THE EVOLUTION OF UWB COMMUNICATION

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Abstract. *UWB communication systems are today's most promising data connection systems because of high data rates, low power profile which guaranties first step privacy and ease of interconnection. Their future employment without band licensing in entire world makes them the natural choice for future networks' buildup and has attracted the attention and investments of about all producers of digital and communication systems. Nonetheless the standardization process for this system is slowly and has a rather defensive character against the consequences of an exploding UWB future implementation.*
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Introduction

The first designs for UWB communication systems and other UWB systems were initially borrowed from the military radars based on short, spectral shaped pulses, sent at high repetition rates. A large number of systems were developed from this point: Ground Penetrating Radar (GPR), Wall Penetrating Radars, medical imagistic systems, asset location devices and of course communication systems. GPR and wall penetrating radars are the only systems which have reached mature technical states and they begin to be widely used by military, life and security support units, engineers and archeologists to mention only a few. At the same time the UWB had to renounce to this initial, attractive system design, in order to ever be used outside university labs.

Initial system characteristics

Initial UWB systems used short pulses (hundredths of picoseconds) inside larger pulse intervals (a few ns). The pulses had their spectral power shaped to occupy the desired band and had low amplitudes.
Extremely short pulses have the advantage of clean separation between direct wave and delayed ones, making multi-path easy to deal with. They also make precise ranging and are considered a viable solution for stealth objects detection due to large spreading of spectral components.

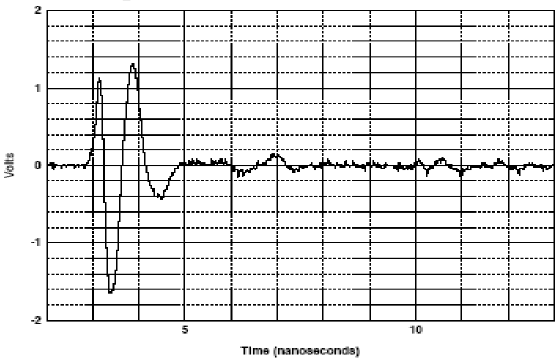

Figure 1. Implemented UWB short pulse, the signal has almost no low frequency components.

Pulse position is an important feature of such systems [1]. Their transmitted signal can be described as convolution product between the generator signal and a sum of Dirac pulses which in frequency is translated in sampling generator spectrum at the Pulse Repetition Rate (PRR) frequency intervals. This mean that spectrum energy is no longer spread in a constant manner over all used band, but rather concentrated at precise intervals. Placing offsets between pulse positions inside distinct pulse periods adds several spectral lines to transmitted signal by lowering the ones at pulse repetition rates. This can be done by placing time offsets from period initial time or last pulse position to mention some methods. The resulting spectrum is composed of spectral lines at the pulse repetition rate, the inverse of the time delay, their sums and difference and may look kind of continuous and constant with some small ripples. This is nonetheless a complex behavior, where pulse dithered UWB emissions may look like AWGN at low PRR because of dither rate and impulsive at high PRR because of aggregate effect of PRR and dither frequency [2]. Initial continuous like spectral envelope made early supporters of UWB systems to sustain that this constant, low profile spectrum can coexist with any already working radio communication environment, as it would act just as AWGN additive noise and will be harmless.

Spectrum allocation

UWB system's requirements for operating bandwidth were not initially concentrated, as system characteristics made him a novelty: usage of a extremely large band, no carrier modulation, no data on channel characteristics.
In order for the system to be successful, it needed the assurance that it can be implemented worldwide in the condition of today's spectrum saturation.
United States of America made the first and most important step by allowing in 2002 the use of a huge band between 3.1 and 10.6 GHz by any UWB device, with no fee, if they respect certain power limitations [3]. Following this example, several states allowed usage of this band for UWB devices, with small technical differences from USA requirements: EU, Japan, South Korea, etc.
The requirements for UWB emissions were: to use at least 500 MHz of granted band at any moment and to respect a strict spectral power mask which allows Equivalent Isotropic Radiated Power (EIRP) of less than a limit of -41.3 dBm inside the band and at least -51.3 dBm to -75.3 and -85.3 dBm below the band and at higher frequencies. They also are required UWB systems not to be used in outside environment and to have low emission distances as to reduce any possibility of interference.
Recent regulations have asked that all UWB communication systems to detect in band interferers and to reduce or stop own emissions in those bands: Detect and Avoid.

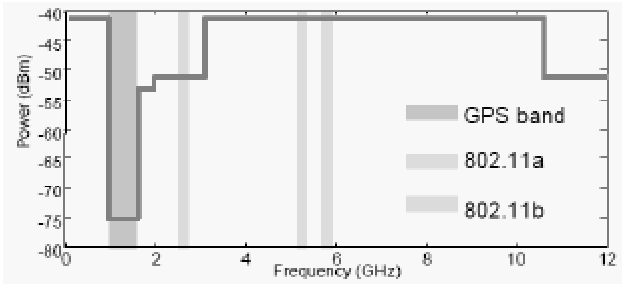

Figure 2. UWB spectral mask and possible victims or interferers.

