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Combined Reed-Solomon and Convolutional codes for IWSN based on IDWPT/DWPT Architecture

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Abstract

In contemporary industry, the wireless technologies trend is growing fast, because it will help to reduce cable cost, deployment time, flexibility, enabling wireless monitoring and control systems, and help to be more environment friendly, a huge research effort is done on wireless sensor networks (WSNs), however there are several issues facing the reliability of these wireless systems such that they can be used properly in harsh noisy or dynamic industrial environments, which led to outline the research direction for industrial wireless sensor networks (IWSNs). This article presents performances of a wavelet modulation and channel coding-based architecture of industrial wireless sensor network under an industrial channel. A model of the industrial channel is described, and performances of error correcting codes compared between multiple combinations of reed Solomon and convolutional codes for multiuser applications.

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Keywords: Industry 4.0, Industrial Wireless Sensor Networks (IWSNs), Discrete Wavelet Packet Transform (DWPT), Industrial Noise, reed Solomon, convolutional codes;

1. Introduction

In this new era, industries have to adapt to the new challenges and reach a sustainable, efficient and smart environment, many researches led to WSN in the early 2000 that was a breakthrough in the world of wireless

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communication with their practicality, low-power and low-cost nodes compared to the wired networks without losing their quality of service [1]. Therefore and since the fourth industrial revolution that was introduced in Germany, WSNs were a major component toward achieving industry 4.0 vision, since then many studies shifted their attention to develop industrial wireless sensor networks IWSN, which are an emerging category of WSN that presents great benefits to industrial organizations such as efficiency, productivity and safety but faced several challenges such as reliability and robustness in severe industrial medium [2]. The harsh industrial environments come with difficult constraints to face such as time delay due to reflection, diffraction and scattering effects, noise coming from electrical fields and the Bit Error Rate BER is relatively high. These drawbacks result in destructive effects on the wireless data transmission performance. This problem can be solved by error control techniques. During digital data transmission and storage operations, the performance criterion is determined by BER and SNR. The less the BER, higher is the SNR and better the performance [3]. With the great interest growing in object connectivity in the industrial environment, it became necessary to propose a communication architecture, based on functional and reliable wireless sensor networks, inside harsh environment. These networks are under the constraints of autonomy, low energy consumption, and ability to process multiple data from different sources, with a low latency in real time [4]. In this paper, we are interested in comparing performances of ECC applied to a multi-user communication system based on wavelet modulation, under two channels, a gaussian noise channel AWGN and an industrial channel, two modes will be used, the first one is a one to many OtM with a communication between one transceiver and two receivers, the second one is many to one MtO mode with a communication between two transceivers and one receiver.

The rest of the paper is organized as follows. Section 2 discusses the importance of IWSN and IIoT in the industry 4.0. Section 3 introduces error correcting codes used in our comparison. Section 4 presents our wavelet modulation-based architecture, along with the industrial channel used in the simulations. Section 5 we discuss the results of the compared performances. Finally, Section 6 concludes this paper.

2. From IWSN to IIoT

Industry is the basis of a nation economy, that produces goods or services. Ever since the beginning of industrialization, technological leaps led to the industrial revolutions. First, mechanical looms driven by steam engines in the 1780s. The second revolution, based on both division of labor and the introduction of conveyor belts, resulted in another productivity explosion of the intensive use of electrical energy. Third, in 1969, Modicon presented the first programmable logic controller that enabled digital programming of automation systems [9-10]. And for the fourth one, Germany is leading the transition toward 4th Generation Industrial Revolution called by Industry 4.0, founded on service innovation and computed manufacturing. With the rise of embedded intelligence and software integrated in industrial products and systems, predictive technologies can further convolute intelligent algorithms with electronics and independent intelligence. All this will then be used to predict product performance degradation, and individually optimize and manage product service needs [6]. On the basis of an advance digitalization within factories, the combination of Internet technologies and future-oriented technologies in the field of “smart” objects (machines and products) seems to result in a new fundamental paradigm shift in industrial production. The future vision concept of manufacturing contains an efficient production systems and scenarios in which products can be able to control their own manufacturing process [5]. In this aspect, wireless sensor networks (WSN) have been gradually entering the industry field, and are becoming one of the vital foundations for realizing the architecture of Industry 4.0 and smart factories [7].

