Overview of Ultra Wideband Multiple Access Systems

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Abstract – **In this paper in brief is presented multiple access system realized by a new technology known as Ultra Wide-band (UWB) radio. The signals, especially the pulses, used in UWB communications are described. Two very important conceptions for realization of UWB multiple-access systems are presented - the classical with Time - Hopping Pulse Position Modulation (TH PPM) and the Delay-hopped transmission - reference (DHTR) systems. The advantage of using chaotic signals in these systems is proposed.**

Keywords – **Ultra wide band, pulse position modulation, time hopping, delay hopping**

I. Introducion

The UWB radio or so called Impulse Radio (IR)[1,2] uses a train of very short pulses with pulse duration in order of nanosecond. In frequency domain the pulses occupy very large bandwidth, greater than 1 GHz. Further, the pulse train has a very low duty cycle, less than 1%. This is the very important property of UWB signals that results in a very low average power. The main advantages of UWB follow:

- The pulse train is directly fed to transmitted antenna and because of that an UWB is known as a " carrier- free" communication. Hence, no need of RF up-converters and down-converters, the both the UWB receivers and transmitters are with lower complexity and are cheaper than conventional systems.

- UWB is very suitable for dense multipath (inherent in indoor as office buildings). For example, if the pulse width is 1 ns, then no fading when differences in the paths are greater than 1 foot (30 cm). Combining of delayed signals with a RAKE receiver is a very simple task and it could obtain an excellent system performance. System designers no need of great margin in link budget.

II. Common Characteristics of UWB Multiple Access Systems

Data modulation in UWB is performed by changing the pulse position, shape or polarity (phase). Multiple access capability of the UWB systems due to nature of UWB signals is realized by spread spectrum Time Hopping (TH) technique. In the common case are used pseudorandom sequences for TH. When the low probability of detection and interception are required then a chaotic signal are well suited.

In essence, by PN sequences or chaotic signals are performed a randomly time shifts of the pulses and this results in two consequences. The first is a smooth spectrum shape without a great spike. Second, the probability of collision between the signals of different users is decreased.

The receivers in the IR are optimal (correlation) receivers. After despreading in the receiver is performed correlation between the received signal and a template signal. The template signal must be aligned with the received signal in the time and must be with identical waveform. In other words, a synchronization process is realized in the receiver and system designers must perform channel estimation. The synchronization process take a finite time and increases software complexity.

Other approach to realize an UWB multiple access system is Delay-hopped Transmission Reference (DHTR) technique. In this system is transmitted a reference signal that undergoes the same distortion and delay as the information signal. Hence, no need of synchronization of the individual pulses and any channel estimations. Multiple-access capability is obtained trough the principle of code division multiple access (CDMA) and usage of Delay-Hopping technique.

III. Basic UWB Pulse Shapes

A. Gaussian pulse shape – monocycle

The basic pulse shape proposed for use in UWB communication system is the Gaussian pulse. The pulse generator produces a smooth impulse, which is approximately Gaussian pulse. The effect of antennas over the pulse is that of differentiation. Hence, the transmitted pulse is first derivative of Gaussian function. This is so called monocycle [3]

$$\nu(t) = A\sqrt{2e}\frac{t}{\tau}\exp\Big(-\frac{t^2}{\tau^2}\Big) \tag{1}$$

where τ is time decay constant that defines the pulse width; A is the peak amplitude of the pulse. On the other hand, the pulse width specifies the bandwidth and center frequency. The monocycle is shown on Fig. 1.

In the frequency domain, the Gaussian monocycle envelope is:

$$\nu(w) = Aw\tau^2\sqrt{2\pi e}\exp\Big(-\frac{w^2\tau^2}{2}\Big). \tag{2}$$

It can be seen on Fig. 2.

The center frequency is then:

$$f_c = \frac{1}{2\pi\tau},\ \text{Hz}. \tag{3}$$

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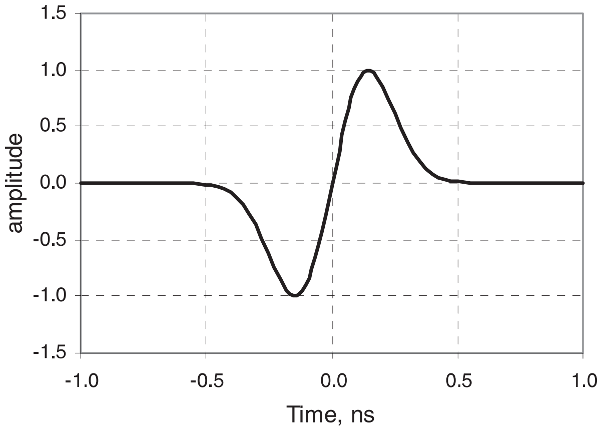

