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Self-Powered Wide Area Infrastructure Based on WiMAX for Real Time Applications of Smart Grid

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Abstract
This work presents a wireless communication network (WCN) infrastructure for the smart grid based on the technology of Worldwide Interoperability for Microwave Access (WiMAX) to address the main real-time applications of the smart grid such as Wide Area Monitoring and Control (WAMC), video surveillance, and distributed energy resources (DER) to provide low cost, flexibility, and expansion. Such wireless networks suffer from two significant impairments. On one hand, the data of real-time applications should deliver to the control center under robust conditions in terms of reliability and latency where the packet loss is increased with the increment of the number of industrial clients and transmission frequency rate under the limited capacity of WiMAX base station (BS). This research suggests wireless edge computing using WiMAX servers to address reliability and availability. On the other hand, BSs and servers consume affected energy from the power grid. Therefore, the suggested WCN is enhanced by green self-powered based on solar energy to compensate for the expected consumption of energy. The model of the system is built using an analytical approach and OPNET modeler. The results indicated that the suggested WCN based on green WiMAX BS and green edge computing can handle the latency and data reliability of the smart grid applications successfully and with a self-powered supply. For instance, WCN offered latency below 20 msec and received data reliability up to 99.99% in the case of the heaviest application in terms of data.
KEYWORDS: BS sector, Distributed Energy Resources (DER), Edge computing, Self-powered, Smart grid, WiMAX.

I. INTRODUCTION

Smart grid concept brings the ability to develop the traditional power grid from compensate new technologies and applications points of view. Generally, the applications of smart grid can be divided into two main branches: applications serve the core of smart grid and applications serve the consumers (terminals) of smart grid [1]. The applications that serve the core of smart grid offering many services like control, monitoring, and supervision. Consequently, the distinguishing feature of such applications is the real time to keep the valuable devices of power grid safe and sound [2]. Such processes include producing significant data destinating to the center of control to compute the data in order to make suitable decisions based on concluded information [3]. In order to accomplish the mission of monitoring and control, it should be implemented in a nominal threshold from time point of view according to the applicable global standards. Nevertheless, many applications in the smart grid yield huge traffic that are threaten the process of monitor and control by adding significant delay can affect negatively on the communication network of the smart grid. Furthermore, the accurate process that reflects the situation of the smart grid infrastructure requires transmission high rate of data.

From the forgoing, the communication network of smart grid should compensate the mentioned issues efficiently. The communication network based-cable techniques have interested resistance against the impairments of the channel and handled respected capacity. Unfortunately, these types of communication network bring other challenges where they do not provide two smart features: resilience, and low-cost initialization and maintenance. Wireless communication networks are classified as an attractive solution to serve the applications of smart grid in the case of meeting the requirements of applications. However, the infrastructure of wireless network (BSs) consumes significant power from the power grid.

In literatures, some of previous related works addressed the infrastructure design for the smart grid applications. The attitude of R. Khan and J. Khan in [4] directed 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 [5] [6] [7] and [8] presented the cloud computing to process the data of the applications at the control center of the smart grid. It is worth to mention, no one of the previous related works handled the issue of wireless access network power consumption. In order to explain the effort of this work compared to other previous related works, Table I illustrates a comparison among this work and previous related works. It is obvious, this research presents intensive work to suggest integrated WCN for smart grid applications.

TABLE I
COMPARISON AMONG THIS WORK AND PREVIOUS WORKS.

Ref.	Real time Application	Green power	BS capacity analysis	Edge computing	QoS	Method	Metric
[9]	Yes	No	No	No	Yes	Qualnet	Delay, Throughput, Packet delivery
[10]	Yes	No	Yes	No	Yes	OPNET	Error rate, Throughput, capacity, Latency
[11]	No	No	No	No	No	OPNET	Signal to noise ratio, Delay, packet drop
[12]	Yes	No	No	No	No	MATLAB	Current, voltage
[13]	No	No	No	No	Yes	OPNET	Delay
[14]	No	No	No	No	No	C++	Power
This work	Yes	Yes	Yes	Yes	Yes	OPNET, analysis	Latency, traffic sent, traffic received, DL capacity, UL capacity, packet loss, power consumption

The contributions of this research are related to design a flexible wireless communication network infrastructure based-green WiMAX system has the ability of meeting the requirements of real time applications of smart grid. Furthermore, this work offers wireless edge computing based on WiMAX system to assimilate the heavy data traffic of real time applications. In addition, this research analysis the capacity of WiMAX BS according to the real time applications of smart grid to submit a clear framework in order to serving the nominal application successfully before occurring the BS capacity congestion.

