Special Issue on Ultra Wide Band (UWB) Communications

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What is Ultra Wide Band communication? Different regulation processes are currently underway at different locations of the planet such as Japan, Korea, Europe, Russia, and the USA. The first observed consequence of such a heterogeneous regulation process is the blurring of what an Ultra Wide Band signal is, and should look like.

A definition around which there is general consensus establishes that a signal is Ultra Wide Band if the occupied bandwidth is large compared to the carrier, or center frequency of the spectrum, and the signal has a high fractional bandwidth. This definition is compliant with the common adoption of the term Ultra Wide Band that comes to us from the UWB radar community, and refers to electromagnetic waveforms which are characterized by an instantaneous fractional bandwidth greater than about 0.20-0.25. With such a high bandwidth these waveforms must in principle friendly coexist with other Hertzian waveforms propagating in the air interface. This principle necessarily introduces strong limitations over UWB Power Spectral Densities, and raises the issue of designing power efficient UWB networks.

Traditionally UWB signals have been obtained by transmitting very short pulses, rather than continuous waveforms, with typically no Radio Carrier Frequency modulation. Thus, a baseband signal drives the antenna directly without r.f. circuits. This technique has been used extensively in radar applications and goes under the name of "Impulse Radio". When applied to the communication field Impulse Radio exhibits several advantages related to its physical characteristics: very broadband (>100 Mbps) data transfer, robustness against fading, flexibility of Power Spectral Density shape obtained by pulse waveforms modification, distributed control of interference levels, and possibly inexpensive transmitter/receivers for relatively short distances.

However, the above UWB definition does not strictly limit the generation of UWB signals to Impulse Radio. Spectrum expansion might be produced by a very high data rate rather than pulse width. In April 2002 the Federal Communications Commission in the USA (FCC, 2002) released UWB radio emission masks and introduced the concept of coexistence with traditional and protected radio services in the frequency spectrum. In particular, the spectral masks protect GPS, Aviation signals, satellite communication and licensed cellular, among others. The UWB definition given in the above recommendation also opened the way - at least in the USA - for non-impulsive UWB schemes. Provided that the fractional or minimum bandwidth requirements are verified at all times of the transmission the FCC established that a signal is ultra-wide if its bandwidth at -10 dB points exceeds 500 MHz, regardless of the fractional bandwidth value. The above 500 MHz value is significantly lower than the 1.5GHz limit established in the 1990's by the Defense Advanced Research Projects Agency (DARPA, 1990); the reduction was motivated by the use of the -10 dB bandwidth rather than the -20 dB bandwidth adopted in DARPA. The 500 MHz limit sets a threshold at 2.5GHz under which signals are UWB if their bandwidth exceeds 500 MHz. Above the 2.5GHz threshold signals are UWB if their fractional bandwidth exceeds 0.2. Methods such as for example Orthogonal Frequency Division Multiplexing (OFDM) and Multi-Carrier Code Division Multiple Access (MC-CDMA) are capable of generating such UWB signals, at appropriate data rates. Recent proposals in the USA, and in particular in the IEEE 802.15 Task Group 3a, refer to a Multi-Band alternative in which the overall available bandwidth is divided into subbands of at least 500 MHz. Not only the Multi-band OFDM but also Direct Sequence Spread Spectrum(DS-SS) is an alternative compliant for non-impulsive UWB scheme and has been discussed in the IEEE802.15 TG3a.

Using well-known and consolidated techniques and technologies may very likely speed-up the process of introducing in the market UWB devices. In this respect Impulse Radio communications still reserves obscured areas in which further research and development must be triggered. Commercial and industrial driven forces should not however hinder or even limit the evolution of our understanding of wireless systems based on Impulse Radio. Rather, increased research effort should tend to in-depth exploration of Impulse Radio potentials in novel communication applications. It is our considered view that cross-layer system design strategies and, in particular, the exploitation of the potential of using the physical layer to modify the definition of MAC and Network algorithms are highly desirable. Precise ranging for example and the peculiar nature of interference as provided by Impulse Radio may enable the definition of novel MAC functions. Further research is needed to go beyond the current trend witnessed in the IEEE 802.15.3 of selecting MAC strategies, typically TDMA-based, which were specifically neither tailored nor optimized to UWB peculiarities.

In this Special Issue we attempted to select papers covering both physical oriented aspects as well as system oriented issues.

The tutorial paper by Di Benedetto and Vojcic provides a short history of UWB communications, followed by a description of modulation and multiple access formats and calculation of their power spectral densities. This is followed by a discussion of multiple access capacity and comparison of time-hopping with pulse position modulation and direct-sequence spread spectrum with binary antipodal modulation. The paper concludes with a discussion of the impact of network topology and inter-network interference on multiple access performance.