Fig. 1. The monocycle

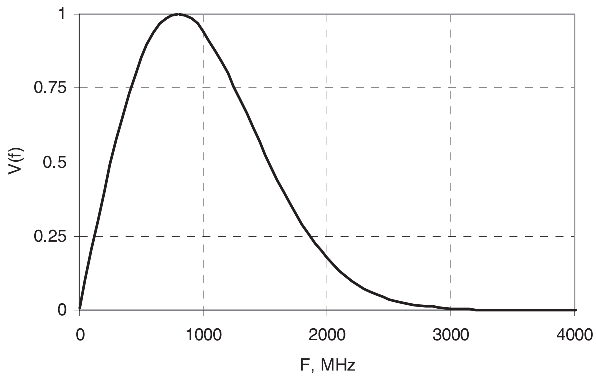

Fig. 2. The spectrum of monocycle

B. Hermite-Based pulse shapes

Recently, in [4,5] was proposed a novel pulse shapes based on a modified Hermite polynomials (MHP) that can be presented by

$$h_n(t) = e^{-\frac{t^2}{4}} h_{e_n}(t) = (-1)^n e^{\frac{t^2}{4}} \frac{d^n}{dt^n}(e^{-\frac{t^2}{2}}) \qquad (4)$$

where $n = 0, 1, 2...$ and $-\infty < t < \infty$. The MHP pulses are shown on Fig. 3.

The variation of pulse width is small when the order is changed. Hence, the bandwidth is not varied significantly. Due to the MHP are orthogonal functions; the pulses could be used for a M-ary modulation or for MA system. For example, 00,01,10,11 can be represented by MHP pulses of order $n = 1, 2, 3, 4$. In this way higher data rates can be achieved simply by sending different pulse shapes. This can be extended to a multi-user system, assigning for example MHP pulses of order $n = 1, 2$ to user 1 for 0,1 and $n = 3, 4$ to user 2 for 0,1.

It can be seen in [6] that the MHP pulses of order equally to or smaller than 8 are applicable. The higher order pulses have very short autocorrelation pick. Hence, they are more sensitive to pulse jitter and it would result in degradation in the system performance.

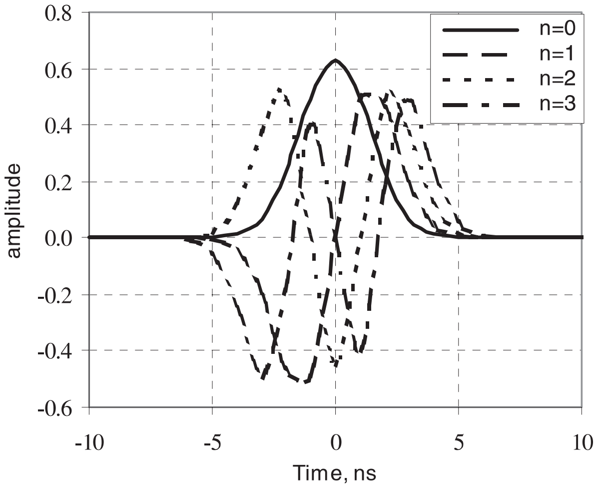

Fig. 3. The MHP pulses of order $n = 0, 1, 2, 3$

IV. Basic UWB Multiple Access Systems

A. UWB multiple access system with time-hopping impulse modulation

This is the first proposed multiple-access (MA) system for UWB communications [7]. In this system multiple access capability is realized by spread spectrum time-hopping (TH) technique and a pulse position modulation (PPM) is used for data modulation. A typical hopping format with data modulation is given by

$$s^{(k)}(t) = \sum_{j=0}^{\infty} w(t - jT_f - c_j^{(k)} Tc - \delta d^{(k)}_{[j/N_s]}. \qquad (5)$$

Here $w(t)$ represents the transmitted monocycle waveform and superscript (k) indicates transmitter-dependent quantities. The j-th monocycle of user (k) nominally beginning at time $jT_f + c_j^{(k)} Tc + \delta d^{(k)}_{[j/N_s]}$. The time shift T_f is the frame (pulse repetition) time and equals the average time between pulse transmissions. The frame time T_f may be a hundred to a thousand times the monocycle width.

