Ad Hoc Networks 42 (2016) 19–33

Contents lists available at ScienceDirect

Ad Hoc Networks

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

Classification of Radio Channel disturbances for industrial wireless sensor networks☆

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ARTICLE INFO

Article history:
Received 27 August 2015
Revised 1 December 2015
Accepted 2 January 2016
Available online 22 January 2016

Keywords:
Radio disturbances
Wireless sensor networks
Software Defined Radio
Classification of radio disturbances

ABSTRACT

The reliability of data transmission in Wireless Sensor Networks (WSN) is always an issue in harsh industrial environments and sets specific challenges for performance optimization. Short-term signal disturbances, in the form of multipath fading and destructive radio interference, are of major concern due to signal path conditions (large concrete and metal surfaces), related line-of-sight (LOS) changes (incoming and outgoing trucks, moving around forklifts and workers), and radio frequency interferences. In this paper we introduce the classification procedure where results of Probability Density Function (PDF) analysis and Spectrogram Analysis are combined to classify the measured radio channel disturbances to a set of predefined disturbance classes. The PDF and Spectrogram analysis methods are used for analyzing the statistical properties of the received signal magnitudes. Tracking the changes of the PDF clearly contributes to recognize and characterize the temporal changes, especially LOS changes in the radio link environment. The spectrogram analysis provides additional information of the radio interferences on co- and adjacent channels.

1. Introduction

The manifold benefits of wireless network technologies have led to their great success in the consumer goods industry. Simple deployment, significant cost savings in installations, lack of cabling, high mobility, and easy re-arrangements related to device configuration and sensor locations make the wireless network technologies, especially wireless sensor networks (WSN) appealing also for industrial applications [1–4].

The adaption of wireless technology in industry poses extra challenges since the factory environments are typically harsh for wireless communications in terms of interferences, noise and physical obstacles [5]. Wireless industrial automation has strict requirements for the Quality of Service (QoS), safety and security. The key aspect of QoS for Industrial Wireless Sensor Networks (IWSN) communication is to ensure the transmission of periodic or sporadic messages within pre-defined deadlines and in a reliable fashion [2]. WINA technical committee has undertaken the development of a QoS design and assessment framework for IWSN [6]. The measures of performances that define QoS are throughput, latency, reliability, security, adaptability, and affordability. Within the industrial environment, adaptability is one true advantage of wireless over wired networks meaning the ability to adapt to changes in the environment while maintaining the required levels of QoS attributes [7].

Within the industrial market six different classes of sensor and control applications have been defined varying from critical safety (class 0) to condition monitoring and regulatory compliance (classes 4 and 5) [8]. The main

☆ Manuscript was submitted on April 20, 2015. This work was part of the DEWI –project (Dependable Embedded Wireless Infrastructure) and it has been partly funded by the Tekes – the Finnish Funding Agency for Technology and Innovation and ARTEMIS Joint Undertaking.

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http://dx.doi.org/10.1016/j.adhoc.2016.01.001

difference between the classes is the latency, timing and reliability requirements. In the closed-loop control applications involving mobile subsystems, coordination among mobile robots or autonomous vehicles, health monitoring of machines and tracking of parts, the wireless data communications must satisfy tight real-time and reliability requirements at the same time, otherwise loss of time and money or even physical damage can result [2]. While in monitoring applications the requirements for real-time transmission are generally loose, the reliability is important especially for critical alarm messages.

Several industrial organizations, such as ISA [9], HART [10], and ZigBee [11], have been actively pushing the applications of wireless technologies in industrial automation. ZigBee, WirelessHart, and ISA100 use the same physical level of IEEE 802.15.4, but they differ substantially concerning the medium access control (MAC) level. WirelessHart and ISA100 are mesh solutions adopting frequency agility and power adaption to improve the data transmission reliability [12,13]. WirelessHART introduces channel hopping and channel blacklisting into the MAC layer, while ZigBee can only utilize Direct Sequence Spread Spectrum (DSSS) provided by IEEE 802.15.4. Since ZigBee does not exploit frequency diversity and network shares the same static channel, it makes it highly susceptible to both unintended and intended jamming, and also to frequency selective fading due to the metal-rich propagation environments. ISA100 Wireless is the only industrial wireless network protocol that satisfies the ETSI EN 300.328 v1.8.1 regulation being in effect January 1, 2015. ISA100 Wireless uses CSMA/CA (LBT- Listen Before Talk) CCA (Clear Channel Assessment) technology to detect co-existence with other unmanaged wireless devices using the same 2.4 GHz frequency spectrum, and spectrum monitoring to avoid congested channels by forcing the operation on specific channels [15].

