Chapter 9: Simulations

In this thesis, we compare the performance of two architectures for AMI deployment: PLC and Mesh networks. To this aim, OMNeT++ [1] has been used as the simulation tool to model both approaches. All of the simulations of this work were implemented in a C++ builder using OMNeT++ and its libraries INET [2] and MIXIM [3]. OMNeT is an open source, object-oriented component-based discrete event simulation framework in which basic components, also called simple modules, are programmed in C++ and then combined into larger components (compound modules), using a network description language (NED). By connecting all compound modules together, the whole network can be assembled. Simulations in OMNeT++ can be run under several user interfaces, being the graphical ones especially useful for debugging purposes, while the command-line user interfaces is better for batch execution. In further sections we present the simulation setup and discuss the results obtained from all of the statistics collected.

9. 1 Characterization of PLC Network

As stated in Chapter 7, PLC becomes a well suited alternative as a communication technology for the implementation of an AMI network, as the electric grid is reused for data transmission between meters and utility. Also, the coverage is the one achieved by the distribution lines. In [4] the authors use the IEEE 802.15.4 MAC layer, which is based on CSMA/CA, to structure a PLC node. PLC follows a bus topology and two well distinguished types of nodes are identified in the characterization of the PLC-based AMI network: Meter Node and Collector Node. The meters are the ones located in the customer premises, utilized for measurement purposes and sending of traffic in the Client-Utility direction. Moreover collectors are meant to forward traffic from utility to customers throughout the distribution lines, as well as to receive and route data regarding consumption readings and other electric grid variables. In this work, we have adopted the IEEE 802.15.4 NIC to specify PHY and MAC layers of two different protocol stacks for meters and collectors involved in several PLC network scenarios. The channel is modeled following the PER model defined for PLC in field measurements [4].

The composite module of the meter node is depicted in Figure 9.1. The protocol stack is formed by four layers: *appMeter*, *dummy*, *routingPLC* and *NIC*. The *appMeter* layer generates traffic of different nature that will be transmitted throughout the network. The very nature of this traffic will be discussed further, when all of the applications considered in the simulation are presented.

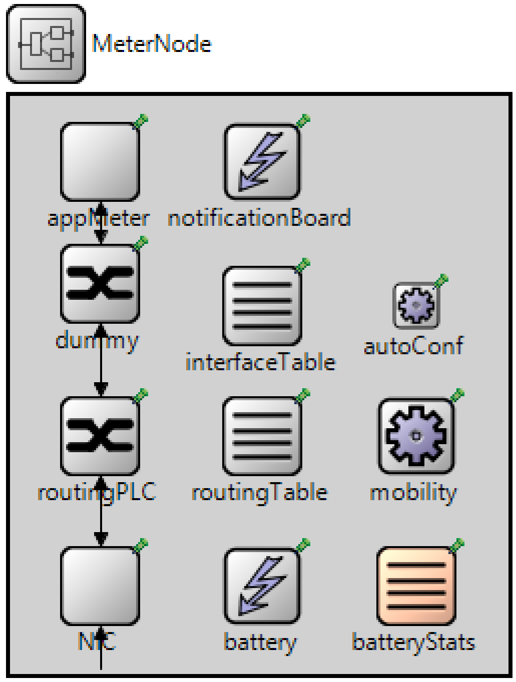

Figure 9.1 PLC Meter Node Protocol Stack

The *routingPLC* layer performs all routing and packets forwarding process in both meters-utility and utility-meters directions. A static routing protocol has been defined, so routing decisions can be made in this layer. Finally, figure 9.2 shows the compound module for the IEEE 802.15.4 NIC used in simulations. The MAC/PHY layers of this NIC are provided by the MIXIM library. MAC layer is defined by the CSMA/CA channel access method, while PHY layer models the losses of a typical PLC network according to measurements taken on-field deployments. On the other hand, *dummy* layer serves as a bridge between the app layer and the routing layer, connecting control gates through which overhead information is passed.