The organization of this work is divided into six sections. Section one handles the introduction and related works. Section two highlights the main real time applications of smart grid and WiMAX system. Section three offers the methodology of green self-powered network infrastructure. Section four presents the designed wireless communication network. The section five explains the results and analysis. Finally, section six shows the conclusions and future works.

II. SMART GRID APPLICATIONS AND WIMAX BS

A. Control and Monitoring Applications

This research highlights three major applications that deal with control and monitoring based-smart grid: wide area monitoring and control (WAMC), video surveillance, and DER based-renewable energy resources.

The power grid requires real time dynamic monitoring 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 cornerstone of WAMC application is the Phasor Measurement Unit (PMU) that can be defined as an electrical device that submits synchronized measurements containing time stamp based-Global Positioning System (GPS) clock for power grid system to addressing some issues like frequency fluctuation control, and state estimation [15]. The PMU is placed at the electrical substation to send the data of power grid parameters to the Phasor Data Concentrator (PDC) that lies in the control center of the power grid 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 famous standard that deals with communication requirements of synchro-phasor data transfer of power systems is IEEE C37.118.2 [16, pp. 118–2005]. It is worth to mention, the threshold time delay of PMU is up to 200 msec with bandwidth about a few 100 kbps [17].

In the context of monitoring application, Video surveillance is used to monitor the substation sites for follow-up and security purposes [18]. This application requires heavy bandwidth reaching to a few Mbps with delay of a few seconds [17]. The latency of the video is depending on the resolutions of the offered video.

One of the smart grid features is the ability to employ the renewable energy resources by the concept of the Microgrid for the consumers [19]. 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 [20]. It can work in one of two types of modes: off-grid or on-grid. In case of on-grid mode, the Microgrid is connected to the control center of the smart grid by the communication networks in addition to power cabling connection. But, in case of off-grid there is disconnecting between Microgrid and smart grid network (isolated Microgrid). 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 grid [21].

B. The Analysis of WiMAX BS Performance

WiMAX is a technology depends on IEEE 802.16 standard. It deals with two types of duplexing: Frequency Division Duplexing (FDD) or Time Division Duplexing (TDD). Licensed band is a mandatory in FDD but in TDD is an option. In fact, TDD is more efficient than FDD in case of the bandwidth because Uplink (UL) and Downlink (DL) between BS and the end devices using one frequency band to offer a flexible partitioning of the nominal bandwidth [22]. In the case of TDD, the main unit of bandwidth is the symbol that is defined as a part of the time that can carry bits. The frame of WiMAX comprises of number of symbols. Therefore, the capacity of WiMAX BS sector represents a specific number of symbols [23]. On the other hand, WiMAX system presents the feature of Quality of Service (QoS) according to the concept of polling to subject a better data performance. Five types of QoS are supported by WiMAX system based on IEEE 802.16d: 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) [24]. The essential point in QoS is the requested bandwidth from BS to the node in order to send the required data. The BS of WiMAX is the manager of the system where it manages the system in centralized fashion. Fig. 1, shows the mechanism of grant the bandwidth based on the request of the nodes that associate to BS.

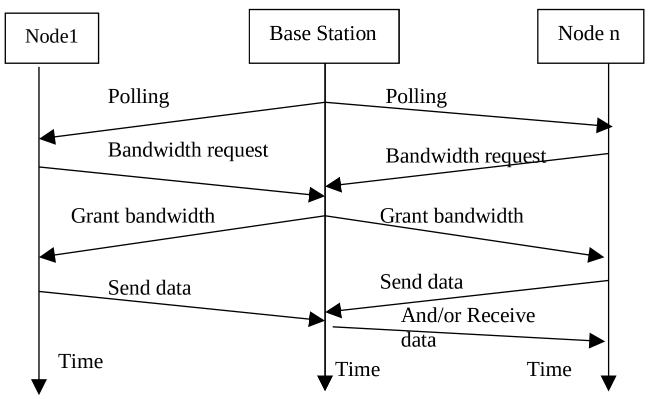

Fig. 1: The mechanism of grant the bandwidth from BS to the nodes.

