INTRODUCTION TO IMPULSE RADIO SYSTEMS

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Abstract - In this document a short description to the idea of impulse radio system has been given. Due to ultra-wide frequency band of the impulse radio the transmitted signal is noiselike and does not substantially interfere with the other existing radio systems which allows the use of overlay schemes. Ultra-wideband systems also offer high accuracy for positioning and ranging applications. Impulse radio utilizes extremely short pulses that makes the spectrum of the transmitted signal ultra wide. Data modulation is introduced by pulse modulation techniques.

INTRODUCTION

Impulse radio (IR) communication systems utilize very short pulses in transmission which results in an ultra-wideband spectrum. However, as long as the regulatory bodies see IR systems as damped wave transmitters, there will be no legal basis for deployment of this technique at the communication arena, at least in the USA. The purpose of this document is to present some basic features of impulse radio systems and start conversation about the topic in Finland. The study is based on a recent literature survey concerning the impulse radio.

In IR communication, the data modulation is introduced by pulse position modulation (PPM), hence this communication method is classified as a pulse modulation technique. IR signal is noiselike which makes interception and detection quite difficult. Due to a low power spectral density, IR signals do not interfere with existing radio systems, and in this light they are not regarded as radio transmissions. This would suggest licence free operation. Technically, impulse radio signal is seen as a carrierless baseband transmission [1]. The absence of carrier frequency is the fundamental character that differs IR transmissions from narrowband applications. On the other hand, direct sequence spread spectrum multi-carrier transmissions can be characterized as (ultra-)wideband signals, as well as wideband transmissions generated by fast slewing chirps.

TECHNOLOGY BASICS OF THE EXISTING IMPULSE RADIO SYSTEMS

Signal is defined to be an ultra-wideband if the fractional bandwith B_f is greater than 0.25 [2]. The fractional bandwidth can be determined using formula $B_f=2(f_H-f_L)/(f_H+f_L)$, where f_L is the lower and f_H is the higher –3 dB point in a spectrum, respectively [2].

In its simplest form time-modulated ultra-wideband (TM-UWB) communication is based on the emission of very short Gaussian monocycles which makes the signal ultra wide in frequency domain [1]. One transmitted data bit is spread over multiple Gaussian monocycles, and the data modulation is introduced by pulse position modulation (PPM). The receiver is a cross correlator matched filter receiver where any frequency conversions are not needed.

Because the transmission is not continuous, the communication is resistant to the severe multipath propagation and thus there is no ISI. Due to the short pulse width and relative slow pulse repetition frequency, the transmitted pulse is attenuated before the next pulse is sent which reduces inter-pulse interference.

In the time domain, a Gaussian monocycle can be defined as the first derivative of the Gaussian function. The nominal center frequency and the bandwidth of the monocycle depends on the monocycle pulse width. Bandwidth is about 116 % of the monocycles nominal center frequency [1]. The spectrum of TM-UWB signal is also asymmetrical. A Gaussian monocycle has a single zero crossing. If additional derivates of the Gaussian function are taken the relative bandwidth decreases, and the center frequency increases for a fixed time decay constant.

PPM allows matched filter technique to be used in the receiver. In this technique the precise timing of transmission of a monocycle is varied about its nominal pulse position. If the transmitted digital bit is “0” the pulse is transmitted some time shift before the nominal time and in the case of “1” the timing is delayd. Time shift can be about one-quarter of a pulse width [3].

PPM spreads the signal RF energy across the frequency band and makes the signal less detectable. When using pseudo random (PR) code to determine random transmission time over a large time frame, the spectrum of the transmitted pulse appears like a white noise. Time hopping randomizes the signal in both time and frequency domains and also eliminates collisions in multiple access systems, where each user has a distinct pulse shift pattern [4]. Due to the PR time-modulation, the detector needs accurate knowledge about the PR code phase. One can imagine impulse radio systems as time hopping spread spectrum (SS) systems. UWB waveforms are, however, generated without modulating with an additional spreading code which simplifies the transmitter structure compared to SS systems [5]. The bit rate of the transmission can be chosen by changing the number of pulses to modulate a single data bit [6].

Because Gaussian monocycles have good signal penetration capabilities, the transmitted power level can even be less than 1 mW, and the transmitter does not need a power amplifier. This reduces cost and power consumption of IR devices. A critical component in the IR systems is antenna which acts like a filter. Generation of a very short pulse is also a key issue in transmitter implementation. This all demands high performance of the digital switches. Also accurate time references are needed to satisfy the coherence requirements.

Optimal receiver for single-user IR system (without ISI) is a cross correlation receiver, whose structure is based on matched filter consisting of an analog multiplier bank followed by an integrator. Integration time at the correlator is the duration of the pulse. This means time slots less than a nanosecond for the multiply and integrate process. Due to the modulation scheme, the receiver can be an early/late detector [3].

Because of noisy propagation environment and low pulse energy, detection of one and single pulse is rather impossible. During the pulse integration process, numerous correlator samples are added coherently together to solve the problems of low SNR. The output of the correlator is an estimator of the time of arrival of the received noisy pulse [3]. TM-UWB systems have high processing gains that result from the duty cycle gains and from the pulse integration gains. Processing gains are typically as high as 50 dB [3].

ADVANTAGES OF THE IMPULSE RADIO

Due to the low energy density and the PR characteristics the transmitted signal is noiselike, which makes its detection difficult. Low power IR systems are not classified as a radio equipments as the low power spectral density of the transmission does not interfere existing radio systems.

Time-modulation systems offer high data rates for communication; tens to hundreds of Mb/s has been proposed for communication links. The estimated number of simultaneous users in an IR communication system has been estimated to be much larger than in conventional systems. However, the range of the system will decrease when increasing the number of users to retain low spectral density towards other systems.

Because of the ultra-wide bandwidth of the transmitted signal, a very high multipath resolution is achieved. Large bandwidth offers (and also demands for) a huge frequency diversity. Together with an intermittent transmission this all makes the IR signal resistant to severe multipath fading and fights effectively jamming/interference. IR systems offer also good LPI and LPD properties, which is attracting especially in military applications. The penetration of IR signals through matter is better than that of conventional radio signals, which added to a precise target resolution suggests profitable applications for rescue and anti-crime operations, as well as for surveying and mining industry. The TM-UWB systems can be implemented in low cost, low power integrated circuit processes [1].

REFERENCES

[1] Time Domain Corporation (1998) Comments of Time Domain Corporation, Docket 98-154. In the Matter of Revision of Part 15 of the FCC's Rules Regarding Ultra-wideband Transmission Systems.

[2] R.J-M.Cramer, M.Z.Win, R.A.Scholtz (1998) Impulse Radio Multipath Characteristics and Diversity Reception. Proceedings of the ICC'98.

[3] P.Withington, R.Reinhardt, R.Stanley (1999) Preliminary Results from Ultra-Wideband (Impulse) Scanning Receiver. Proceedings of the MILCOM'99.

[4] M.Z.Moe, R.A.Scholtz (1997) Comparisons of Analog and Digital Impulse Radio for Wireless Multiple-Access Communications. Proceedings of the ICC'97.

[5] R.J.Fontana, J.F.Larrick, J.E.Cade: An Ultra Wideband Communications link for Unmanned Vehicle Applications. www.multispectral.com

[6] S.S.Kolenchery, J.K.Townsend, J.A.Freebersyser, G.Bilbro (1997) Performance of Local Power Control in Peer-to-Peer Impulse Radio Networks with Bursty Traffic. Proceedings of the GLOBECOM'97.