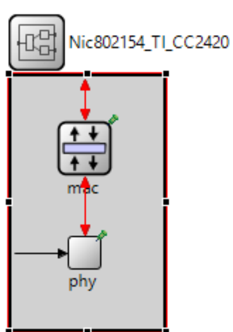

Figure 9.2 Compound module for IEEE 802.15.4 NIC

Similarly, the collector node is formed by a four layer protocol stack, which also includes an application layer for traffic generation (that, in the case of this type of node will be of a different nature than the one generated from the meters), a routing layer for packets forwarding decisions, and the NIC. The *autoConf* submodule is used in both Meter and Collector Nodes to fill in the interface table with the correspondent IP and MAC addresses. A more detailed view of the protocol stack for the collector node is depicted in Figure 9.3.

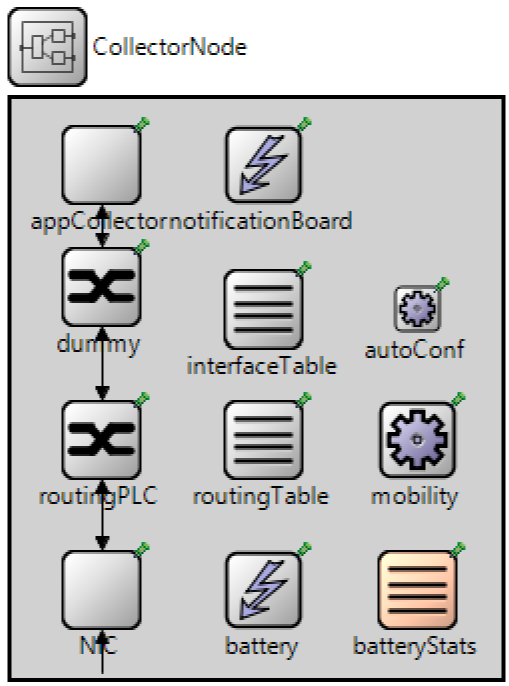

Figure 9.3 PLC Collector Node Protocol Stack

9.1.1 PLC network set up

According to interviews conducted by the author, in Colombia collectors serve around 20-50 meters in urban scenarios. These collectors are strategically positioned according to the area to be covered and the corresponding meters density. In [5], a 250 meter AMI network was tested, in a 10.000 m² area with LTE and Wi-Fi as technologies for evaluation. Since the purpose of this work is to compare PLC and a mesh topology for the implementation of an AMI network in Colombia with several applications running simultaneously, we will adopt the same density defined in the previous research work (i.e. 0,025 meters per m² or its equivalent 25000 meters per km²). Finally, the *connectionManager* module establishes connections between nodes that are within the maximal interference distance of each other, which is influenced by objects that might be in the line-of-sight of two nodes [6]. Figure 9.6 shows the NED design for the PLC network.

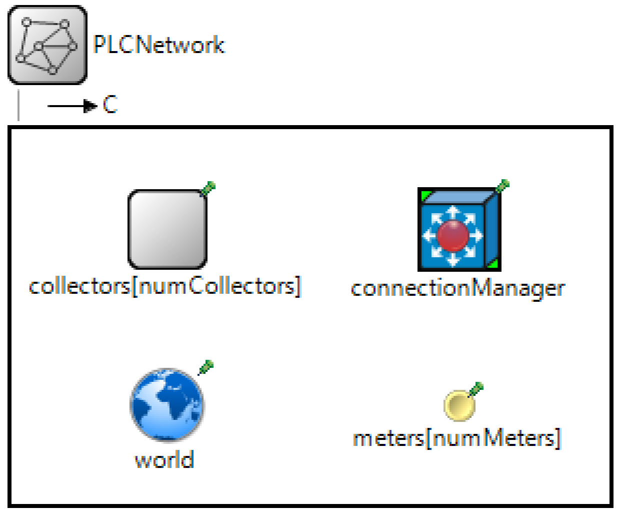

Figure 9.6 PLC Network Set up

9.2 Characterization of the mesh network

One of the reasons because mesh networks have become an appealing research topic in the field of networking is the possibility to conform networks in an adaptive, infrastructureless and self-organizing way. Through multihop connections, coverage area of the network can be expanded. This has an impact on both the transmission power and power consumption of the mesh nodes. Since mesh networks are usually intended for static radio nodes (as the ones that form the AMI network in a mesh approach), we will compare the performance of such a mesh network with that obtained with PLC.

The choice of IEEE 802.15.4 standard for the characterization of such networks is quite suitable, as it is the predecessor of the 802.15.4g standard for NANs [9]. Thus, the NIC submodules in the Meter Node and Collector Node are also based on IEEE 802.15.4. However, unlike PLC, the routing process is performed differently, as the collector is not one hop away and multiple meters must be passed by in order to reach the final collector. Protocol stacks for both the Mesh Meter Node and Mesh Collector Node are depicted in figures 9.5 and 9.6, respectively.