Pseudorandom Time-Hopping: To eliminate catastrophic collisions in multiple accessing, each link (indexed by k) is assigned a distinct time-hopping code $\{c_j^{(k)}\}$. These hopping codes $\{c_j^{(k)}\}$ are periodic pseudorandom codes with period N_p. Each code element is an integer in the range $0 < c_j^{(k)} < N_h$. It assumed that $N_h T_c < T_f$. On the other hand, using pseudorandom time hopping the shape of spectrum is smoothed.

Data modulation: The data sequence $\{d_i^{(k)}\}$ of transmitter (k) is a binary (0 or 1) symbol stream. In essence, a pulse position modulation used in this system means that, when data symbol is 0, no additional time shift, but time shift of δ is added to a monocycle when the symbol is 1. In this system is used oversampled modulation with N_s monocycles transmitted per symbol. In the receiver's correlator is performed an integration over N_s hops and it suggests that the signal to noise ratio (S/N) is increased. Usually, the number of pulse per symbol N_s is a few hundreds and the system performance is improved significantly.

This system uses simple approach to realize basic advantages of UWB for Multiple Access (MA) system in dense multipath environment.

B. UWB multiple access system with time-hopping and M-ary PPM modulation

Further investigation of MA system described above results in a Block Waveform or M-ary PPM modulation [8-11]. Let the TH PPM signal is

$$x^{(\nu)}(t)=\sum_{k=0}^{\infty} w(t-kT_f-c_k^{(\nu)}Tc-\delta^k_{d^{(\nu)}_{[j/N_s]}}). \quad (6)$$

Where the superscript (ν) indicates user-dependent quantities $1<\nu<N_u$ and the number of simultaneous active users is N_u. The index (k) is the number of pulses that has been transmitted. The time shift corresponding to the data modulation is $\delta^k_{d^{(\nu)}_{[j/N_s]}} \in \{\tau_1=0<\tau_2<\cdots<\tau_\eta\}$ with $\eta \geq 2$ an integer. The data sequence $\{d_m^{(\nu)}\}$ of user ν is an M-ary symbol stream.

If we define a hopping function

$$\begin{aligned} H_m^{(\nu)}(t) &= \sum_{k=mN_s}^{(m+1)N_s-1} T_c c_k^{(\nu)} p(t-kT_f) \\ p(t) &= \begin{cases} 1, & \text{if } 0 \leq t \leq T_f \\ 0, & \text{otherwise} \end{cases} \end{aligned} \quad (7)$$

and a signal set

$$S_i(t)=\sum_{k=0}^{N_s-1} w(t-kT_f-\delta_i^{(k)}) \quad (8)$$

for $i=1,2,...,M$, then (6) can be rewritten

$$x^{(\nu)}(t)=\sum_{m=0}^{\infty} S_{d_m}^{(\nu)}(t-mN_sT_f-H_m^{(\nu)}(t)) \quad (9)$$

where m indexes the transmitted symbols. The PPM signal $S_i(t)$ represents the i-th signal in an ensemble of M information signals, each signal completely identified by the pulse shape w(t) and the sequence of time shifts $\{\delta_I^k\}$, $k=0,1,...,N_s-1$. In [8] are represented M-ary PPM sets, namely orthogonal (OR), equally correlated (EC) and N-orthogonal (NO) signal sets. For example, EC M-ary PPM signal set is defined by time shift pattern $\delta_i^k=a_i^k.\tau_2$, with $\tau_2 \in (0,T_w]$, where the pulse duration is T_w and $a_i^k \in \{0,1\}$, $k=0,1,2,...,N_s-1$ the i-th cyclic shift of the m-sequence, for $i=1,2,...,M$. It can be shown that the EC M-ary PPM signals have normalized correlation values $\alpha_{ii}=1$ and $\alpha_{ij}=\lambda$, $i\neq j$, where $\lambda<1$.

The simulation results in [8,11] depicts that using higher values of M other than 2, it is possible either to improve the probability of detection for a fixed number of users N_u, or to increase the number of users for a fixed probability of error, without increasing each user's signal power.

