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Wireless Sensor Networks for Smart Micro-Grids

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Abstract— Smart micro-grid has emerged as a new infrastructure to further enhance existing power grid through the integration of renewable energy sources and communication technologies. In fact, smart micro-grid infrastructure is characterized by renewable energy integration, automatic metering infrastructure, distribution automation and complete monitoring and control of the entire power grid. The monitoring is based on a set of sensors, which are used for collecting data production, data consumption and weather conditions. These data should be transmitted by a wireless network to a main location or sink for visualization and analysis. For this reasons, it is important to develop a self-configured wireless sensor network able to handle efficiently the massive amount of data. This paper investigates the ZigBee network in the context of micro grid by comparing two routing topologies.

Keywords- *Wireless Sensor Networks, Smart Micro-Grids, Data Collection, ZigBee, Routing Topologies.*

I. INTRODUCTION

Smart micro-grid (SMG) communication infrastructure is a set of Wireless Sensor Networks (WSNs) that collect different data (e.g., power production, consumption, weather conditions...). These data are analyzed for controlling the power flow and balancing the power Demand/Response in order to avoid the blackout problem. The data are transmitted by different sensors' nodes to a base station named Sink. In fact, the sink acts like an interface between the users and the network and the nodes sense their environment (e.g., power production, temperature) and route sensed data from one node to another until it reach the sink node (see Figure 1).

Sensor nodes can wirelessly communicate with other its neighboring nodes via radio signals; it is equipped with radio transceivers, sensing/computing devices, and a power supplier component. However, their efficient deployment is an important issue that needs to be considered. In fact, after their deployment, they have to self-configure and self-organize in order to form an appropriate communication infrastructure. These sensors are battery powered devices with limited resources (i.e., processing speed, communication bandwidth and storage capacity), and therefore, these characteristics need to be taken into consideration when developing this type of wireless communication network, especially in the context of micro-grid, which requires extensive communication among its nodes.

Since only a small size of data that need to be transmitted sensors does not need a high bandwidth, low latency and very low energy consumption are highly required. There are a multitude of standards like WiFi and Bluetooth that address

mid to high data rates (e.g., voice, video...). However, up till now, there is only ZigBee that could meet WSN requirements for micro-grid. In fact, ZigBee was deployed (e.g. Xbee) in several applications that does not require high data rates but does require low cost and low power. This proprietary system was designed because there were no standards that meet these requirements. The ZigBee is not pushing a technology, rather it is providing a standardized base set of solutions for WSNs [1, 2]. This work provides first an introduction to WSNs and their applications in the smart-grid. A performance study of different communication topologies using ZigBee technology was then conducted and results are reported to show their efficiency in SMG.

II. RELATED WORK

Recent research work in WSN focused mainly on the development of a wireless communication with low-cost and very low power protocols communication. The aim is to extend the life of the network while improving their bandwidth management and processing speed. For instance, authors in [15] presented different factors (e.g., energy efficiency), which need to be considered for designing WSN. They studied several constraints, such as topology change, scalability and power consumption in order to build a WSN with high flexibility and reliability for almost all applications' requirements. Authors in [16] discussed and analyzed various wireless communication standards, cyber security issues and solutions for WSN and explored topology control for cyber security especially for Smart Grid.

A smart grid communications system is presented in [3, 4, 13, 14], authors explored three major systems, namely the smart infrastructure system, the smart management system, and the smart protection system. For the smart protection system, authors explored various failure protection mechanisms, which improve the reliability and the flexibility of the Smart Grid. For the smart infrastructure system, authors explored the smart information subsystem, the smart energy subsystem and the smart communication subsystem. For the smart management system, they have explored various management objectives, such as improving energy efficiency, profiling demand, maximizing utility, reducing cost, and controlling emission. They have also explored various management methods to achieve these objectives. In [5], a statistical characterization of wireless channel in different electric-power-system environments has been presented. WSN design and deployment challenges on wireless communication

reliability are identified and experimentally studied. The impacts of electric-power-system environments on low-power wireless communications have been also revealed and the potential applications of WSNs in smart grid are summarized. Authors in [6] have proposed a various smart grid applications, which are achieved through standardized wireless

communication technologies (e.g. IEEE 802.11 based wireless LAN, IEEE 802.16 based WiMAX, 3G/4G cellular, ZigBee based on IEEE 802.15, IEEE 802.20). Moreover, challenges related to each wireless communication technologies have been briefly discussed.