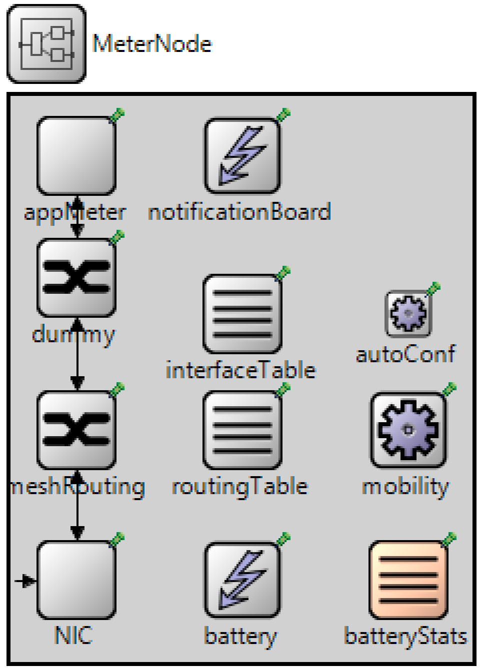

Figure 9.5. Mesh Collector Node Protocol Stack

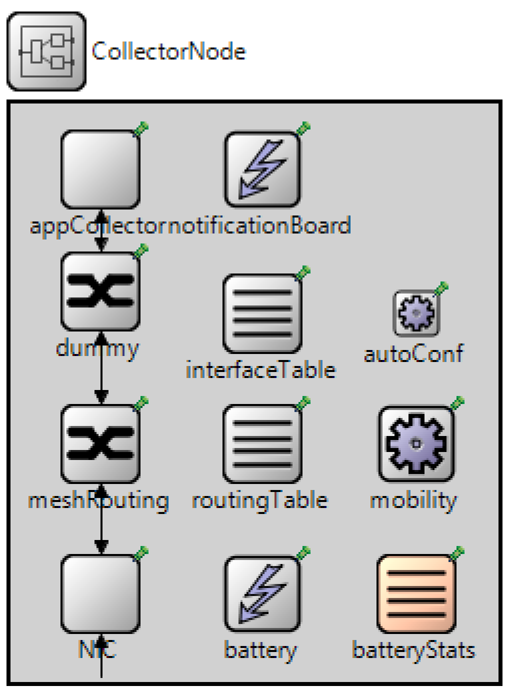

Figure 9.6. Mesh Collector Node Protocol Stack

9.3 Applications

While many different applications are expected to emerge in the Smart Grid, we have focused only on three of them, in order to keep the scope of this work limited. The applications that have been characterized for simulations purposes are: Automatic Meter Reading (AMR), Real Time Pricing (RTP), and Wide Area Measurement (WAM). In the rest of this section we shall discuss the characteristics and main requirements and features of these applications in the communication backhaul.

9.3.1 AMR

Automatic Meter Reading (AMR) refers to the collection of consumption readings, events and alarms data from the meters. Considering this application in the simulation of AMI networks is a must, as it enables the gathering of essential information for Utilities (clients' consumption, non-technical losses, etc.). The average size of a AMR packet is around 200 bytes, and this may be sent every 5 minutes, 10 minutes, 15 minutes, 30 minutes or one hour. A data rate from 10 to 128kbps is generally required for transmission of meter reading reports [10] [11].

9.3.2 WAM

Wide Area Measurement (WAM) refers to a sensing and measurement system that continuously monitors the power grid state. Due to the precise synchronization of the measurements, the utility control center can gather phase information. This enables the utility to prevent black-out events or respond more properly in such cases. While WAM systems were usually located on the generation and transmission domain, in Smart Grid they are expected to be deployed at the distribution domain as well, in order to enable real-time monitoring of the overall power grid [10]. The average size of a WAM packet is around 46 bytes. Packets sending occur every 0.4s or every 0.1s. Data rate required for this application ranges between 6-24 kbps [10] [12].

