Viability of Powerline Communication for the Smart Grid

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Abstract*—There is currently an ongoing debate surrounding what would be the best choice for smart grid communication technology. One of the promising communication technologies for smart grid realization is Powerline Communication (PLC). However, because of its noisy environment and the low capacity of Narrowband Powerline Communication, its viability for smart grid realization is being questioned. To investigate this issue, we studied smart grid communication network requirements. We categorize smart grid data traffic into two general traffic classes including home area network data traffic and distribution automation data traffic. Then using network simulator-2, we simulate powerline communication and a smart grid communication network. To have a better understanding of the viability of powerline communication for smart grid realization, some future smart grid advanced applications are considered. Latency and reliability are considered to be the main smart grid communication network requirements. In this paper, the delay of different traffic classes under different network infrastructures and traffic applications have been calculated. Furthermore, a viable powerline communication network infrastructure for smart grid communication network is proposed.

Keywords- Narrowband Powerline Communication; Broadband Powerline Communication; Smart Grid Communication Network

I. INTRODUCTION

THE smart grid technology becomes possible by applying sensors, field automated devices and smart meters to the electrical distribution power grid. These devices measure and control power grid conditions and communicate the information to customers, operators and utilities, providing this opportunity to dynamically respond to changes in grid conditions [1]. Therefore, a reliable two-way digital communication network is essential for smart grid implementation.

However, there is currently an ongoing debate on what will be the best choice for smart grid communication technology (SGCT) [2]. One of the promising communication technologies for smart grid realization is powerline communication (PLC). Due to the fact that the powerline infrastructure already exists, there is no need for new cable installation and, moreover, utilities prefer to have their own networks [3]. However, it is difficult to guarantee communication system reliability and availability under extremely adverse channel conditions as offered by the PLC transmission channel [4], [5]. To the best of our knowledge, there is no precise investigation on whether powerline communication can satisfy the smart grid communication requirements. In this paper, we used Network Simulator-2 to simulate a smart grid communication network and powerline communication. To simulate the noisy environment of powerline communication, the PLC bit error rate is imported to the system. Latency and reliability are considered as the main performance metrics for the smart grid communication network. To evaluate latency, the delay is measured for each of several traffic classes.

To have a better evaluation of the viability of powerline communication for smart grid realization, some future smart grid advanced applications are investigated. We have considered traffic loads of both current and future smart grid applications.

Furthermore, we propose a combination of Narrowband Powerline Communication (NBPLC) and Broadband Powerline Communication (BPLC) to be used as a communication infrastructure for the smart grid communication network. The reason to use NBPLC is that the price of NBPLC devices is much less. To make the use of BPLC possible, Golay coding is applied on OFDM modulation.

This paper is organized as follow: Section II presents an overview of all data traffic to be passed through a smart grid communication network. Section III gives a brief introduction to two types of powerline communication standards, the powerline channel model and the bit error rate in powerline communication. In Section IV, simulation settings, simulated topology, importing bit error rate and simulation results are discussed. Finally, the conclusion is presented in Section V.

II. SMART GRID TRAFFIC CHARACTERIZATION

In our study, smart grid applications were divided into two general traffic classes:

Two-way data traffic between home area network and utility: in this case, we assume that all the traffic needed to be communicated between Home Area Network and Utility Company will be aggregated in the smart meter. Thus, this kind of traffic not only consists of reading smart meters, but also includes other traffic data such as safety, maintenance, demand-response, billing, peak hours and time of use rates.

- **Two-way data traffic between distribution automation system and utility:** in this kind of traffic, all the distribution automation system and fault detectors will sense and measure data from distribution system and then they will send it to the related collectors. We classified this kind of traffic into two general categories:
  - Distribution Automation and Control
  - Monitoring and Maintenance

III. POWER LINE COMMUNICATION SPECIFICATIONS

A. Powerline Communication Standards

There are generally two types of powerline communication standards: Narrowband PLC and Broadband PLC. These two types of communication operate in completely different frequency bands and provide different speeds for the customers. Narrowband PLC operates in the frequency range specified by the CENELEC-A norm (9 KHz to 95 KHz) while the US FCC part allows the use of up to 500 KHz [3], [6], [7]. The PRIME standard is based on CENELEC-A band and provides up to 128kbps bit rate [7].To provide higher data rate, higher frequency ranges should be used. Hence, Broadband PLC operates in the frequency range of 1.8 MHz to 28 MHz while providing a maximum bit rate of 220Mbps [3], [8].

