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DWPT vs OFDM Under a Noisy Industrial Channel

Safa Saadaoui[a], Mohamed Tabaa[a, *], Khadija Bousmar[a], Fabrice Monteiro[b], Abbas Dandache[b]
[a]*LPRI, EMSI Casablanca, Morocco*
[b]*LGIPM, Lorraine University, Metz, France*

Abstract

In the industrial world, a trend towards connected, robotic and intelligent factories is in constant development to face competition from countries with low production costs. The industrial revolution 'Industry 4.0' is considerably reducing the boundaries between the physical and digital worlds. This has given rise to interconnected factories in which people, machines and products interact with each other using smart sensors. Commonly referred to as Industrial Internet of Thing (IIoT). Except that, it requires adapted communication systems for the industrial environment. Such a propagation environment is known by its complexity that should be considered in order to propose a robust and reliable communicating system. In this paper, a performance evaluation between a pulse-modulated Discrete Wavelet Packet Transform (DWPT) system and an Orthogonal Frequency Division Multiplexing (OFDM) multicarrier modulation system over a noisy industrial channel will be presented. Thus allowing not only to provide an alternative to conventional high-rate industrial wireless communication systems but also to know the limits of both techniques.

Keywords: *IIoT, Industry 4.0, DWPT/IDWPT, OFDM, Industrial Channel*

1. Introduction

The permanent technological evolutions of wireless communication systems have occurred in recent decades, allowing the emergence of growing user needs in terms of accessibility, data throughput, data quantity and energy consumption. These technologies are in permanent innovation in order to improve user connectivity but also to connect billions of objects between them. These connected objects are characterized by autonomous physical/digital elements, capable of communicating with each other in order to provide reliable information that impacts decision making. This development has brought ambitious innovations in several fields such as health, transport, smart cities, energy and industry. The evolution in the industrial field is marked by the industrial revolution called "Industry 4.0" [1]. This revolution gives the opportunity to create smarter factories and particularly to have interactions that aim at flawless production with real-time traceability of products at the various stages of production [2].

The industrial IoT is the technological foundation of the Intelligent Factory allowing real-time exchanges within a factory or company to facilitate coordination and collaboration between the various operators. Its deployment will ensure gains in productivity and operational efficiency for the industry. In addition, it offers the possibility to adapt the available skills in real time to cope with rapid changes or unforeseen events. There are many wireless connectivity technologies for things. The choice of connectivity strategy is made according to several criteria and is based on the choice of the sensor [3,4]. Much research has focused on the development and optimization of wireless sensor networks that are deployed in various fields of application. The design of these networks differs for each application, taking into consideration the constraints of the propagation environment. The main objective of this paper is to compare the performance of a communication architecture based on Inverse Discrete Wavelet Packet Transform IDWPT and DWPT with OFDM system under a noisy industrial channel. For simulations, we used a subdivision of the channel into 16 and 32 sub-channels. Wavelet-based pulse modulation for the frame composition of the IDWPT/DWPT architecture and several digital modulations (BPSK, QPSK and QAM16) for OFDM. The simulations showed that the IDWPT/DWPT architecture has certain advantages under industrial channel and the composition of this architecture does not require channel access management unlike OFDM.

This paper will be presented as follows: the second section will present a review of Industry 4.0. Then, a quick comparison between DWPT and OFDM systems will be given. In section 4, the IDWPT/DWPT architecture will be explained. The communication system model with propagation channel will be presented in section 5. Followed by section 6, where simulation results and discussions will be given. In section 7 will finish by a conclusion and perspectives.

2. Industry 4.0

Industry 4.0 is characterized by a new way of organizing the company to put an end to complex hierarchical structures. Therefore, information and communication techniques must be merged with industrial technologies. In Industry 4.0, embedded systems, IoT and CPS (Cyber Physical Systems) technologies link virtual space to the physical world to create a new connected generation known as "intelligent" factories. These factories are able of more efficient allocation of production resources, with the main objectives of customizing products, minimizing time to market and improving business performance. This opens the

* Corresponding author. Tel.: +212661943174
E-mail: tabaa.mohamed@emsi-edu.ma

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way to a new mode of industrial transformation. The concept of Industry 4.0 was first introduced at the Hanover Industrial Technology Fair in 2011, the world's largest technology and industrial trade fair. In 2013, the German government's adopts officially the concept of identification of Industry 4.0 in its future projects within its action plan "High-Tech Strategy 2020". It has rapidly evolved as a German national strategy based on 4 aspects: Building the CPS network, addressing two main themes based on the plant and intelligent production, thus achieving 3 types of integration: Horizontal, vertical and point-to-point. The result is that German industry has welcomed the initiative with open arms [5]. Small, medium and large companies from all sectors participated in the creation of this new area. However, the boost from the government has helped to internationalize the concept of Industry 4.0 [6] (Fig.1.).