WiMAX BS is the main organizer of exchanging the data between clients and the control center of smart grid by *allocation* the suitable bandwidth for each requested. Based on TDD duplexing, the available capacity of BS depends on the number of symbols that are offered by BS. The performance of WiMAX system is related to the available capacity of WiMAX BS and the requested capacity of the clients that are linked to the BS. The available capacity (ava cap) and demand capacity (dem cap) are represented in term of symbols. In general, the equation of estimated the performance of WiMAX BS in the simplest description is shown below [22] [25]:

$$BS\ PER=(Ava\ cap)/(dem\ cap) - X \quad (1)$$

Ava cap represents the number of symbols that are estimated by dividing the length of the WiMAX frame over the length of one symbol. While *dem cap* addresses the demand capacity of clients based on the nominal applications. Equation (4) shows the calculation of demand capacity [26]:

$$dem\ cap=B.FL.(Cons(BS))/BBM \quad (2)$$

B represents the demand bit rate of application in bit per sec, *FL* is the length of the frame in sec, *cons (BS)* is the number of consumers that are linked to BS, and *BBM* represents the number of bits that are transferred based on the nominal modulation. WiMAX system can support many types of modulations like binary phase shift keying (BPSK), Quadrature Phase Shift Keying (QPSK), and Quadrature Amplitude Modulation (QAM). In fact, each type of modulation can carry nominal bit, this work considers the modulation scheme is 16QAM and coding rate ½ [20]. However, other factors play important role in the calculation of the performance of WiMAX system such as the overhead data in the level of data link layer and physical layer. The secondary factors that effect on the capacity of WiMAX BS sector is represented by X factor as shown in equation (1).

C. Edge Computing

The cloud computing seems as a centralized processing scheme offering services while the *applications* of smart grid are various and expandable therefore the needing to decentralized fashion of cloud computing raises. Edge computing is a decentralized paradigm of computing that offers the computation and the data storage nearer to the end users [27]. It submits advantages in terms of network delay, availability, overhead, and security [28]. The servers of edge computing are closer to the consumers of smart grid than the control center [29]. In the case of smart grid real time applications, WiMAX server is an attractive candidate to compute the data in the edge computing fashion.

III. The Methodology of Green WiMAX Communication

The proposed system to exploit the renewable energy is solar energy system, it includes four parts: electricity generation subsystem, energy storage subsystem, inverter device, and the load as shown in Fig 2. This is related to the solar radiation that is generally available either wholly (sunny day) or partially (cloudy or rainy). While other types of renewable energies suffer from some issues such the absence of permanent and continuous, scarce availability, and/or technical problems to deal with [30]. The solar cell is exploited to generate the electricity for the load and the surplus of electricity charges the batteries of the storage subsystem. The role of inverter in such system organizes the flow of electricity permanently and continuously in an appropriate form to the load and it transforms the surplus of electricity to charge the batteries of storage subsystem. However, the features of permanent and continuous with respect to solar system cannot be achieved without taken under consideration a successful design that addresses the worst cases to guarantee the continuity of the electrical power to the load for 24 hours. On the whole, the suitable number of solar cell panels and batteries depends on the expected power consumption in the worst cases in particular maximum power consumption in a cloudy or a rainy day where the efficiency of solar cell panels may reduce to 70% or 50% in such cases respectively [3].

In fact, there are various types of solar cell panel from power generation point of view like 350w, 450w, and 660w etc. [31] [32]. 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 [6].

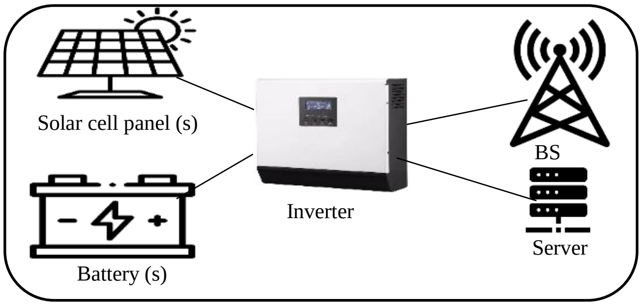

Fig. 2: Green WiMAX infrastructure self-powered supply.

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, see equation 3.

$$T = \frac{\textit{The current capacity of battery in amper hour (AH)}}{\textit{The current of the load A}} \quad (3)$$

The batteries should deliver the load by the current in the cases of absent the generation of electricity by the panel of solar cell for any reason.

It is worth to mention that, the calculation of solar cell panels depends on the maximum power consumption of the load (in watt). However, 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 in the consideration.

