RESILIENCE AND SELF-POWERED WIMAX SYSTEM ENHANCED BY FOG COMPUTING FOR SMART GRID APPLICATIONS

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Abstract. This research suggests a communication network infrastructure based on WiMAX technology for smart grid applications to address the features of resilience, expansion, availability and self-powered based-renewable energy. The suggested communication network proposes self-powered infrastructure consists of WiMAX base stations (BSs) enhanced by decentralized data processing based on fog computing to compensate the various types of smart grid applications (real time and non-real time applications) such as wide area monitoring and control (WAMC), video surveillance, metering, tariffs, alarm, and demand side management (DSM). Further, this work compares among the proposed infrastructure with two traditional cases: wireless scenario with centralized processing, hybrid scenario includes WiMAX BSs connected to the control center by cables. The results indicated that, the wireless proposed case based-decentralized processing and self-powered could handle the various types of smart grid applications in terms of data reliability, capacity, and latency. Moreover, the enhanced wireless scenario offers privileges compared to other scenarios from: resilience, availability, and power consumption independence points of view.
Keywords: *advanced metering infrastructure, bs sector, demand side management, fog computing, renewable energy*

Introduction

The communication network of smart grid is a wide area infrastructure should assimilate the requirements of various types of data applications in residential, industrial, and markets places, etc. Therefore, such infrastructure suffers from high-cost initialization, maintenance, and rigidity. WiMAX technology is a charming candidate providing a package of features such as long coverage area, respected capacity, and the flexibility in term of the terminals. But, the employing of wireless access networks faces challenges related to the power consumption of BSs in the cellular system and the preferable sites to initialize the BSs of such systems (Deruyck et al., 2010). On the other side, the smart grid network involves in huge number of different types of data sources and many kinds of applications producing heavy data traffic. In this sense, the communication network of smart grid should handle the obstacles in terms of power consumption, data processing, and resilience.

However, some previous works exploited WiMAX system to design communication network to serve the applications of smart grid. It is noted that, the works in Islam et al. (2014) and Priya and Saminadan (2014) built AMI Network infrastructure based- one WiMAX BS for a limit number of users in term of smart meters. These works analyzed the results of AMI applications in term of delay based-type of service. In the same context, the works in Castellanos and Khan (2012), Al-Omar et al. (2015) as well as

Neagu and Hamouda (2016) designed WiMAX network infrastructure to support more clients compared to the previous mentioned works in term of SMs and estimated the coverage area of BS under nominal wireless channel. Whilst, the attitude of the work in (Khan and Khan, 2012) paid attention to exploit WiMAX system to design a wide area network for connect multi Phasor Measurement Units (PMUs) to the control center of power grid to deal with WAMC applications. The authors dedicated their infrastructure to handle one type of applications. Other works such as Akram et al. (2021), Mishra et al. (2019), Talaat et al. (2020) as well as Forcan and Maksimović (2020) presented the cloud computing to process the data at the control center of the smart grid.

However, it is concluded from the previous related works that design an infrastructure for smart grid applications some issues. There is no previous work adopted the following points in an integrated work: (1) one communication network infrastructure based-WiMAX for a wide area network can assimilate various applications related to real time applications and non-real time applications from data processing, latency and data reliability points of view; (2) a flexible methodology to handle the appropriate number of BSs to meet the requirements of smart grid based on the nominal applications and the number of clients; and (3) the issue of power for BSs infrastructure and logistic stuff.

In order to address the previous issues, this work presents the following contributions: (1) to compensate the power consumption of WiMAX BSs and mitigate the burden on the power grid, this work offers green WiMAX infrastructure which could generate self-powered based on renewable energy; (2) the physical cables of WiMAX cellular network infrastructure backbone that connect the BSs to the control center or provide the connectivity among BSs, it restricts the network infrastructure in terms of flexibility, and, the cost of initialization and maintenance. This research presents completed wireless system based on WiMAX without physical cables for communication; (3) the scope of this paper includes wide range of applications of smart power grid typical case that address the real time applications and non-real time applications such as WAMC, DER, video surveillance, metering, tariffs, alarm, and demand side management; and (4) such network infrastructure deals with heavy data traffic may lead to network congestion or increasing the latency and packet loss in term of network performance. Therefore, this work suggests fog data processing in a wireless fashion to handle the distributed environment of smart grid, data reliability, small latency, and assimilate the heavy data traffic points of view.

The structure of this research is divided into four sections. Section one explains the introduction and the contributions while section two states the smart grid applications, the convenient of WiMAX system to smart grid, and the decentralized processing. Section three offers the methodology of this work. Finally, section four presents the conclusions and future work.

The applications of smart grid and WiMAX based-decentralized computing

According to the national institute of standards and technology (NIST) reference model, seven dimensions are introduced to describe the concept of smart grid: generation, transmission lines, distribution networks, markets domain, operations domain, customers, and service providers (Greer et al., 2014). These dimensions are broad variety of the electrical activities including multi levels of applications. However, the basic applications of the smart grid are related to: monitor the generations, the integration between traditional resources and renewable energy resources, improve the convenience of transmission lines, supervision and controlling on the status of electrical substations, peak demand and cost reduction, and the affective interaction between the utility and the consumers. In general, the previous mentioned applications can be classified into two approaches: real time applications and non-real time applications.