Although the Internet of Things holds great promise and new opportunities, challenges may prevent the adoption and integration of new wireless technology:

- Connectivity.
- The noisy nature of the industrial environment.
- Interoperability.
- Regulatory constraints.
- Security and confidentiality.

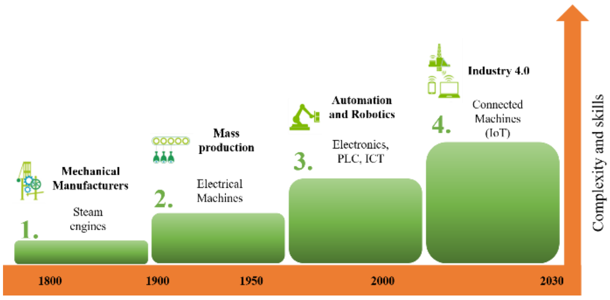

Fig. 1. Industry evolution

3. DWPT compared to OFDM

Wireless sensor networks operate mostly in Wide and Ultra-Wide band. Their effectiveness is conditioned by the performance of the physical layer, which is essentially based on the search for the best compromise between transmission quality and energy consumption. For broadband applications, multi-carrier modulation techniques are the most widely adopted by wireless communication standards (802.11a, 802.11g 'WiFi', and 802.16 'WiMax'). OFDM (Orthogonal Frequency Division Modulation) modulation is a multi-carrier modulation technique that consists of distributing the signal over a large number of individually modulated orthogonal sub-carriers at low bit rates. This allows to reach a spectral efficiency very close to the optimum, but also provides an excellent resistance to frequency fading of the channel [7].

However, the major disadvantage of this technique is that the OFDM receiver requires precise synchronization of the frequency at reception and at the transmission [8,9]. Any offset between the two frequencies results in the loss of orthogonality of the sub-carriers, thus creating interference between them. This synchronization problem arises particularly when the sensors are mobile with different speeds. In this work, the sensors are stationary or with low mobility so that synchronization is not a particular constraint. Hence the choice to compare our impulse architecture to a system with a multi-carrier modulation.

OFDM modulation is based on the discrete Fourier transform (DFT). It uses a cyclic prefix CP that is a guard time added to cancel symbol interference caused by multiple paths during wireless propagation. However, the addition of this CP increases the bandwidth occupied by OFDM symbols. In addition, this technique uses sinusoidal carriers with large lobes in frequency range that generally cause high sensitivity to narrowband interference [8]. Hence the interest for the discrete pulse-modulated wavelet packet transform which have a low lobe wavelet carrier. This multi-band modulation technique also offers better synchronization between transmission and reception, and not using a cyclic prefix does not change the bandwidth occupied by the signals.

OFDM, is a multi-carrier modulation based on the discrete Fourier transform that uses the complex exponential series as basic modulation functions. These functions are limited in the time domain by the use of sinusoidal carriers while wavelet packet modulation uses wavelet packets as multi-carrier modulation functions. These wavelet packets are obtained by using Discrete Wavelet Packet Transform (DWPT), which is designed by digital filtering techniques [11]. The input signal is decomposed into a filter bank by a low-pass filter and a high-pass filter. Therefore, outputs of the low-pass filter and the high-pass filter are then sampled by two to give approximation and detail coefficients respectively.

4. IDWPT/DWPT architecture

The concept of IDWPT/DWPT is based on multi-resolution analysis, which consists in breaking down an approximation space into two or more resolution spaces. This decomposition is done in such a way as to transform the resolution space into two orthogonal basis obtained by projecting the approximation and detail spaces [12]. This subsequently simplifies the management of the samples provided at the input of the filter banks, as well as their synchronization in a symmetrical structure [13,14].

