Computer Networks 67 (2014) 1–13

Contents lists available at ScienceDirect

Computer Networks

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

Adding accurate timestamping capability to wireless networks for smart grids ☆

Paolo Ferrari *, Emiliano Sisinni, Alessandra Flammini, Alessandro Depari

Department of Information Engineering at the University of Brescia, Via Branze 38, 25123 Brescia, Italy

ARTICLE INFO

Article history:
Received 20 December 2012
Received in revised form 11 March 2014
Accepted 12 March 2014
Available online 18 March 2014

Keywords:
Smart grids
Time synchronization
Wireless sensor networks
Software defined radio

ABSTRACT

Smart grids rely on bi-directional communications between energy production sites and utilization sites. Usually, different approaches are used for implementing the required Wide, Field, and Home Area Networks (WAN, FAN and HAN, respectively). These networks are realized using very different (hybrid) technologies, for instance wired for WAN and wireless for FAN and HAN. However, an accurate common sense of time must be guaranteed among all smart grid participants, as it happens in any other distributed systems. Satisfying this need is challenging for wireless networks, while mature time distribution technologies are available for wired networks. The major issue for wireless devices is to provide accurate timestamping of network events, the key element of any time synchronization protocol. The objective of this paper is to propose low-cost and low-complexity timestamping techniques that also maintain full compatibility with already existing (unlicensed) communication standard for wireless nodes used in smart grids. In addition, a suitable platform exploiting the Software Defined Radio paradigm for comparative evaluation of these techniques is also discussed. Simulation and experimental results confirm the feasibility of the proposed approach, with the standard deviation of the timestamping error scalable down to 5 ns.

1. Introduction

The advantages offered by smart grids are widely known: improved safety and efficiency, better use of existing assets, enhanced reliability, and power quality. Several governments are pushing the transformation of the legacy power grid into a newer smart grid in order to satisfy efficiency, sustainability, resilience and global warming issues [1,2].

From the architectural point of view [3], a smart (power) grid can be divided into three different tiers: the physical power tier (including generation and distribution), the communication networking tier, and the application tier (including advanced services as smart remote metering and load management).

The communication tier allows devices to exchange information on power demand, thus maximizing the overall efficiency. An ensemble of very heterogeneous solutions is adopted in order to cover different requirements ranging from power plants interconnection by means of high-speed geographical networks to local networks of home appliances, as confirmed by several survey works [4,5].

Despite the hybrid approach previously described, an accurate common sense of time must be guaranteed among all smart grid participants. Sharing the time reference is

☆ This work was supported in part by the Italian research grants MIUR PRIN 2009 "New generation hybrid networks in measurement and industrial automation applications – Characterization and wired/wireless performance measurement" N. 2009ZTT5N4_002.

* Corresponding author. Tel.: +39 030 3715445; fax: +39 030 380014.
E-mail address: emiliano.sisinni@ing.unibs.it (E. Sisinni).

http://dx.doi.org/10.1016/j.comnet.2014.03.005
1389-1286/

crucial for merging/elaborating the information collected through the entire network, as it happens in many other distributed systems [6]. Time distribution on wired networks is widely investigated [7] and may be applied, for instance, to Wide Area Networks (WAN) for smart grids. Conversely, if certain sections of the network are implemented using wireless communication, some issues may arise. Even if a high number of wireless time synchronization protocols have been proposed [8], the major problem for wireless devices is to provide accurate timestamping of network events due to intrinsic characteristics of the communication medium (noise, interferences, etc.).

The aim of this paper is to propose new accurate timestamping techniques that can be used, potentially, with any existing solution for wireless networking maintaining low-cost and low-complexity. The proposed methods are designed to have the following characteristics:

- full compatibility (at data level) with unlicensed wireless standard communications systems used in smart grid networks;
- full interoperability between devices with (enhanced) timestamping and devices without timestamping (i.e. using today commercially-available transceivers).

In particular, this work suggests two possible solutions: received signal thresholding, and adding chirp preamble to frames. The feasibility of the proposal is proved by means of a flexible transceiver based on a Software Defined Radio (SDR), as done in [9].

The paper is structured as follows. A brief overview of the smart grid network architectures, focusing of wireless technology and time synchronization, is given in Section 2. In Section 3 some timestamping methodologies are introduced. In Section 4, the proposed approach for timestamping evaluation is described, and in Section 5 a case study is analyzed, showing the effectiveness of the proposed solutions. Finally, conclusions are drawn.

2. Smart grids networks

The communication networks used by smart grids must cope with very dissimilar requirements: high availability and reliability; large coverage area; interconnection of different objects. The smart grid network may be divided into three different segments [3,10]:

1. The home area networks (HANs), connecting appliances with smart meters.
2. The advanced metering infrastructure or field area networks (AMI/FANs), moving information from premises towards an aggregation point.
3. The wide area network (WAN) which is the actual backbone for communication among aggregation points (a.k.a. gateways) and the utility data center.

Clearly, there is not a "one-size-fits-all" technology capable to satisfy all the needs: the smart grid is implemented as a "system of systems", whose different technologies and applications areas are shown in Fig. 1.

Nowadays most smart grid communications are based on specialized and proprietary solutions, even if the need for standardization has been long understood [11]. Just to mention most interesting efforts in this direction, consider the work of NIST and the Smart Grid Interoperability Panel (SGIP) in the United States or the European Mandate on Smart Grids (M/490) which requests CEN, CENELEC and ETSI to develop a standard framework capable to ensure interoperability despite a continuous innovation. These documents highlight (but do not solve) some of the key issues on the smart grid infrastructure:

- the adoption of the IP protocol suite as the unifying protocol for intra and inter-network segment interoperability;
- the use of wireless links as a substitute of wired medium when it is too costly or not workable;
- the reliable distribution of a common sense of time among network actors in order to accurately correlate different network events.

Despite its wide diffusion in most telecom networks, the IP protocol is still in its infancy of adoption in the overall End-to-End smart grid connections due to several problems that still need to be addressed (e.g. security aspects). Nevertheless, many HAN solutions are already based on IP (e.g. ZigBee Smart Energy, HomePlug, 6LoWPan, etc.), and most of WANs are realized using fiber-based IP backbone placed along the main electric lines, from substation to substation [12].

The use of wireless links helps in reducing installation and maintenance costs [13], even if the debate about the winning technology for the different network segments is

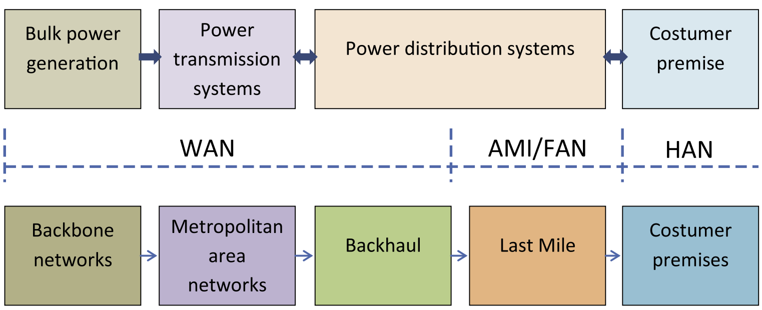

Fig. 1. The End-to-End architecture of a smart grid considering both the communication network and the electric system point of views.