Real time applications

The grid of power requires real time dynamic monitoring and control for essential power systems parameters such as frequency, voltage, current, and the angle of the load, etc., to avoid the generation system failure, the faults line occurrence, and uncontrolled blackouts, etc. The main applications of real time in smart power grid are wide area monitoring and control (WAMC), video surveillance, and Distributed Energy Resources (DER). In WAMC application, phasor measurement unit (PMU) that can be defined as an industrial device at an electrical substation submitting synchronized measurements to the phasor data concentrator (PDC) that locates in the control center of the utility in terms of the processing and control. The data of PMU should be transferred to PDC within a specific time to handle the correct calculation at suitable time. With respect to the data of PMU, the limit of received time, the data unit size, and the frequency rate are organized by international standards. However, the most well-known standard that deals with communication requirements of synchro phasor data transfer of power systems is IEEE C37.118.2 (Gharpure, 2011). It is worth to mention, the threshold time delay of PMU is up to 200 msec with bandwidth about a few 100 kbps (Obaidat et al., 2012).

On the other side, The microgrid is a special type of the grid including decentralized resources that are used to generate the electricity by traditional resources and/or renewable energy sources (RES) and it may contain energy storage systems (ESS) and different loads (de Souza and Castilla, 2019). International electrotechnical commission (IEC) 61850 is the standard that organizes the communication requirements of DER application. It defines sampled values and Goose messages to reflect the status of microgrid in term of power system to the control center of smart power grid (Parikh, 2012). Finally, video Surveillance is another real time application used to monitor the substation sites for saving and security purposes (Babazadeh et al., 2013). This application requires heavy bandwidth reaching to a few Mbps with delay of a few seconds (Obaidat et al., 2012). It is depending on the resolutions of the offered video.

Non-real time applications

The interaction between the utility and consumers is important in smart power grid and it requires a specific infrastructure called advanced metering infrastructure (AMI). The applications of AMI are classified as a non-real time applications, this research highlights the major applications of AMI: automatic meter reading, tariffs, system alarm, and demand side management. In the context of metering, AMI is a collection of smart meters and data collectors or concentrators. On one hand, Smart Meter (SM) is defined as an intelligent meter can implement two major functions: measurements and communication, and connecting the consumers with the utility servers in two-way communication (Eissa, 2016). Moreover, it represents the method to handle the interaction between the consumer and the utility. Generally, smart meter consists of six parts: quantitative measurement, control, communication, power management, synchronization, and display. On the other hand, data collector (DC) or concentrator is a device representing a sink for a group of SMs (Reinhardt and Pereira, 2021). Firstly, the concentrator gathers the data from SMs then it sends these data to the control center of metering. In addition, concentrator receives the data from the control center and redirected these data to its destinations (SMs). The standards IEC 61968 and IEC 62056 are responsible of addressing the communication requirements between SMs and the control center of the smart grid.

One of the methods to enhance the interaction between the consumer and the utility is sending the tariffs to consumers periodically in term of demand-response applications in AMI. Smart meters are timely enabling the application of tariff to facilitate the consumers to actively respond to generations of smart grid. The server of metering updates SMs with the latest tariff information (He, 2016). On the other side, tampering, major system faults, and disconnects etc., is weighted events related to the power system of smart power grid. In the case of occur such events, the alarm is reported between the control center and SM immediately. In fact, the mentioned events are infrequently happened (about 5 to 10 times monthly). Finally, the demand side management is the operation of remote control for connection or disconnection the power flow, it may implement by the server of metering management to address some issues like illogical consumption of electricity or failure to comply with the contract signed between the company and the customer (He, 2016).

WiMAX system for smart grid applications

This subsection discusses important points addressing the convenient of employing WiMAX system as a communication network infrastructure for the smart grid applications in terms of architecture and system capacity. However, WiMAX is a technology combining among the wireless and the broadband to raise the data rate and coverage area compared to the older wireless technologies particularly in the case of fixed stations that simulates the environment of the smart grid from industrial and metering infrastructure. This technology depends on the BSs as a cellular system to provide the coverage area for the mobile or fixed clients. In general, the default mode of WiMAX architecture to cover metropolitan area network consists of a group of BSs, the communication among these BSs relies on physical cables to mitigate the effect of distance on the unguided media to handle a respected coverage area. On the other hand, the BSs of WiMAX need to the power supplies which deliver the electricity for the appropriate operation. Traditionally, the delivering of electricity is fed by the power grid. Consequently, the consuming of power and logistic stuff will break the features of the flexibility and the green communication in WiMAX.

