Chapter 10: Results

Traffic of different nature was run simultaneously in all of the scenarios simulated. Network traffic was characterized according to each application's traffic load. As stated in chapter 9, Automatic Meter Reading (AMR), Wide Area Measurement (WAM), and Real Time Pricing (RTP) were the applications considered in this work. Varying the frequency to which every application generates traffic, several test scenarios are formed. In this chapter we shall discuss the results obtained for all of the scenarios tested in both PLC and Mesh topologies.

10.1 Performance Metrics

Comparison of the two technological approaches will be performed on the basis of latency and reliability, as those two metrics give valuable information about how well the technology would perform in a possible future AMI environment. On the first hand, latency provides information regarding the delay of the data transmitted between the smart grid components. This metric is relevant as applications in the smart grid may have different latency requirements. Mission-Critical applications such as WAM may not tolerate any latency values, as wide- area situation awareness information losses significance with time. For other applications such as AMR, latency is not critical [1].

We have adopted the End-to-end delay (EED) statistic to measure latency for every application. EED is the average time it takes a data packet to reach the destination. This includes delays caused by buffering during route discovery latency, packet forwarding, and queuing processes [2]. End-to-end delay for application X (*EEDAppX*) is calculated as the sum of individual time spent to deliver *S* packets to the destination over the number of received packets at the destination. Mathematically, this metric can be defined as follows:

$$EEDAppX = \frac{\sum_{j=1}^{S} EEDPj}{N} \qquad (1)$$

On the other hand, reliability gives information about how effective packet delivery is throughout the network. It refers to how reliable the system can perform data transfers according to the specific communication requirements. While high frequency applications such as WAM may expect highly reliable data transmission, others such as RTP may tolerate some outages in data transfer. For reliability measurement purposes, Packet Delivery Ratio (PDR) was calculated for every application. PDR is defined as the quotient of number of data packets received at the destination and those generated by all sources. PDR for application X (*PDRAppX*) is defined by

$$PDRAppX = \frac{R}{S}, \qquad (2)$$

where R is the number of packets received at the destination, and S is the number of packets sent by all sources involved in the communication.

10.2 Simulation Results for PLC

Given that meter reading reports in current PLC deployments in Colombia are sent at around 128kbps, PLC scenarios are simulated under this data rate. Considering that PLC is a bus topology- based technology, and under the assumption that no collisions take place among different buses, results have been gathered per bus. Every run corresponds to a PLC bus, in which traffic is forwarded in both ways: meters-Collector and Collector-meters. Once all statistics regarding number of packets sent, number of packets received, and end-to-end delay are gathered, results for the whole network are summarized.

We evaluated the performance of a 100 node PLC network in a 64mx64m area by running five different buses. In this work we have considered three different cases for PLC performance assessment purposes: i) Worst case (WCPLC), which corresponds to the highest packets sending frequencies for every application; ii) an intermediate case (ICPLC), in which lower packet inter-arrival time is simulated; and iii) the Best case (BCPLC), which refers to the scenario with the lowest packet sending frequencies. Table 10.1 provides a general overview of the PLC scenarios simulated, and their correspondent parameter values.

Scenario ID	AMR Frequency (s)	WAM Frequency (s)	RTP Frequency (s)	Number of Buses	Bus density (meters per collector)	Total Network Density	Data Rate (kbps)
WCPLC	300	0.04	900	5	20	100	128
ICPLC	600	0.1	900	5	20	100	128
BCPLC	1800	0.1	900	5	20	100	128

Table 10.1 Parameter values for simulated PLC scenarios

Within each bus of every scenario simulated, 20 meters generate AMR and WAM traffic towards the collector, which forwards RTP traffic to the meters. Overall, the total PDR value for every application in the whole network is calculated by considering the average PDR of all buses. Similarly, EED is calculated as the average of individual EEDs for every bus. An estimated EED between the collector and concentrator at Utility premises is also added, in order to get the total EED in the whole AMI backhaul. Results for the worst, intermediate, and best cases are presented in tables 10.2, 10.3, and 10.4, respectively.

Bus ID	F AMR (s)	F WAM (s)	F RTP (s)	PDR AMR (%)	PDR WAM (%)	PDR RTP (%)	EED AMR (s)	EED WAM (s)	EED RTP (s)
WCBus1	300	0.04	900	28.75	21.74	50.00	1.909	2.686	0.018
WCBus2	300	0.04	900	27.50	21.77	50.00	1.901	2.707	0.018
WCBus3	300	0.04	900	26.25	21.72	50.00	1.939	2.663	0.049
WCBus4	300	0.04	900	23.75	21.68	0.00	2.154	2.777	0.000
WCBus5	300	0.04	900	37.50	21.72	50.00	1.817	2.820	0.035

Table 10.2. PDR and EED values for five PLC buses in the worst case.

Bus ID	F AMR (s)	F WAM (s)	F RTP (s)	PDR AMR (%)	PDR WAM (%)	PDR RTP (%)	EED AMR (s)	EED WAM (s)	EED RTP (s)
ICBus1	600	0.1	900	51.67	46.10	50.00	1.909	2.686	0.018
ICBus2	600	0.1	900	40.00	45.43	50.00	0.044	0.022	0.018
ICBus3	600	0.1	900	51.67	45.47	0.00	0.0406	0.022	0.000
ICBus4	600	0.1	900	58.33	45.43	45.00	0.0349	0.0224	0.0178
ICBus5	600	0.1	900	63.33	46.09	0.00	0.045	0.0222	0.000

Table 10.3. PDR and EED values for five PLC buses in intermediate case.

