Field analysis of PRIME PLC system performance in the rural distribution grid

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Abstract

The paper presents an error performance analysis of a narrow-band power line carrier (PLC) system utilized for smart metering. The performance analysis is based on the probability theory using limited, long-term measurement data of a rural 400 V distribution grid during operation, with an assumption that the bit error rate (BER) was a random variable, where errors are randomly distributed in the sample rather than clustered into messages. The confidence interval of the true BER is calculated for different SNR values. The presented work is crucial for the research of upper layer communication protocols performance incorporating advanced phenomena at the physical layer.

Index Terms

narrow-band power line carrier, PRIME, smart metering, performance analysis

I. Introduction

THE idea of smart metering originated from the Automatic Meter Reading (AMR), a system that provides distribution system/network opretators (DSOs/DNOs) with the basic capability to collect consumption data remotely usually for the billing purposes. Inside the smart grid paradigm, AMR systems evolved into Advanced Metering Infrastructure (AMI), which is consumer-centric platform that provides monitoring of the energy consumption, power quality, renewable generation as well as distribution of pricing information [1].

Basic AMI applications require throughput up to 100 kbps and the message latency not exceeding 15 s. Available narrow-band power line carrier (NB PLC) standards could fulfill these requirements. However, their performance will vary in different power grids, due to topology, consumption patterns and quality of cables and connections. Some other AMI applications, such as real-time metering, require higher data rates and latency bellow 20 ms [1].

Various communication technologies compete to become a dominant technology for AMI deployment [2]. Competing technologies must meet communication requirements set up by AMI for proper operation [3]. On the other hand, power utilities give preference to a technology, which makes the development of their own communication infrastructure more efficient. Under such circumstances, a networking concept that deploys data concentrator and PLC communication technology appeared as adequate solution.

PRIME (PoweRline Intelligent Metering Evolution) is NB PLC technology appropriate for implementation for smart metering systems, in which traffic is consist of a large number of short messages. Implementation of smart metering systems in rural systems is challenging and costly, due to low density of population. Besides smart metering, DSOs have a strong incentive to monitor rural distribution grids, for many reasons such as: distributed generation presence is often in rural areas, the grid strengthening is costly due to long lines, faults are more common than in urban areas because of overhead lines, and some areas are not frequently visited. In such cases, NB PLC technology appears to be acceptable solution for implementation of smart metering systems in rural low voltage distribution grids for the following reasons:

- PRIME technology utilizes switches and message routing at the MAC layer to achieve large communication ranges and provide connectivity for stations which can't communicate directly with the base station.
- Utilizes tree topology which fits to the topology of the distribution grids.

This paper presents performance analysis of PRIME-based NB PLC system deployed in the rural distribution grid. The measurement methodology used for the data collection is briefly described and results of performance analysis are given.

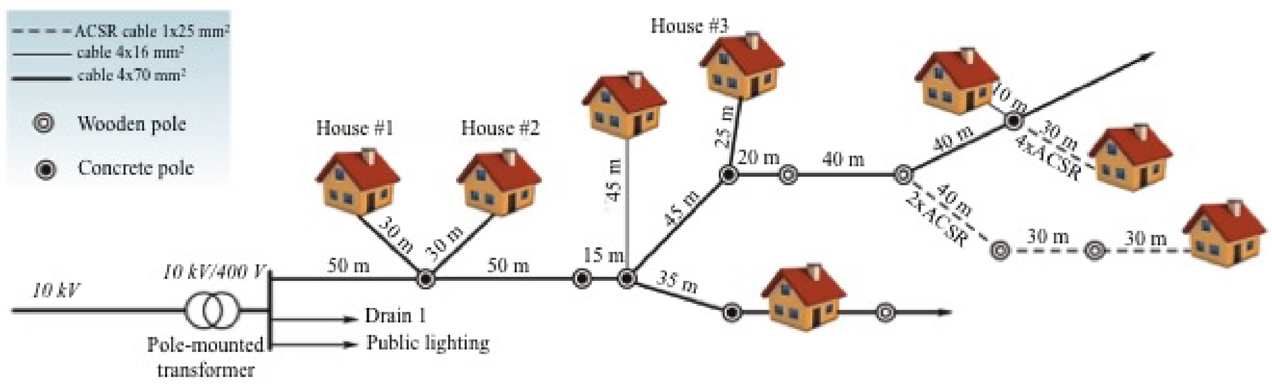

Fig. 1. A 400 V distribution grid topology

II. Measurement methodology

The detailed description of the measurement methodology describes procedures for collecting and processing data necessary for the performance analysis of the PRIME system is given in [4]. Measurement procedures include the following:

1) PLC channel frequency and noise characteristics, in the frequency range devoted to the NB PLC communication systems.
2) Registration time of the PRIME service node at the base node.
3) Plots describing bit error rate (BER) versus SNR class, a measure of PRIME error performance.
4) Promotion of service nodes into a switch mode.