In the context of capacity, the BS of WiMAX system plays the main role in administration the data streams among the clients in a centralized fashion. BS grants the capacity in term of symbols (slot of times) to the clients in order to transfer the required data. The mechanism of grant the bandwidth to the clients is accomplished according to nominal quality of service (QoS) in the form of dedicated minimum bandwidth. Five types of QoS are supported by WiMAX BS based on IEEE 802.16: unsolicited grant service (UGS), real time polling service (RTPS), non-real time polling service (NRTPS), extended real time polling service (ERTPS), and best effort (BE) (Ahson and Ilyas, 2018). *Figure 1* shows the mechanism of grant the bandwidth based on the request of the clients that associate to the base stations. The capacity of BS feeds the DL and UL streams, hence this capacity is limited and decreased with the increment of requested capacity of the associated clients and heavy data applications. The available capacity of BS is divided into two parts: DL part and UL part. The magnitude of BS capacity in DL and UL is related to many variables, the major effected variables are the bandwidth, the frame length, and the symbol length. The available capacity of BS sector is configured after identifying the previous factors. Whilst, the requested capacity from BS sector relies on the specifications of applications themselves. For instance, the large size of data packets and high frequency rate of transmission could consume effected capacity from BS sector.

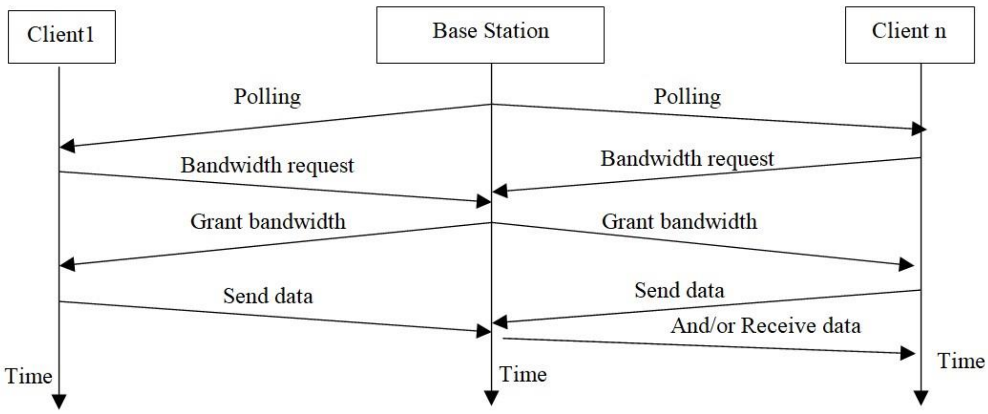

Figure 1. *The mechanism of grant the bandwidth from BS to the nodes.*

Centralized and decentralized computing

After mention the sources of data (the applications) and the core of the network infrastructure (WiMAX BSs), it is essential to explain the method of processing the data. In general, the concept of cloud computing is an attractive solution to assimilation the severe data processing of the control center of smart grid from the data processing point of view. Cloud is the pattern of computing that provides resources (such as storage, processing, software systems, and applications, etc.,) dynamically in scalable fashion on demand over the internet regardless of knowing how to implement the nominal services. There are three major models of services that are offered by the cloud: software as a service (SaaS), platform as a service (PaaS), and infrastructure as a service (IaaS) (Ye et al., 2018). However, the concept of cloud is affected by the network itself where the end-to-end delay and the packet loss may increase due the impairments of the packet path via the core of the network.

Nevertheless, the cloud computing seems as a centralized system offering services while the applications of smart grid are various and expandable therefore the needing to distributed fashion of cloud computing raises. Fog is a decentralized computing contributes in bringing the services of cloud closer to the clients. In general, the servers or node of fog computing are placed near to the sources of the data (Ashraf et al., 2022). Moreover, the flexible position of servers that processes the data in decentralized fashion offering the feature of resilience to the communication network. Such computing presents advantages in end-to-end delay and the bandwidth in addition to save the capacity of the network. The previous advantages support the smart grid to make decision quickly particularly in the case of real time applications.

Materials and Methods

Generally, there are no doubts that many previous studies and related works provided interesting results related to design a communication network infrastructure for smart grid applications. However, by addressing and analyzing the literature that had the same perspective of our research scope, we are highlighted some important issues. Firstly, smart grid is a variety environment of applications therefore the communication infrastructure of smart grid should take into consideration this diversity (real time applications and non-real time applications together). Secondly, the resilience of such infrastructure is vital and crucial in terms of logistic (free of physical cables, self-powered, and low-cost maintenance). Third, a clear framework handles the capability of the expansion to assimilate the heavy expected data applications. Consequently, this work presents a developed methodology to offer integrated communication infrastructure handling the requirements of smart grid applications as shown in *Figure 2*.