The introduction of the industry 4.0 led to the concept of smart factories that uses wireless communication rather than wired network. Devices can be easily connected without any restricting cables. For this purpose, the use of industrial wireless sensor networks (IWSNs) that are an alternative for WSNs in the industrial environment, will undoubtedly change the industrial automation technology [8], it have inherited many features from WSNs, especially industrial applications and communication protocols[9], IWSNs use replaceable batteries and generally have wider range than WSNs. Sensors in IWSNs are autonomous and monitor environmental and physical

conditions applicable in several domains, including industrial automation and control industrial equipment, but with that comes more complications and constraints such as latency, energy consumption, Mobility and the operating Environments [10]. As an emerging technology brought about rapid advances in modern wireless telecommunication, Internet of Things (IoT) has attracted a lot of attention and is expected to bring benefits to numerous application areas including IWSN systems, [12]. To accomplish the vision of the industry 4.0, the usage of IOT and IIOT applications, it applies analytical models and data science to analyze real-time data from multiple machines, systems and processes, and to advance production, transportation, distribution, maintenance and service in the manufacturing process [13]. The rise in IOT usage in manufacturing systems has attracted researchers to explore the possible benefits of adopting it.

3. Error Correcting Codes

IWSN applications need the delivery of high priority events in a faster and reliable manner without any loss of information on the path from sensor nodes to the receiver, therefore, the usage of error correction codes ECC is a prime solution for effective communications, it introduces redundancy into an information sequence by the addition of extra parity bits based on various combinations of bits to enable the receiver to detect and correct errors[11]. The system with ECC provides better bit error rate BER performance as compared to an un-coded data for the same signal to noise radio SNR [14]. Several ECC have been investigated for WSNs, including low density parity check LDPC codes, BCH codes, Turbo codes, Reed Solomon RS codes and convolutional codes CC [15]. The last two codes have been proven suitable and energy efficient for WSN with reasonable and simple coding and decoding complexity [16].

4. Architecture Based on WT

4.1. Our Architecture

Our architecture is based on wavelet packet transformation, For a multi-user mode, it should be noted that all emitters are based on the IDWPT, implemented as a synthesis filter banks, and the receiver is based on the DWPT, implemented as an analysis filter bank [4], The input of each filter to the transmission side, contains either a bit or a binary frame, coded using ECC, so that the inputs can be activated or not. These binary data might differ from one input to another and is modulated by pulse modulations. In our work, two modes were used for the simulation:

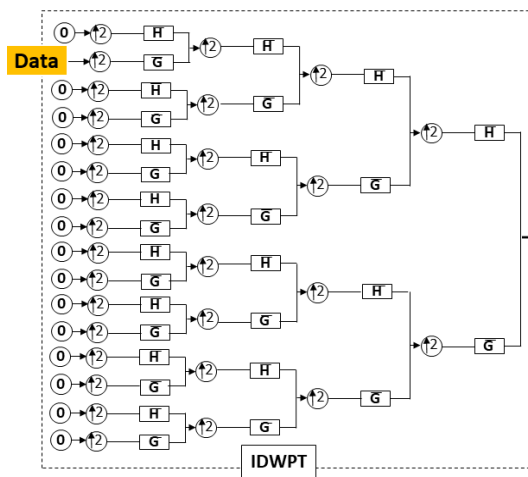


Fig. 1. One to Many mode

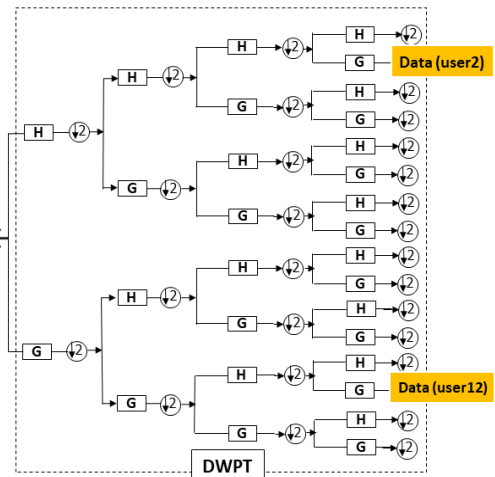


Fig. 2. Many to One mode

- One to Many OtM: This mode of communication corresponds to a Master-Slave communication in conventional industrial communication systems, the information sent in the input ‘j’ is retrieved in the output ‘i’. the Fig. 1 shows the architecture used in the simulation, where the data is coded using ECC, and activating

the input i , the data then is sent in a wireless channel using industrial noise to receive it in two DWPT receivers, then the initial data is retrieved after being decoded.

- Many to One MtO: this mode corresponds to a multi-user transmission from several users to a single receiver. As shown in Fig. 2, it uses the same operation as the OtM, where each transmitter send data after being coded using ECC and activating an input in the IDWPT block, every user uses a proper input so that it can be retrieved in the same output in the DWPT block.

4.2. Propagation Channel

The biggest challenge that faces the wireless technologies for industrial applications is the harsh environment, that leads to performance degradation, due to diverse electric machinery, multi-path propagation increased by the numerous metallic elements as well as with the displacement of workers, transportation equipment and repair work that may also cause time varying effects and so on. That's why a good estimation of the channel is required to design and evaluate reliable WSNs for industrial applications.

Usually the noise affecting a given wireless communication system is modeled as additive white Gaussian noise (AWGN). However, in harsh industrial environments, wireless communication systems are also subject to impulsive noise coming from motors, heavy machineries, inverters, voltage regulators and electrical equipment. The noise in industrial environment might then be modeled as the superposition of two terms, AWGN and impulse noise, expressed as $n(t) = w(t) + i(t)$, with $t \in \{1, 2, \dots, T\}$, Where $w(t)$ and $i(t)$ are Zero-mean Gaussian distributed processes with variance σ^2 .

4.3. Interleaving

The performance of ECCs systems used under harsh industrial environments in the presence of burst errors is improved by passing the transmitted data through an interleaver. To disseminate burst errors across a larger range, the interleaving process is inserted between two codes, it is a methodology that makes a communication system more efficient, faster and reliable by arranging data in a noncontiguous manner. it is a technique regularly used in communication systems to surmount correlated channel noises such as fading or burst errors. The interleaver code reorganize input data such that adjacent data are spaced apart. At the receiver end, the interleaved data is organized by the deinterleaver back into the original sequence. As a result, correlated noise in the transmission channel turns out to be statistically autonomous at the receiver and thus allows better performance at error correction.

5. Discussion

Figure 1 show the diagram of our communication system, a combination of two EECs where tested in the channel encoding/decoding discussed in section 3 using reed Solomon RS(31,17) and convolutional codes CC with rate of 1/2, the transceiver is based on IDWPT, and the receiver on DWPT, two modes where exploited in the simulations, the first one is OtM where one transceiver sends data activating one user to two receivers, the second one is MtO where two transmitters send data activation two different users and receiving it in one receiver, all under two channels, AWGN and industrial noisy channel :

