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A New Multi-user Ultra Wide Band System Based on Modified Gegenbauer Functions and M-OAM Modulation for Communication of Intelligent Transportation Systems

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Abstract Ultra-wideband technology is based on the transmission of very short pulses with relatively low energy, which make it a promising option for short range wireless communication system. In this paper, we propose to use this technology to establish a new multiuser technique dedicated to intelligent transport systems, especially vehicle-to-vehicle and vehicle-to-infrastructure communications. Indeed, the design of such system must provide good quality of service for a large number of users simultaneously and with high data rate. The proposed system is based on the use of a new modulation schemes named orthogonal amplitude modulation to reach high data rate; and an original multiple access technique that allows a maximum number of users simultaneously with good performances.

Keywords IR-UWB · M-OAM · MGF · Multi-user · Wireless Communication

1 Introduction

There has been increasing interest in the issue of road safety, comfort and traffic efficiency in intelligent transportation systems recently. These transportation systems (ITS) integrate advanced electronics, communications, sensing and information technologies to improve the services required on the road network.

However, the deployment of these multiple services requires data exchange between vehicles (V2V) or with infrastructure (V2I). For this, the multiple access and the high data rate are two strategic conditions in this new class of networks. Our project provides a very high data rate system with high number of users simultaneously, applied on UWB technology.

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The ultra wide band is an important topic in wireless communications. In the near future, this technology may see increased use for high-speed short range wireless communications, ranging and ad hoc networking. There are two competing technologies for the UWB, namely: impulse radio (IR) and multi-band UWB (MB). In our work, we propose the first category (IR-UWB), which is a carrier-less transmission. This technology has a low transmit power and a fine time resolution because of narrowness of the transmitted pulses. Thus, UWB systems have many potential advantages such as low power, short-range high data rate communication, robustness against fading, immunity to multipath and multiple access capability [1]. By consequence, the major properties of UWB motivate several potential applications for this technology.

The proposed system is designed for intelligent transportation systems, especially for inter-vehicular communication and vehicle to infrastructure communication. Thus, designing such system requires the understanding of mechanisms, which allow us to have high transmission data rate and high level of security and quality of service (QoS).

Indeed, the challenge to overcome the design of such communication system is to provide good quality of service to a wide number of users simultaneously and with high data rate.

Therefore, this paper proposes the use of original modulation schemes called orthogonal amplitude modulation (M-OAM) in order to improve data rate. This proposal is based on the use of modified Gegenbauer function (MGF), derived from orthogonal polynomials. Indeed, the principle of the M-OAM modulation is to replace the carriers used in quadrature amplitude modulation (QAM) with orthogonal waveforms. Therefore, the cosinus of the QAM modulation may be replaced by an order of Gegenbauer polynomials and sinus may be replaced by a second order. This proposed modulation can offer a very high data rate with low complexity and a high robustness against the propagation channel effects [2–4].

Concerning the multiple access issue, literature presents several techniques such as direct sequence ultra wide band (DS-UWB) and time-hopping ultra wide band (TH-UWB) techniques. It should be noted that other previous studies [5–7] used the orthogonality of MGF waveforms to achieve the multiple access but with conventional UWB modulation. These functions allow us to replace the pseudo-random code used in code division multiple accesses (CDMA) and offer good performances in terms of bit error rate (BER). In our case, we use the new modulation schemes M-OAM, with new multiple access technique to construct an original UWB system for intelligent transportation with very high data rate, a maximum number of users and good performances.

This paper is organized as follows. Section 2 describes the existing multi-user system presented in the literature. Then, Sect. 3 details the M-OAM modulations and the application of this new modulation scheme in the classical multi-user UWB systems in order to increase data rate. Section 4 presents the proposed communication system based on the new multiple access technique. It gives also the computation of the simulation parameters and results under the Gaussian approximation, considering the bit error rate and the signal to interference noise ratio to evaluate the quality of the link. The experimental test of the proposed systems in real conditions will be analyzed and discussed in Sect. 5. Section 6 summarizes the results and presents future works.

2 Existing Multi-user Systems

Several techniques of multiple access, in UWB context, can be found in the literature such as DS-CDMA, DS-UWB, TH-UWB [5,8] and MGF–UWB [9]. In this section, the principle of each technique will be explained.

2.1 TH-UWB

In the time-hopping (TH-UWB) technique, the pulse is much shorter than the duration of a symbol T_s. Thus, it is possible during the time interval of duration T_s to repeat several times this impulse. This creates a pattern of separation of users based on the technique of time-hopping. In this technique, the position of each impulse is determinated by a pseudo random (PR) code. Besides, different users distinguished by their unique TH code can transmit at the same time. These codes should be chosen to minimize interferences between users [8].

A symbol of a TH-UWB signal is composed of N_f frames of duration T_f. Each frame is divided into N_c chips of duration T_c and thus includes one and only one pulse associated with the information symbol [10–12].

The transmitted signal $s(t)$ for a train of binary information for the user k, is given by the following expression, in PPM modulation case:

$$S^{(k)} = \sqrt{P_k} \sum_{i=-\infty}^{+\infty} \sum_{l=0}^{N_f-1} w(t - iN_fT_f - lT_f - c_l^{(k)}T_c - d_i^{(k)}\delta) \tag{1}$$

with $w(t)$ the transmitted monocycle waveform, P_k the transmitted power, d_i^k the ith bit transmitted by user k, δ time shift of PPM modulation, T_f the duration of a frame, N_f the number of frames, T_c the duration of a chip, N_c the number of chips, $c_l^{(k)}$ the TH code associated to user k, with integer values in $\{0, N_c - 1\}$.

2.2 DS-UWB

The direct sequence ultra wide band technique (DS-UWB) appears rugged in the multiple access interference and multipath effects of the channel. In this case, the pulse waveform takes the role of the chip in a spread spectrum system. Each user is distinguished by its specific pseudo random sequence which performs pseudo random inversions of the UWB pulse train. All the pulses are transmitted at the beginning of the frame. The spreading sequence is used to polarize the pulse [13,14].