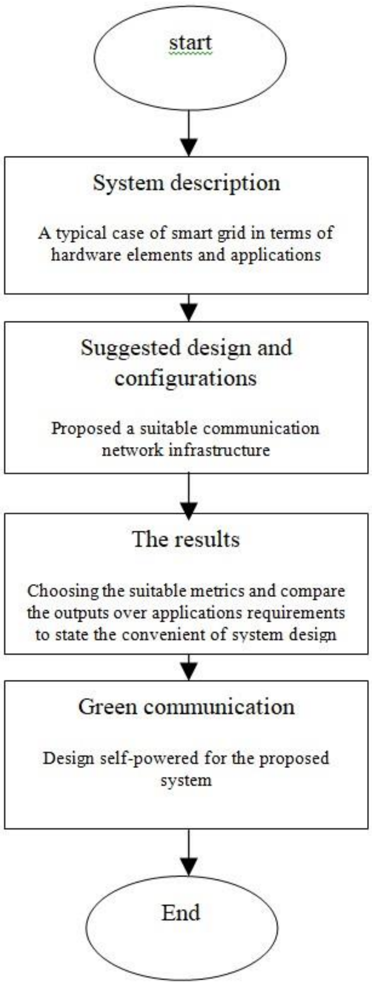

Figure 2. *The diagram of adopted methodology.*

System description

This work adopts a typical case for the smart power grid including two types of applications (real time and non-real time). It consists of 16 substations, one microgrid, smart meters (SMs), and the control center. All traffic of applications is exchanged between the devices of field and metering in one hand, and the control center on the other hand. The control center of smart grid receives the data from the sources then it processes the data to produce the appropriate responses according to the requirements of applications. In terms of real time applications, each substation has two industrial clients: PMU and camera while the microgrid sends sampling values messages to the control center to mirror the status of it (*Table 1*). On the other side, SM deals with four types of non-real time applications as shown in *Table 2*. Each 100 SMs are connected to one SM concentrator to transfer the data of AMI from/to SMs to/from AMI servers. The model is built and the results are collected using OPNET modeler. It is worth to mention, the applications such system alarm and DSM are a little shared between SMs and the data center of power grid compared to other applications. It is considered that all the adopted non-real time applications are transmitted in concurrent fashion in addition to the continuous streaming data of real time applications of field area (substations and microgrid) to test our model in the hardest conditions.

Table 1*. The applications of real time data for substations and microgrid.*

Application types	Traffic	
	Data size (byte)	Frequency rate in one second
PMU based WACM	44	60
Video surveillance	1024	200
Microgrid status	256	480

Source: Babazadeh et al. (2013); Parikh (2012).

Table 2*.The adopted applications of AMI in the smart grid.*

Application types	Advanced metering infrastructure (AMI)		Data size (byte)	Frequency rate	Transport protocol
	Source	Destination			
AMR	Metering center (Server)	SM	101	10min, 15min, 1hour, 6hour, 12hour, or 24hour (based IEC 62056)	TCP
	SM	Metering center (Server)	89		TCP
System alarm	Metering center (Server)	SM	21	Based indicator events	TCP
	SM	Metering center (Server)	115		TCP
Tariffs	Metering center (Server)	SM	445	10min, 15min, 1hour, 6hour, 12hour, or 24hour (based IEC 62056)	TCP
	SM	Metering center (Server)	13		TCP
DSM	Metering center (Server)	SM	53	Based indicator events	TCP
	SM	Metering center (Server)	67		TCP

Source: He (2016)

The proposed communication network infrastructure

This work designs a communication network infrastructure based on WiMAX system to serve the smart grid applications. The reasons of adopting WiMAX technology for smart grid are mainly related to three points: (1) fixed WiMAX technology could cover long distance wirelessly compared to other wireless technologies (up to 50 km) to compensate the different sections of smart grid applications; (2) WiMAX technology offers suitable data rate synergy with wireless coverage area; and (3) WiMAX technology is a closed system in contrast with the traditional cellular system, the utilities could own the system and administrated it without request third parity for the operation. Consequently, this choice provides privileges in terms of resilience logistic design, low-cost maintenance, and better security. However, the main parameters of WiMAX system: the bandwidth, duplexing technique, frame length, and symbol length are 20MHz, time division, 5msec, and 102.86µsec respectively. In addition, this research addressed the proposed infrastructure in three different cases.

Case_1: It is assumed that the smart grid wirelessly covered by WiMAX BSs; all consumers of AMI (non-real time applications) and industrial field clients (real time applications) connect wirelessly to BSs. All the servers of the smart grid control center are owned by the utility based-WiMAX technology.

case_2: This case has two different points compared to the first case: (1) all WiMAX BSs are connected to the control center using point to point protocol (PPP) digital signal level 3 (DS3) cable that represents copper cable and it offers bandwidth up to 44.736Mbit/sec; and (2) the processing of collected data at the control center is implemented using servers based-Ethernet under the property of the utility of smart grid.

case_3: This scenario simulates the case of employing the fog computing using local servers based-WiMAX, the servers are placed near to consumers to take the advantage of fast processing and addressing the availability and the reliability. In this case, consumers deal with local severs of the fog computing locally and there is a connection between the local servers and the main servers at the data center of smart grid in order to receive any update or sending a copy of the data (*Figure 3*).

