Communication Improvements for Intelligent Systems in Microgrids - Part II

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***Abstract*—The development of microgrids allows improving the electrical system from renewable energy sources. Costumers have started to install small-scale microgrids formed by wind turbines and photovoltaic panels, to guarantee their energy needs. This paper presents an evaluation of communication performance in small-scale microgrids and vehicle to grid (V2G), based on standard protocol IEC 61850. Three technologies were compared, Ethernet, WiFi and ZigBee according to the costs of implementation, reliability and end-to-end delay. To simulate the behavior of each technology in small-scale microgrids, the Riverbed Modeler software was used. The simulation uses three types of data to evaluate the performance of the network, such as periodic data stream, random data stream and burst data stream, accordingly to the control on intelligent applications. The specific study using these models allowed to reveal the behavior of each technology in front of different data streams and performance of the best technology, according to CPU utilization, data size and application protocol.**

Keywords*—Microgrid; Communications; Riverbed Modeler; Intelligent applications, V2G, IEC 61850.

I. Introduction

Microgrids emerge as a need to solve the current problems of power grids, since they include distributed energy resources (DERs), storage and loads [1]. One of its most attractive features is the ability to disconnect from the network in case of failures and work in islanded mode. Microgrids are considered the next generation of the electrical system because they are able to provide a safe and reliable electrical network and efficient power generation. High penetration of renewable energies and intelligent control applications makes them more efficient and flexible than conventional power grids.

To take advantage of these benefits, several consumers have begun to install small wind turbines (WT) and photovoltaic panels (PV), to meet their needs locally. For consumers it is beneficial because they can operate in islanded mode in case of failure, store the energy generated, or feed the excess power into the grid to reduce their costs. On the other hand, in order to take advantage of the benefits, an efficient control mechanism is necessary to guarantee the rapid recovery of the system in case of failure. For this reason, several recent investigations have been focused on intelligent systems for the control of microgrids parameters. This task requires a reliable communication system, capable of supporting the changing needs in real-time electrical environment. In addition, these applications have critical communication requirements that must be addressed, such as latency or data rate error, to achieve secure operation of the microgrid.

From the communications point of view, there are still shortcomings to meet the minimum requirements of intelligent applications [1], [2]. The appropriate infrastructure for a small-scale renewable energy system has not been studied in depth. Some of these researches have been focused on electrical engineering and control aspects [3] instead of communication. The decision to choose an intelligent system, to solve a certain control problem, varies according to multiple elements. For example, the network topology, the type of data and the volume of information, computational and time requirements, or the minimum error rates allowed.

Recent research recommendations suggest the use of different technologies to ensure reliable communication in the microgrid environment [4]. In this paper is compared three widely used communication technologies according to the literature, in order to evaluate the behavior of small-scale microgrid applications. For this purpose, a communication architecture based on the IEC 61850 standard is defined for Ethernet, WiFi and ZigBee technologies, and simulated using the Riverbed Modeler software.

The fundamental contributions of this research can be considered as i) designing communication architecture focused on the control of intelligent applications for three widely used technologies, ii) the impact of message transmission delay is discussed and the influence of the data size in real-time transmission, iii) the performance of each topology according to the end-to-end delay (ETE), reliability and cost, to characterize the data stream of each architectures.

II. Architectures and technologies on microgrids communications

The architecture for evaluating the performance of communication technologies only considers fifteen smart electronic devices (IEDs) connected in a star topology to a central node, in which different parameters of intelligent applications are simulated, according to the IEC 61850 standard and previous research. WiFi network model uses IEEE 802.11g standard, because it operates at 2.4 GHz and can reach speeds up to 54 Mbps. On the other hand, ZigBee (IEEE 802.15.4) is chosen for its low cost and low power consumption, despite having a low data rate (around 250 Kbps). For the Ethernet scenario

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it was necessary to connect a switch between the application server and the IEDs, with links at 100 Mbps.

Data stream in substation communication network can be defined as [5]: i) periodic data stream, ii) random data stream, and iii) burst data stream. In this case, periodic data stream consists of a regular data series about the state of the switches and the protection of IEDs during normal operation. Intelligent control applications in microgrids require some of this type of data, they need a good performance in real-time, good stability, and small transmission errors.