The shape of the transmitted signal is given by the following expression:

$$S^{(k)}(t) = \sqrt{P_k} \sum_{i=-\infty}^{+\infty} \sum_{n=1}^{N_c} d_i^{(k)} c_n^{(k)} w(t - iT_f - nT_c) \tag{2}$$

with d_i^k the modulated data symbols for the kth user, c_n^k the spreading chips. $N_c = T_f/T_c$ the spread spectrum processing gain.

2.3 MGF–UWB

Modified Gegenbauer function model is used to perform UWB waveforms, which are very useful for communication due to their orthogonality. This technique exploits the orthogonality of MGF waveforms to reach multiple access. Thus, each user is characterized by a specific order of MGF. In the next section, we explain the principle of these waveforms.

2.3.1 Modified Gegenbauer Function

Gegenbauer polynomial are orthogonal in the interval $[-1, 1]$ with a weight function $\omega(x) = [(1-x^2)]^{(\beta-1/2)}$, where $\beta > 1/2$ is a shape parameter and n is the degree of the polynomial.

They satisfy the differential equation of second order defined as follows:

$$(1-x^2)G(n,\beta,x)-(2\beta+2)xG_n(x)-n(n+2\beta+2)G_n(x)=0 \tag{3}$$

with $\beta > 1$.

In order to use them in an UWB communication system, these pulses must be directly orthogonal. By consequence, the polynomials are multiplied by the square root of the weight function $w(x)$. The modified Gegenbauer functions are thus given by:

$$G_u(n,\beta,x)=\sqrt{w(x,\beta)}*G(n,\beta,x) \tag{4}$$

The first orders of the MGF pulses are given as follows:

$$\begin{aligned}
G_0 &= G_u(0,1,x) = 1*(1-x^2)^{1/4}\\
G_1 &= G_u(1,1,x) = 2x*(1-x^2)^{1/4}\\
G_2 &= G_u(2,1,x) = (-1+4x^2)*(1-x^2)^{1/4}\\
G_3 &= G_u(3,1,x) = (-4x+8x^3)*(1-x^2)^{1/4}
\end{aligned} \tag{5}$$

Figure 1 shows the time presentation (a) and the autocorrelations (b) of the first four orders of the Gegenbauer pulses.

The peak width of the autocorrelation function becomes narrower as the order of the pulse increases. However, the side lobe level increases accordingly.

2.3.2 MGF–UWB Multiaccess Technique

We consider the case of simultaneous transmissions of multiple users, where each user k is assigned to a unique order of MGF, G_k.

In case, the generated signals are modulated using the binary phase shift keying modulation (BPSK). The associated signal for the kth code is given by:

$$S^{(k)}(t)=\sum_{q=0}^{Q-1}\sqrt{E_b}d_q^{(k)}G_k(t-qT_s-\delta_k) \tag{6}$$

where N the number of the transmitted bits, E_b the bit energy, T_s the symbol period, $d_q^{(k)}\in\{1,-1\}$ the data symbol of the kth user.

3 Multi-user Systems with M-OAM Modulation

In this section, the M-OAM modulation schemes will be presented. These proposed modulations have the advantages of high data rate and low complexity compared to classical UWB modulations. Thus, our novel approach will be applied to the existing multiple access techniques detailed in the previous section.

3.1 M-OAM High Data Rate Modulations

The principle of M-OAM modulations is to modulate the transmitted pulse in M states. M is a multiple of 2, $M=2^n$ when n is the number of bit per symbol. Increasing n increases the

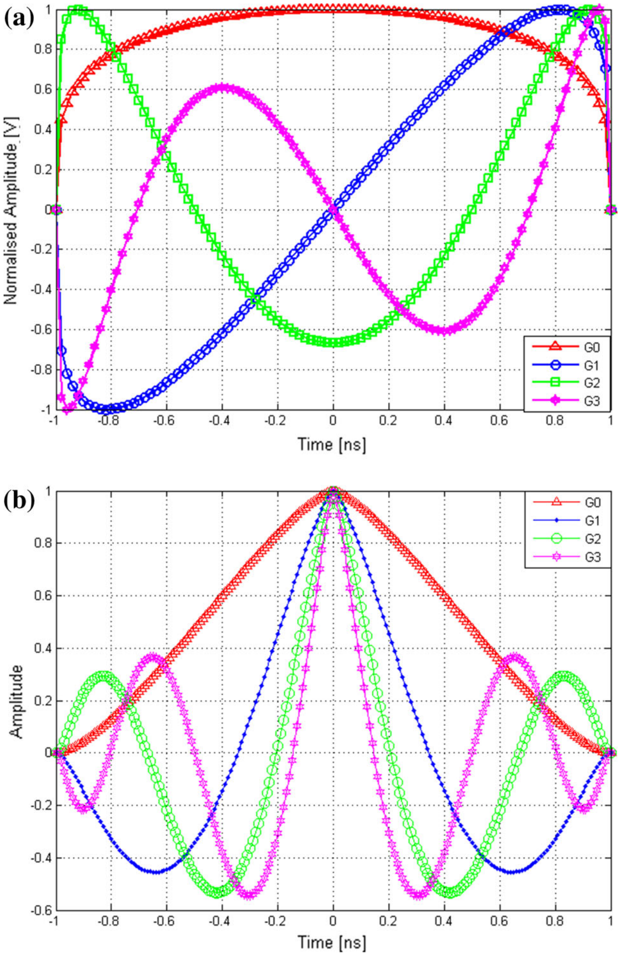


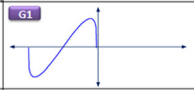
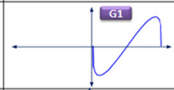
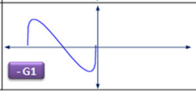
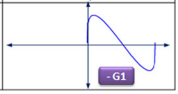
Fig. 1 Characteristics of Gegenbauer polynomials. **a** Time presentation, **b** autocorrelations

Table 1 Data rate of each M-OAM modulation, where D is the data rate of conventional UWB system

N	M states	Modulation	Data rate
2	4	4-OAM	2D
3	8	8-OAM	3D
4	16	16-OAM	4D
5	32	32-OAM	5D
6	64	64-OAM	6D

number of bits transmitted per symbol and hence the data rate offered, as shown in Table 1. This modulation exploits the orthogonality of MGF waveforms to differentiate between each sub symbol.