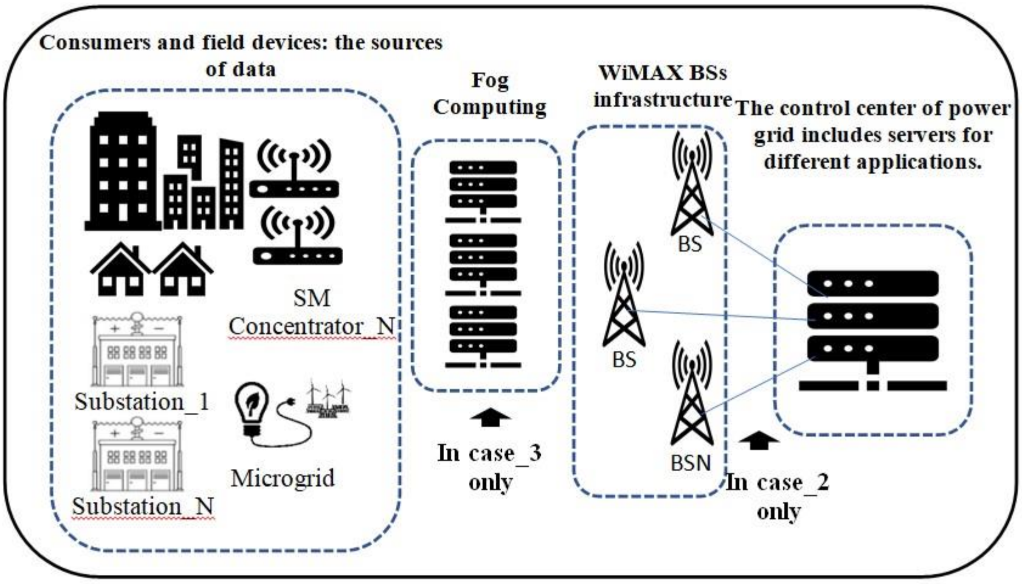

Figure 3. *The architecture of adopted network infrastructure.*

Results and Discussion

Firstly, the author discusses the results of real time applications (PMUs, DER, and video surveillance). Hence, our target is explanation that WiMAX BS sector capacity could deeply effect on the requirements of real time applications in terms of latency and received data reliability (sent traffic, received traffic, and packet loss metrices). Therefore, it is a crucial to interpret these metrices together in order to design a successful communication network infrastructure. *Table 3* illustrates three metrices: latency, received data reliability (i.e., the percentage of received traffic over sent traffic), and BS capacity for the application of video surveillance in the with respect to the first case of proposed infrastructure. The application of video surveillance is the heaviest data application in our model. In other words, it represents the hardest challenge to our design in terms of latency and data reliability. The result shows that, it is not preferable to link more than 6 clients of video application to one BS sector for high resolution. This is related to the limited capacity of BS sector; it could not handle the requirements of 7 clients of video surveillance in terms of latency and received data reliability together where about 14% of the traffic is lost. According to the requirements of video surveillance application, the threshold of the video latency should be less than 200 msec to handle acceptable resolution accuracy (Islam et al., 2014).

Table 3. *Video surveillance and BS sector capacity.*

No. of video application clients per BS sector	Max global Latency (msec)	Traffic received data reliability (%)	Capacity of WiMAX BS sector (Msps)	
			Demand UL capacity by video application	Remaining UL capacity of BS sector
6	17.82	>99	3.69	1.61
7	318.09	86	3.91	1.40

In the same context, *Figure 4* states the latency and the packet loss in one hand comparison among the different cases with the period of simulation time (24 hours) for video surveillance application for 16 video surveillance clients. The latency of wireless scenario (case_1) is about 37 msec while the latency of cabling backbone scenario (case_2) is about 18 msec. It is noted the employing of wireless fog computing enhanced the performance of wireless scenario (case_3) near to 19msec with the advantage of no physical cables among BSs and the control center. In term of data reliability, case_1 suffers from packet loss compared to case_2 while case_3 could compensate the packet loss to null. The results of this Figure indicate the benefit of employing the decentralized processing (wireless fog processing) from the latency and the data reliability points of view for video surveillance application. In other words, without the fog processing, the wireless scenario fails in meet the requirements of this application in the term of data reliability.

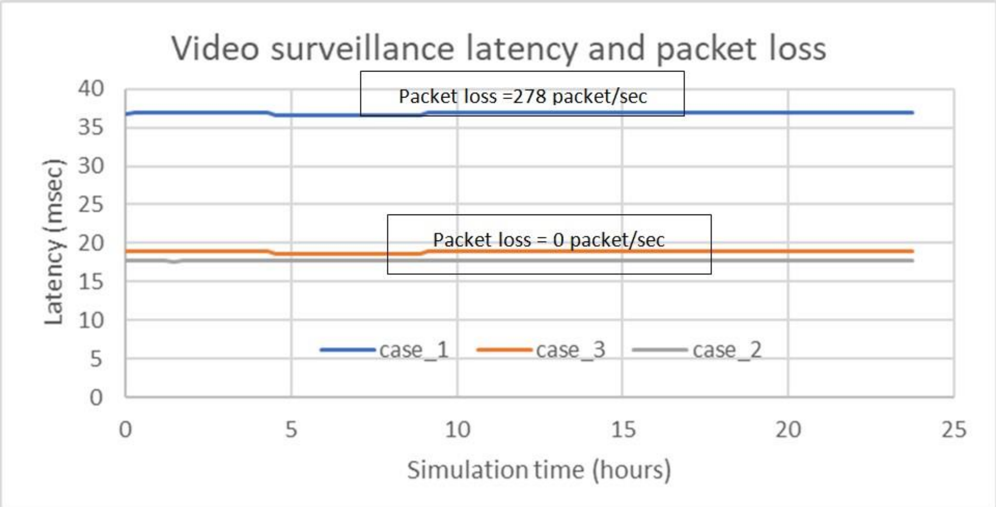

Figure 4. *Latency and packet loss of video surveillance application in all scenarios.*