Channel model for this low power, large band, frequency selective affected signal was firstly developed by Saleh and Valenzuela [4]. They defined channel target characteristics based on signal versions arrival on clusters and rays and have proposed four channel models for UWB indoor environment.
Several UWB prototypes were built after band recognition, in order to present the technology to the large public and test the channel parameters.
Also, several authorities began testing UWB interference using most pessimistic cases for important communication and electronic systems: GPS, military and civil aviation radars, etc.
Although the GPS is out of UWB regulated band, the tests of its interference by UWB emissions showed that the initial model was not appropriated. The test targeted GPS because of its importance, small bandwidth and received carrier shift due to Doppler's effect during satellite movement over receiver station [5]. The scenario showed that if UWB emissions centered on discrete frequencies were allowed inside GPS operational bandwidth, there was a certain chance for signal superposition and GPS signal loss and hard re-acquisition.
Other tests made on civil and military radars also showed that these systems were vulnerable to these interferences.
The reason was that the UWB was discrete. For systems with very narrow bandwidths, signal superposition is catastrophic, through rare to

happen. For system with narrow, but larger bandwidths, the ratio between UWB PRR and system bandwidth B is of real interest. When the PRR/B is >5, the victim's receiver integrates several UWB pulses and captures their envelope signal, noisy like. If the PRR is comparable or smaller than the receiver bandwidth, the pulses are resolvable and their interference becomes destructive.

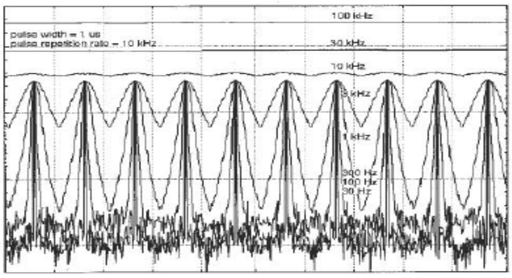

Figure 3. The victim's receiver band filter view: large PRR UWB signals appear with continuous specter, while low PRR pulses are easily resolved and their specter is impulsive for the victim.

Pulse position modulation PPM was tried in different methods in order to reduce spectral lines amplitude, populate the UWB more densely and generally to obtain the desired continuous power spectral density, but generally without achieving the desired noise like or continuous wave format required by Federal Commission for Communication FCC.

From the shortest pulse to full period wave

UWB were seen not to be appropriated for data transmission. They are still used for ground and wall penetrating radars. The device complexity was to be increased due to signal modulation on a carrier and multi-path will be solved by Rake receivers or synchronized correllators.

IEEE played a crucial role in this period of UWB implementation by offering a well documented physical layer of the indoor environment and a medium access control layer for network management.

The two most viable and technical mature solutions for UWB which are close to standardization are:

1. Direct Spectrum Code division Multiple Access: DS-CDMA;
2. Multi Band Orthogonal Frequency Division Multiplexing: MB-OFDM.

Both versions use large bands: 500MHz per symbol for OFDM and app. 1.32 MHz per piconet for CDMA. The global band is split into 2 bands: an inferior mandatory one for all UWB devices, and a second one for enhanced devices.

OFDM is largely orientated for power spectral optimization by dividing the band into smaller bands, controlling power level for each sub-band and allowing the possibility of turning some channels off in order to avoid interference with in band narrow systems. This system is sustained by a large group of communication and electronic device producers and is the most technically complete UWB system, with abilities to start large scale production immediately after an eventual IEEE recognition.

DS-CDMA is less technically complete as is supported only by a few producers and some organizations. It also has a lower control over power spectral distribution. Still, it is attractive by the technical simplicity when compared to the OFDM's IFFT and ADC structures. It can also reach more then double transfer rates and support several overlapping or superposed piconets without any risk of interference. This situation is not well resolved by MB-OFDM which depends on random band access in order to avoid collisions.

Other interesting feature of these systems is that they use low data rates and high data redundancy for dispersive Non Line Of Sight channels. For the 55 and 110 Mbps mandatory data rates there is an interesting question of what will be the result if these systems will turn these modes to be used for low dispersion channels and achieve multiple accesses. Because of good channel parameters, power could be reduced to meet emission restrictions even for aggregate users and a more flexible network could be achieved. DS-CDMA needs only to use its low cross-correlation spreading codes [6], while MB-OFDM would find difficult to share data channels between random users and still achieve the IFFT for remaining ones. This is because MB-OFDM will still have to keep the Time

Frequency Codes and Rotation Sequences for its piconets.

Both systems have adapted IEEE mandatory UWB frame for their special transmission features. The general structure is composed of:

1. preamble, for synchronization between transmitter and receiver;
2. PHY header, which transfers transmission characteristics: band, modulation, coding rate, data payload length and scrambler initialization;
3. MAC header;
4. HCS Header Check Sequence;
5. Frame payload , between 0 and 4096 bytes;
6. FCS Frame Check Sequence;
7. Tail bits.

The two system proposals were largely confronted inside IEEE 802.15.3a Task Group because of several technical targets which were not yet reached by any of them in order to deliver a long term usage protocol.