Wavelet packet decomposition is performed by a tree structure and provides a uniform spectral analysis that consists of decomposing the signal into sub-bands of identical width. As a result, the synthesis step is to specify the type of data for each sub-band. The *h* and *g* digital filters are related by the following equation:

$$g_n = (-1)^n h(1-n) \quad (1)$$

The impulse response coefficients of the filters satisfies the following conditions:

$$\sum_{n=-\infty}^{+\infty} h_{n-2k} h_{n-2l} = \delta_{kl}, \; and \; \sum_{n=-\infty}^{+\infty} h_n = \sqrt{2}$$
$$\sum_{n=-\infty}^{+\infty} g_{n-2k} g_{n-2l} = \delta_{kl}, \; and \; \sum_{n=-\infty}^{+\infty} g_n = 0 \quad (2)$$

The synthesis filters for signal reconstitution are the conjugates of the filters used in the decomposition of the signals $\bar{h}$ et $\bar{g}$. Wavelet packet decomposition depends on its depth, which illustrates the scale of analysis. Example, for a decomposition at depth 4, the input signal will be decomposed according to $2^3 = 8$ output signals as shown in Fig. 2.

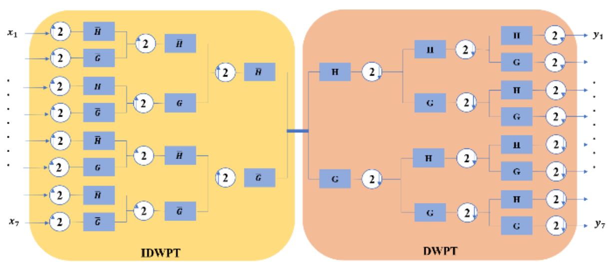

Fig. 2. Decomposition and synthesis level 3

In other words, for our multi-carrier modulation, the number of sub-carriers will depend on the scale of analysis. The communication architecture proposed in this article is based on wavelet packet transformation for industrial wireless sensor networks. It uses an inverse discreet wavelet packet transform IDWPT to transmit signals and a direct transform DWPT in reception as shown in Fig. 2.

It can be deployed in single or multi-users communication without using multiple access techniques but only by enabling and disabling filter bank inputs. Regardless of how the architecture is operating, the analysis scale provides information on the number of possible inputs and users. The activation or not of one or more inputs generates a waveform, orthogonal to all the others from the different inputs.

5. Communication System Model

DWPT system model is illustrated in Fig. 3. Signals at the output of the serial to parallel (S/P) block will be a power of 2 and will indicate the depth of the analysis scale of the IDWPT block. The propagation medium is an industrial channel modelled as a multi-path fading channel in addition to an impulsive noise combined to a Gaussian white noise [15]. This channel model, was already presented and well explained in our previous work at [16].

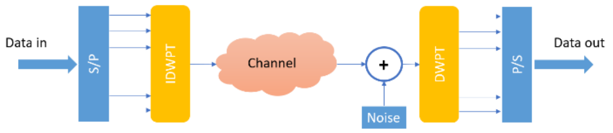

Fig. 3. Communication system model

This system will be compared to an OFDM system using several digital modulations. The main advantage of our architecture is the fact that it can be deployed in a multi-carrier configuration without using a multiple access technique. The use of wavelet packet decomposition separates the spectrum and thus the frequency bands for each user. Unlike OFDM system, where all multi-carriers share the same frequency band. On the other hand, an OFDM system cannot be used in multi-user communication without using a multiple access technique, such as OFDMA.

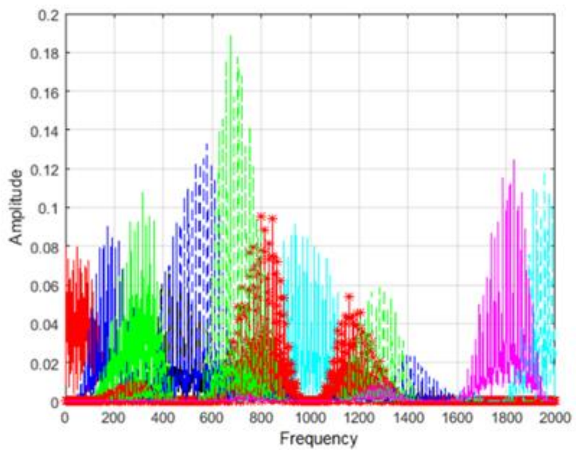

Fig. 4. Frequency bands for several different users

To illustrate the separation of bands, Fig. 4 shows the different frequency bands for an architecture at a depth of 4 with 16 inputs (16 users). Each user is identified by a different color.