B. Powerline Channel Model

One of the main concerns regarding powerline communication is that it is affected by stochastic attenuation and deep notches which can lead to the limitation of channel capacity and achievable data rate of powerline communication. Therefore, investigating a reasonable channel model for powerline communication is essential. A universal and practically useful form of the complex transfer function for powerline channels has been proposed by Zimmermann [9].

$$H(f) = \sum_{i=1}^{N} g_i e^{-(a_0+a_1 f^k)d_i} \, e^{-j2\pi f \frac{d_i}{v_p}} \quad (1)$$

This model represents the superposition of signals from N different paths, each of which is individually characterized by a weighting factor g_i and length d_i. Furthermore, frequency dependent attenuation is modeled by the parameters a_0, a_1 and k. The first exponential function describes attenuation while the second one including the propagation speed v_p, represents the echo scenario [10]. In our investigation, to model powerline channel, Zimmermann method was used.

C. Powerline Communication Bit Error Rate

One of the most promising modulation methods for powerline communications is OFDM [3]. OFDM has some desirable properties, which can be utilized properly in order to mitigate the harsh characteristics of powerline channels [11]. According to the [12], it is known that the Bit Error Rate (BER) of a QAM scheme under Additive Gaussian Noise follows (2). In (2) and (3) M is the modulation level and $\mathrm{M} = 2^{\mathrm{k}}$ with k is even. $\mathrm{E_{av}}$ is the average symbol power and $\mathrm{N_0}$ is the noise power. Thus, if QAM modulation is used for each subcarrier, we can express the average BER of an OFDM system with N subcarriers (assuming no inter-carrier interference (ICI) and no inter symbol interference (ISI)) as (2) and (3).

$$BER_{avg} \leq \frac{1}{log_2 M}\left(1 - \frac{\sum_{k=1}^{N}\left(1-P_{k,\sqrt{M}}\right)^2}{N}\right) \quad (2)$$

Where

$$P_{k,\sqrt{M}} = 2\left(1-\frac{1}{\sqrt{M}}\right) Q\left(\sqrt{\frac{3\,{H_k}^2 E_{av}}{(M-1)N_0}}\right) \quad (3)$$

In (3), $\mathrm{H_k}$ is the channel transfer function of the $\mathrm{k^{th}}$ subchannel. In low speed PLC, the BER has been calculated using (2) and (3). Based on our calculations and also based on [11], we observed that the performance of broadband powerline communication using OFDM modulation without any kinds of coding is very poor and it has to tolerate high bit error rate. Therefore, to make the use of BPLC practical, some kind of coding such as Golay coding is combined with OFDM without any kinds of coding is very poor and it has to tolerate high bit error rate.

IV. SIMULATION

The study was carried out using MATLAB and Network Simulator-2.

A. Simulation Settings

The PLC MAC protocol is considered to be CSMA/CA [8], [13]. To provide the system with the required reliability, TCP connections are used for all the traffic classes.

Using MATLAB, a PLC channel model was simulated and the bit error rates in the PLC channel were calculated. To simulate the noisy environment of powerline communication, PLC bit error rates were imported to the Network Simulator 2.

According to the IEEE P1901TM 1 /D4.01 draft standard [8], the BPLC link speed is considered to be 100Mbps and according to the PRIME standard, the NBPLC link speed is considered to be 128kbps [7].

The PRIME PHY layer uses OFDM modulation with Forward Error Coding (FEC) and data interleaving that allow for robust high speed powerline communication [7]. Thus, an acceptable packet error rate (PER) has been defined for each traffic class in Table I.