Table 2 Symbols of 4-OAM modulation

MSB \ LSB	0	1
0	 G1	 G1
1	 - G1	 - G1

Depending on the value of n, three cases of modulations are proposed: 4-OAM, 16-OAM and 64-OAM; as well as the particular cases 8-OAM and 32-OAM with odd values of n.

In the next section, we detail the principle of the 4-OAM modulation used in this paper.

3.2 The 4-OAM Modulation

4-OAM modulation is based on the association of the PPM modulation and antipodal modulation. Each symbol is characterized by 2 bits, the first bit sent determines the sign of the pulse and the second determines its position. Subsequently, this modulation allows the double of the data rate value compared to the classical UWB system. The symbol equation is:

$$x_i(t) = (2S_{iMSB} - 1)m(t + (2S_{iLSB} - 1)T) \tag{7}$$

$$m(t) = 2\alpha K t exp(-\alpha t^2) \tag{8}$$

where S_i symbol sent, $m(t)$ waveform used, T, time interval, *LSB* low significant bit, *MSB* most significant bit.

Table 2 presents the four obtained symbols of 4-OAM modulation using G_1 waveform.

By our new technique, the signal is quantified on multi-bit and correlation is optimized thereby increasing the performance of the correlator. To find the bits sent, we take a decision by evaluating the peak position and its polarity. Figure 2 corresponds to the decoding algorithm applied to signals modulated with 4-OAM.

3.3 MGF–UWB with 4-OAM Modulation

In this case, our 4-OAM modulation is implemented, instead of BPSK or PPM used in classical MGF–UWB technique, in order to increase data rate. Indeed, each user k is associated to a unique order G_k of MGF waveform,as shown in Fig. 3. The associated signal for the kth user is given by:

$$s^{(k)}(t) = \sum_{i=-\infty}^{+\infty} \sqrt{P_k} b_{iMSB}^{(k)} G^{(k)}(t - iT_f - b_{iLSB}^{(k)}\delta) \tag{9}$$

where $G^k(t)$ the transmitted Gegenbauer waveform for the kth user, *LSB* low significant bit, *MSB* most significant bit, T_f the frame period, P_k the transmitted power, δ PPM time interval.

The received signal from different transmitters may then be written as:

$$r(t) = \sum_{k=0}^{N-1} s^{(k)}(t) + n(t) \tag{10}$$

where N_u the number of users, $n(t)$ the Gaussian white noise with zero mean and variance $N0/2$.

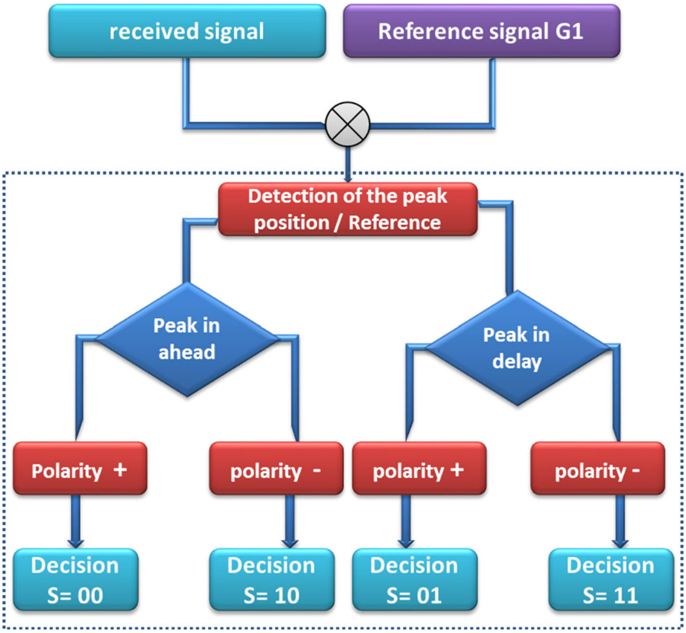


Fig. 2 Decoding algorithm of 4-OAM

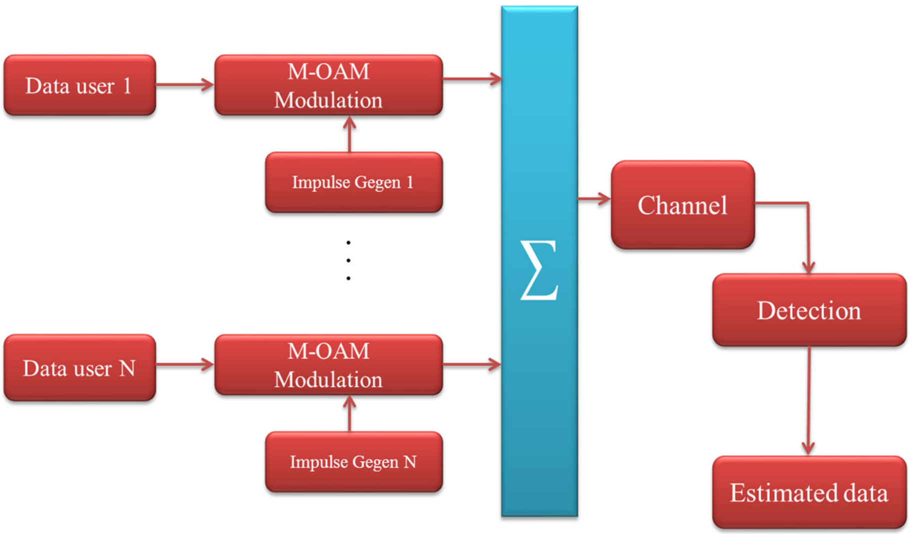


Fig. 3 Block diagram of MGF–UWB multi-access technique

The detection is achieved using a matched filter to the received signal $r(t)$ to perform a perfect synchronization of the data of the desired user. If the user 1 is considered as the desired user, the decision variable $y_q^{(1)}$ at the instant $t = qT_s$ is given by:

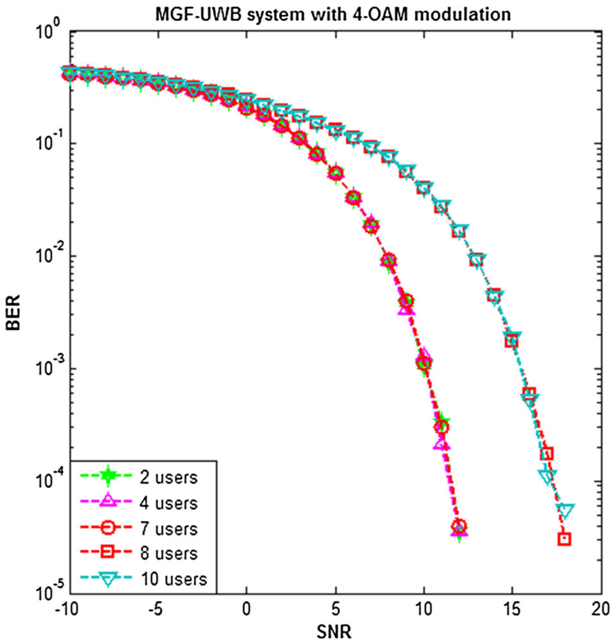


Fig. 4 MGF–UWB technique with 4-OAM modulation for 1 to 10 users

$$y_q^{(1)} = \int_{(q-1)T_s}^{qT_s} r(t)G_1(t)dt = \sqrt{P_1}b_q^{(1)}\Gamma_{1,1} + \sum_{k=0,\neq 1}^{N-1} \sqrt{P_k}b_q^{(k)}\Gamma_{k,1}$$
$$+ \int_{(q-1)T_s}^{qT_s} n(t)G_1(t)dt = \sqrt{P_k}b_q^{(1)}\Gamma_{1,1} + I_k^1 + \eta \tag{11}$$

The first term is the useful signal, the second is the multi-user interference and the third term is for Gaussian noise.

Where $\Gamma_{1,1}$ and $\Gamma_{k,1}$ are auto and cross-correlation functions respectively.

To evaluate the performances of the MGF–UWB system, we simulated the transmission chain with 4-OAM modulation; an order of MGF is assigned to each user. By consequence, we provided multiple access with high data rate

Seen that, the Gegenbauer waveforms give good properties of orthogonality, we can then provide multiple access of 10 users simultaneously with very good performances in terms of bit error rate.

In Fig. 4, the performance of the system in term of bit error rate BER versus signal to noise ratio is given. Considering 1–10 active users, where each one is assigned to a unique order of MGF G_k. This implies the use of ten different MGF codes in the system.

Figure 4 shows that for a number of users between 1 and 7 users, we have the same performances. This is a consequence of the higher orthogonality of the first seven MGF code. However, the performances degrade for eight users and remain the same for the higher degrees. This is due to the increase in the side lobe level according to the order of the pulse.

Table 3 Codes existing in the literature

Family	Code length (N)	Number of codes	Maximum cross correlation	Max autocorrelation
Gold	$2^n - 1$	$2^n + 1$	$(2^{(n+2)/2} + 1)/N$	1
Kasami	$2^n - 1$	$2^{n/2}$	$(2^{n/2} + 1)/N$	1
SBPA	$2^n - 1$	Depending on the length	$(2^{n/2} + 1)/N$	1
Walsh	2^n	2^n	1	1

Thus, in the absence of strict orthogonality, the interference term is one of the sources of performance degradation. The lack of orthogonality between MGF leads to the multi-user interference for some users.

3.4 DS-UWB with 4-OAM Modulation

In this part, the same classical DS-UWB technique detailed above is considered, but here with the 4-OAM modulation. To allow a multi-user transmission, an orthogonal Gold code is assigned to each user. But before choosing the adequate code, a small study is addressed to compare different codes existing in the literature as shown in Table 3.

3.4.1 System Model of DS-UWB

For the following analysis, we shall assume 4-OAM modulation for the transmitted symbols.

Let us consider the case of simultaneous transmissions of multiple services, sharing the multiple accesses where each user k is associated to a unique code c_k and modulated with 4-OAM modulation. All users have the same order of Gegenbauer function. The transmitted signal of the kth user is given by the following expression:

$$S^{(k)}(t) = \sqrt{P_k} \sum_{i=-\infty}^{+\infty} \sum_{n=1}^{N_c} b_{iMSB}^{(k)} c_n^k G(t - iT_f - b_{iLSB}^{(k)} \delta - nT_c) \tag{12}$$

where $G(t)$ the transmitted Gegenbauer waveform, *LSB* low significant bit, *MSB* most significant bit.

We are interested in receiving the signal of user 1, which we can assume that the receiver is perfectly synchronized. The received signal may then be written as:

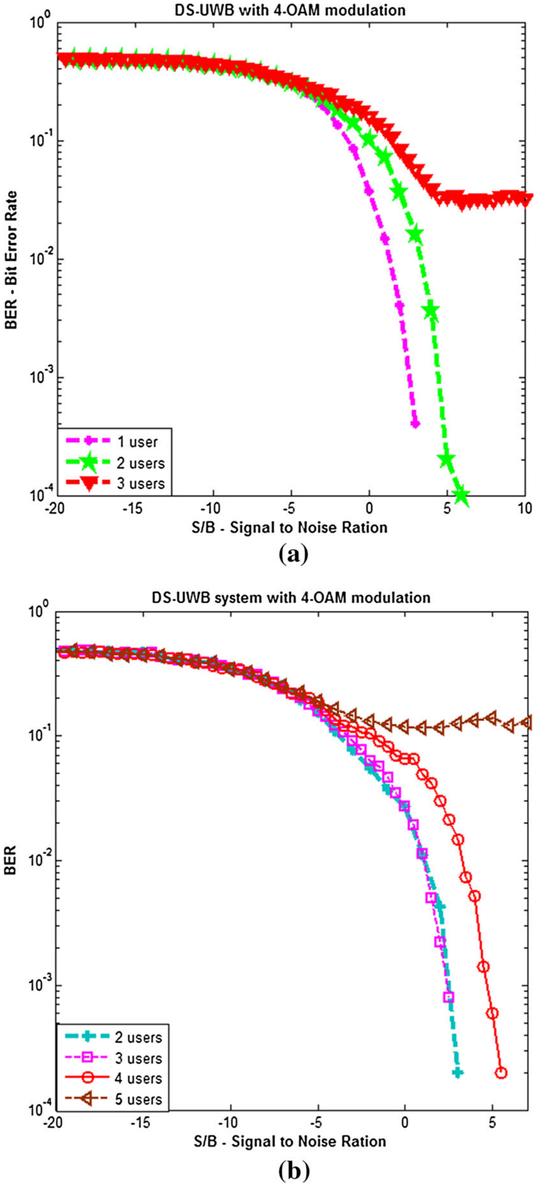
$$r(t) = \sum_{k=0}^{N-1} \sqrt{P_k} \sum_{i=-\infty}^{+\infty} \sum_{n=1}^{N_c} b_{iMSB}^{(k)} c_n^k G(t - iT_f - b_{iLSB}^{(k)} \delta - nT_c) + n(t) \tag{13}$$

In order to detect the first data symbol of the desired user r_1; the received signal is correlated with the code $c_n^{(1)}$, assigned to the first user, and then correlated with the reference $G(t)$.

3.4.2 Simulation Results

Figure 5 shows the BER of the DS-UWB system with 4-OAM modulation, using a Gold code of length 7 (in Fig. 5a). We note that the system has good performance for two users and degrades from 3 users. Therefore, when increasing the length of the code to 31 (in Fig. 5b), we will have good performance up to 4 users. Except that when the code length increases,

Fig. 5 DS-UWB with 4-OAM modulation



we lose on data rate. It is then necessary to find a compromise between data rate and user number, a problem that will not be posed with our new technique.

4 Design of a New Multi-user Ultra Wide Band System

The block diagram of our system is illustrated in Fig. 6. This system consists in the transmitter, the channel and the receiver. In these simulations, the transmitter and the receiver are assumed to be perfectly synchronized.

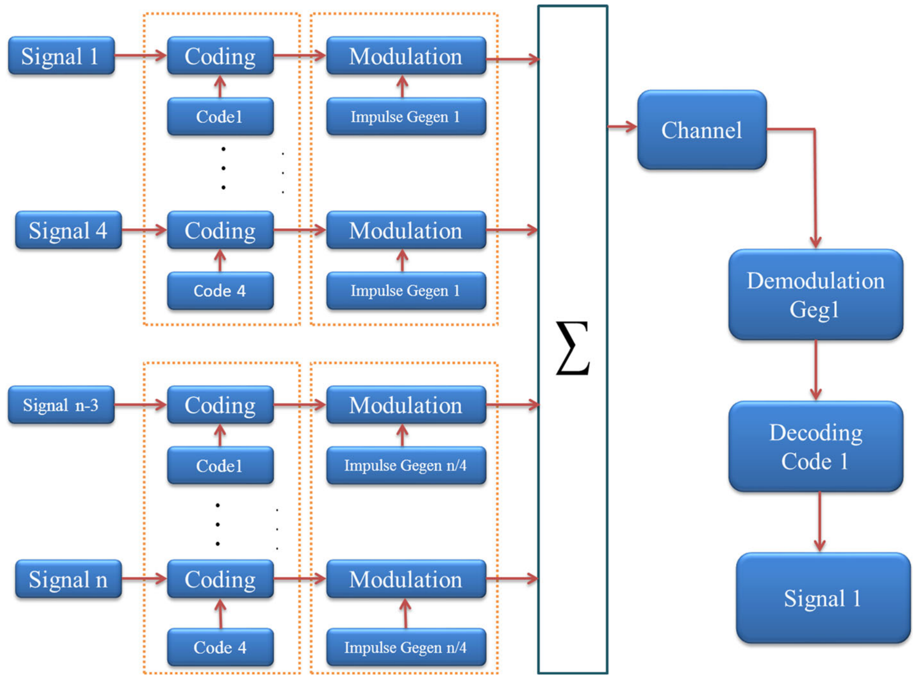


Fig. 6 Block diagram of the new DS-MGF–UWB system

The idea is to combine the two existing techniques DS-UWB and MGF–UWB, to exploit the double orthogonality of Gold codes and MGF waveforms. By consequence, we'll increase the number of users compared to all existing UWB systems, increase data rate thanks to the M-OAM modulation considered, and especially keep good performances in terms of BER.

This system consists to create subgroups of N users, as shown in the block diagram. In each subgroup, the user signals are spreaded with DS-UWB technique and modulated with the same order of Gegenbauer waveform. Between subgroups, we change the order of MGF.

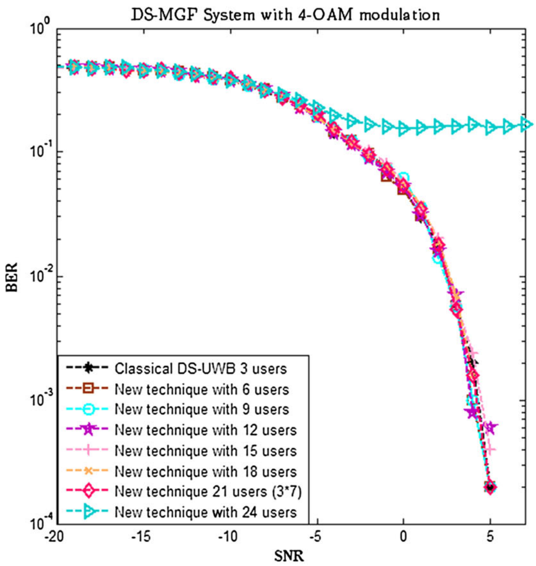
The choice of the number of users per group depends on the length of the Gold code used. According to Sect. 3.3, we see that the system using code of length 7 gives good performance up to 3 users; and a system using code of length 31 reaches 4 users. So we can choose $N = \{3; 4\}$ to have a maximum of users. On the other side, the best orthogonality of MGF waveforms is presented for the first 7° according to Sect. 3.2.