IV. The Suggested Wireless Communication Network (WCN)

This work designs WCN for a typical electrical grid, it consists of 16 substations. Each substation contains PMU device and a camera for video surveillance, both of them send the data to the Control Center (CC). In addition, it is assumed that a Microgrid handling the renewable energy resources sends data to reflect the status of it. All the traffic of applications is exchanged between devices of field and the control center. The control center of smart grid is receiving the data from the industrial clients then it processes the data to produce the appropriate responses according to nominal applications. Table II explains the data traffic of applications for control and monitoring. The assumptions of WiMAX equipment power consumptions that are dealing with the industrial clients and green communication system, are shown in Table III. However, the minimum consumed power per one BS sector starts from 1800 watt and it rises to greater values [33]. It is worth to mention that, the BS of WiMAX may contain either one sector or three sectors. Therefore, in the case of three sectors, the calculation of power consumption handles the values of air conditioning and microwave one time but the other factors are multiplied by 3.

The research introduces three scenarios: In the first scenario (scenario_1), WiMAX BSs cover the network of smart grid wirelessly. Each client in the network sends its data to the destination wirelessly via WiMAX BS. Hence, the clients are

PMU and the camera at each substation in addition to the Microgrid that sends the data to the control center via WiMAX BS where the control center includes wireless server based-WiMAX technology.

Whilst, the second scenario (scenario_2) has two different points compared to the first scenario: (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. (2) the processing of collected data at the control center is implemented using servers based-Ethernet under the property of the utility of power grid. This scenario represents the reference case of WiMAX infrastructure.

TABLE II
THE APPLICATIONS OF REAL TIME DATA [18][15]

Application types	Substation infrastructure		Attributes of transmitted data	
	Source	Destination	**Data size (byte)**	**Frequency rate in one second**
PMU based WAMC	Substation	CC	44	60
Video surveillance	Substation	CC	1024	200
Microgrid status	Microgrid	CC	256	480

TABLE III
THE POWER CONSUMPTION OF WIRELESS NETWORK [34] [33] [35] [36]

Assumption	**Item**
WiMAX BS sector	
Power amplifier	300 w
Baseband processor	100 w
Transceiver	100 w
Converter	100 w
Signal generator	384 w
Microwave	80 w
WiMAX SERVER	
Baseband card	60 w
Chassis	40 w
Radio frequency	50 w
Cooling system	
Air conditioning	690 w
Green self-powered system	
The availability of sunlight	9 hours
Weather performance	Rainy (worst case)
Capacity of battery	200AH
Battery L*W*H (cm)	52.5*24*22
Battery weight (kg)	21.6
Solar panel capacity (w)	660 w
Panel dimension L*W (m)	2*1

Finally, the third scenario (scenario_3) handles the edge computing in wireless fashion based on WiMAX technology to enhance the performance of the first scenario. In the case of edge computing, there is a connection between the wireless local servers and the main wireless servers at the control center of power grid in order to receive any update or sending a copy of the data. Fig. 3, explains the details of adopted scenarios. Fig. 4 shows the flowchart of adopted methodology.

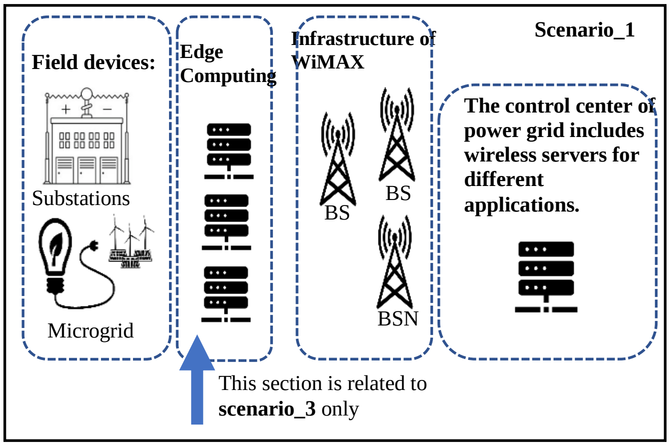

Fig. 3: The architecture of adopted Scenarios.

