

BROADBAND REPEATER FOR ULTRAWIDEBAND TECHNOLOGIES

Abstract

In the coming years, ultrawideband (UWB) transmissions will dominate high data rate communications in the last 10 meters of wireless/portable access. With the huge datarates afforded by UWB, offices, homes, and small environments such as doctors offices or small buildings, will be able to rely on UWB communication devices for connections between consumer electronic devices and computer devices. The proposed invention provides a very low cost infrastructure solution that avoids the need of more expensive network hubs or access point routers required in today's WiFi/WLAN networks.

INVENTION

This invention is a low cost repeater that is taylorred for easy and rapid deployment to facilitate the interconnection of ultrawideband devices, which will likely be standardized in 2003-2004 time frame. Currently, IEEE 802.15.3a is working on creating a standard that may either be Multiband OFDM transmission, with 500 MHz channels, or a Direct Sequence Spread Spectrum impulse radio standard that has broader channel bandwidths. Ratification of one or both of these standards is likely to occur by the end of 2003, as described in a recent paper submitted by the inventor and some of his students at the University of Texas (submitted to High Frequency Electronics -- paper attached with this application, along with the references which appear at the end of the paper).

As UWB devices proliferate, it will be possible to provide immense datarates, at rates up to 480 Megabits per second, in order to create a wireless Universal Serial Bus (USB) capability. This will allow cameras, cellphones, computers, and computer and home entertainment and video systems to have very good and fast datarate transmissions in small (say 10 to 20 to 30 feet) distances. The great datarates of UWB will open up an entire new world of high speed personal area networks which currently does not exist. Companies such as Time Domain, Xtreme Spectrum Inc, Motorola, Intel and Texas Instruments, are likely to be leading manufacturers or developers of Intellectual Property for UWB communications.

In typical doctors offices, homes, apartment buildings, and large rooms, etc, today there are Wireless (WiFi) access points that can be connected to the ethernet backbone in order to provide WLAN access and internet access to computer platforms. The backbone is typically Cat-3 or Cat-5 cabling that has 10baseT, 100baseT or 1 GHz ethernet signaling. In the future, this backbone may be wireless, in last mile MIMO modem devices that bring broadband video, audio, and data/internet traffic to homes from lampposts or street corners.

Today, the expense of the WiFi access points is on the order of several hundred dollars when the hardware and installation is factored in. These access points provide the ability of multiple WLAN users (typically computer or PDA users) to gain portable access the internet, and hot spots such as those implemented by Schlotskys are becoming popular throughout the world. However, these WiFi access points are made to allow users to access the internet, which is a

different use and approach than is likely to emerge with UWB networks, which connect devices together in piconets.

In future UWB applications, it is likely that only one or two devices, such as a computer, a server, or a television set, will be connected to the ethernet/internet backbone, while many other devices, such as home entertainment systems, telephones, portable computers, and display/video/audio/entertainment devices will be untethered within the same room or within several feet of these "fixed" internet-connected devices. In hospitals, hotels, or homes and offices and businesses, the UWB technologies will open up an entirely new way of communicating high data rate, and will create entirely new architectures for communications within small spaces.

The invention described here is a low cost repeater device, which allows a home or office user to rapidly deploy a repeater which can extend the range of these UWB piconets, so that a home or business owner does not have to install wiring such as Cat -5 cable throughout an office or home. Instead of wires which carry the internet traffic from today's cable or T1 or DSL jack to a particular device, the UWB repeater invented here will allow just one or a handful of internet-connected devices to serve as the "source" for a local wireless network, and the disclosed invention will enable that "source" to serve as the local hub for a whole host of portable or fixed UWB devices in a home or office.

The Ultrawideband repeater will serve to "repeat" data signals coming from one or many devices so that other devices, located farther away from the "source" will be able to access the internet via the repeater. This will obviate the need for any wiring whatsoever in homes and offices, and will enable rapid deployment of networks beyond the standard range of stock UWB equipment. The repeater will provide for additional coverage and will enable high data rate channels to work in confined environments more efficiently and more reliably than stock UWB equipment.

Repeaters are well known in the art, and they have been manufactured for decades in the cellular and PCS industries, and more recently, a company in Melbourne FL, WiDeFi has developed WiFi repeaters for the IEEE 802.11a/b marketplace.

Our invention differs from prior art because of the much greater bandwidth of UWB, and the presently unforeseen challenges that UWB provides. Our invented repeater architecture treats only one or two sources as the key link between the ethernet (or the central server/hub and the rest of the UWB equipped devices that may exist in a room or office. In this way, for example, a doctors office would only need to have a single computer, say the receptionist's desk computer, which might be connected to the internet or not connected at all to the internet but which would serve as a host computer or server to the office. If this receptionist's desk computer was equipped with a UWB radio, and all other devices, say portable computers, pen tablets, or video monitors, or Voice over IP portable communicator devices used in the office, were configured to be on the same network (piconet) as this desk computer, then our invention would allow coverage and data transmission throughout the entire office, rather than being limited in range to 10 or 20 or 30 feet, etc.