It is worth to mention, the applications of PMUs and DER represent light applications compared to video surveillance and they do not represent hard consumers for the capacity of BS. For instance, our model addresses 16 PMUs each one sends 44 bytes in 60 times rate per second to the PDU in the control center. That is, the aggregate traffic of 16 PMUs is 42.2kbyte/sec. Moreover, one microgrid (DER client) sends 256 bytes in 480 times rate per second to the control center (i.e., 122.8k byte/sec). Whilst for video surveillance, the sent traffic of 16 clients is 3.27M bytes/sec. Therefore, this research assimilates the results of the rest of real time applications and video surveillance in table 4 in the interests of brevity. Table 4 demonstrates the better distribution for real time applications of our model on the three sectors of BS in the case_1. The results explain that the better metrices of sent and received traffic as well as the global latency of the system are achieved in the scenario 3 to handle all real time applications requirements successfully (16 clients of PMUs, 16 clients of video surveillance, and one microgrid). Referring to Ali et al. (2016) and Parikh (2012), the latency for WAMC (PMUs) and DER (microgrid) applications consider acceptable up to 50 msec.

Table 4. *The distribution of real time applications on BS sectors.*

Scenario	ONE BS (Load of the BS sectors)			Traffic (M byte/sec)		Max global latency (msec)
	Sector 1	Sector 2	Sector 3	Sent	Received	
1	6 video clients	6 video clients	16 PMUs clients and 1 microgrid	2.627	2.627	19.5
2	7 video clients	6 video clients	16 PMUs clients and 1 microgrid	2.832	2.642	127.9
3	6 video clients	6 video clients	16 PMUs clients and 4 video clients	3.447	3.447	19.88

On the other side, the applications of non-real time are Alarm, AMR, and Tariffs besides DSM (AMI applications) are applications dealing with transmission control protocol (TCP) protocol to provide the reliability of data. The vital metric of non-real time applications is the data reliability to prove that all sent traffic is received successfully while the latency does not consider the more significant metric for non-real time applications. *Table 5* explains the traffic in terms of sent and received data of AMI applications in the case_1 with the increment of SMs up to 30000 SMs. The adopted maximum number of SMs per one BS was 30000 SMs related to the maximum capability of one BS sector is to connect 100 nodes (100 SM concentrators equivalent to 10000 SMs). Furthermore, all sent data is received correctly (i.e., the reliability of received data is 100%). The results indicate that the AMI applications are not represent as heavy applications from the size of the data point of view but the increment in the number of smart meters may lead to form a burden on the capacity of WiMAX BS sector and the servers in the control center. As shown in *Table 5*, the tariffs application is the heavier application compared to other applications of AMI from the size of the data therefore *Figure 5* shows the effect of proposed infrastructure cases on the packet network delay of Tariffs application at 30000 SMs (maximum adopted number of SMs per BS) to explain the performance of the designed infrastructure. Case_2 and case_3 offer smaller delay compared to case_1. It is worth to mention, each 10000 SMs is linked to one BS sector.

Table 5. *The traffic with the increment of SMs for AMI applications.*

Alarm: Traffic (bytes/sec) case 1							
8000SMs		10000SMs		20000SMs		30000SMs	
S	R	S	R	S	R	S	R
2009	2009	2486	2486	4997	4997	6303	6303
AMR: Traffic (bytes/sec) case 1							
8000SMs		10000SMs		20000SMs		30000SMs	
S	R	S	R	S	R	S	R
2489	2489	3080	3080	6191	6191	7809	7809
DSM: Traffic (bytes/sec) case 1							
8000SMs		10000SMs		20000SMs		30000SMs	
S	R	S	R	S	R	S	R
1867	1867	2310	2310	4643	4643	5857	5857
Tariffs: Traffic (bytes/sec) case 1							
8000SMs		10000SMs		20000SMs		30000SMs	
S	R	S	R	S	R	S	R
4871	4871	6028	6028	12117	12117	15283	15283

Notes: S=Send; R=Received.

