SPQ algorithm failed to service the smart meters traffic once the number of meters exceeded 250.

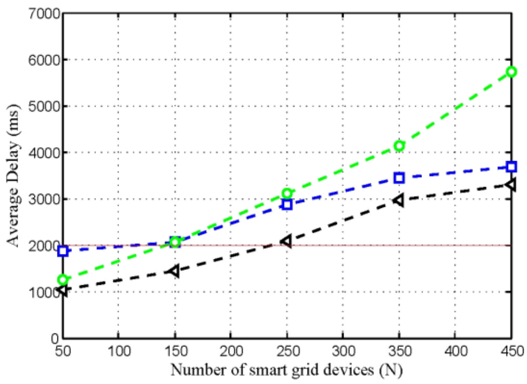

Fig. 6. Class 3 end-to-end delay under different queuing disciplines

Claim 3: For class 3 applications, it is recommended that no more than 250 smart grid devices should be used to satisfy the latency requirement and the CB-WFQ scheduling algorithm is the best. Fig. 6 shows the simulation results for class 4 traffic.

The data traffic is generated from demand response and demand side management applications with a minimum delay requirement of 5,000 ms compared with 200 ms, 300 ms and 2,000 ms in class 1, class 2 and class 3 respectively. This is due nature of these applications.

Fig. 6 and Fig. 7 also show that CB-WFQ algorithm achieves the most favorable results among all schedulers.

This has been done through sacrificing the delay of the higher classes traffic i.e., class 1 and class 2, within a tolerable range. From the same perspective, the excess time slots of any higher traffic class are allocated to the other lower classes which enhance their performance without degrading the higher traffic class QoS performance.

Claim 4: For class 4 applications, it is recommended that no more than 450 smart grid devices should be used to satisfy the latency requirement and the CB-WFQ scheduling algorithm is the best.

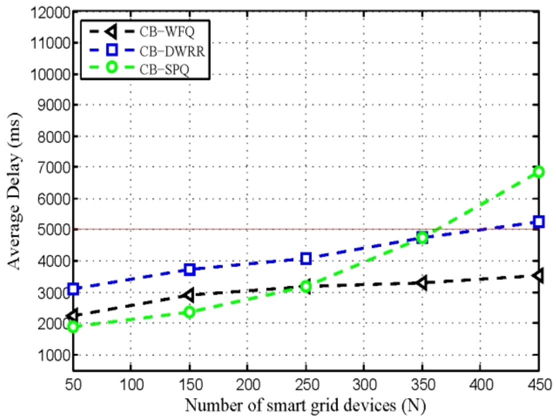

Fig. 7. Class 4 end-to-end delay under different queuing disciplines

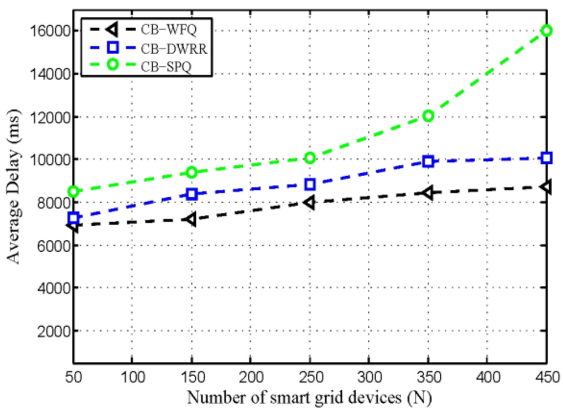

Fig. 8. Class 5 end-to-end delay under different queuing disciplines

In Fig. 8, the simulation result of class 5 showed that the three queuing disciplines satisfied the time delay latency. This is due to the nature of the application delay requirements which is classified as best offer.

It is worth mentioning that this class traffic is generated from the assets management application that quite large delay times that may run into minutes.

Claim 5: For class 5 applications, it is recommended that no more than 450 smart grid devices should be used to satisfy the latency requirement and the CB-WFQ scheduling algorithm is the best and the other two can best used, as well.

In [30], a simulation model for the Distribution Area Network (DAN) is implemented. The DAN integrates the AMIs payload from the consumer area. Different smart grid applications have been considered in the simulation; i.e. substation automation, PHEV, video surveillance voice, and metering data. Applications experienced different average delays from less than 50 ms to more than 400 ms.

In [13], the authors studied the performance of a WiMAX smart grid last mile network. The network serves the customers Energy Services Interfaces. The traffic model included alarm commands, network joining, metering data, pricing signals, telemetry signals, ESI information reports, information broadcast and firmware updates.

Applications experienced different average delays from less than 200 ms to more than 1,000 ms.

VI. Conclusion

The proposed model maps the smart grid applications with the WiMAX MAC service flow types and the differentiated service code point. The simulation results demonstrated that different DSCP values and service flow types affect the delay of the network. It was found that no more than 450 smart grid devices should be used to satisfy the delay requirement of class 1 and class 2; and the CB-SPQ scheduling algorithm is the best. As for class 3 applications, results showed that in order to satisfy the latency requirements, the maximum number of smart grid devices that can be placed in a cell should not be more than 250, and CB-WFQ scheduling algorithm is the best. Results also showed that for class 4 applications, a cell could accommodate up to 450 smart grid devices and the CB-WFQ scheduling algorithm is the best.

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Ban Al-Omar holds a master degree on computer engineering from the American University of Sharjah. Her research interests include wireless network design, implementation and testing in the smart grid.

T. Landolsi received his Ph.D. in Electrical Engineering from the University of Texas at Dallas, USA. He is currently an associate professor at the American University of Sharjah. He has worked in the US telecommunication industry for more than seven years designing and planning wireless and optical networks.

A. R. Al-Ali (SM-IEEE) received his Ph.D. in Electrical Engineering from Vanderbilt University, TEN, USA-1990. Since 2000, he has been a professor of computer engineering at the American University of Sharjah. His research interests include smart grid, and cloud computing and Internet-of-Things applications in the smart grid.