9.3.3 RTP

Real Time Pricing (RTP) is one of the different Demand Response (DR) programs, which main expectations are encouraging energy efficiency and encouraging customer to limit their energy usage or shift it to other periods [10]. Thus, DR programs entail the control of the energy demand and loads during critical peak hours. In this way, customers can be an active agent of the energy market, as they are no longer subject to fixed prices, but instead they can get profits from the unused energy [12]. Benefits for the utilities are also envisaged, as they can manage more efficiently the power generation and supply, according to the specified demand. In RTP application, the price information is conveyed to the smart meter at the customers' premises, so that they can take the necessary actions to regulate their consumption patterns. Basically, a RTP packet carries the price of the real market cost of delivering electricity, and its size varies between 100-210 bytes. The packets are sent every 15 minutes or every hour. It usually requires a data rate between 10-100kbps [12] [13].

In table 9.1 we provide a summary of the three applications described above, with their main communication and traffic requirements.

Application	Packet Size (bytes)	Frequency (s)	Data rate (kbps)	Requirements
Automatic Meter Reading (AMR)	200	300, 600, 900, 1800, 3600	10-128	HTTP and TCP
Real Time Pricing (RTP)	210	900, 3600	10-100	HTTP and TCP, Delay-tolerant, reliability, sensitive to packet loss
Wide Area Measurements (WAM)	48	0,04 - 0,1	6 - 24	IP and UDP, delay-sensitive (max 20ms)

Table 9.1 Applications simulated

As indicated in previous sections, the App layer submodules of the Meter Node and the Collector Node are different. The appCollector submodule is defined by a different logic. In this layer, only those packets carrying information from Utility to customers are generated and forwarded through collectors. As mentioned before, RTP entails the sending of information regarding energy price, and this is done in the Utility-Customer way. Thus, RTP packets are generated in the appCollector submodule, while AMR and WAM packets are sent from the customer premises to the Utility collectors, in the appMeter module.

9.4 Simulation Parameters

In this section main parameters used for building the simulations are listed. Basically parameters at PHY, MAC, Routing and App Layers are presented. While Mesh network has a multi-hop topology, different from the bus topology on which PLC operates, main difference between them rests on the packets forwarding process. In PLC traffic from a meter is directly forwarded to its associated collector (which is previously specified in the simulation configuration file). On the other hand, in the mesh approach a packet is forwarded through several hops before it gets to the corresponding collector. As discussed earlier, the routing algorithm used to this aim uses a distance parameter to determine whether two nodes are neighbors or not. As this distance decreases, increases the number of hops the packet must pass by to reach the collector. In the mesh approach, the maximum distance between two nodes is set at 10m. In PLC, this distance is around 200m [8]. Parameters for the NIC (MAC and PHY), connection manager and routing layers are listed in Table 9.2, Table 9.3, and Table 9.4, respectively.

Parameter	Value
Propagation model	PERModelPLC
Receiver Sensitivity	-94dBm
Transmission Power	1.1mW

Table 9.2 Parameters for PHY submodule in the PLC scenarios

Parameter	Value
Transmission power	1.1mW
Data rate	128 kbps

Table 9.3 Parameters for MAC submodule in the PLC Scenarios

Parameter	Value
Maximum transmission power	1.1mW
Minimum signal attenuation	-94dBm
Minimum path loss coefficient (alpha)	2.1
Minimum carrier frequency of the channel	2.4 GHz

Table 9.4 Parameters for connection manager in the PLC scenarios

Parameter	Value
Packet error rate (PER)	0.05
PER lower bound	0
PER upper bound	0.056

Table 9.5 Parameters for PER Model in the PLC scenarios

Parameter	Value
Propagation model	SimplePathLossModel
Receiver Sensitivity	-94dBm
Transmission Power	1.1mW

Table 9.6 Parameters for PHY submodule in the Mesh scenarios

Parameter	Value
Transmission power	1.1mW
Data rate	128 kbps

Table 9.7 Parameters for MAC submodule in the Mesh scenarios

Parameter	Value
Maximum transmission power	1.1mW
Minimum signal attenuation	-94dBm
Minimum path loss coefficient (alpha)	2.1
Minimum carrier frequency of the channel	2.4 GHz

Table 9.8Parameters for connection manager in the Mesh scenarios

Parameter	Value
AnalagueModel	SimplePathlossModel
Environment parameter (alpha)	2.5
Carrier frequency of the signal	2.4GHz

Table 9.9 Parameters for PER Model in the Mesh scenarios

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