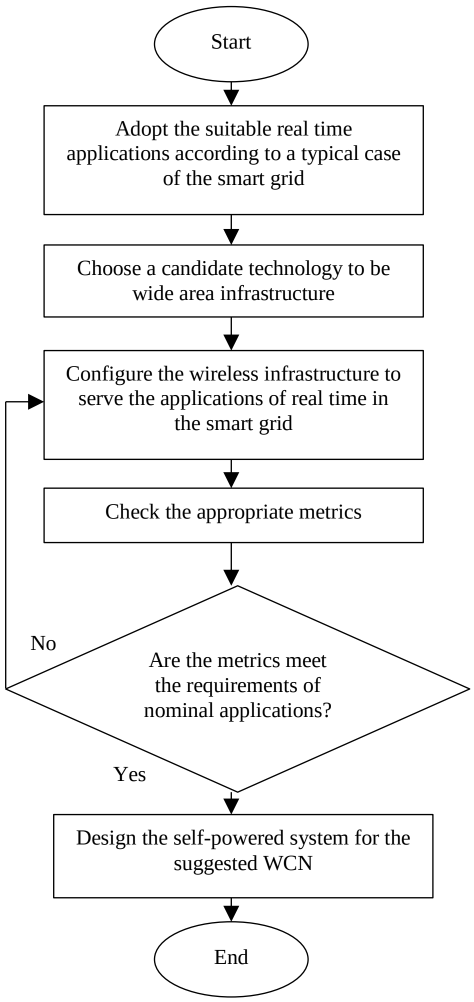

Fig. 4: The flow chart of the work methodology.

V. Results And Analysis

In this section, firstly each application will be analyzed alone to understand the application characteristics from real time attitude. Then, it is discussed the results of all applications in one hand to handle the practical case. The adopted metrics of this article will focus on the latency and the traffic reliability (sent traffic, received traffic, and packet loss) that offer clear conceptualization on the applications from real time point of view. Moreover, this section offers analysis for the available capacity of WiMAX BS and requested capacity of heaviest data application. Later, the design of self-powered system will present. Then, a comparison among this work and previous works will show.

With respect to PMU application, the end-to-end delay of PMU data is introduced as a global latency of PMU packet from sending at the source until reaching at the destination (PDU). The result of Fig. 5, shows the latency in the case of first scenario (scenario_1: pure wireless scenario without edge computing) for PMU application only, the result of latency is collected according to the first scenario for 16 PMUs linked to one BS sector. WiMAX system introduces the reserved traffic rate for each data link in term of quality of service. The results illustrate three cases of reservation data rate to exchange the data of PMUs based on scenario_1: 50kbps, 100kbps, and 384kbps. This Fig., explains that the increment in reserved traffic rate for PMU application contributes in offering lower latency, hence the latency is reduced about 81% from 136 msec to 26 msec in the case of reserved traffic equal to 384kbps. However, the increment of reserved data traffic largely may consume the available capacity of BS rapidly.

Referring to [15], the latency for WAMC application considers acceptable up to 50 msec. General speak, the sending data of PMUs is relatively small and it does not form a huge burden on the capacity of BS sector. For instance, one PMU sends 44 bytes with frequency rate equal to 60 so the sent traffic per PMU is about 2640 byte/sec.

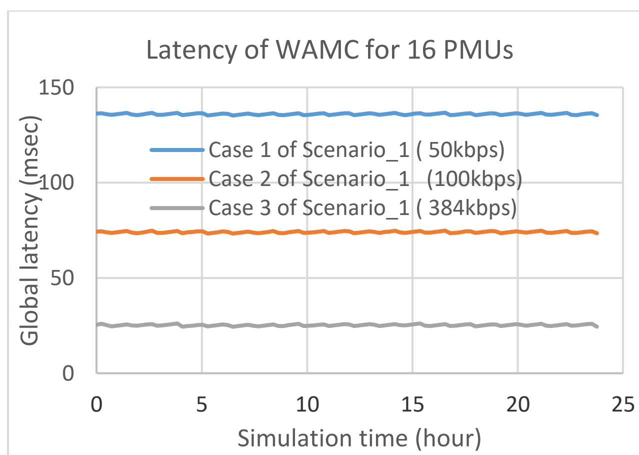

Fig. 5: Global latency of WAMC application for 16 PMUs.

Moreover, WiMAX BS could address the whole traffic of PMUs in the first scenario (pure wireless scenario without any support) as shown in Fig. 6 in terms of traffic sent and traffic received. In addition, it illustrates that the curves of traffic sent and traffic received are identical (42.1 k byte/sec). As a consequence, the reliability of traffic received is 100% where no lost bytes.

In the case of video surveillance applications, Table III demonstrates the increment of the substations from video surveillance point of view on the BS sector with respect to scenario_1 in the terms of latency, traffic, and capacity. This part of results handles the analysis of BS capacity in addition to the metrics of latency and traffic because the video application is a heavy data traffic and it requires significant capacity to meet its requirement.