In all the scenarios, simulation was carried out on 1200 smart meters, 120 transformers and 1 substation. The simulation run times are 3600 seconds.

B. Importing Bit Error Rate

To model powerline channel using MATLAB, equation (1) was used. Wherever we used Low Speed PLC, the BER was calculated using equations (2) and (3). Fig. 2 shows the performance of NBPLC in different SNR when the QAM scheme is used. Parameters of the reference channel for the access network were gotten from [14]. In BPLC, to reduce the BER, a coded OFDM system was used for which there is no precise formula for calculating the BER. Therefore, we referred to [10] in which they modeled BPLC and calculated BER for the case that a 16PSK (23, 12) Golay scheme is used for OFDM modulation.

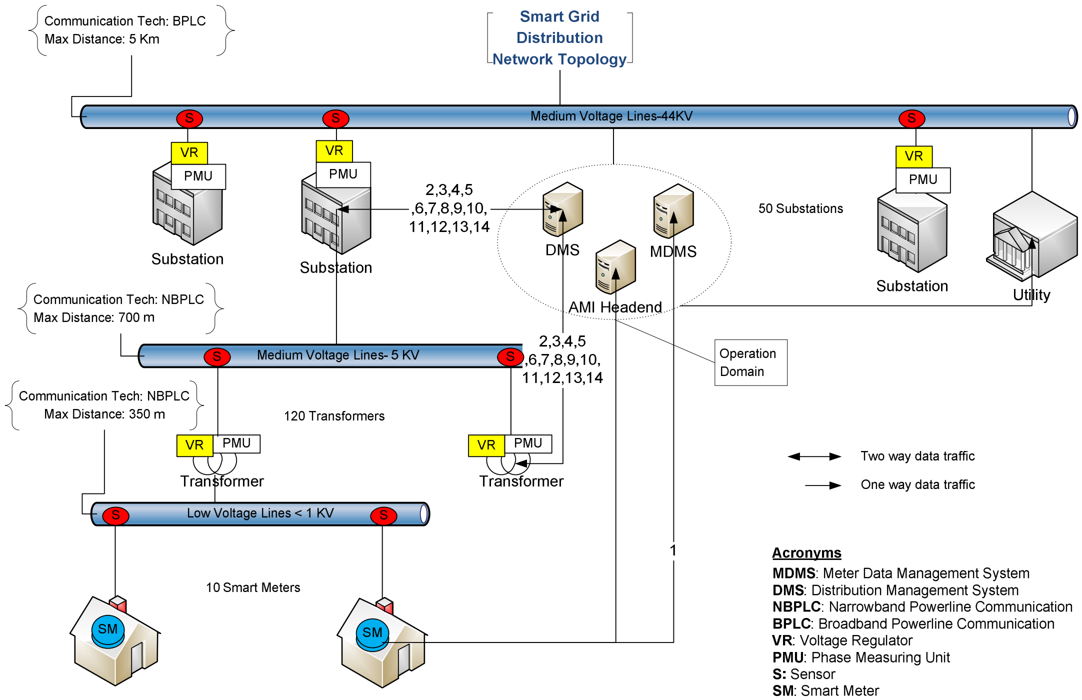

Fig. 1: Smart Grid Communication Network Topology

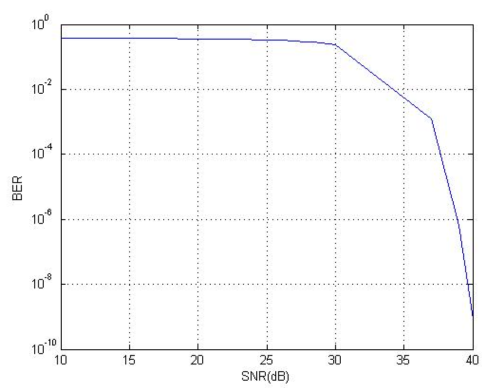

Fig. 2: Performance of NBPLC in Access Network (Class "350m, Good")

C. *Simulated Topology*

Depending on the area and geographical conditions, different power grid topologies can be considered. The most prevalent structure which is also the cheapest and simplest structure for a distribution or transmission grid is a radial structure. This is a tree shape where power from a large supply spreads out into progressively lower voltage lines until the destination homes and businesses are reached [15].