In wireless access systems with terminals equipped with significant power resources, radio and baseband processing chains, different countermeasures against fading can be realized. In WSN's with often simpler and low power sensor nodes, the situation is usually more complicated, and careful design of the overall system given the realization constraints is needed. Due to restricted computing power, signal measurements and further analysis established in sensor nodes cannot be computationally demanding.

In this paper we introduce a novel approach to improve the quality of wireless communication in WSN's. We introduce signal analysis methods and a classification algorithm to identify radio channel disturbances typical for industrial environments in the physical layer. Signal analysis methods based on statistical analysis of the received signal properties help to recognize the temporal disturbances affecting the signal propagation in a radio channel, and have been described in details in our previous work [26,28].

The focus of this work is to introduce the classification procedure; combining the results of signal analysis methods in time and frequency domains we construct a classifier to categorize the radio channel disturbances. We use 2.4 GHz RF transceiver as the transmitter [19] and Software Defined Radio (SDR) [20] as the receiver. Capturing signal with SDR gives us possibilities to analyze the statistical properties of the received signal even in intra-symbol scale. Our channel diagnosis methods are generally applicable to wireless technologies using physical level of IEEE 802.15.4. Our focus is on Layer 1 (PHY), and it applies to all techniques in Layer 2, and above it. The rest of this paper is organized as follows. In Section 2 the overview of reliability of wireless communication is given. In Section 3 we present our signal analysis methods for radio channel disturbance identification. In Section 4 we show the main principles of disturbance classification and in Section 5 test results of the disturbance classification. Finally, the paper is concluded and results discussed in Sections 6 and 7.

2. Reliability of communication in IWSNs

Wireless Local Area Networks (WLANs) based on the IEEE 802.11 specification, cordless telephones and Bluetooth have fully reached the process plant, and when introducing WSN's in the plant, one must accept that the environment is under influence from nearby interference sources. Performance evaluation results on WirelessHART for factory environments have shown that interference from the WLAN will cause increased packet loss rates [14]. Exposing WirelessHART network to attacks from a 2.4 GHz linear chirp jamming device has caused the WirelessHART network braking down completely, with no data reception on the gateway and a resulting reliability of 0% [14]. Zigbee does not have frequency diversity like WirelessHART, and thus is even more exposed to radio channel interferences [15].

The reliability of data transmission in WSNs has been studied from different perspectives. Great amount of research results have been reported on such topics as reliable routing techniques, and reliable transport protocols for WSNs, which aim to overcome the data transmission problems on MAC-, Network- and higher layers. Physical level transmission problems have received less attention though providing feedback of channel disturbances from physical level to upper level could significantly improve the transmission reliability [16]. In channelization, to overcome the problem of spectrum scarcity in a WSN, a new concept of cognitive wireless sensor network (CWSN) has been proposed. The main difference between traditional WSN and CWSN is that in CWSN nodes change their transmission and reception parameters according to the radio environment [17]. Spectrum sensing is a commonly used technique in cellular cognitive radio helping to avoid the most crowded frequency channels, and it considerably improves the radio channel reliability. However radio interference is not the only concern in the industrial environment. The signal strength can be severely affected in factory environments due to multipath fading, originating from large objects blocking the signal path, and reflections from walls and floors.

A common approach for the physical layer measurements is to rely on the Received Signal Strength Indication (RSSI) values provided by the chipset. The main attraction to RSSI as a metric is that the measurements and calculations involved with RSSI are less complicated, and RSSI values are easily available from the chipsets [18]. The