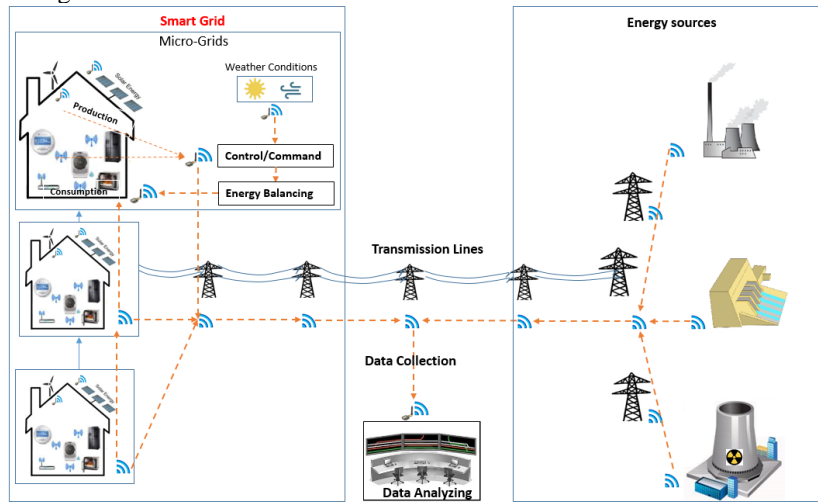


Fig. 1. Wireless sensors network architecture applied to the smart grid

III. WSN FOR SMART MICRO-GRID

WSNs have been successfully applied in various application domains [1, 2, 7, 8, 9], such as in transportation, healthcare, and environment monitoring. In the context of SMG, WSN could be deployed to measure physical quantities (e.g. current, voltage, frequency). When sensors detect the event being monitored, the event is reported to one of the base stations, which then takes appropriate action as illustrated in Figure 2. In fact, a microgrid is a localized grouping of electricity generations, loads and energy storages. In the normal operation, it is connected to a traditional power grid. In the traditional power grid, the electricity is generated by the hydraulic generator, fossil or nuclear energy then moved by transmission and distribution grid to users. In a microgrid the users can generate locally a low power electricity using renewable energy sources, such as solar panels, wind turbines and fuel cells. Through the application of control strategies

[10], we can manage the power flow in order to minimize the consumption from the grid [11]. Several works were also carried out to minimize the consumption [12] by controlling active equipment inside the building.

The smart infrastructure system applied to manage the power sources flow can be divided into three subsystem [3]: *i*) smart energy subsystem for power generation, *ii*) a smart information subsystem for information metering and measurement (Sensor, Smart meter) as well as information management for data analyze and control decision, and *iii*) a smart communication subsystem for wireless data transfer between sensors nodes and the information management subsystem. In other words, the smart information subsystem is responsible for advanced information monitoring, metering, and management in the context of the SMG. The smart communication subsystem is responsible for communication connectivity and information transmission among all SMG devices and applications.

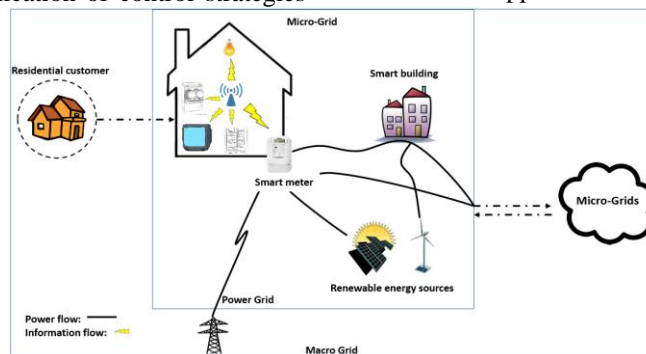


Fig. 2. Micro-grid infrastructure

In this work we focus mainly on the smart communication subsystem by investigating different ZigBee topologies in the context of SMG. In fact, three main topologies could be deployed as a communication medium, start, mesh, and hybrid

topologies as depicted in Figure 3. For example in a start topology, a single base station can send and receive the data to a number of remote nodes. The remote nodes are not permitted to send messages to each other (Figure 3-a). The advantage of

this type of network is the simplicity and the ability to keep the remote node's power consumption to a minimum. It also allows low latency communications between the remote node and the base station. Alike star topology, mesh topology is known as multi-hop communications in which data is transmitted from one node to another in the network, which is within its radio transmission range. (Figure 3-b). This network topology has the advantage of redundancy and the range of the network is not necessarily limited by the range between single nodes; it can simply be extended by adding more nodes to the

system. Unlike these abovementioned topologies, a hybrid between the star and mesh topologies could provide a robust communications network, while maintaining the ability to keep the wireless sensor nodes power consumption to a minimum. The sensor nodes with lowest power are not enabled as data forwarder, while other nodes are enabled with multi-hop capability, allowing them to forward the data from the low power nodes to other farther nodes in the network. In the rest of this work, we investigate these three topologies by conducting simulations in different context.