The two proposals are presented as follows.

Multi Band – Orthogonal Frequency Division Multiplexing MB-OFDM

MB-OFDM is an UWB system capable of achieving transfer rates of 55, 80, 110, 160, 200, 320 and 480 Mbps. The devices are defined as Mod 1, using the band 3168 – 4752 MHz (bands 1-3), and Mode using the bands 3168 – 4752 and 6072-8184 MHz (bands 1-3 and 6-9).

Data bits are convolution coded, scrambled, interleaved and then mapped on QPSK constellation and passed to IFFT block for signal generation [7].

Convolution encoder is obtained by using a 1/3 standard encoder from which higher data rates are obtained by puncturing: 11/32, 1/2, 5/8, 3/4.

Each coding rate corresponds to specific data rate.In order to maximize the bit transitions, data bits are scrambled using a 15 order polynomial. The polynomial is based on a seed updated for each OFDM symbol sent.

$$r_{data,k}(t) = \sum_{n=0}^{N_{SD}} c_{n,k} \exp(j2\pi M(n)\Delta_F (t - T_{CP})) + p_{\mathrm{mod}(k,127)} \sum_{n=-N_{ST}/2}^{N_{ST}/2} P_n \exp(j2\pi n\Delta_F (t - T_{CP}))..(Eq1)$$

The polynomial's coefficients are also updates for each data bit.

Bit interleaving is performed in order to avoid noise/error burst during OFDM symbol period and selective frequency interference. Data bits are interleaved between 3 consecutive OFDM symbols and inside each symbol between groups of 10 bits.

Data stream is enlarged with additional bits in order to place receiver convolution decoder to initial state after frame end and then split in 2 in order to be mapped to Grey coded QPSK constellation.

The complex numbers are used to calculate the IFFT and generate the transceiver signal.The signal is sent using 100 data sub carriers, 12 defined pilot sub carriers, 10 user undefined pilot sub carriers and 6 channels used to generate spectral nulls.

Equation 1 shows OFDM signal buildup using the 100 data complex numbers c_n and pilot symbols p_n and depicts the frame format.

Data sub carriers are modulated QPSK (Quadrate Phase Shift Keying) and pilot sub carriers BPSK (Bi-Phase Shift Keying) for better synchronization.

Mode 1 devices use three 500MHz bands and Mode devices seven bands. Hopping from one band to another is achieved using Time Frequency codes which are periodically changed using Rotation Sequences. Randomizing these variables assures that neighboring piconets will not collide data packets when entering same channel groups. Because the superposition would be complete, OFDM's specific channel allocation based on transmission parameters could not change as no channel could be used inside current group.

DS UWB Direct Sequence UWB

DS-CDMA has a natural link to initial UWB principles as it uses large bands to overcome noise, own users interference and jamming. It also makes reduced use of analog blocks being a more "digital" protocol.

The system can achieve data rates of 28, 55, 110, 220, 500, 660, 1000 and 1320 Mbps. The band is split into 12 piconet channels with guard intervals, placed in two bands: from 3.1 to 4.85 GHz and from 6.2 to 9.7 GHz

This proposal for UWB implementation makes use of same data processing as OFDM one: convolution encoder, scrambler and interleaver but in a different version.

Because data protection to noise is better achieved by spectrum spreading, the convolution encoder has a rate of only ½, from which the rates 3/4 is obtained by puncturing. For higher data rates, data bits are no longer encoded. Data scrambling is achieved with the same generator polynomial but with different seed values. Bit interleaving is achieved in a more complex by placing transmit bits into 10 FIFO registers with depths 0(line), 7, 14 to 63 bits. The receptor places received data into a similar structure with inversed register depths, from 63, 56 to 7, 0 in order to extract data [8].

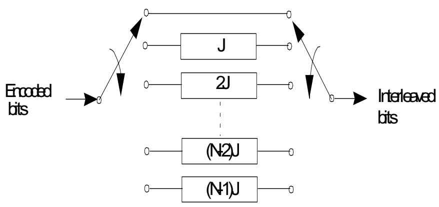

Figure 4. Bit interleaver block, reduced emission-reception scheme. N = 10 lines and J = 7 bits placed on each register at each step.

Data stream is multiplied with the spreading code with maximum length 24 and minimum 1, then coded BPSK. For enhanced devices the transmission can be achieved using 4BOK (Bi-Orthogonal Keying) modulation. In this case the spreading code values must be even values from 12 to 2, also 2 spreading codes are used for this modulation instead of 1 for BPSK.

The transmission using 4BOK is requested for all devices, but its reception and demodulation is optional in order to make the UWB more scalable in technical complexity and cost.

Base band reference pulse is root raised cosine low pass filter with 30% bandwidth excess. Transmitted band is always F_{chip}, though this frequency slowly increases from inferior piconet channel to the superior one inside the two bands: app. 1.3 GHz for inferior band and app. 2.6 -2.7 GHz for upper band.

The DS devices are mandatory to transmit and receive using BPSK modulation, 4BOK transmission is requested for all devices and its modulation is optional.

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