For the PRIME PLC system error performance analysis, Atmel evaluation boards SAM4SP32AMB were used for data collection. The evaluation boards are comprised of PRIME modem SoC (System on Chip) as well as an adequate coupling device. Evaluation boards can be configured either as a base node or as a service node in compliance with the PRIME standard [5]. The base node is connected to the selected phase conductor at the low-voltage side of the transformer and programmed to broadcast messages over the PLC network. For measurement purposes, service nodes should be directly registered at the base node without any intermediate switches. This ensures that the obtained error performance corresponds to the point-to-point link between the service node and base node evaluated. PRIME SoC implements all primitives defined by the standard and read-out registers within the system inside.

The confidence interval that contains the long-term BER with some probability p is calculated utilizing sequential Bayesian bit error measurements presented in [6]. All N transmitted bits were considered as one sample without clustering them into messages. This approach, however, disregards the fact that PLC channel incorporates impulsive noise and that error bits appear in bursts. Therefore, the obtained result is related to the long-term averaged BER.

III. Results of error performance analysis

The performance of PRIME PLC network deployed in the rural overhead 400 V distribution grid is analyzed utilizing presented methodology. Test grid topology is depicted in Figure 1. The first modem was located in the substation and was configured as the base node. The other three modems were configured as terminal nodes and located at power meters in houses #1, #2, and #3. Because the measurement equipment could not be left unattended or installed for a long period, the duration of the measurements was limited to the presence of utility personnel. Thus, the same measurements were repeated several times at the same location over a two-year period.

Confidence intervals that contain the true BER with a 95% probability were computed applying the procedure described in the previous section. The estimated long-term BER for House #1 and House #2 are presented in figures 2 and 3, respectively.

IV. Conclusion

An error performance analysis of PRIME NB PLC system at the physical layer based on a limited amount of measured data has been presented. The experimental measurements in the 400 V rural distribution grid were used for the error performance analysis, which was the starting point for the performance analysis of a smart metering system that utilizes NB PLC communications. The results characterize the PLC PHY layer behavior crucial for the design and analysis of upper-layer protocols that enable communication systems within smart grids.

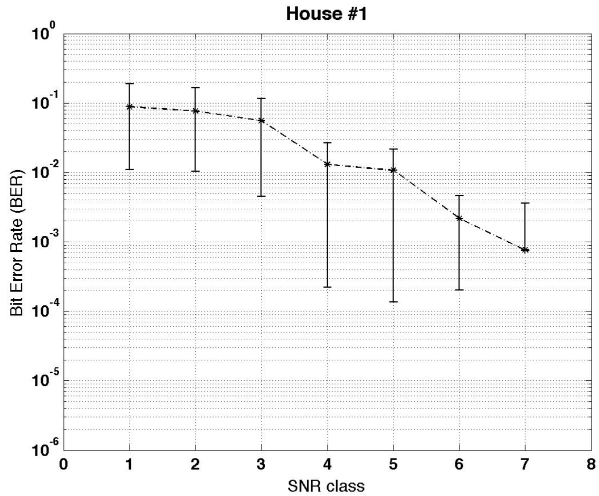

Fig. 2. Estimated long-term BER for House #1

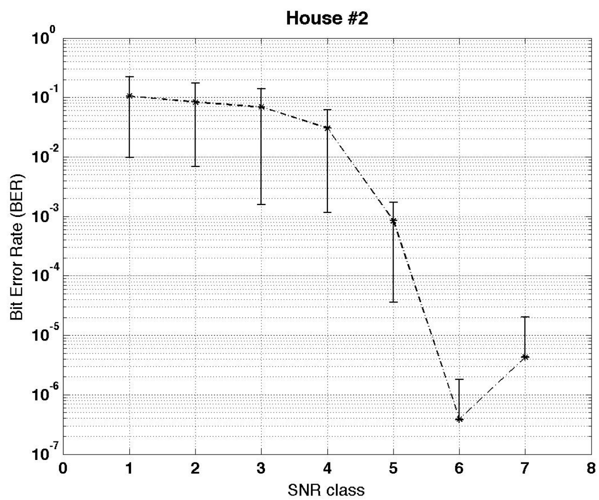

Fig. 3. Estimated long-term BER for House #2

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