As explained in [13], the simulated discrete industrial noise $b[n]$ is modeled as a superposition of a Gaussian noise $w[n]$ and impulsive noise $i[n]$ with a high variance value:

$$b[n] = w[n] + i[n] \tag{3}$$

Where $w[n]$ and $i[n]$ are Gaussian processes of zero mean whose probability density functions are respectively:

$$P(w[n]) = \frac{1}{\sqrt{2\pi\sigma^2}} exp\left(-\frac{w[n]^2}{2\sigma^2}\right) \tag{4}$$

$$P(i[n]) = \frac{1}{\sqrt{2\pi R\sigma^2}} exp\left(-\frac{i[n]^2}{2R\sigma^2}\right) \tag{5}$$

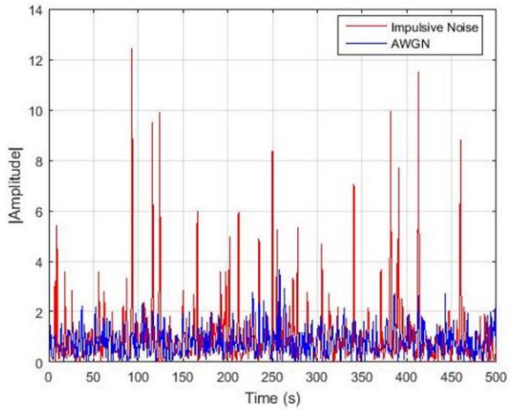

Fig. 5. Illustration of AWGN and Impulsive noise

With $R \geq 1$ is a scaling constant of impulsive noise amplitude. The most this constant value is higher the most the noise is significant. For simulations, $R = 50$ which corresponds to a high impulsive noise (Fig.5.).

6. Simulations

In this section, simulation results are presented to evaluate performances between DWPT and OFDM systems in terms of Bit Error Rate (BER) versus Signal to Noise Ratio (SNR) in a multipath industrial wireless channel. The DWPT architecture uses a pulse modulation with Symlet wavelet. The choice of Symlet wavelet was based on previous work which has shown that it is the optimum choice for IDWPT/DWPT architecture [17]. Analysis scale for DWPT architecture is used with a depth of 4 and 5 which allows respectively 16 and 32 input signals to the filter bank, so 16 and 32 different sub-channels.

Three digital modulations are used to test OFDM System; BPSK (Binary Phase Shift Keying), QPSK (Quadrature Phase Shift Keying) and QAM-16 (Quadrature Amplitude Mudulation), Matlab Software is used as a simulation tool (Table 1).

Table 1. Simulation parameters

	OFDM	DWPT
Modulation	1BPSK, QPSK, QAM16	Pulse modulation
N° Sub Channels	16, 32	16, 32
Wavelet	-	Symlet
FFT point	128	-
CP prefix	20% of the period	-

Simulation results presented in Fig. 6 compare BER of OFDM system with a DWPT system over a fading channel with additive white Gaussian noise (AWGN Channel) for 16 users or sub-channels. In Fig.7 and 8, BER comparison for both DWPT and OFDM systems over a fading industrial channel with 16 and 32 sub-channels respectively are illustrated. The results clearly demonstrate for 16 users the robustness of DWPT system over both AWGN and industrial channel compared to OFDM system. For more details, with 16 users, DWPT architecture achieves results of lower BER than those of an OFDM system for BPSK, QPSK and QAM-16 digital modulations. However, for 32-users configuration over an industrial channel, the BER of the OFDM system with BPSK and QPSK is lower than what we had for DWPT architecture for SNR less than 25dB. But DWPT system is taking over and getting better than OFDM with QAM modulation.

When industrial noise is considered, the OFDM system fails to operate properly as illustrated in Fig. 7 in case of 16 users. Here, our architecture demonstrates its robustness to industrial noise even without using an optimal receiver to reduce noise neither an equalization technique to counter multi-paths effects. However, for a number of users of 32, our architecture is better for OFDM using QAM modulation, but for low SNR values, OFDM using BPSK and QPSK modulations is better. It is clear that for a wireless sensor network requiring a number of sensors less than 32 in a harsh industrial environment, our DWPT system is better to make communication more reliable than conventional OFDM-based systems.

