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On the feasibility to deploy mobile industrial applications using wireless communications

Javier Gozalvez, Miguel Sepulcre [1,*], Jose Antonio Palazon

Ubiquitous Wireless Communications Research Laboratory (Uwicore) of University Miguel Hernandez of Elche, Avenida de la Universidad s/n (Edificio Quorum V), 03202 Elche, Alicante, Spain

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ABSTRACT

Wireless communications can facilitate the deployment of novel industrial applications to improve productivity or health and safety conditions. Health and safety applications require mobile solutions capable to operate under harsh propagation conditions at low cost and energy consumption. This paper presents the results of an extensive measurement campaign that demonstrate the feasibility to deploy industrial mobile sensing applications with reliable wireless connectivity levels using short-range IEEE 802.15.4. The campaign also analyses the capability of various wireless technologies to provide the throughput levels necessary for wireless local data distribution and backhaul connectivity.

1. Introduction

Wireless communications are being gradually introduced in industrial environments to provide ubiquitous communication opportunities at reduced costs. Wireless solutions can also better adapt to changing operating and network environments than wired networks, and can offer better scalability and reconfigurability perspectives. The introduction of wireless communications in the factory of the future will also facilitate the deployment of distributed and mobile sensing applications for improving productivity levels and the workers' health and safety. In this context, the FASyS project (Absolutely Safe and Healthy Factory, http://www.fasys.es/en/) is investigating the design of an end-to-end heterogeneous wireless solution for continuously sensing the working environment and the workers' health and physiological conditions in order to be able to detect in advance any potential risks. FASyS exploits Wireless Sensor Networking (WSN) technologies (IEEE 802.15.4/ZigBee) to locally monitor the working environment and the workers' conditions. To transmit the sensed data to a control center, a wireless backhaul including medium range technologies for communications within the factory, and long range technologies for the transfer of the aggregated data to the control center has been designed. The medium range technologies (IEEE 802.11/WiFi and IEEE 802.16/WiMAX) transmit locally sensed data from different areas of the factory toward a gateway. The gateway can then transmit the received data using WiMAX and/or cellular to a remote control center. FASyS adopted a centralized approach in which a control center is in charge of controlling and supervising the sensors deployed and managing the heterogeneous wireless network. In particular, the control center manages the database of deployed nodes and sensor observations, and is also in charge of the real-time processing of all received information to trigger the necessary alarms when an unsafe or dangerous situation is detected. Additionally, the control center implements a toolbox that monitors the state of all wireless connections, and takes the necessary countermeasures to prevent link failures or congestions. While certain control functionalities can be distributed over different nodes, FASyS adopted a centralized approach so that the control center has a global view of the sensor network and can hence control the end-to-end Quality of Service (QoS). The adopted approach also facilitates a more scalable and cost-efficient deployment in the case of an industrial complex comprising several buildings or facilities. In this case, the different buildings will just require backhaul links to the control center. In Fig. 1, FASyS's industrial communications architecture is depicted.

Distributed communication systems in industrial environments are being evolved from the 1st generation of industrial networks, known as fieldbus systems and characterized by low bandwidths, to the 2nd generation using Real-Time Ethernet to reduce costs and increase data transfer speed [1]. Some of the most

* Corresponding author at: University Miguel Hernandez of Elche, Avenida de la Universidad s/n (Edificio Quorum V), 03202 Elche, Alicante, Spain. Tel.: +34 96522 2031; fax: +34 96665 8903.
E-mail addresses: j.gozalvez@umh.es (J. Gozalvez), msepulcre@umh.es (M. Sepulcre), jpalazon@umh.es (J.A. Palazon).
[1] http://www.uwicore.umh.es

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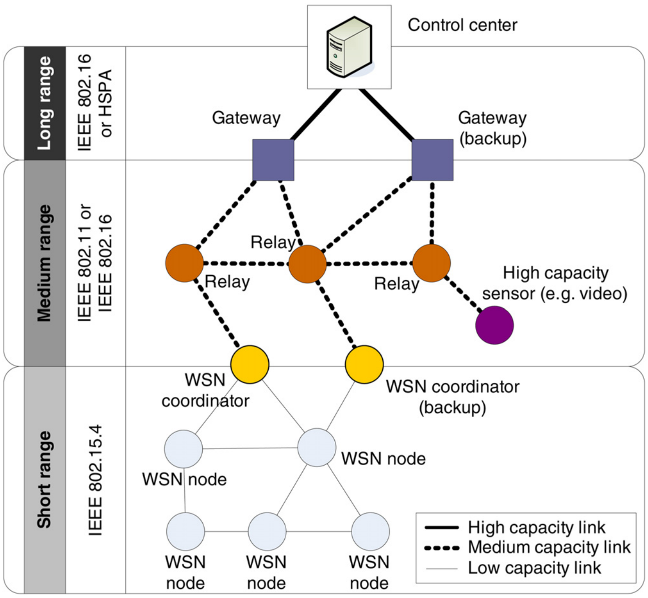