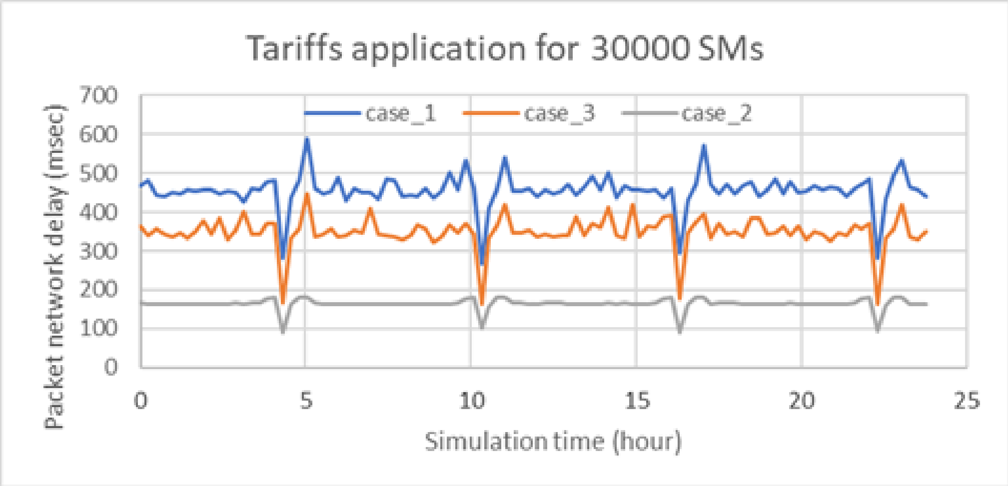

Figure 5. *Packet network delay for 30000 SMs in the case of Tariffs apoplication.*

All cases present an acceptable delay with respect to AMI application (Siqueira de Carvalho et al., 2018). However, the maximum recorded delay is less than 600 msec while the threshold of AMI applications reaches up to 2 sec. In the same context, *Figure 6* explains that all sent data is successfully reaching at its destinations. In addition, case_3 presents an excellent scenario in the terms of the network delay and data traffic due to the assimilation ability to the traffic. The decentralized processing could reduce the overall exchanged traffic among SMs and the local server. As a result, WiMAX BS sector capacity could deal with more SM concentrators.

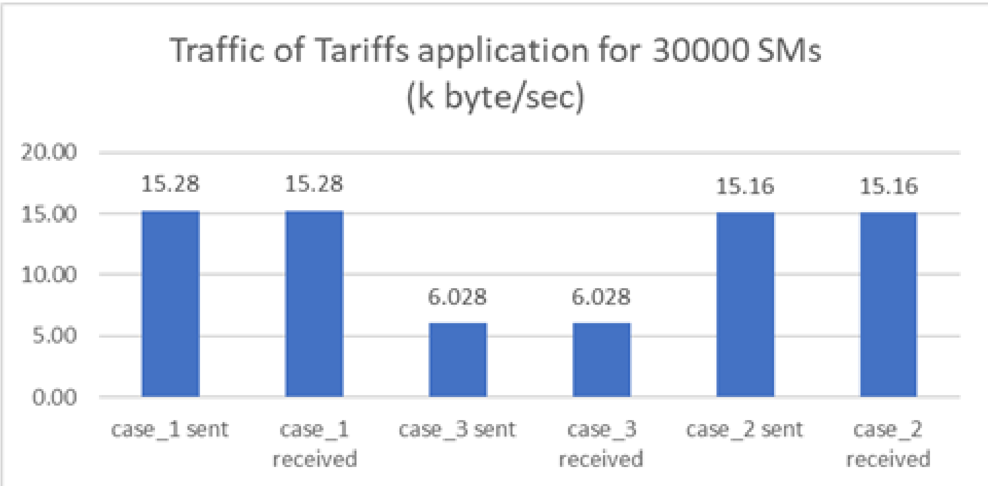

Figure 6. *Sent and received traffic for 30000SMs in the case of Tariffs application.*

The design of self-powered for WiMAX BS

The aim of this subsection is to design self-powered based renewable energy for WiMAX BSs according to submit suitable power performance under the worst conditions. Generally, WiMAX BS requires a source of power to feed the components of BS in the suitable power. *Table 6* shows the main components of WiMAX BS that consumes the power like power amplifier, processor, transceiver, converter, signal generator, microwave, and cooling system (Alsharif, 2017; Deruyck et al., 2010; Endo and Shibuya, 2008; Intel Corporation, 2006).

***Table 6**. The power consumption of WiMAX BS components.*

Assumption	Item
Power amplifier	300 w
Baseband processor	100 w
Transceiver	100 w
Converter	100 w
Signal generator	384 w
Microwave	80 w
Air conditioning	690 w

The suggested self-powered for BS sectors is a solar energy system consists of four parts: electricity generation subsystem (solar cell panels), energy storage subsystem (batteries), inverter device (controller), and the load (BS sector) as shown in *Figure 7*.