The next three papers that deal with channel issues are in Section Channel Modeling and Estimation. The paper "An Empirical Indoor Path Loss Model For Ultra-Wideband Channels" by Ghassemzadeh, Greenstein, Kavčić, Sveinsson, and Tarokh introduces a statistical model for the path loss in indoor environments. Reported data are for a bandwidth of 6 GHz and center frequency at 5.0 GHz. Separate models are given for commercial and residential environments and within each category, for line-of-sight (LOS) and non-line-of-sight (NLS) paths. The next paper "Ultra Wideband Channel Model for Indoor Environments" by Alvarez, Valera, Lobeira, Torres, and Garcia presents an analysis of the UWB indoor channel model between 1 and 9 GHz, which is then used for developing a statistical UWB multipath channel model for short range indoor scenarios. The paper "Low-sampling rate UWB channel characterization and synchronization" by Maravic, Kusuma and Vetterli deals with a high-resolution frequency domain method for channel estimation and synchronization. It was shown that high-resolution channel estimates could be obtained with a sub-Nyquist sampling rate of the received signal.

Two papers deal with pulse shaping for UWB communications. The first paper "On the Design of Orthogonal Pulse-Shape Modulation for UWB Systems Using Hermite Pulses" by de Abreu, Mitchell and Kohno reviews orthogonal pulse-shape modulation using Hermite pulses. Closed-form expressions of cross-correlations among Hermite pulses and their corresponding transmit and receive waveforms are provided. A new set of elementary Hermite pulses are also derived for simple implementation. The paper " Designing optimal pulse-shapers for ultra-wideband radios" by Luo, Yang and Giannakis considers the pulse-shaper design in compliance with the FCC spectral mask, for both single- and multi-band systems.

Section Performance and System Issues contains four papers. The paper entitled "A general method for error probability computation of UWB systems for indoor multiuser communications" co-authored by Durisi, Tarable and Benedetto, describes evaluation of symbol error probability of UWB systems with various schemes of modulation and multiple access in presence of multipath channel, multiuser and narrowband interference. The next paper "Performance of M-ary PPM UWB radio in fading channels" by Abdel-Hafez, Alagoz and Hamalainen, uses the Gaussian approximation for multiple access interference to estimate the symbol error rate for several pulse shapes. The paper by Yang and Giannakis, " Digital-carrier multi-band user codes for baseband UWB multiple access", deals with codes for multi-band design. Finally, the paper " Medium access control design for UWB communication system: review and trends" by De Nardis and Di Benedetto, addresses the MAC issues in UWB communications systems, including medium sharing, MAC organization, packet scheduling, power control and ranging and positioning.

We are most pleased to have been part of the effort in getting this timely and, we hope timeless, technical contributions to the new field of UWB; a technology that will arguably impact the wireless world in large, but not yet fully knowable ways.

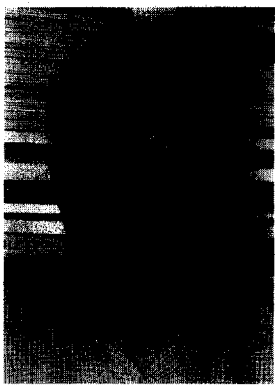
Acknowledgements

We would like to thank all authors for their contributions. We unfortunately also had to reject some interesting contributions due to space and time limitations associated with a special issue and its natural deadlines. We are very grateful to the reviewers for their effort, and to the JCN editorial board and in particular Prof. B. G. Lee, our Editor-in-Chief and the editorial staff.

References

DARPA (1990), OSD/DARPA, Ultra-Wideband Radar Review panel, "Assessment of Ultra-Wideband (UWB) Technologies," DARPA, Arlington, VA.

FCC (2002), "Revision of Part 15 of the Commission's rules Regarding Ultra-Wideband Transmission Systems," Federal Communications Commission, ET Docket 98-153, 2002.



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Maria-Gabriella Di Benedetto obtained her Ph.D. in Telecommunications in 1987 from the University of Rome La Sapienza, Italy. In 1991, she joined the Faculty of Engineering of University of Rome La Sapienza, where currently she is a Full Professor of Telecommunications at the Infocom Department. She has held visiting positions at the Massachusetts Institute of Technology, the University of California, Berkeley, and the University of Paris XI, France. In 1994, she received the Mac Kay Professorship award from the University of California, Berkeley.

Her research interests include speech analysis and synthesis, and digital communication systems. From 1995 to 2000, she directed four European projects for the design of UMTS.

Since 2000 she has been active in fostering the development of Ultra Wide Band (UWB) radio communications in Europe. She is currently the director for the Infocom Dept. of two European projects (whyless.com and UCAN) aimed at the design and implementation of UWB ad-hoc networks. Within the forthcoming 6th EU Framework her "Networking with UWB" research group will participate to the Pulsers Project which will integrate UWB research and development in Europe for the next years. Dr. Di Benedetto was co-editor for IEEE JSAC of a Special Issue on UWB Radio in Multi-Access Wireless Communications (December 2002).

Raymond L. Pickholtz, professor and former chairman of the Department of Electrical and Computer Engineering at The George Washington University received his Ph.D. in Electrical Engineering from the Polytechnic Institute of Brooklyn. He has worked on many aspects of wireless communications including Ad-Hoc Networking, CDMA, Satellite Systems, Digital Audio Broadcasting and UWB. He served on the FCC working group of the Spectrum Policy Task Force, 2002.

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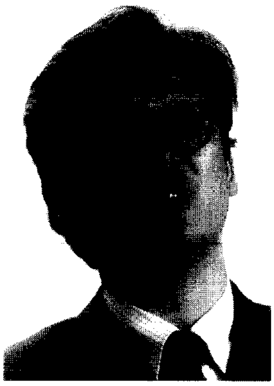

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