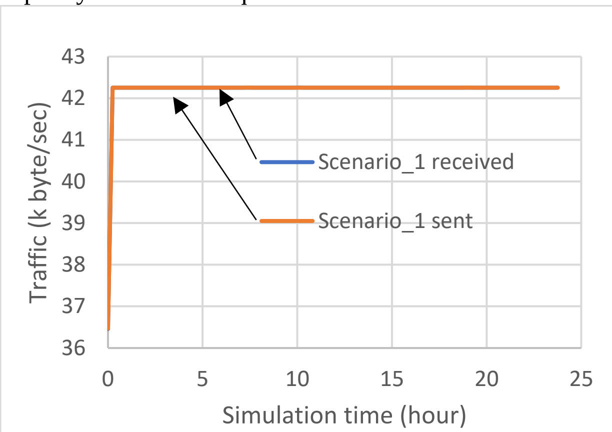

Fig. 6: Traffic of WAMC application for 16 PMUs.

Table IV demonstrates that, BS sector can support 6 clients of video surveillances application successfully. Whilst in the case of 7 video applications per BS sector, the offered of BS UL capacity could not handle the requirements of application traffic therefore the latency and lost packets are increased obviously.

TABLE IV
VIDEO SURVEILLANCE METRICS PER BS SECTOR

No. of clients (video applications)	Latency (msec)			Average packet lost (Packet/sec)
	Min	Ava	Max	
4	10.23	10.24	11.96	<1
5	10.35	10.35	10.61	<1
6	17.71	17.77	17.82	<1
7	**314.73**	**317.45**	**318.09**	**195**
No. of clients (video applications)	**Capacity of the system (Msps)**			
	Demand UL capacity by Video application		**Remaining UL capacity of BS sector**	
4	3.27		2.04	
5	3.48		1.83	
6	3.69		1.61	
7	**3.91**		**1.40**	

It is obvious that, the demand capacity in mega symbol per second (Msps) of video surveillance is increased with the increment of video surveillance clients. In contrast, the available capacity of BS is decrement with the increment of video surveillance clients. It is worth to mention, the uplink capacity of BS sector is about 5.3 Msps.

Fig. 7, shows the global latency in terms of Minimum, Average, and Maximum values of 16 video surveillances clients for all adopted scenarios: scenario_1, scenario_2 and scenario_3. The maximum latency of the first scenario is about 642 msec because the BS sector cannot handle the required capacity of video surveillance for 16 substations. Referring to Table IV, no more than 6 video surveillance applications are linked to one BS sector. Therefore, the clients of video surveillance should distribute on the three sectors in the case of no more than six clients linked to one sector.

The results indicate that the employing of edge computing (scenario_3) after distributing the clients on three sectors can improve the latency of the system significantly compared to scenario_1. Consequently, scenario_3 handles a perfect magnitude of latency as well as the features of flexibility and low-cost maintenance compared to the pure wireless system and the scenario of cabling backbone of the smart grid. In other words, scenario_3 submits the advantages of scenario_1 and scenario_2. According to the requirements of Video surveillance application, the threshold of the video latency should be less than 200 msec [37].

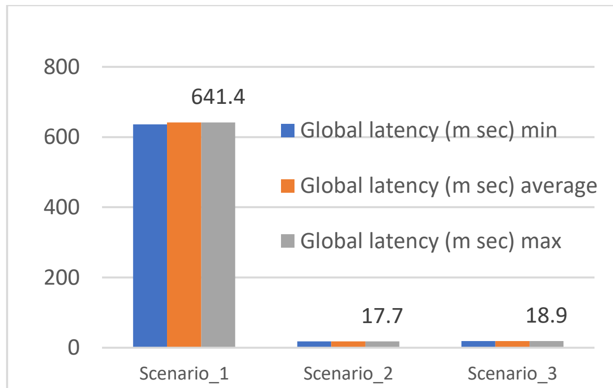

Fig. 7: Latency of 16 video surveillance applications with different scenarios.

To understand the capability of BS sector in terms of available and demand capacity of video surveillance application and to validate the results of the adopted software, Fig. 8, explains the performance (per) of BS sector in the case of video surveillance application based on two approaches: mathematical analysis and OPNET modeler. It is noted that, the horizontal domain represents the number of video clients that are served by one BS sector.

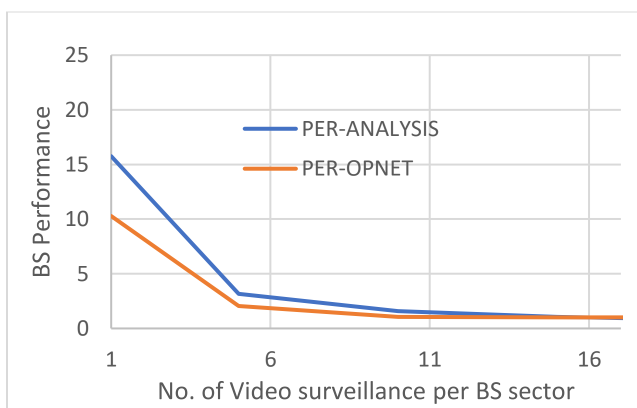

Fig. 8: BS performance based on Video surveillance application.