Bus ID	F AMR (s)	F WAM (s)	F RTP (s)	PDR AMR (%)	PDR WAM (%)	PDR RTP (%)	EED AMR (s)	EED WAM (s)	EED RTP (s)
BCBus1	1800	0.1	1800	50.00	45.47	33.33	0.048	0.022	0.018
BCBus2	1800	0.1	1800	50.00	45.48	33.33	0.048	0.022	0.018
BCBus3	1800	0.1	1800	52.50	45.43	30.00	0.032	0.022	0.043
BCBus4	1800	0.1	1800	50.00	45.48	33.33	0.048	0.022	0.018
BCBus4	1800	0.1	1800	52.50	45.43	33.33	0.032	0.022	0.048

Table 10.4. PDR and EED values for five PLC buses in the best case.

Scenario ID	PDR AMR (%)	PDR WAM (%)	PDR RTP (%)	EED AMR (s)	EED WAM (s)	EED RTP (s)
WCPLC	28.75	21.73	40.00	1.9445	2.7314	0.0243
ICPLC	51.33	45.46	19.00	0.0404	0.0224	0.0070
BCPLC	51.00	45.46	32.67	0.0419	0.0224	0.0292

Table 10.5 Summarized results for PLC network

10.3 Simulation Results for AMI Mesh Network

Wireless Mesh Networks (WMN) are proving to be an alternative approach for sensor networks like those in the AMI context. By enabling meters and collectors to be accessed through a multihop forwarding mechanism, WMN reduces the number of collectors required [3]. Since multiple meters must be passed by in order to reach the destination, this forwarding mechanism may increase latency. However, new standardized technologies like G3-PLC, recently approved by the International Telecommunications Union (ITU), have arisen as alternatives for the AMI communication backhaul. Although initially developed as a joint effort between Maxim Integrated Products and the Électricité Réseau Distribution France (ERDF), G3-PLC is a non-proprietary specification that provides a base protocol for the development of technologies aimed to support high-speed and highly reliable IP-based communications across the generation, transmission and distribution lines that comprise the smart grid. G3-PLC's MAC layer is designed to support mesh network topologies. It uses orthogonal frequency division multiplexing (OFDM), and delivers up to 250 kbps [4].

As indicated in previous sections, we have implemented a mesh AMI network, using the NIC IEEE 802.15.4. A 100 meter network was simulated, with a data rate of 250kbps in both PHY and MAC layers. With mesh networking capability in every meter, no direct connection between meters and collector is required. In this approach meters form the network in a self-adaptive way. A Dijkstra based-routing algorithm is run at the beginning of the simulation. Thus, routing tables are generated in every node, according to the connections established between them, and packets from and towards the meters can reach their destination.

We evaluated the performance of a 100 node mesh network. The simulation set up involved the deployment of 100 meter nodes in a 64mx64m area. A single collector was strategically located to serve all network demand. A general overview of the simulation set up parameters is detailed in Table 10.6.

Following the same methodology used in the PLC network assessment, several scenarios were tested. By considering the different traffic load frequencies for all applications evaluated, the three representative scenarios corresponding to the worst case (WCMesh), intermediate case (ICMesh), and best case (BCMesh) were also analysed. Results for all of the cases above mentioned are presented in Table 10.7

Scenario ID	AMR Frequency (s)	WAM Frequency (s)	RTP Frequency (s)	Total Network Density	Data Rate (kbps)
WCMesh	300	0.04	900	100	250
ICMesh	600	0.1	900	100	250
BCMesh	1800	0.1	900	100	250

Table 10.6 Parameter values for simulated Mesh scenarios

Scenario ID	PDR AMR (%)	PDR WAM (%)	PDR RTP (%)	EED AMR (s)	EED WAM (s)	EED RTP (s)
WCMesh						
ICMesh						
BCMesh						

Table 10.7 Summarized results for Mesh AMI network

10.4 Analysis

Varying the packets sending frequency for every application, and keeping constant network density, a comparison between the two approaches is performed according to the values obtained for PDR and End to end delay (EED). Results per PLC bus have been gathered and summarized for a 100 node network. PDR is obtained as the average value for all of the five buses, in every single case, for every application. On the other hand, in the case of mesh topology, PDR and EED are calculated in every one of the three representative cases (worst, intermediate and best).

Regarding AMR, the results for the PLC and the mesh networks are depicted in figures 10.1 and 10.2, for PDR and EED, respectively. In terms of packet delivery efficiency, {technologyX} performs better than {technologyY}, as constant higher PDR values are obtained to the extent that data packets sending frequency decreases. On the other hand, regarding latency, {technologyX} shows better performance. This is because of …

In applications such as WAM, lower values of latency are expected, because data need to be transmitted in a specific time. Once this time has passed, the information losses its relevance. In this regard, {technologyX} performs better, as depicted in Figures 10.3 and 10.4. Lower values of latency are consistently obtained with this approach.

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