In our study, a three-level hierarchical structure was considered. Fig. 1 illustrates the topology simulated for the SGCN using PLC. Based on the information drawn from Utilities Kingston [16], the maximum distance between the first level and the second level is 350m and the maximum distance between the second level and the third level is 700m. We investigated the system with different communication technologies in different link levels. We will talk about these scenarios in details in the following sections.

Among those traffics mentioned in Section II, 14 essential traffics, illustrated in Table I, distinguished and applied into the system. To compensate other kinds of traffics, 30% background traffic was added to the system. The properties of each traffic class and the acceptable traffic latencies have been drawn from Open SG documents [17].

D. *Results and Analysis*

The study was carried out on three different scenarios. By running the first two scenarios, we aim to find a PLC infrastructure which satisfies the desired requirements, e.g. latency. Then after finding an appropriate PLC infrastructure for the smart grid realization, to investigate the viability of PLC better, in the third scenario, some future smart grid applications are also added to the system. The main communication requirements of smart grid services are latency and reliability. To provide smart grid communication network with the required reliability, for all kinds of traffics, TCP connections have been considered.

1) *Scenario I*

In the first scenario, as illustrated in Fig. 1, the communication technology which has been used in the first level (access network) and in the second level (field area network) to connect smart meters and field automated devices to the wide area network is Narrowband PLC. Broadband PLC has been used as a communication technology in the third level of the network (wide area network) to connect the field area network to the utility and operation domain. Fig. 3 shows the delay values which have been observed for the first scenario.

Table I: Smart Grid Communication Network Data Traffic

From	*To*	*How Often*	*Acceptable PER*	*Latency*	*Payload Size (Bytes)*	*ID*
Smart Meter	MDMS	25 trans per 1000 meters per day	2%	< 15 sec	200- 2400	1
DMS	Feeder VR	every 5 min	0.5%	< 2 sec	250	2
DMS	Feeder VR	every 5 min	0.5%	< 2 sec	250	3
DMS	Feeder VR	every 15 min	0.5%	< 2 sec	150	4
Feeder VR	DMS	every 1 hr	0.5%	< 5 sec	1000	5
DMS	Feeder Sensor	every 5 sec	0.5%	< 2 sec	150	6
Feeder Sensor	DMS	every 5 sec	0.5%	< 2 sec	250	7
Feeder VR	DMS	every 5 min	0.5%	< 5 sec	50	8
Feeder VR	DMS	every 15 min	0.5%	< 2 sec	1000	9
Feeder VR	DMS	every 1 hr	0.5%	< 5 sec	1000	10
DMS	Phasor Measurement Unit	every 5 min	0.5%	< 5 sec	150	11
Phasor Measurement Unit	DMS	every 5 min	0.5%	< 2 sec	1536	12
DMS	Transformer	every 5 min	0.5%	< 5 sec	150	13
Transformer	DMS	every 5 min	0.5%	< 5 sec	250	14

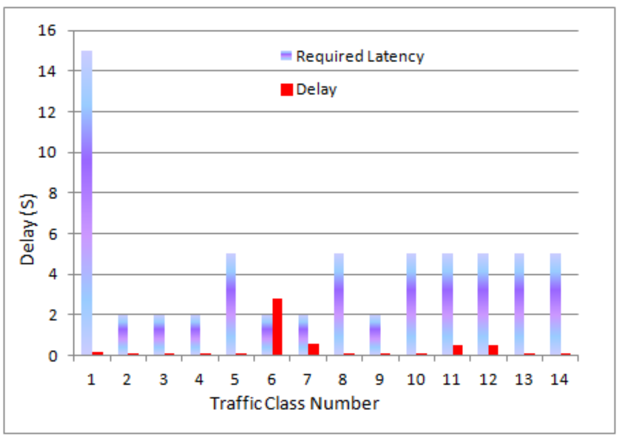

Fig. 3: Observed delays for different traffic classes – Scenario I

It is observed that for most of the traffic classes, obtained delay is higher than required latency. This is because there is a bottleneck in the transformer connecting the access network to the field area network. Many packets are generated in the access network while the bandwidth in the second level is not sufficient to service all of them on time. Furthermore, very high delays are observed for the traffic classes sending packets from DMS to the field automated devices. It is because there is a bottleneck between the operation domain and the second level of the network. Hence, it can be concluded that low speed powerline communication does not satisfy smart grid communication requirements.