In fact, there is an excellent agreement between the analytical approach and the OPNET approach results for all the values of video surveillance number. Moreover, the BS sector can success in serve the nominal applications if the curve of BS performance (available capacity/demand capacity) is ≥1.

Theoretically after 13 clients of video surveillance, Analytical and OPNET results indicate that the available capacity of BS sector is equal to the demand capacity. This result shows that, BS sector suffers from consuming the available capacity of BS due to the heavy data traffic of video surveillance.

On the other hand, the traffic received of video surveillance application for 16 substations is shown in Fig. 9. Scenario_3 offers better performance from traffic received point of view compared to scenario_1. Edge computing enhances the performance of the system to handle the heavy traffic of video application. It is obvious that, scenario_3 can offer the same performance of scenario_2 but without needing to any physical cables for communication in the backbone of the network in the system.

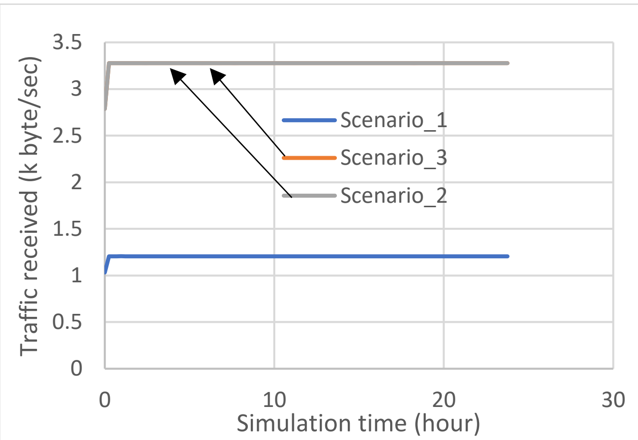

Fig. 9: Traffic received of 16 video surveillance applications with different scenarios.

Packets loss in the case of video surveillance are shown in Fig. 10. Scenario_3 can protect the packets from the lost as the performance of scenaario_2. Whilst, scenario_1 suffers from the significant packet loss could negatively effect on the performance of the real time application quality.

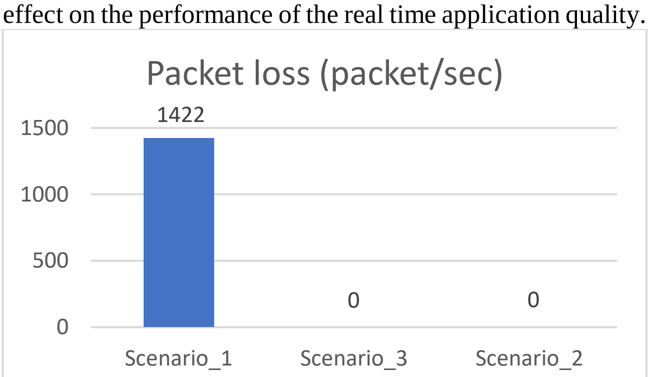

Fig.10: Packet loss of 16 video surveillance applications.

Table V presents the analysis of DER application. This type of application is a very sensitive time application, the latency should be less than 20 msec with 99.99% data reliability according to IEC 61850 [21].

The results of Table V explain no problems in the case of handling one microgrid with condition of the value of reserving data rate equal to 0.5M bps because the latency is less than 20msec and the reliability of data is 100%. But in the case of dealing with three microgrids, it is necessary to raise the reserved data rate up to 1M bps to address the requirements of the application. However, the increment of adopted microgrid requires increment in the reserved data rate at BS to handle the nominal requirements of the application.

TABLE V
THE METRICS OF DER APPLICATION

No. of Microgrids	Max latency (msec)		Packet loss (Packet/sec)	
	Reserved data rate by BS		Reserved data rate by BS	
	0.5Mbps	1Mbps	0.5Mbps	1Mbps
1	18.87	11.18	0	0
3	26.65	12.49	0	0
5	479.89	102.97	15.7	15.1

After analysing the real time applications one by one, Table VI presents all applications of adopted smart grid together in one view.