Subsequently, with this new technique, we can move from N users presented in a conventional DS-UWB system to $7 * N$ users in the new system and with the same performances found in the conventional system with N users.

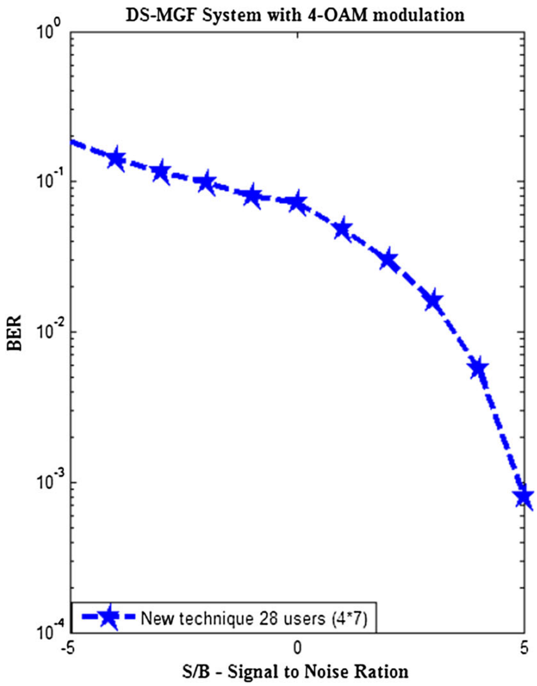
Figure 7 shows the simulation results of BER for our DS-MGF system with subgroup of $N = 3$ users in the Fig. 7a, and sub-group of $N = 4$ users in the Fig. 7b. The transmitter consists on the data generator, the encoder and the modulator. The data is modulated with 4-OAM modulation in order to reach high data rate. In these simulations, we consider the case of simultaneous transmissions of multiple users, sharing the same channel where each user k is assigned to a unique combination (Gold code C_k, Gegenbauer order G_k).

We notice in both figures that the system keeps the same performances up to $7 * N$ users. But at higher levels, the performance will degrade and that proves the results found previously.

Fig. 7 DS-MGF system with 4-OAM modulation



(a)



(b)

To conclude, our new system allows multiplying the number of users of conventional multiple access systems by a factor of seven and to double data rate through the M-OAM modulation, while keeping the same performances.

5 Experimental Tests

This section describes the tests carried out in laboratories IEMN/DOAE in Valenciennes and IFSTTAR in Lille, in indoor environment in order to take into account the effects of equipments and real channel. Let us start with the characteristics of used equipments:

Pulse generator

- Bandwidth exceeds 3 GHz
- Kind AWG7102
- Sampling rate up to 20 G sample/s
- Depth of 10 bits

Oscilloscope

- Wide bandwidth of 6 GHz
- Sampling at 20 GSa/s on 4 channels
- Sampling frequency maintained on the time interval exploitable
- Memory Standard 64 Mpts/Ch
- 8-bit resolution
- Sensitivity between 2 mV and 1V/div

Vivaldi antenna

- Frequency: 700 MHz–18 GHz
- Antenna Factor: 22–44 dB
- Gain: 1.4–15 dBi
- Maximum continuous power: 300 W
- Impedance: 50
- Type: directional
- Field of maximum radiation: 200 V/m

Preamplifier

- Kind BBV 9742
- Frequency range: 9 kHz–4 GHz
- Noise factor: 4.5 dB
- Input/output impedance: 50

The architecture in both laboratories is composed of a pulse generator provides Gegenbauer pulses and multi-user signals, two Vivaldi antennas, a preamplifier connected to the receiving antenna, an oscilloscope and finally a computer to extract the results of different tests from the Matlab files given by the oscilloscope (Figs. 8, 9, 10).

In Lille, the tests were conducted in an anechoic chamber to eliminate the effect of obstacles and create the ideal conditions for signal propagation (Fig. 11).

In IEMN laboratory, tests are performed in a real environment as shown in Fig. 12.

To create the DS-MGF system in real conditions, we chose the 4-OAM modulation with waveforms G1-7 and Gold code. The pulses are generated with amplitude 1 V peak to peak and width 550 ps. We use packets of 180 data symbols. Each symbol consists of 111 samples and the order of 5.5 ns. The transmitter and receiver are on the same axis at a distance of 3 m.

In order to find the beginning of the data sent and to solve the problem of synchronization between the transmitter and the receiver, a training sequence is used at the beginning of

Fig. 8 Pulse generator

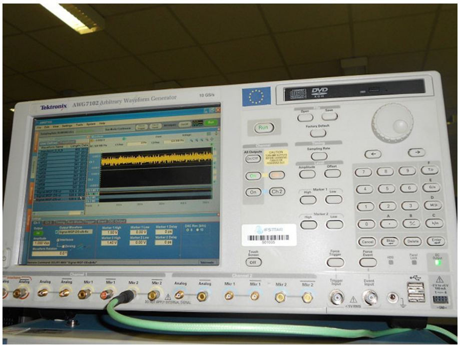
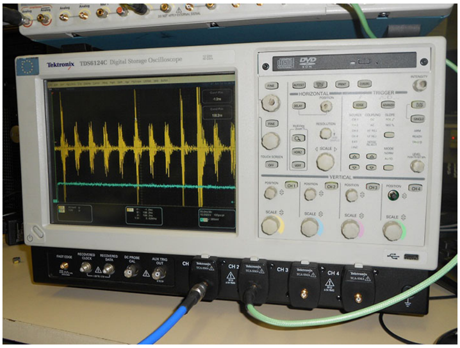