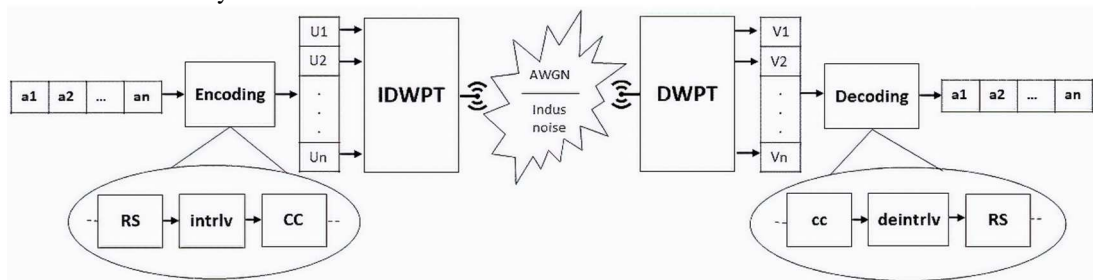


Fig. 3. Communication architecture

The results of the simulation are presented in this section, using the architecture presented previously, under two modes, OtM using one input and two receivers, and MtO using four inputs and one receiver, all the simulations were executed under MATLAB, the system model is based on IDWPT/DWPT, the transmission was done under two channels, AWGN and industrial channel. The wavelet used in the simulation is the "Symlet" wavelet, this choice is based on a study on the optimal choice of wavelet, published in [4], which has demonstrated the lowest BER for the IDWPT/DWPT architecture, the data frames for each user were binary, with a length of 16 bits, generated randomly, since sensors in the industrial environments transmit short packets of data. These data frames were modulated according to the same pulse modulation and each user was identified by a unique signal, we compared in this work two ECC, reed Solomon RS(31,17), with 31 symbols of codeword and 17 message symbols based on the length of data transmitted, and convolutional codes with a rate of 1/2, the choice of this rate is based on a study done in [4].

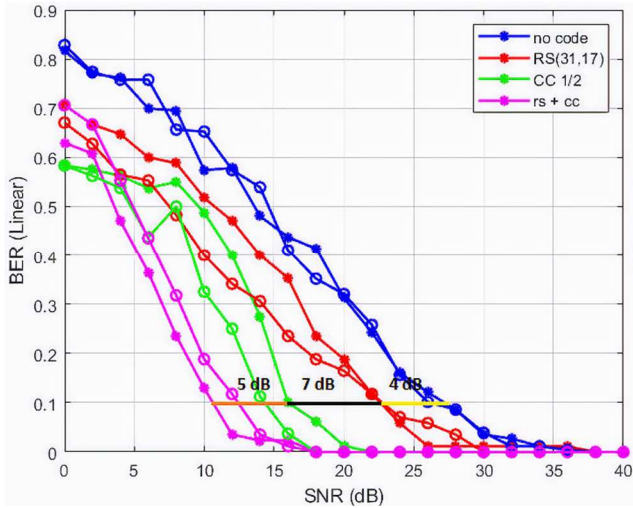


Fig. 4. BER over industrial channel for OtM mode

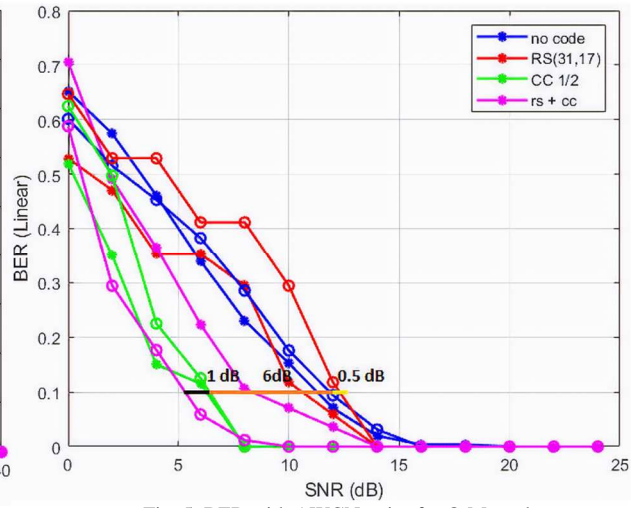


Fig. 5. BER with AWGN noise for OtM mode

Fig. 4. and Fig. 5. provide the performance of the combination of RS and CC in OtM with one transceiver and two receivers mode under industrial channel and AWGN noise, Fig. 6. and Fig. 7. Provide the performance of the same codes in MtO mode with four transceivers and one receiver, Table 1 summarize results of BER of 10^{-1} to E_b/N_0 :