The repeater, in order to work , requires careful signal processing that is able to null out noise

and interference across the very wide bandwidth used by UWB. In addition, the repeater must provide significant isolation between the input and the output, typically 40 to 50 dB minimum and more if possible, in order to prevent oscillation and feedforward interference. Furthermore, the UWB repeater must faithfully retransmit both the forward and reverse paths of a two way communication, and must provide uniform/even group delay across most, if not all, the occupied bandwidth of UWB. The best way to implement this invention is to use two UWB devices, standard UWB modem devices, encapsulated in a chamber which has good electromagnetic isolation between the input side (the side in which signals needing to be repeated are entering) and the output side (the side in which signals that are being repeated are regenerated and reradiated). Each physical side of the UWB repeater invention may at one time serve as the input and another time serve as the output, as the invention offers simplex, half duplex, or full duplex capability. Similarly, the forward or reverse path may use either side of the UWB repeater. Antennas, such as those developed by Prof. Hao Ling at the WNCG at University of Texas, and by Warren Stutzman of Virginia Tech, allow wideband UWB transmissions with some directionality, and these are easily sprayed on or built from metal stock using metallic film on plastic cases. Dielectric antennas may also be incorporated as is known in the prior art. The directionality will help with isolation between the input and output of the repeater. Further, the repeater may use multiple antennas, in a sector arrangement, that can automatically be sensed and switched by the UWB devices inside the repeater, in order to focus energy in directions of where devices needing to be transmitted through the repeater are located. This could be used on both or either transmit or receive operations.

An alternative approach to creating the UWB repeater invention, rather than using two stock UWB devices with some additional control logic for antenna switching or diversity/beam forming, would be to use a true bent-pipe repeater approach, where all signals at the input are simply re-radiated at the output. Note that the very wide bandwidths involved with UWB make this approach more difficult, yet viable in a low noise environment that does not have swamping. Even in higher noise environments, DSP noise cancellation and wideband compensation such as phase linear processing across the wideband spectrum could be employed. This type of DSP processing will be available in reasonably low cost platforms in the next several years.

The form factor of the UWB repeater may take on a wide range of sizes, shapes, and mounting/fixture options. This repeater could be installed in PCs, servers, or appliances, or they could be stand alone devices that could be purchased and placed in any home or office, much like one purchases a fire alarm or a fire extinguisher today. Fixtures, colors, shapes, and sizes may be very similar to fire alarms or air fresheners that plug into AC outlets in the home, and the repeater device may also become embedded in objects that are typically carried around the home or office, such as but not excluding cordless phones, cell phones, portable computers, home stereos, tvs, pet collars, tennis shoes, and a wide range of portable, common devices that when moved could provide a wide array of range extension and coverage improvements of UWB devices.

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The Evolution of Ultra Wide Band (UWB) Radio for Wireless Personal Area Networks (WPAN).

ABSTRACT

Ultra wideband wireless networks are in their infancy, but are poised to become a vital component of consumer electronics and computer equipment. The IEEE 802.15.3a standards task group is currently developing a standard which involves most of the major chip manufacturers, including Texas Instruments, Intel, Motorola, and Xtreme Spectrum. This article provides a snapshot of the current state of the UWB standards process, which is presently set to be determined by 2004. We also discuss the benefits of UWB radio, the regulatory environment of UWB, and the design issues facing WPAN standards makers.

Introduction

There are huge bandwidths (many GHz) authorized for license-free Wireless Personal Area Networks (WPANs), using a new spectrum called UWB. UWB promises to usher in an era of unprecedented high-connectivity consumer products in the home, such as video conferencing, wireless video and audio distribution systems in the home, new home entertainment appliances, diskless computers, and position location and navigation applications.

The concept of ultra wideband communication originated with Marconi, in the 1900s, when spark gap transmitters induced pulsed signals having very wide bandwidths. Spark transmissions created broadband interference and did not allow for coordinated spectrum sharing, and so the communications world abandoned wideband communication in favor of narrowband, or tuned, radio transmitters that were easy to regulate and coordinate.

The FCC, in the mid 1980's, encouraged an entirely new type of wideband communications when it allocated the Industrial Scientific and Medical (ISM) bands for unlicensed spread spectrum and wideband communications use. This revolutionary spectrum allocation is most likely responsible for the tremendous growth in Wireless Local Area Networks (WLAN) and Wi-Fi today, as it led the communications industry to study the merits and implications of wider bandwidth communications than had previously been used for consumer applications. The Shannon-Hartley theorem states that channel capacity grows linearly with bandwidth and decreases logarithmically as the signal to noise ratio (SNR) decreases. This relationship suggests that radio capacity can be increased more rapidly by increasing the occupied bandwidth than the SNR. Thus, for WPANs that only transmit over small distances, where signal propagation loss is small and less variable, greater capacity can be achieved through greater bandwidth occupancy.

