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PI-based Transmission Power Control for *Wireless*HART Field Devices ⋆

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Abstract: Wireless networks are gaining space in industrial environments due to the low installation costs and low maintenance. Robustness is also one of the main requirements for these systems to be adopted, and, in this context, *Wireless*HART (WH), ISA SP100.11a, and WIA-PA protocols met these characteristics. In order to provide low maintenance, these protocols must provide reliable radio links while keeping low power consumption to allow battery powered devices. Unfortunately, the standards of these protocols do not impose any RF power modulation technique, which is a form to increase even more the battery endurance of a wireless field device. Instead, RF power levels are fixed and selected by commissioning, and must allow the longest link per device. In this case, devices in closer ranges waste energy during transmissions, as they could save energy by modulating the RF power. This paper presents a RF power modulation technique that employs a proportional-integral controller and allows reduction of energy consumption while keeping the robustness of RF links. A proof of concept of the power modulation technique is implemented and verified showing good results and proving that the proposed controller is feasible. The proposal has the advantage to be fully compatible with the standard.

Keywords: Transmission power control; *Wireless*HART protocol; PI controller; industrial wireless sensor networks

1. INTRODUCTION

The *Wireless*HART (WH) protocol was specifically developed for industrial applications, as well as ISA SP 100.11a and WIA-PA (Song et al., 2008; Chen et al., 2010). All three standards employ IEEE 802.15.4 physical layer, with WH imposing at least three power levels for the field devices, which are −10, 0 and +10 dBm. They reach reliability and security in a way they can replace cable based systems for industrial process control (Doherty and Teasdale, 2006). After WH launch in 2007, several studies were proposed and developed aiming to improve its performance (Zand et al., 2012). One important issue pointed in that study is the power consumption, which should be as low as possible while keeping good radio link characteristics. An industrial wireless field device should work as many years as possible before battery replacement because this is the most important characteristic related to maintenance.

A typical IEEE 802.15.4 transceiver presents several power levels that can be chosen according to the necessary RF link. In WH, the RF power level is adjusted by commissioning and must be carefully chosen based on device position inside the plant to provide a reliable link while keeping power consumption as low as possible. This can lead to a situation when RF power must be selected to provide the longest links: energy is wasted in short-range communications, as illustrated in Fig. 1.

A direct relation between RF power levels and DC power levels can be established as well as a relation between RF power levels and radio range. There is a trade-off between optimal link range and lowest energy consumption: as the RF power levels are adjusted by commissioning, they are not optimal concerning all the links between field devices. Therefore it is important to reduce energy consumption that consequently extends battery life by modulating the RF power of each field device in relation to a specific peer. In this work, a power modulation scheme based on a proportional-integral (PI) controller is developed for transmission power control (TPC) in WH field devices.

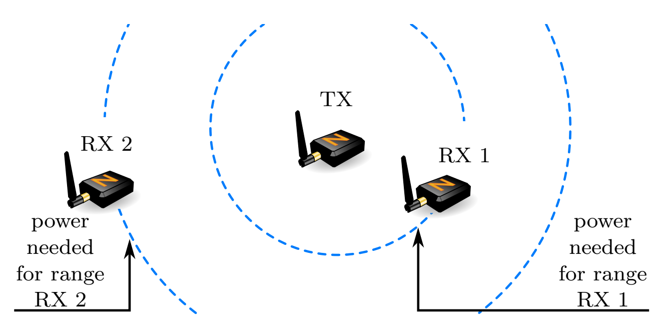

Fig. 1. RF power adjusted by comissioning in a WH network.

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This proposal improves a previous one, which presented a non-linear control system (Muller et al., 2014). The improvement is obtained by the constant power regulation, which was not achieved before. Previous experimental results showed up to 50 % of energy reduction, depending on the communication schedule. Also, the proposal does not change any aspect of the WH standard and therefore is fully compatible with standard commercial field devices.

The remaining of this work is organized as follows: Section 2 provides some context to this work through related works, Section 3 states the control problem, Section 4 presents the theory and the proposed controller, Section 5 describes the experiment used to validate the proposal, in Section 6 an analysis of the experiment outcomes is presented, finally in Section 7 the conclusions and future works are presented.