TABLE VI
REAL TIME APPLICATIONS TOGETHER

case	ONE BS (Load of the BS sectors)			Traffic (M byte/sec)		Max Global Latency (msec)
	Sector1	Sector2	Sector3	Sent	Received	
1	6 video clients	6 video clients	16 PMUs clients and one Microgrid	2.627	2.627	19.5
2	7 video clients	6 video clients	16 PMUs clients and one Microgrid	**2.832**	**2.642**	**127.9**
3	6 video clients	6 video clients	16 PMUs clients, one Microgrid, and 4 video clients	**3.447**	**3.447**	**19.88**

Table VI presents three different cases for all real time applications of smart grid together covering by one BS that has three sectors with respect to wireless scenario. Case one explains that the capacity of one sector can compensate 6 clients of video without impairments where all sent traffic is received successfully with small latency. However, the adopted typical smart grid has 16 clients of video surveillance. Case two shows adding any extra clients to Sector one or Sector two of BS could raise the latency hugely and causing packet loss. While case three demonstrates the suitable adding of the rest of the video clients (4 clients of video surveillance) should link to the Sector three because the traffic of other applications (DER and PMUs) is relatively small compared to video surveillance application. In summary, case three is the efficient distribution for the clients of applications to handle the optimum latency and traffic of the wireless scenario of adopted typical smart grid.

In the folowing subsection, the issue of designing self-powered system based-renewable energy (green energy) for the infrastructure of WiMAX system will be discussed.

Table VII demonstrates the designed green self-powered for the suggested WCN according to the power consumptions of WiMAX system that operates in 48 volts.

The design of green self-powered infrastructure is calculated based on the worst weather conditions (rainy weather) and the period of no sunlight is about more than 15 hours. On the other side, the designed system offers maximum power capability of solar panels (660w) that are commercially available with storage system of lithium batteries (200AH) as a source of the stored power in the case of absent the sunlight. This is related to attractive features of such batteries. In fact, the expected loads of WiMAX system are shown in Table 2. For robust conditions at least, the green self-powered supply of WiMAX BS sector consists of 2*200AH batteries and either 3 panels of 660w. It is worth mentioning, the hot weather places require robust cooling system and as a result lead to increase the consuming of the power but the period of sunlight is long relatively. On the other side, the cold places have short period of sunlight but the required level of cooling is less than the hot weather places so the consuming of power for cooling is lower compared to hot places.

TABLE VII
THE DESIGN OF GREEN WIMAX SYSTEM

Case	Load (w)	Green self-powered system		
		Batteries		No. of solar panels
		No. of (200 AH)	Delivered electricity continuously (hours) until full discharging	Capacity 660w
BS sector without cooling system	**1064**	**2**	**18**	**3**
BS sector with cooling system	**1754**	**3**	**16**	**5**
Server	**150**	**1**	**64**	**1**
BS sector and server with cooling system	**1904**	**3**	**15**	**6**
Three BS sectors and server with cooling system	**3872**	**6**	**15**	**11**

On the other side, Edge computing that represents WIMAX server which are feeded by a solar energy too. Table VII demonstrates that the storage system can deliver the electricity from the charged batteries to the load for 15 hours at least to compensate the absent of the sunlight in the case of the worst weather conditions.

VI. CONCLUSIONS AND FUTURE WORKS

The suggested WCN based on WiMAX technology is enhanced by edge computing and green communication to serve the real time applications of smart grid. The results indicated that the wireless scenario can handle the requirements of PMUs application comfortably. Furthermore, video surveillance application produces heavy data traffic and it consumes the available capacity of WiMAX BS quickly. However, employing the edge computing in a wireless fashion offered attractive solution to compensate the requirements of the heavy data traffic application. The results proved that the employing of wireless edge computing reduced the latency about 34 times with more than 99.99% data reliability compared to the wireless scenario without employing the edge computing. Moreover, DER data is a very time sensitive application required hard conditions. The adopted wireless scenario can address these requirements in the case of dealing with one Microgrid at reserved data rate equal to 0.5M bps where the latency was less than 19 msec and without lost packets. It is recommended to raise the reserved data rate at BS in the case of dealing with more than one Microgrid to handle the appropriate requirements of this application.

On the other side, the research presented a green WiMAX BS by offering a simple methodology based on the power consumption of the BS and servers' loads.

The designing of a hybrid system comprises of solar cell panels and storage subsystem (batteries) for WiMAX infrastructure to provide the self-powered supply based-renewable energy resources to enhance the system in terms of resilience and logistic .

The future work is going to handle the applications of advanced metering infrastructure (AMI) in the smart grid based on green WiMAX system in addition to analysis the cyber-attacks in the environment of smart grid and highlighting the possible cyber security methods to address such attacks in efficient ways.

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CONFLICT OF INTEREST

The authors have no conflict of relevant interest to this article.

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