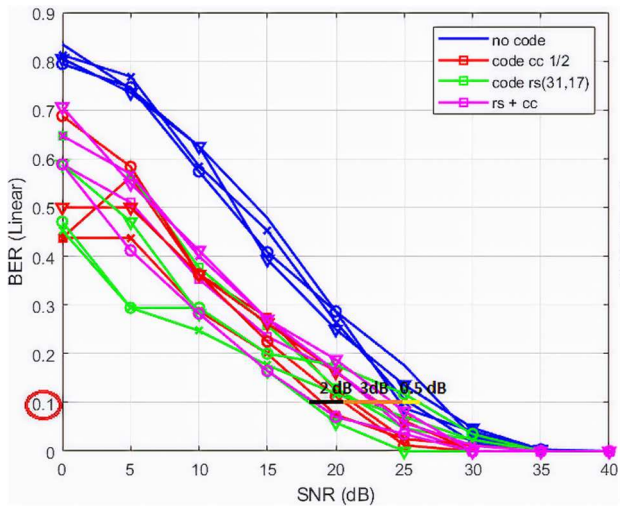


Fig. 6. BER over industrial channel for MtO mode

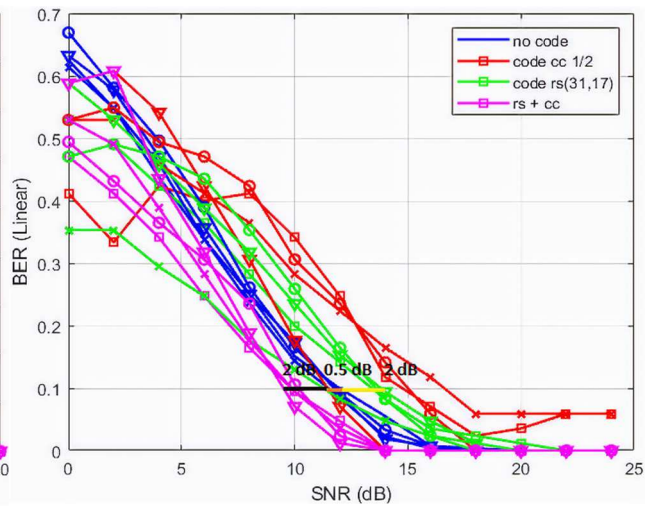


Fig. 7. BER with AWGN noise for MtO mode

We can see in table 1. That the combination of RS/CC codes gives better results than RS and CC codes alone, with

1 dB with AWGN noise, and 5 dB under industrial channel compared to CC, while in the case of MtO mode, the combined codes were better with 2.5 dB under AWGN and 2 dB under the industrial noise.

Table 1. performance results of comparing BER at 10^{-1}

Mode	OtM				MtO			
	No code	CC 1/2	RS(31,17)	RS + CC	No code	CC 1/2	RS(31,17)	RS + CC
AWGN	13 dB	6 dB	11 dB	5 dB	12 dB	14 dB	14 dB	9,5 dB
Industrial channel	26 dB	16 dB	23 dB	11 dB	25 dB	21 dB	26 dB	18.5 dB

6. Conclusion

We compared in this paper the performances of RS, CC and a combination of the two ECCs with interleaving under two channels, an industrial noisy channel and a channel with AWGN noise, we can see in Table 1 that the combination of RS and CC perform better in the two modes in term of BER, with AWGN noise, and under industrial noise channel, knowing that RS codes are well suited for detecting and correcting burst data errors and CC codes are effective in random error, we will observe in future works the performance of concatenated RS(255,230) and CC with a rate of $\frac{1}{2}$ used with interleaving, with the all communication modes, OtM, MtO, and Many to Many MtM, under industrial noise and fading.

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