2. RELATED WORKS

Many works have been published that try to make WH networks more efficient using either data aggregation, packet routing, or link scheduling strategies. See for example (Zhang et al., 2014; Li et al., 2016; Neander et al., 2011), and for more energy saving strategies see (Rault et al., 2014). This proposal have the same goal (which is to save power), however it uses only the transmission power modulation to achieve its goal.

The RF power control has been subject of several researches in different areas. The main idea is to promote reduction of energy consumption while maintaining stable links. Also, power reduction cleans up the spectrum, which is very important in coexistence-based systems. A survey about TPC in wireless networks can be found in Olwal et al. (2010). The paper presents an extensive study about dynamic power control for mesh networks. A closed loop control for power reduction is presented in Dhamdhere et al. (2008) where the authors considered a bio-medical wireless sensor network (WSN) composed by movable sensor nodes. The impacts in received signal strength indication (RSSI), which varies along the time due to multipath and shadowing phenomena, are explored. An adaptive RF power control for WSN is presented in Lin et al. (2006). The proposed algorithm was tested in MicaZ motes in a real application subject to weather conditions. An RF power control was developed in Cascado et al. (2010) for IEEE 802.15.4 networks that employ beaconing. The authors tested the proposal and found up to 57.7 % of power reduction in a case study. In Son et al. (2004) the authors made an extensive experimental study, where the TPC impact in communication reliability was verified. They proposed a TPC algorithm based on packet error rate and included a blacklisting for unreliable links. In Jeong et al. (2007), the authors verified the effectiveness of an RF power reduction control over WSN. In their study they argued that WSN power control is useful when combined with radio cycling techniques which promote greater reduction in overall consumption. Another work about the issues of power control in WSN was presented in Fu et al. (2012). Control theory was applied to produce a practical power control which was tested in real environment.

All of the previous works are related to WSN and some of their techniques can be incorporated in a WH field device for RF power control. This can be used to improve WH field devices by changing RF power level, allowing reduction of power consumption and thus increasing battery life. This work is an improvement of a previous one (Muller et al., 2014), employing a proportional-integral controller which allows continuous power modulation, while keeping full compatibility with WH protocol by not transmitting power information directly.

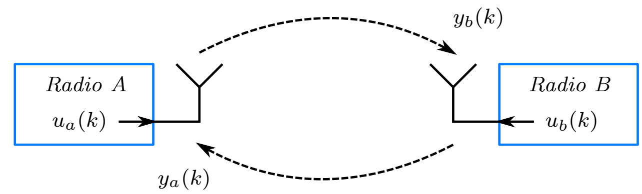

Fig. 2. The unknown LQI problem — each radio only knows the strength of the other radio's signal.

3. PROBLEM STATEMENT

In this work we assume there is a WH network where two radios A and B communicate with each other. We define $u_a(k)$ as the transmission power level of *radio A* and $u_b(k)$ as the transmission power level of *radio B* (both dimensionless), when sending packet k. This levels are configured in the radio firmware, and they are usually integers from 0 to $N-1$ where N is the number of power levels. Whenever a radio receives the packet k, it can measure the link quality indicator (LQI) which depends on the transmission power and the attenuation of the environment. Figure 2 shows a basic diagram of the communication, the LQI of a packet with index k received by *radio B* and converted to decibel-milliwatts is denoted $y_b(k)$, while it is denoted $y_a(k)$ if the packet is received by *radio A*, i. e. it is traveling in the opposite way.

We also assume that there are *desired* levels for the received strength of the signals, which are denoted $r_a(k)$ and $r_b(k)$, such that *radio A* expects to receive the packets with $y_a(k) = r_a(k)$ and *radio B* expects to receive the packets with $y_b(k) = r_b(k)$. The objective of the TPC is to automatically choose the transmission levels $u_a(k)$ and $u_b(k)$ to ensure that both radios receive the packets with the desired strength level.

The main challenge in choosing the transmission power level is that radio A only knows how strong it is receiving radio's B signal and vice-versa, as shown in Fig. 2. In other words, radio A only knows y_a but it only have direct control over y_b. The WH does not transmit the LQI information over the network, so in order to do that one should change the protocol. This work aims to develop a transmission power controller that keeps compatibility with the actual technology, therefore any such changes in the protocol are unwanted.

In order to better understand the problem, let us describe the system. Using a WH radio described in (Muller et al., 2010), a simple power consumption model is obtained through measurement. The employed transceivers have a transmission power table with 18 levels, but only the 13 lower levels are available for power adjustment because of