Fig. 9 Oscilloscope



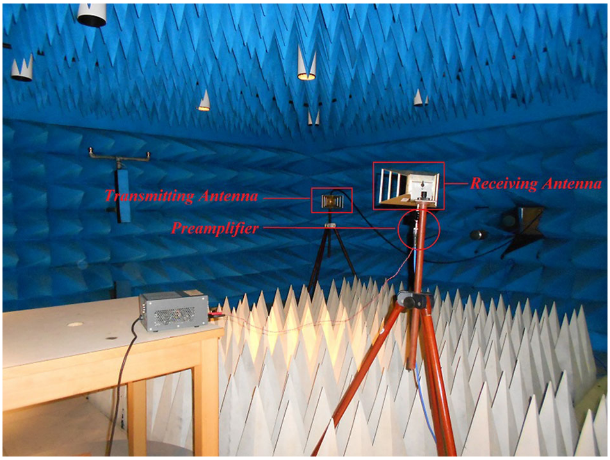


Fig. 10 Vivaldi antenna and preamplifier

each packet. By consequence, the first step is the construction of training sequence. To do so, a serie of monocycle pulses are modulated in BPSK and received after passing through two separated antennas by a reasonably low distance. Figure 13 shows the training sequence transmitted (a) and passed (b) through the two antennas:

An example of the received signal of 28 users with 4-OAM modulation is shown in the Fig. 14.

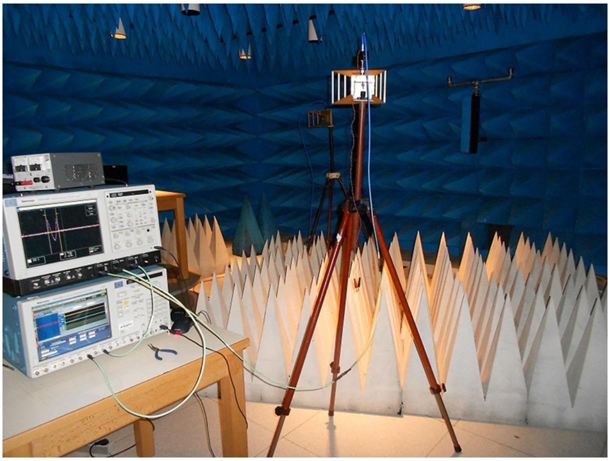
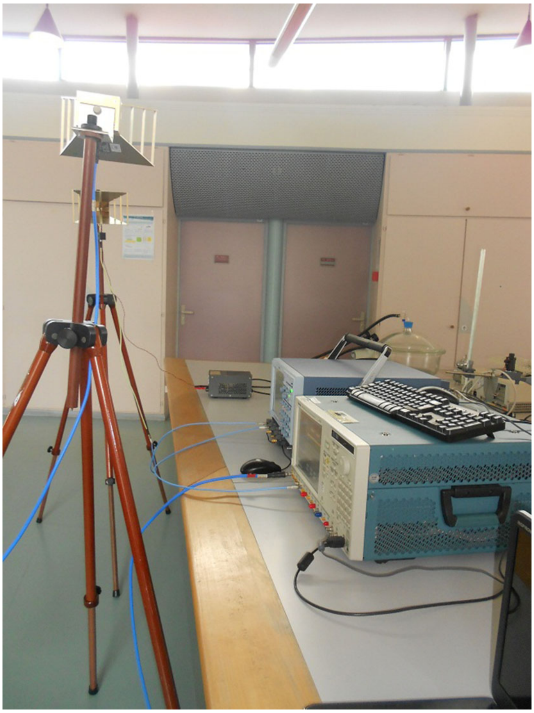


Fig. 11 Manip in Lille

Fig. 12 Manip in IEMN



In order to find the beginning of the useful data, the correlation between received signal and training sequence is used as shown in Fig. 15. Then, the output signal is correlated with used Gold code. The corresponding peaks could be easily detected.

Test results show that our new technique is operational under real conditions of propagation channel for a transmitter/receiver synchronously.

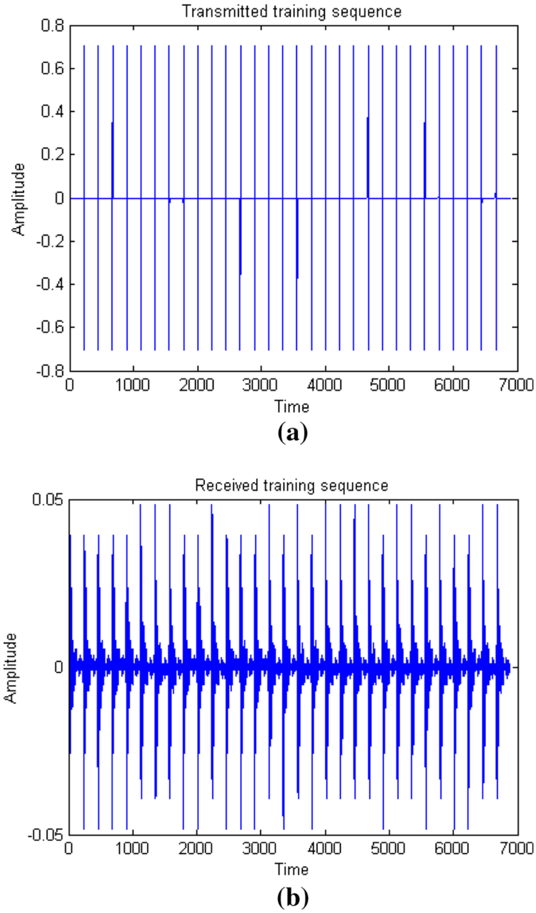


Fig. 13 Training sequence

6 Conclusion

A new DS-MGF UWB system employing the high data rate modulation and orthogonal polynomial MGF have been proposed in this paper. These modulations are M-OAM based on replacing the concept of the carrier by the order of MGF waveforms.

This system takes advantage of both multiple access techniques DS-UWB and MFG–UWB, which have been described. The obtained results show that the MGF–UWB technique gives good performances up to ten simultaneous users, but the number of MGF orders is limited. On the other hand, DS-UWB technique is sensitive to the number of users, it is therefore necessary to increase the length of the code for more users, but the data rate will be decreased.