Random data stream are some short-term, real-time and delay sensitive packets, such as switching operation commands, time synchronization, long-duration packets, and real-time short-duration packets, among others. The burst data stream is responsible for transmitting data protection actions and the change of the switches from the IEDs to the intelligent applications [5]. It uses a high volume of package and requires real-time performance.

The communications architecture commonly used in wireless communication systems has two alternatives. The first is to install an access point (AP) between the sensor nodes and the server, to increase the coverage area. The other variant can be designed without an access point, where the sensor devices are connected directly to the servers. In this research, the AP is not considered due to the delay that it introduces in communication, justified by data processing and the computation in the devices. The ZigBee topology include a coordinator node and different IEDs, while the WiFi network consists of several wireless stations connected to the application server.

Periodic data stream and random data stream simulation were made from the video conference service, because it is affected by the delay of the packages. In the case of burst data stream, the FTP service was used, in order to simulate a failure and its respective response to the control station.

III. Data stream configuration for simulation purpose

The simulation of the critical parameters required by intelligent applications was made in a small-scale microgrid environment. Three technologies are presented and the communication parameters are modified considering the worst case of the application. The types of data used for the evaluation are based on [6] and are denoted as follows:

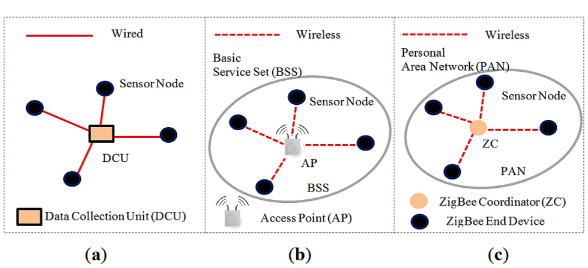

Fig. 1: Network architecture proposed a) Ethernet, b) WiFi c) ZigBee

1) Periodic data stream: the simulation considers the use of UDP (user datagram protocol) for sending the data from each IED to the application server. The frequency is 20 ms and the message length is 256 bytes.
   The elements to configure the video conference service and generate periodic data streams are as follows:
   - In the Application Definition module in Riverbed Modeler, the videoconference parameters are set as incoming and outcoming stream interarrival time as: constant (0.02 seconds).
   - To define the length of the message, the Application Definition parameters are configured as incoming and outcoming stream frame time as: constant (256 bytes).
2) Random data stream: the message has a length of 128 bytes and the packets received by the applications obey an exponential distribution of $\lambda = 0.01$.
   The configuration parameters selected for the simulation are defined as follows:
   - When considering an exponential distribution of the packets, incoming and outcoming stream interarrival time are defined as: exponential (0.01 seconds).
   - Also, incoming and outcoming stream frame time is defined as: constant (128 bytes).
3) Burst data stream: the messages are sent using the FTP file transfer protocol from each of the nodes to the server and vice versa. The arrived packages obey the Pareto distribution characterized by the elements k = 0.512 ms, $\alpha = 1.1$ during the time in ON, and the time in OFF is defined by the negative exponential distribution $1/\lambda$. The average size of each of the packets in this type of data is 1024 bytes, which follow a uniform distribution [6]. For this simulation the FTP protocol is used and the parameters are configured as follows:
   - Command Mix (Get / Total): 50%
   - Inter-request Time (seconds): Pareto (0.000512, 1.1)
   - File Size (Bytes): constant (1024)

The streams are evaluated in the topologies presented in this paper and the results are verified as shown below.

IV. Results and discussions

In this section we analyze the delays of communications for Ethernet, WiFi and ZigBee technologies, as well as the effect that the increase in the size of the packets causes in communications. To evaluate the performance of the network, the end-to-end delay (ETE), the CPU utilization, the network reliability and the implementation costs are considered. The technology proposed and the main results of this investigation are described below. The simulation based on Ethernet technology connects the IEDs to the application server through 100 BaseT links in Riverbed modeler.

It is necessary to locate a switch between these devices to handle the number of links to the server. Under appropriate conditions this technology will allow sending and receiving data at 100 Mbps, with distances less than 100 meters. Fig. 2 shows the topology used to evaluate the behavior of Ethernet, according to the simulated data types.