2) Scenario II

The difference in the second scenario is that Broadband PLC has been used in the second level of the distribution network (field area network) to connect devices from the access network to the wide area network. The communication technology in the first level is NBPLC and in the third level is BPLC. Simulation results show that when we equip the system with broadband powerline communication in the second level of the network, it will act completely fine, all traffic delays are less than accepted latency and they are almost zero. The next step is to evaluate the performance of the system considering future smart grid services.

3) Applying Advanced Traffics

Video surveillance from the assets and substations, voice data (talking with one of the staff and direct crew dispatch), sending advertisements to displaying devices at home and promotional videos with respectively 2Mbps, 80kbps and 88kbps data rates are considered to be future smart grid applications. Fig. 4 shows delay values in different traffic classes once we applied advanced traffic and compared it with the time we had applied current considered smart grid traffics to the system.

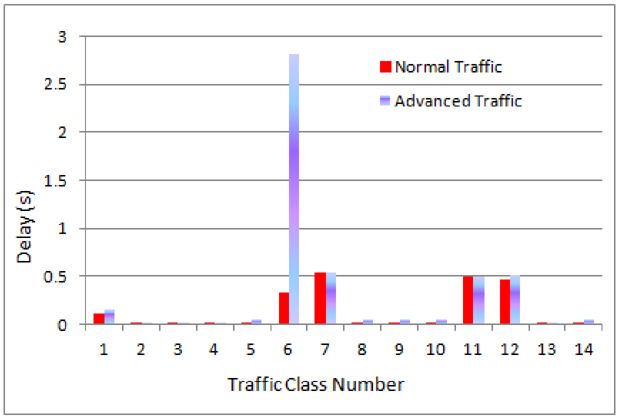

Fig. 4: Delay Comparison when Advanced Traffic Is Added to the System-Scenario III

We can observe that while most of the traffic classes experience higher delays, they are still less than maximum acceptable latency. The only traffic class which can not satisfy the latency requirement of smart grid communication network is class 6 with 655ms higher delay than the required latency.

There is a bottleneck between operation domain and field automated devices. Lots of packets must be transmitted from operation domain to automated devices. By adding advanced traffic, the network will become congested and the condition for traffic class 6 is much worse than others. This is because that Class 6 generates too many packets into the network too quickly, every 5 seconds, while the frequency of packet generation in other traffics is less and based on fairness algorithms in transport layer, its packets experience higher delays. Therefore, it is suggested to use priority algorithms such as differentiated services to improve its high delay.

V. CONCLUSION

In this paper, the viability of powerline communication for smart grid realization has been investigated. The major challenge of using powerline as a communication technology is its noisy environment. The noisy condition of powerline has been modeled by importing bit error rate into the system. From the results, we concluded that low speed powerline communication did not achieve required performance criteria instead the PLC infrastructure which is a combination of NB-PLC, BPLC and BPLC can satisfy smart grid communication network requirements. We propose this architecture as an economic architecture that can be used for smart grid communication network using PLC technology. The reason for using NB-PLC in the first level of the network (access network) is that the price of required devices that should be installed in the power grid would be much less versus to the time we have to use BPLC. In addition, we studied uncoded and coded OFDM system for BPLC and concluded that to make the use of BPLC practical, coded OFDM system has to be used for BPLC.

By applying advanced traffic to the system, a high delay is observed for traffic class 6. It is suggested to use priority algorithms such as differentiated services to improve its high delay.

VI. ACKNOWLEDGMENT

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