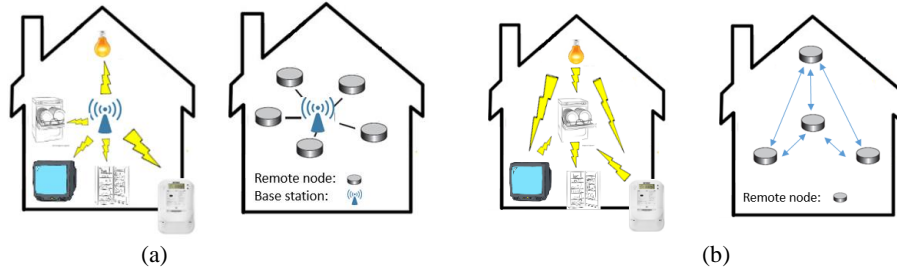


Fig. 3. Micro-grid communication topologies, a) star, b) mesh

IV. SIMULATION RESULTS

In this section, a wireless sensor network system was designed using OPNET Modeler Academic Edition 17.5 as a simulation tool. Different ZigBee topologies are created and evaluated. Using the ZigBee standard, a performance analysis of the two topologies has been conducted. The different network topologies built up by ZigBee devices are star, and mesh network. In the star topology a coordinator is responsible for the network. All other devices are end devices and communicate directly with the coordinator. This topology is suitable for time critical applications and for networks with a centralized device. In mesh network, the coordinators are still responsible for the network initialization and maintenance, while the routers are used to extend the network. A mesh network shall allow full peer-to-peer communication and the

different devices perform the routing in the network. Routing of data is decentralized in mesh network. A mesh network is in this way self-healing so that if a node fails another route is used for the delivery.

For conducting performance evaluation, different scenarios have been considered. The first scenario studies the behavior of a ZigBee network when the coordinator fails. We use two coordinators each fails for a period of time to figure out the behavior of network nodes accordingly. The network contains two coordinators and 24 routers and terminals. Each router and terminal in the scenario has its PAN ID set to Auto-Assigned. The coordinators respectively have all their PAN IDs at 1 and 2. Some of the nodes should join one of the two coordinators (Coordinator or Coordinator_0).

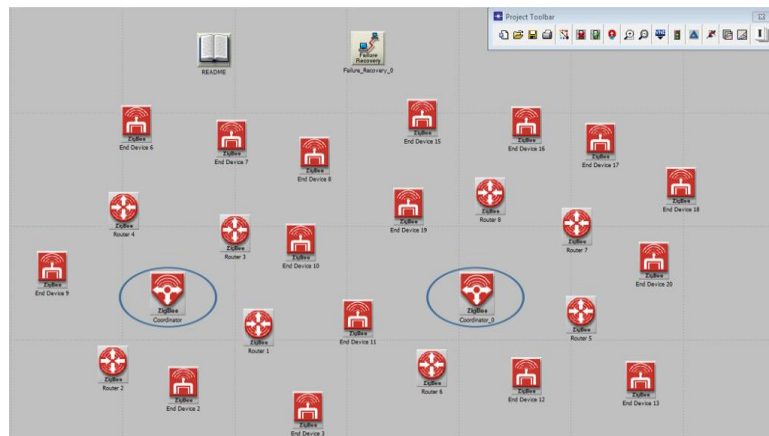


Fig. 4: Scenario of coordinator fails in a ZigBee network with two coordinators

Two minutes of simulation, the first coordinator fails. It will remain unsuccessful until the fourth minute, and it will recover and restore the network again. At eight minutes, the second coordinator will fail. It will remain unsuccessful until the second minute. The expected behavior initially is that about half of the nodes will join one of the two coordinators and the rest will join the other coordinator. When the first

coordinator fails, the nodes connected to this PAN should leave and join the second coordinator. When the second coordinator fails, all nodes must join the first coordinator.