The proposed multi-user communication system overcomes the limitation of the user number of the first technique and performance of the second. As a result, our system reaches a high number of users, and especially with the same performance, independent of the user number. In addition, the use of 4-OAM modulation gives double data rate provided by a conventional UWB system, without losing in quality of service, which is the goal of current communications systems.

Fig. 14 Received signal

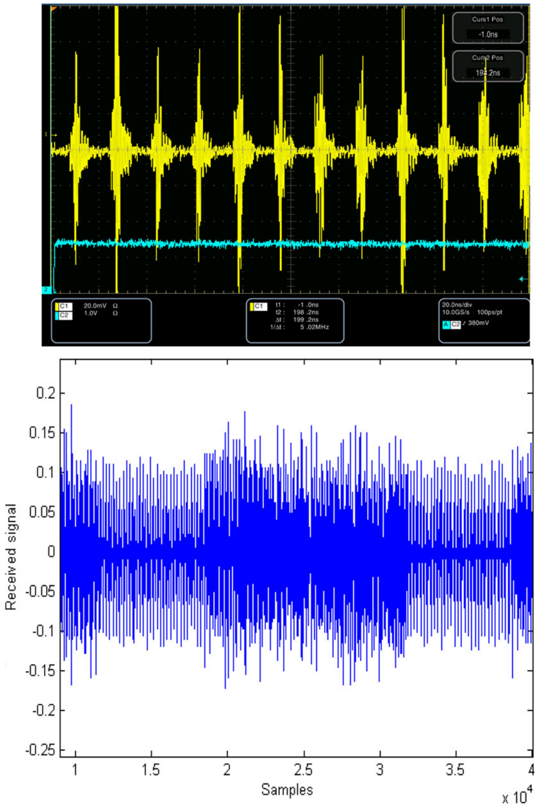
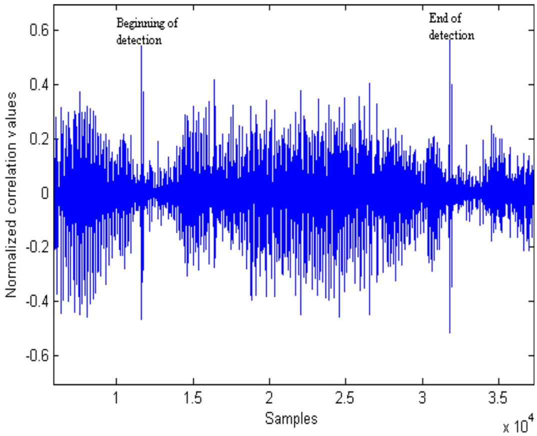


Fig. 15 Correlation result



Future works will be dedicated to the evaluation performances of our proposed system in multipath channels. Finally, we propose to implement this technology in FPGA component.

References

1. Nikookar, H., & Prasad, R. (2009). *Introduction to ultra wideband for wireless communications*. Berlin: Springer Science+Business Media B.V.
2. Hamidoun, K., Elassali, R., Elhillali, Y., Elbahharr, F., Rivenq, A., & (2012). New adaptive architectures of coding and modulation UWB for infrastructure vehicle communication. In *ISIVC 2012, 6th international symposium on signal, image, video and communications*.
3. Amel, E., Elbahhar, F., Elhillali, Y., Rivenq, A., & Elassali, R. (2012) UWB communication system based on bipolar PPM with orthogonal waveforms. *Wireless Engineering and Technology, 3*, 181–188. doi:10.4236/wet.2012.33026.
4. Elbahhar, F., Rivenq-Menhaj, A., Rouvaen, J. M., Heddebaut, M., & Boukour, T. (2005). Comparison between DS-CDMA and modified Gegenbauer functions for a multi-user communication ultra wide band system. *IEE Proceedings Communications*, *52*, 1021–1028.
5. Elbahhar, F., Rivenq, A., & Rouvaen, J. M. (2005). Multi-user ultra-wide band communication system based on modified gegenbauer and hermite functions. *Wireless Personal Communications, 34*, 255–277. doi:10.1007/s11277-005-3922-2.
6. Lamari, A. (2007). Conception et modélisation d'un système de communication Multi-Utilisateurs basé sur la technique Ultra Large Bande. PhD thesis, University of Valenciennes and Hainaut Cambrsis.
7. Okassa Mfoubat, A., Elbahhar, F., & Tatkeu, C. (2012). *A novel ultra wide band multi-user receiver for transportation systems communication*. University of Lille Nord France, IFSTTAR, LEOST.
8. Salem Bahri, F. (2009). Contribution à l'étude des systèmes ultra wide band différentiels. PhD thesis, the national school of Telecommunications of Britain with the national school of engineers of Tunisia.
9. Deleuze, A.-L. (2006). Contributions à l'étude des systèmes ultra large bande par impulsions. PhD thesis, Higher National School of Telecommunications.
10. Durisi, G., & Benedetto, S. (2003). Performance evaluation of TH-PPM UWB systems in the presence of multiuser interference. *IEEE Communications Letters*, *7*(5), 224–226.
11. Win, M. Z., & Scholtz, R. A. (2000). Ultra-wide bandwidth time-hopping spread-spectrum impulse radio for wireless multiple-access communications. *IEEE Transactions on Communiccations*, *48*(4), 679–691.
12. Durisi, G., Tarable, A., Romme, J., & Benedetto, S. (2003). A general method for error probability computation of UWB systems for indoor multiuser communications. *Journal of Communication Networks*, *5*, 354364.
13. Pursley, M. B. (1977). Performance evaluation for phase-coded spread-spectrum multiple access communication–Part I: System analysis. *IEEE Transactions on Communications*, *25*, 795–799.
14. Durisi, G., Benedetto, S. (2003). Performance evaluation and comparison of different modulation schemes for UWB multiaccess systems. Presented at ICC 2003, Ancorage USA.

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