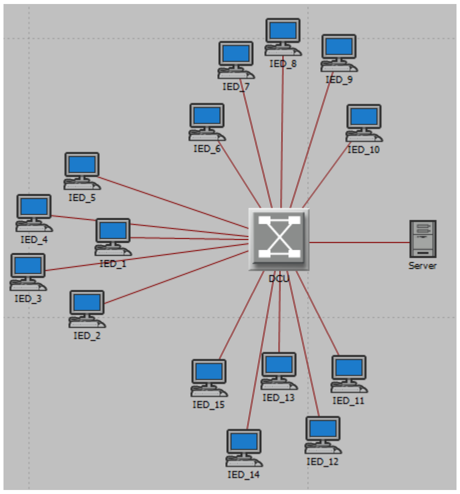

Fig. 2: Ethernet-based topology in Riverbed modeler software.

WiFi technology has become a popular communications alternative in recent years, due to low installation costs and the possibility of relatively high transmission speeds. Generally, WiFi devices are connected to an access point, which distributes and regulates the traffic between devices. Our proposal is based on a topology removing the access point, justified by the need to achieve the highest possible data rate and reduce the ETE delay. The drawback of this structure is that it has a smaller coverage area (between 100 and 200 meters), under ideal conditions. In this sense, each device relay the traffic to the control server wirelessly, as can be seen in Fig. 3.

ZigBee technology is based on the IEEE 802.15.4 standard whose specifications allow to reach transmission speeds about 250 Kbps.

The proposed topology is distributed in a star shape, for which it is possible to reach a coverage area of 100 meters without repeaters. Currently, ZigBee is one of the most used technologies in the home network environment, and its applications vary from the control appliances, the supervision of the distribution system or the intelligent power metering. For this reason it is included within the possibilities of communication in a small scale microgrid, despite being focused on low duty-cycle applications. The network consists of the coordinating device and the sensor nodes as shown in Fig. 4.

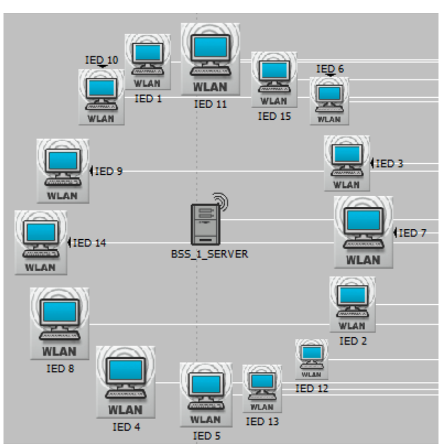

Fig. 3: WiFi-based topology in Riverbed modeler software.

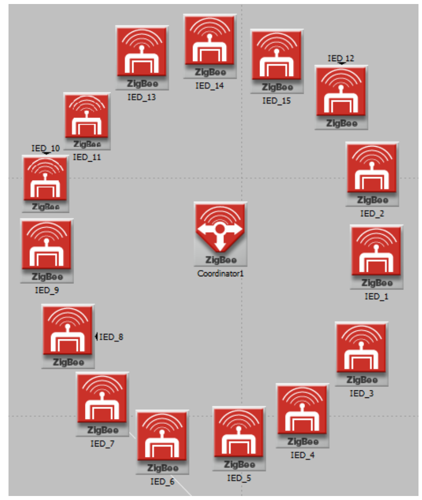

Fig. 4: ZigBee-based topology in Riverbed modeler software.

A. Evaluation of the end-to-end delay

End-to-end delay refers to the time needed for a packet to be sent by a device until it is received by another node within the network. This parameter is frequently used to evaluate the status of the most delay sensitive communications, such as voice over IP (VoIP) or video conference services. For this reason, this parameter is chosen to compare applications with high communication requirements. ETE delay is affected by the delay in the transmitter, the delay added by the communication network links and the delay in the receiver. For fault location and restoration, the ETE delay should not exceed 10 milliseconds as seen in part I of this investigation. For its part, the delay in transmission lines should not be more than 200 milliseconds to ensure the availability of the data in intelligent applications.