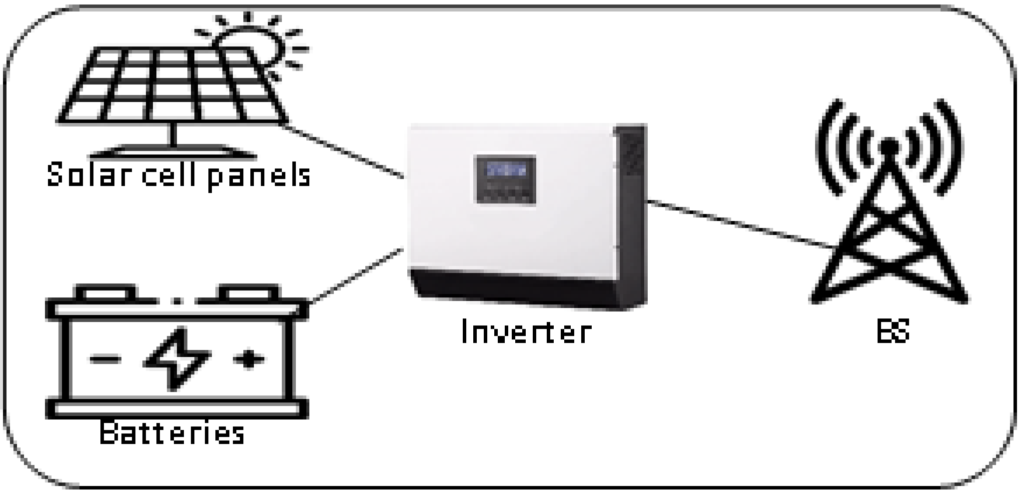

***Figure 7.** Green self-powered system.*

In fact, there are various types of solar cell panel from power generation point of view like 350w, 450w, and 660w (Ali, 2016). Furthermore, different types of batteries with various characteristics are available commercially. Lithium batteries are one of the most attractive researchable batteries offering smart features such as slow loss of charge during the using, suitable weight, high open circuit voltage, and relatively long operating life (Neagu and Hamouda, 2016). The mechanism of choosing the suitable number of batteries relies on the time estimation (in hours) that offers electricity flow by battery to the load continuously until full discharging as in Eq. (1).

$$T = \frac{\text{The current capacity of battery in ampere hour } (AH)}{\text{The current of the load } A} \qquad \text{Eq. (1)}$$

The batteries should deliver the load by the electrical current in the cases of absent the generation of electricity by the panel of solar cell for any reason. The calculation of solar cell panels depends on the maximum power consumption of the load (in watt). However, on one hand the optimum number of solar cell panels number represents the panels of photovoltaic that submit 120% of maximum power consumption of the load in order to take the process of charging the batteries under consideration. On the other hand, the design should take into account the bad weather where in the rainy weather the efficiency of the electricity generation reduces to 50% of the solar panels' efficiency (Ali, 2016). *Table 7* shows the designed self-powered of WiMAX BS according to the power consumptions that operate in 48 volts. In addition, the design of batteries takes into consideration to deliver the power for 15 hours continuously without sunlight. Finally, *Table 8* highlights a comparison among this work and the previous related works. It is obvious that, our work designed self-powered WiMAX infrastructure enhanced by decentralized data processing to handle the various types of smart grid applications in one hand.

***Table 7**. The design of self-powered system.*

Case	Load (w)	No. of batteries (200Ah)	No. of solar panels (600w)
One BS sector	1064	2	3
One BS sector including cooling system	1754	3	5
There BS sectors with cooling system	3722	6	11

***Table 8**. Comparison among this work and previous related works.*

Ref.	Real time application	Non-real time application	Self-powered system	BS capacity analysis	Decentralized computing (Fog)	Method	Metric
(Gómez-Cuba et al., 2012)	Yes	No	No	No	No	Qualnet	Delay, Throughput, Packet delivery
(Al-Omar et al., 2015)	Yes	Yes	No	No	No	OPNET	Delay
(Neagu, 2015)	Yes	No	No	Yes	No	OPNET	Error rate, Throughput, capacity, Latency
(Premkumar and Saminadan, 2015)	No	Yes	No	No	No	OPNET	Signal to noise ratio, Delay, packet drop
(Neagu and Hamouda, 2016)	Yes	Yes	No	No	No	OPNET	Capacity, packet loss, latency, throughput
This work (or current research study)	Yes	Yes	Yes	Yes	Yes	OPNET, analysis	Latency, traffic sent, traffic received, capacity, capacity, packet loss, power consumption

Conclusion

Designed a communication network infrastructure based on self-powered WiMAX BSs to serve the applications of smart grid is addressed by this work. Three types of cases based on WiMAX technology are adopted for our model to capture the requirements of smart grid applications: Pure wirelessly environment, cabling connection between BSs and the control center, and wireless scenario engage to wireless fog computing. The results proved that three sectors of WiMAX BS could handle the requirements of real time applications (WAMC, video surveillance, and one microgrid) in terms of latency and data reliability. In the context of video surveillance application, it exhausts the capacity of WiMAX BS rabidly therefore it is recommended to link no more than six substations' clients from video surveillance point of view to one BS sector. Furthermore, wireless fog computing supported the wireless scenario to handle the requirements of video surveillance application without using any physical cables by compensate the packet loss to null and reducing the latency to the half compared to the case of without employing fog computing.

The results indicated that the designed communication network can support the AMI applications for all scenarios because this type of applications is not sensitive to the time. However, the increment of SMs of AMI infrastructure forms a heavy burden on the servers of control center. Employing the fog computing improves the performance of the communication network from energy consumption point of view more than 60% in addition to reduce the packet network delay and enhance the reliability. Moreover, according to exchanged data via BS sector, it is designed self-powered to the BS consists of solar panels and batteries in order to take the advantages of independently in term of power and resilience (without physical cables for the power and the communication purposes). Finally, the security issues of the smart grid applications for a wide network communication based on WiMAX system will address as a future work

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Conflict of interest

The authors declare no conflict of interest, financial or otherwise.

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