There are two main results registered with this network model. The network structure can be better visualized via the output report or visualization functions (Figure 5.a). The blue curve is the first coordinator (PAN 1), while the red is the

second coordinator (PAN 2). At first, the two PANs have the same loads (PAN 1 has more than PAN 2 due to a little more nodes of assembly of this network). After 2 minutes, the PAN 1 load drops to zero while the load increases in the PAN 2. These loads remain constant even after the first coordinator is recovered (i.e., after 4 minutes). When the second coordinator

fails at eight minutes, the load increases from PAN 1, while it drops to zero for PAN 2. Figure 5.b presents the PAN affiliation, in these two graphs, we can see that when the coordinators have failed they have a negative PAN ID (i.e., ID equal -1), which is the code indicating that they are not currently connected to the network.

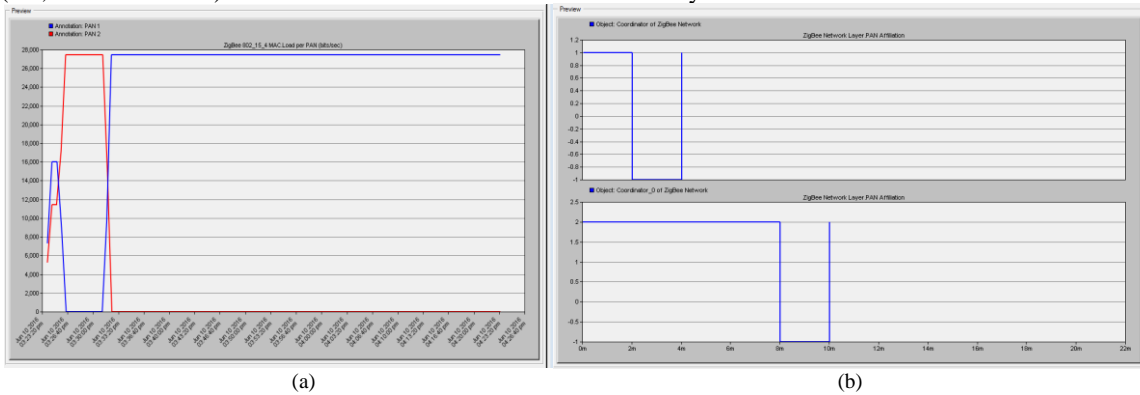


Fig. 5: a) Global MAC load per PAN, b) PAN Affiliation for the two coordinators

We can also see that 15 nodes are connected to PAN 1, while 11 are connected to PAN 2 with a balance in the number of packets sent for each node. At the beginning, the nodes connect by the automatic routing to the different coordinator and each time a coordinator fails, the nodes change the PAN ID with as result a concentration of the traffic on the coordinator which is running.

this network model. Firstly, Figure 7.a shows the numbers of Hops for a router (Mesh and star routing). This graph shows the number of network traffic hops from Router 1 to reach its destination. Which is a hops for the mesh routing (blue curve), and two hops for the star routing topology. Figure 7.b shows the End to End Delay (e2e delay) for the two topologies. The curve in blue indicates the e2e delay for the mesh routing scenario while the curve in red indicates the e2e delay for star routing. The e2e delay of mesh routing is lower, because the routing process finds more efficient paths than star routing. The delay for the mesh routing varies between 0.009s and 0.016s while the delay for star routing varies between 0.017s and 0.021s.

ZigBee.Global Report at Simulation Time 60

PAN ID	Channel	Packets Sent	Packets Received	Packets Dropped	Packets Outstanding	Initial Network Formation Time (seconds)	Number of Nodes	Tree Depth	Network Structure
1	1	25	600	560	40	0	11.32	15	2 Click Here
2	2	26	440	400	40	0	11.46	11	2 Click Here

(a)

ZigBee.Global Report at Simulation Time 360

PAN ID	Channel	Packets Sent	Packets Received	Packets Dropped	Packets Outstanding	Initial Network Formation Time (seconds)	Number of Nodes	Tree Depth	Network Structure
1	2	26	8500	7457	440	603	11.46	25	3 Click Here
2	1	25	220	600	120	0	241.60	1	0 Click Here

(b)

ZigBee.Global Report at Simulation Time 720

PAN ID	Channel	Packets Sent	Packets Received	Packets Dropped	Packets Outstanding	Initial Network Formation Time (seconds)	Number of Nodes	Tree Depth	Network Structure
1	1	25	17380	13782	730	2868	496.69	25	3 Click Here
2	2	26	580	2760	120	0	601.60	1	0 Click Here

(c)

Fig. 6: a) Two coordinators are connected to the network, b) coordinator 1 fails, c) coordinator 2 fails

The second scenario compares the performance of a sensor network for a mesh topology based on the routing performance in a ZigBee network, the same topology will be analyzed later but with a star topology. There are two results registered for

Finally, Figure 7.c shows the Global Load MAC per PAN. The curve in blue represents the global load for the mesh routing scenario while the second is the global load for star routing. The load for mesh routing is lower due to fewer hops for application traffic, which results in less overall traffic seen at the MAC layer. Also note that it has a very small peak load for mesh routing near the beginning of the simulation that is not seen for star routing. This is due to the routing of messages broadcast at that time.