In this section we compare the total end-to-end delay of for three different communication technologies Ethernet, WiFi and ZigBee. In Fig. 5 we compare the results of each tested technology according to the types of data stream defined. As can be seen, the end-to-end delay in Ethernet is practically zero, which favors control applications with delay sensitive requirements. WiFi presents delays of 0.5 milliseconds, while ZigBee has the highest delay of about 3 milliseconds. This simulation was made from the periodic data stream profile, defined above.

As in the previous case, Ethernet technology has the best performance, while ZigBee's behavior is not the most suitable. For these reasons we can say that Ethernet has a better performance compared to the rest of technologies for small-scale microgrid scenario tested in this paper. Next step was to modify the transmission times in 10 milliseconds, 20 milliseconds, 50 milliseconds and 100 milliseconds for Ethernet technology and evaluate the end-to-end delay. Fig. 6 allows us to appreciate that the ETE real-time performance is affected by transmission times of periodic data stream, or relay protection data stream.

Another parameter modified for the technology with best performances was the size of the message. The simulation included sizes of 256, 512, 1024 and 2048 bytes to check these effects on the network delay. As shown in Fig. 7, with the increase in package size, the ETE delay increases and the variations show more pronounced peaks. In this way, in order to meet the real-time requirements for intelligent applications, a large variety of data streams must be avoided, as well as big data size between the nodes.

On the other hand, the quality of service is evaluated in Ethernet technology in order to prioritize the traffic generated by five nodes with respect to the others. The configuration uses "Weighted Fair Queueing (WFQ)", which provides a queueing strategy to packets with a different priority. Five nodes transmit random data with service differentiation EF (expedited forward), while the rest of the nodes transmit data from the default communication protocol without preferences. As can be seen in Fig. 8, the topology with differentiated services has good behavior, while the packages with critical requirements will benefit if they use QoS.

Finally, an evaluation of the CPU load background utilization for 80%, 60%, 40%, and 20% is carried out in the Ethernet-based topology. Fig. 9 shows that with the increase in CPU utilization, the delay of the network increases. In addition, it can be seen in Fig. 10 that high-level protocols perform worse than lower protocols in the application layer. This is mainly due to the necessary encapsulation at high level protocol to guarantee the communication, and the delay of the codification of intelligent algorithms.

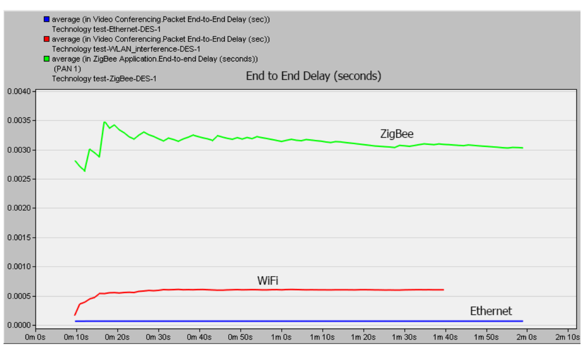

Fig. 5: Comparison of end-to-end delay for random data stream in Ethernet, WiFi and Zigbee technolgy.

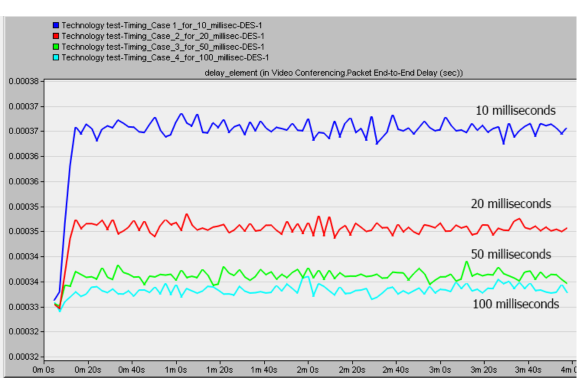

Fig. 6: Comparison of the end-to-end delay, for different packet transmission timing in Ethernet.

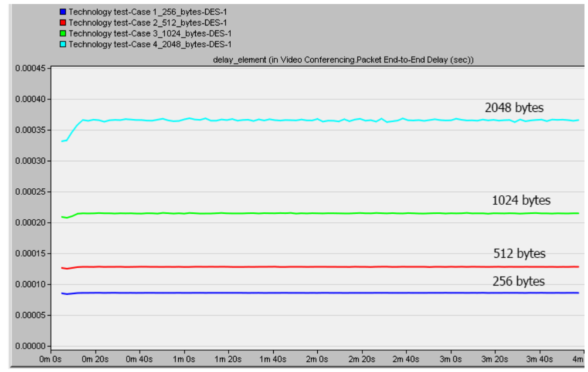

Fig. 7: End-to-end delay for different packet sizes in Ethernet technology.