Fig. 1. FASyS's heterogeneous communications architecture.

significant challenges of distributed industrial communication systems include their integration with public IP-based networks for interconnecting remote subsystems [2], or standardization/interoperability issues [1]. In this context, several studies have highlighted the benefits of exploiting wireless communications technologies in general, and WSN in particular, in industrial communication distributed systems [1,3–7]. These benefits include deployment flexibility, low cost and reduced power consumption. However, the deployment of heterogeneous wireless communications in industrial environments presents significant challenges. On one hand, industrial environments are usually characterized by challenging propagation conditions (obstructions, multipath propagation, interferences, etc.) that difficult the establishment of robust wireless links. In addition, safety-related industrial applications are characterized by strict reliability and timing requirements, and therefore require a reliable mobile sensing and communications platform. In this context, this paper presents the results of a large field testing campaign that evaluated the communications performance of mobile IEEE 802.15.4 sensing communications, as well as the QoS that IEEE 802.11/WiFi, IEEE 802.16/WiMAX and HSDPA technologies can provide for backhaul connectivity. The campaign also included the deployment and testing of three use cases (collision avoidance, restricted access, and working at height) to highlight the safety-related potential of wireless industrial communications. The wireless traces obtained during the field testing campaign are openly released to the community to further facilitate research activities in wireless industrial communications. The traces can be downloaded from [8].

2. Related work

Different studies have analyzed wireless communications in industrial environments. They can be classified in three categories depending on their specific objectives and methodologies. A first group of studies focused on the characterization of the industrial radio propagation environment. A second category can be formed by studies that evaluate the achievable industrial communications performance using off-the shelf devices. Finally, the third category includes simulation-based and laboratory studies.

The studies focusing on the characterization of the industrial radio propagation environment typically analyze the received signal strength, amplitude probability distribution, *rms* (root mean square) delay spread, impulse response measurements, and coherence bandwidth. These parameters help understanding and characterizing propagation loses and distortions suffered by radio signals within factories. For example, the work in [9] has recently characterized three factory automation infrastructures at 439 MHz, 440 MHz, 570 MHz, and 2.45 GHz. The study revealed that the analyzed facilities have different levels of reflectivity, which can have a negative impact on the reliability of wireless technologies. Similarly, Tanghe et al. [10] reports a series of narrow-band measurements performed in two wood processing and two metal processing factories at three frequencies bands (900 MHz, 2.4 GHz, and 5.2 GHz). The study found limited path loss variations between measured factory buildings, mainly because of their similar constructional details. Temporal fading was found to be most significant in manual production lines, and to be overall less important than in office environments. The obtained measurements were later used to create a propagation model validated in [11] using IEEE 802.11 received signal strength measurements. An empirical propagation model was also presented in [12], where the wireless communications performance was characterized in a large industrial hall and four typical indoor office environments.

Other studies have evaluated the performance of wireless technologies in industrial environments, with many of these experiments based on the IEEE 802.15.4 and IEEE 802.11 standards due to their low cost and wide market acceptance [13]. For example, the work in [14] presents the results obtained in different field tests performed in various electric-power-system environments, including a 500-kV substation, an industrial power control room, and an underground network transformer vault using IEEE 802.15.4-compliant wireless sensor nodes. The obtained results (Packet Reception Ratio, background noise, channel characteristics, and attenuation) provide valuable information for the design and deployment of IEEE 802.15.4-compliant sensor networks for smart-grid applications. The study in [15] experimentally investigates the nature of IEEE 802.15.4-based packet transmission errors resulting from common stationary (e.g. machine shop) and moving obstacles (e.g. moving forklift) in small-scale manufacturing environments. The measurements show that transmission errors closely depend on the received signal strength, and could be mostly avoided by controlling the transmission power in order to ensure received signal strengths above the receiving sensitivity level. Other studies analyze the performance of IEEE 802.15.4 devices under particular industrial operating conditions. For example, the work in [16] experimentally evaluates the speed-dependent PER (packet error rate) of a rotating IEEE 802.15.4 device in a fast changing channel, which is typically experienced at a rotating mechanical structure. The study in [17] investigates the influence of the temperature on IEEE 802.15.4 communications in an outdoor WSN in an oil refinery, demonstrating that the temperature has an important effect on signal strength and link quality, and that operations at lower temperatures might require up to 16% less power to maintain reliable communications. Other experimental studies evaluating the performance of IEEE 802.15.4 and IEEE 802.11 devices in industrial environments can be found in [18–21]. These studies demonstrate that the physical layer of IEEE 802.15.4 can be suitable for industrial environments, and that reliability levels above 99% are possible under adequate node deployments. However, the studies also concluded that strong link quality variations can be found under frequently changing industrial environmental conditions.

The difficulties to conduct measurement campaigns in industrial environments have spurred many wireless industrial performance studies using simulation platforms [22] or off-the shelf devices in laboratory-controlled environments [23,24]. For example, Cena et al. [22] analyzes the performance that can be