In summary, the mesh topology is more adaptive to the sensor network thanks to the set of topology stabilization performances with less load compared to the star topology, less exchange of packets for routing with a number hops equal to 1 in order to reach the coordinator. We always consider the energy constraints for the sensors, the listening of the channel, the exchange of the frames of the routing protocol, the retransmission in case of error and the number of nodes to reach the coordinator are energy constraints for the sensors and a network that degrades these parameters makes it possible to have a longer duration of a WSN.

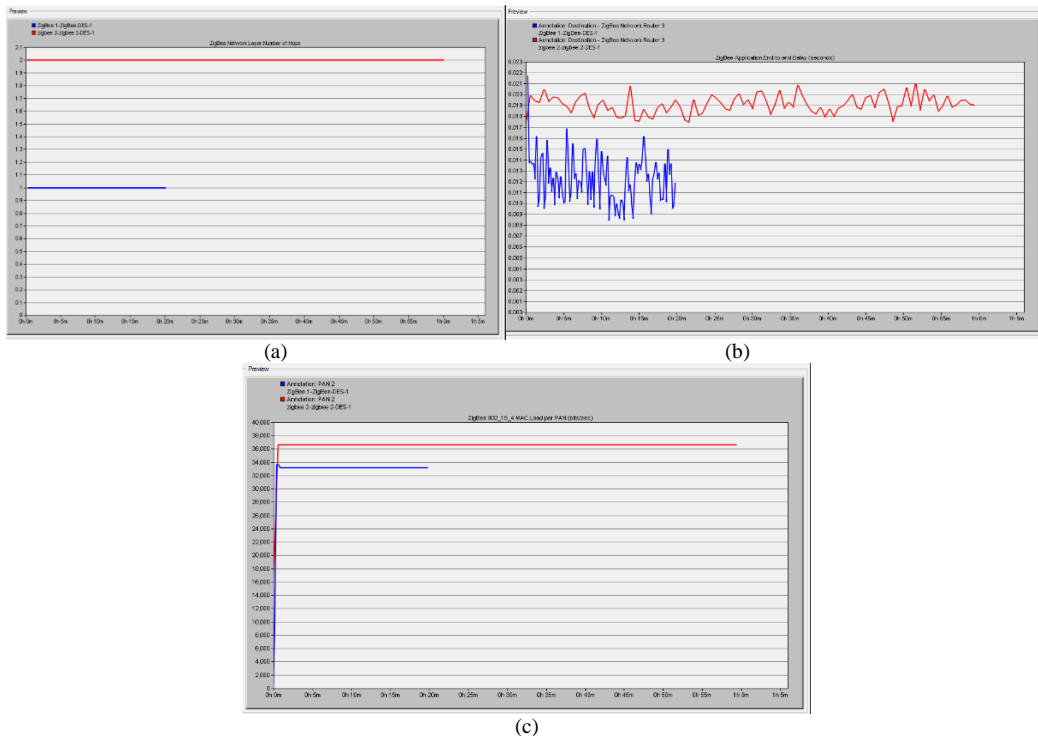


Fig. 7: Comparison: Mesh and Star Routing, a) Numbers of Hops for a router, b) Global End-to-end Delay, c) Global Load MAC per PAN

V. CONCLUSION AND PERSPECTIVES

The deployment of SMG technology needs a smart infrastructure system for managing the power production and consumption flows. This infrastructure is based on a distributed collection of sensor nodes situated at various places for measurement and communication of dedicated parameters such as current, voltage, and frequency. WSNs are effective solutions for energy management system in SMG, it will make the system cost and power effective, it is a cost effective solution for measurement, monitoring and controlling SMG. In this paper, we investigated two WSN topologies based on ZigBee standard. Preliminary simulation results showed that the mesh topology outperforms the star topology, mainly it provides a better reliability, quality of service, packet loss, energy consumption and delay. Extensive simulations will be conducted together with experiments to further investigate these topologies in real-sitting scenarios

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