B. Reliability

Reliability is the communications systems property to behave consistently according to the specifications [6] for which it was designed and is used as a measure to contrast how secure communication is. In this research, the calculation of this parameter is considered as the ratio between the bits that are successful received in the server and the bits sent from the IEDs.

The reliability calculated shows stable performance for Ethernet and WiFi technologies, with a ratio of 100% in each verified stream. On the other hand, the behavior of the reliability in ZigBee has a ratio of 100% for the case of the periodic data stream, but when the package size is increased the reliability begins to deteriorate until reaching a 99.23%, for frames of 2048 bytes. This is another element that leads to avoid ZigBee technology if the size of the data tends to be high.

C. Network Cost

Deployment costs in this paper are defined as the sum of the costs of the active elements such as the routers and the costs of the passive elements as the means of transmission.

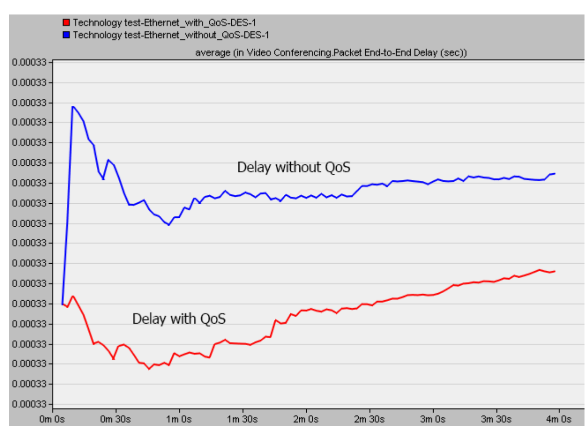

Fig. 8: Comparison of the end-to-end delay with QoS and without QoS.

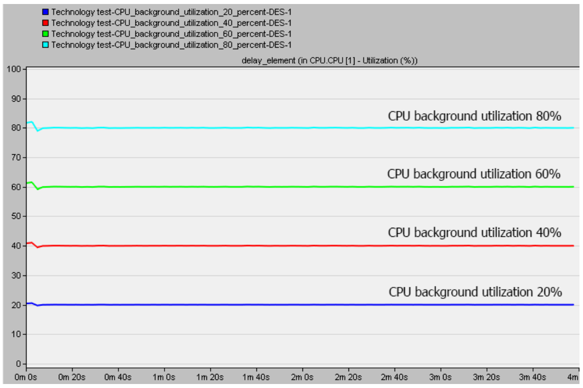

Fig. 9: Comparison of the end-to-end CPU background utilization in Ethernet.

TABLE I: Deployment costs for the proposed technologies [7]

Technology	**Chip cost**	**Cable cost**
Ethernet	1-13 dollars per unit	1 dollar per meter
WiFi	3-20 dollars per unit	no cost
ZigBee	2.75-3.5 dollars per unit	no cost

Equation below describes the formula used to calculate costs based on [7]:

$$C_{total} = C_{active} + C_{passive}$$

where C_{active} refers to the costs of the active devices and $C_{passive}$ represent the cost of passive components. The costs of each technologies is defined in equations (1) - (3), in which C_{CM} means costs of chip module, C_{ESW} is the cost of Ethernet switch, C_{Cable} refers to cost of cable, and C_{AP} is the cost of the access point. Table I shows the implementation costs for each topology tested on this paper.

