Computer Networks 69 (2014) 35–50

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Energy efficient network protocol architecture for narrowband power line communication networks

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A R T I C L E I N F O

Article history:
Received 27 January 2013
Received in revised form 16 April 2014
Accepted 19 April 2014
Available online 30 April 2014

Keywords:
Narrowband power line communication
Advanced metering management system
Adaptive routing protocol
Energy efficiency

A B S T R A C T

This paper presents newly researched and developed network layer protocol for narrowband power line communication (PLC) within the last mile of advanced metering management systems. This communication medium is known for its low data rates and issues with signal propagation and noise inherence. After the network properties are introduced and some of the published PLC routing papers are discussed, our network layer protocol concept is described with emphasis on the routing algorithm and route optimizations. The protocol is designed to optimize the energy efficiency of the PLC network. The next part of the paper briefly describes the network simulator and its model, which was used during the protocol development and debugging. Several networks with constant and dynamic channel parameters were simulated. The results are presented at the end of the paper. Final results proving energy efficiency and its positive influence on the network performance are presented in comparison to the minimum hop count metric.

1. Introduction

The motivation behind this paper is to describe a new protocol architecture concept designed for the narrowband power line communication networks gathering data in the last mile of the smart metering systems. The paper emphasis is on the network layer design and special energy efficient routing protocol with minimized protocol overhead and overhead traffic. The reason for energy efficiency is in the advantageous and contemporary saving of energy spent by millions of communicating devices. Simulation results, presented in a case study below, show also improvements in network robustness in typical power line networks.

1.1. Power line communication networks

Power line communication – PLC is a method of sending data over the wiring, which is primarily designed to distribute electrical energy. PLC decreases installation costs thanks to communication cables reduction, but it also has its drawbacks. PLC is usually divided into two main areas according to the frequency bandwidth used: narrowband PLC (several kHz to hundreds of kHz bandwidth), and broadband PLC (frequency band up to tens of MHz). The main applications, which are prioritized in the field of narrowband PLC, are the master–slave applications such as home automation, automatic meter reading (AMR) and advanced metering management (AMM) systems. Broadband PLC (BPL) is usually used to provide local network access or for audiovisual data streaming. The paper and the proposed routing protocol are focused on narrowband PLC for AMM applications where the common internet protocol suite and common routing protocols cannot be effectively used. This limitation originates in the limited

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http://dx.doi.org/10.1016/j.comnet.2014.04.012
1389-1286/

bandwidth and PLC channel characteristics. The goal of our research is to provide universal routing protocol optimized for the AMM systems and minimizing power consumption used for communication.

PLC is in principle superposition of the higher frequency digital modulation signal to the low frequency electrical energy distribution signal. Despite the galvanic connection between power line network nodes, the communication channel is well known to be relatively unstable and hard to predict in the urban areas. The data transfers in the power lines can be compared to the wireless communication signal propagation and models rather than to the ordinary communication busses with defined signal propagation parameters as it is depicted in Fig. 1. In this simple PLC network example it can be seen that the individual nodes cover a limited communication area. This range is usually not fixed and the reasons are described in following paragraph.

Most problems arise from signal attenuation and fading. Signal attenuation depends on many factors (network topology, connected loads, used wires), but generally it increases with increased signal frequency. Fading is caused by multipath signal propagation (topology and impedance mismatch) and is more related to the BPL and higher signal frequencies. The signal to noise ratio is another limiting problem in PLC. Power line channel is specific with the presence of various noise types in urban power line distribution network (background noise, synchronous and asynchronous noise and impulsive noise) [2]. PLC channel model and communication limits can be found in many publications, e.g., in [1–3,17,18].

Narrowband PLC operates with signal in a frequency range of several kHz to hundreds of kHz. Recent developments have left the simple implementations of the narrowband digital modulations and have focused more on the wide band techniques; mainly the OFDM [10]. There are many manufacturers producing PLC modules for the smart metering applications fulfilling the European CENELEC EN-50065 standard, where the bandwidth is limited to a range of 3–148.5 kHz and the transmitter power output is strictly limited as well [11]. Producers also provide solutions up to hundreds of kHz (following FCC 15 and ARIB standards) raising the raw bit rates up to hundreds of kilobits per second.

1.2. PLC routing

Direct end-to-end data transfers are often impossible in the PLC smart metering last mile urban scenarios due to the power output and frequency bandwidth limitations, varying signal attenuation, and noise inherence. Therefore, a way to deliver the data over the network to the distant nodes should be implemented in every PLC sub-network. The master–slave network traffic is always demanded in the PLC AMM networks. There is no reason to support the slave to slave communication in the AMMs (at the application layer), therefore our routing protocol is designed and adapted for this master–slave network traffic. The master node is assumed to be the PLC node which is embedded in the data concentrator. It represents the interface between the meters (power line network) and the AMM system network. It is usually located near the power distribution substation. The slave node is assumed to be the electricity meter with the PLC interface. Its main communication task is to respond to the master node requests. An example scenario of the small AMM PLC network with constant channel parameters is shown in Fig. 2. The left part shows the application protocol traffic. The odd arrows represent the end-to-end application request packets sent periodically by the master node to the slave nodes (e.g., periodic profile requests). The even arrows represent the application respond packets (recent profile entries) from the slave nodes to the master node, sent immediately after the request. The right part of the figure shows the bright links, which are the only links used in this particular network to deliver the application packets when the routing protocol stabilizes.

In real industrial applications the packet delivery was ensured by the proprietary protocols in most cases, with disputable reliability and functionality. The PRIME

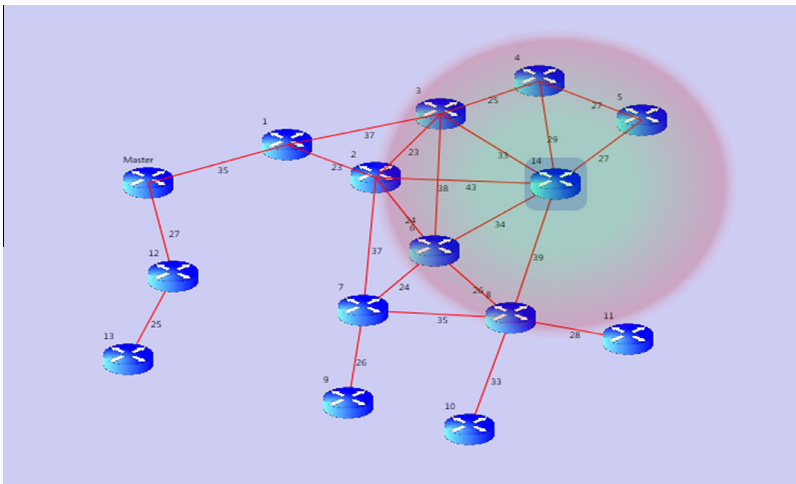

Fig. 1. Simple PLC network model.