A comparison of the BER at SNR of 24dB over an AWGN channel and a fading channel with industrial noise is presented in Table 2.

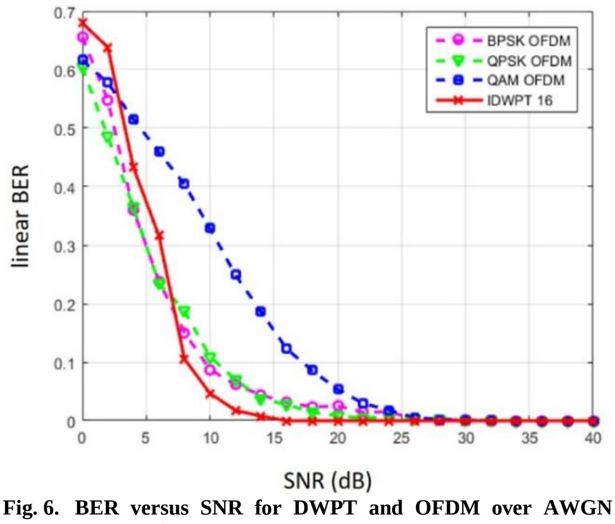

Fig. 6. BER versus SNR for DWPT and OFDM over AWGN Channel for 16 users

Table 2. BER for 16 and 32 users at SNR = 24dB

	IDWPT/ DWPT	OFDM- BPSK	OFDM- QPSK	OFDM - QAM16
Industrial fading channel for 16 users	0.15	0.36	0.36	0.66
Industrial fading channel for 32 users	0.3	0.18	0.2	0.7

5. Conclusion

In this paper, we have evaluate BER performance using two communication systems; DWPT and OFDM under industrial channel with white noise and industrial noise. The comparison of our architecture with a multi-carrier OFDM modulated system showed a better robustness of our architecture in a noisy industrial environment than the OFDM system with three different modulations in case of 16 sub-channels. Also, our model is better than OFDM using QAM modulation in the case of 32 sub-channels. Systems based on conventional multi-carrier modulations are less suitable for communications in difficult environments for a network requiring a number of sensors less than 32. As a perspective, it is useful to investigate the contribution of using an optimal receiver based on thresholding to reduce the effect of industrial noise before demodulation. Also, we can add a channel encoder and decoder to enhance the robustness of the architecture against errors introduced by the channel.

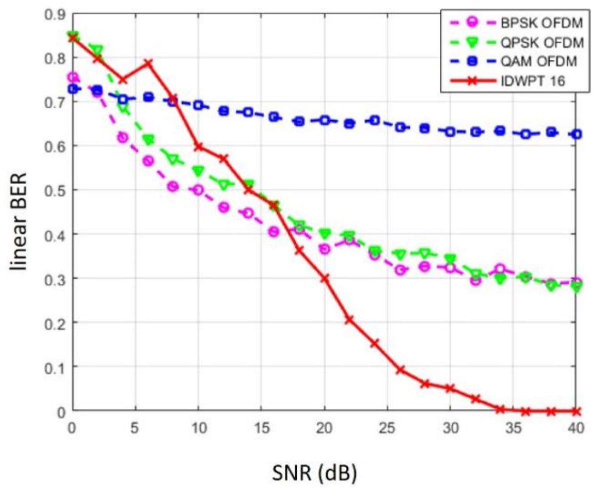

Fig. 7. BER versus SNR for DWPT and OFDM over fading industrial channel for 16 users

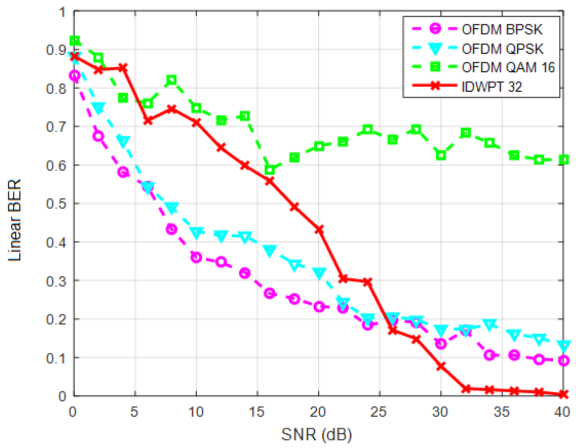

Fig. 8. BER versus SNR for DWPT and OFDM over fading industrial channel for 32 users

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