$$C_{Ethernet} = C_{CM} + C_{ESW} + C_{Cable} \quad (1)$$

$$C_{WiFi} = C_{CM} + C_{AP} \quad (2)$$

$$C_{ZigBee} = C_{CM} \quad (3)$$

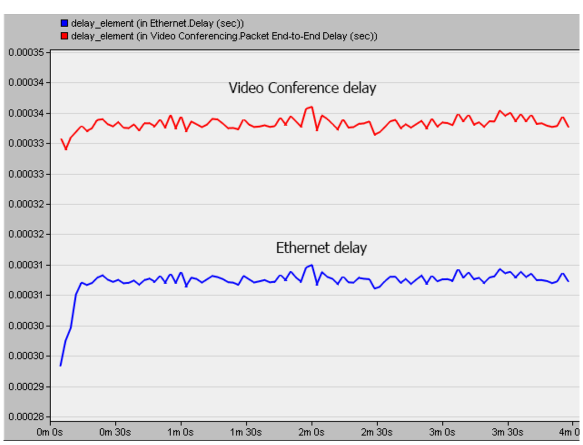

Fig. 10: Performance between protocols from different application layers.

The previous results show that the costs of implementing ZigBee technology are lower than their counterparts. On the other hand, deploying systems based on WiFi or Ethernet technologies would have approximately the same costs, although it is important to emphasize that Ethernet needs an investment that guarantees the transmission wire. In addition, WiFi technology has the best adaptability to physical conditions.

V. Communications in Vehicle to Grid (V2G)

One of the most important applications, which promises to revolutionize the transport sector is the connection of vehicles to grid (V2G). Its importance lies in the fact that the electric vehicle can be connected to the power grid and operate as loads, or as a feeder, injecting energy into the network. In this way these vehicles are considered as distributed generation sources, so they need to maintain communication with the central controller to guarantee the operation and control. The structure of the communications network for V2G is composed by a central controller, an aggregator whose objective is to provide or receive electricity from the vehicle and the vehicle.

Some of the most important challenges in V2G are defined in [8], while [9] shows the benefits and the inconveniences of the technology.

Another important aspect to consider is sustainability. In [10] the potential benefit and sustainability of V2G is presented. In [11], the authors review the IEC 61850 standard and propose an extension of it, to satisfy some elements that still consider that they have not been addressed enough.

To guarantee communications in V2G, the literature uses diverse wireless communication technologies. Some of the most important are WiMAX, machine-to-machine (M2M) and Long Term Evolution (LTE). WiMAX technology is generally used for communication between the aggregator and the vehicle. In [12], WiMAX is proposed as a communication protocol and system losses are evaluated. On the other hand, [13] simulates two types of Off-Board and On-Board integrators as a communication architecture.

Technologies such as ZigBee or WiFi can be used as a complement to communications, or as communication alternatives in case of failures in the fundamental systems.

In addition, the low cost of implementation and effective operation in small area, makes them an important element to consider. M2M and Internet of Vehicles is investigated in [14], Finally, in [15] LTE is proposed as an alternative communication between the central controller and the vehicle. The operation principle, applications, control techniques, advantages and disadvantages of LTE in V2G are described in [16].

From the point of view of the intelligent applications, V2G has been characterized by a wide variety of algorithms, which they try to find the optimal load, best source location and improve the control technique. The algorithms most used are the Genetic Algorithms (GA), Differential Evolution (DE), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) and Linear Programming (LP). In [17] a review of each of these techniques is made and the advantages and future projections are exposed.

VI. Conclusion

In this paper we compare Ethernet, WiFi and ZigBee technologies for a small scale microgrid according to different data streams. Data streams were implemented based on the IEC 61850 communication standard for some critical requirements presented by intelligent applications such as latency as shown in previous research. It was found that in order to ensure the optimal performance of intelligent applications, it is necessary to reduce the size of messages. In addition, sending different data streams should be avoided, because they deteriorate the reliability of the network, and increase the delay of the devices.

For applications that require high real-time communication, the UDP / IP protocol must be used, while if high reliability is required, TCP / IP must be selected. The technology with best performances was Ethernet since it showed lower delays for the different types of streams used, and lower CPU utilization. According to the implementation costs, the technology with the best results was WiFi. It also has good adaptability to the ground and the possibility of reaching relatively high transmission speeds in certain conditions.

The factors that most influence the delay are: the size of the message, the CPU utilization, the transmission intervals and the protocol of the application layer. The main contribution of this research lies in the study of the appropriate technology for the control of intelligent applications in small-scale microgrids. Future work should be aimed at verifying the performance of other technologies for much wider network models, such as neighbor area network (NAN) and wide area network (WAN).

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