This very attractive property of M-ary PPM modulation could be proved by following considerations. If the pulse frame time T_f and the bit rate are fixed, then the number of pulses N_s used in the M-ary modulation $N_s=\log_2(M).N_s^{(2)}$ are increased with respect to the number of pulses used in a binary modulation. In this way $E_s=N_sE_w=\log_2(M)N_s^{(2)}E_w=\log_2(M)E_b$, where E_s and E_b are the energy of symbol after receiver's correlator in M-ary and binary communications, respectively. Hence, after integration in an M-ary PPM receiver correlator we have energy greater than those in the binary receiver.

Using the M-ary PPM sets with large values of M, it is possible to increase the number of users supported by the system for a given multiple-access performance and bit transmission rate, making efficient use of the signal to noise ratio available.

C. Delay-hopped transmitted-reference UWB multiple access system

The Delay-Hopped Transmitted-Reference (DHTR) is the last proposed technique for UWB communications [12,13]. As shown on Fig. 4, a DHTR UWB signaling scheme is implemented by transmitting pairs of identical pulses (called doublets) separated by a time interval D, known to both the receiver and the transmitter. The transmitted data is encoded by the relative phase of the two pulses; in this scheme is used binary phase modulation, e.g. a changing of pulse polarity is performed. More than one doublet is associated with each information bit, as long as all the associated doublets have the same time interval D between pulses and the same relative polarity of pulses.

The interval between doublets, called the pulse repetition time (PRT), may be varied in order to shape the spectrum of the transmission.

The sequence of early pulses in the sequence of doublets on Fig. 4, since it contains no information, it should be considered as a carrier (reference) signal. The sequence of second pulses would then be a modulated (information) signal.

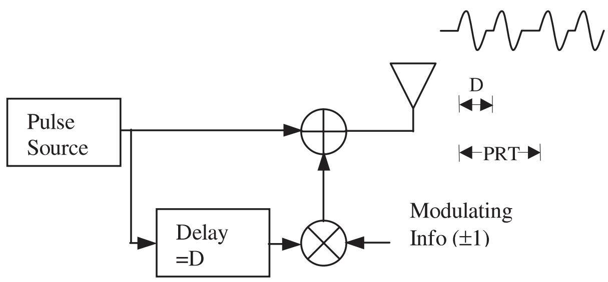

Fig. 4. Generation of DHTR signal

The Delay-Hopping refers to the method of varying the delay used in DHTR transmission according to a fixed pattern known to the transmitter and to the receiver. This pattern constitutes a code word, and multiple-access capability is obtained trough the principle of code division multiple access (CDMA).

On the signal level, a DHTR code word consists of N_c chips, transmitted sequentially. Each chip is composed of N_p doublets, with interpulse delay D_i, for $i=1,2,...,N_c$ and with the same polarity.

The DHTR receiver consists of a bank of pulse-pair correlators connected trough a LNA to an antenna. Each correlator in the bank of pulse-pair correlators responds to a different delay. A CDMA code word correlator follows the bank of pulse-pair correlators. The code word correlator adds the individual chip waveforms in phase, producing an output, which is a high SNR version of the individual chip waveform.

In contrast to conventional pulsed UWB receivers, the use of the transmitted-reference technique makes synchronization with the individual pulses unnecessary.

D. UWB MA system with chaotic pulse position modulation (CPPM)

In the classical UWB MA system is used a pseudorandom sequences for a time hopping technique. In the CPPM, which is proposed in [14], is used chaotic signal for this purpose.

In the more chaos-based communication schemes synchronization is very sensitive (susceptible) to distortions and noise. In the CPPM the information about the state of the chaotic system is contained entirely in the timing between pulses, the distortion that affect the pulse shape will not significantly influence the ability of the chaotic-pulse generators to synchronize. Furthermore, using chaotic-pulse generators the system reacquires synchronization automatically, without any specific “hand-shaking” protocol. The decoder only need to detect two correct consecutive pulses in order to re-establish synchronization.

In the previous described UWB systems the use of pseudorandom sequences results in the presence of characteristics frequency in transmitted signal spectrum. Chaotically varying spacing between the pulses enhances the spectral characteristics of the system by removing any periodicity from the transmitted signal. Due to the absence of characteristic frequencies, chaotically positioned pulses are difficult to observe and detect for an unauthorized user.

V. Conclusions

In this paper was presented the main UWB multiple access communication systems. The M-ary PPM modulation has a system performance better than this in binary PPM system for a given signal to noise ratio (SNR). The Delay-Hopped Transmission-Reference (DHTR) technique is very suited for burst mode communications where synchronization process must be take up very short time. It was represented that the usage of chaotic signal in UWB systems is viable and has many advantages over the usage of classical PN sequences.

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