Many companies (such as Xtreme Spectrum and Time Domain) argued that they should be allowed to intentionally transmit at the incidental radiated power limits set by the FCC (where other narrowband users were already allowed to transmit accidentally), over an

ultra-wide bandwidth, to take advantage of the capacity potential of UWB. This argument, that low power wireless services could operate below authorized out-of-band emissions limits to provide meaningful communications, was the key motivation for the FCC approval of UWB. This important concept is still being discussed by the FCC and its Technological Advisory Council (see minutes of FCC TAC, July 7, 2003, presentation by Michael Marcus).

On February 14, 2002, the FCC amended the Part 15 rules which govern unlicensed radio devices to include the operation of ultra wideband (UWB) devices. The use of UWB under the FCC guidelines [1] offers tremendous capacity potential (several Gbps) over short ranges (less than 10 meters) at low radiated power (mean EIRP of -41.3 dBm/MHz). The FCC defines UWB signals as having a fractional bandwidth (the ratio of baseband bandwidth to RF carrier frequency) of greater than 0.20, or a UWB bandwidth greater than 500 MHz. UWB bandwidth is defined as “the frequency band bounded by the points that are 10 dB below the highest radiated emission” [9].

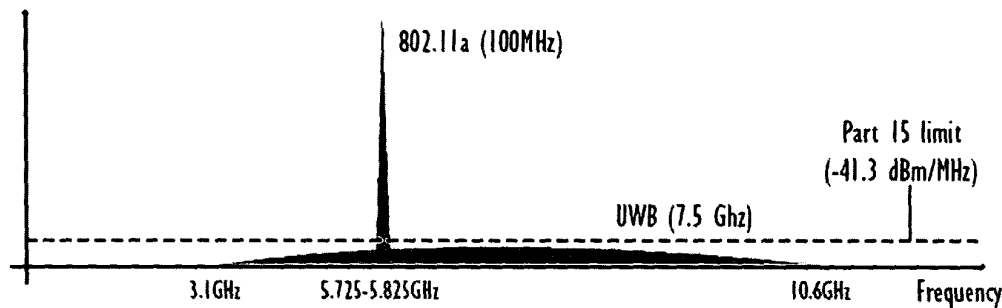


Figure 1 – Spectrum of UWB Signal Compared with Wi-Fi (802.11a) Signal [10].

The FCC ruling allows UWB devices to operate at low power (an EIRP of -41.3 dBm/MHz) in an unlicensed spectrum from 3.1 to 10.6 GHz (see Figure 1), with out of band emission masks that are at substantially lower power levels. The low in-band and out-of-band emission limits for UWB are to ensure that UWB devices do not cause harmful interference to (i.e. are able to coexist with) “licensed services and other important radio operations” [9] (such as cellular, PCS, GPS, 802.11a, satellite radio, and terrestrial radio). Table 1 summarizes a few of the guidelines most relevant to the use of UWB technology in WPAN devices. The fact that the FCC allowed UWB to be a minimum bandwidth of 500 MHz is important, because while UWB can occupy several GHz of bandwidth using small pulses (as pioneered by Xtreme Spectrum and Time Domain [23], [30]), the 500 MHz bandwidth rule has provided the impetus for chip makers to consider “channelization”, or a multiband approach, in the UWB standardization activity, as a hedge against foreign governments who may not authorize the full 3.1 – 10.6 GHz UWB band allocation.

Operating frequency range	3.1 GHz to 10.6 GHz
Average radiated emissions limit	
Frequency range (MHz)	mean EIRP in dBm/MHz (indoor/hand held)
960-1610	-75.3 / -75.3
1610-1900	-53.3 / -63.3
1900-3100	-51.3 / -61.3
3100-10600	-41.3 / -41.3
Above 10600	-51.3 / -61.3
Peak emission level in band	60 dB above average emission level
Max unacknowledged transmission period	10 seconds

Table 1 – FCC requirements for indoor and hand held UWB systems [9].

The key to UWB will be the development of low power CMOS chip technology up to the 10 GHz band, which most manufacturers are presently perfecting. Spectrum regulators in other countries have yet to authorize UWB in other countries, and are waiting to see how UWB performs in the US. In fact, the standards activity in the US is being developed to anticipate varying spectral allocations in other countries.

Standards Activity of WPANs: IEEE 802.15

The standards activity of Wireless Personal Area Networks (WPANs) are governed by IEEE 802.15, an international standards working group which involves dozens of major companies. IEEE 802.15 (<http://grouper.ieee.org/groups/802/15/>) is responsible for creating a variety of WPAN standards, and is divided into four major task groups which are summarized in Figure 2. While this article focuses on the standardization efforts of UWB, which is the purview of IEEE 802.15.3a, an overview of all IEEE 802.15 efforts is useful to understand the WPAN landscape.

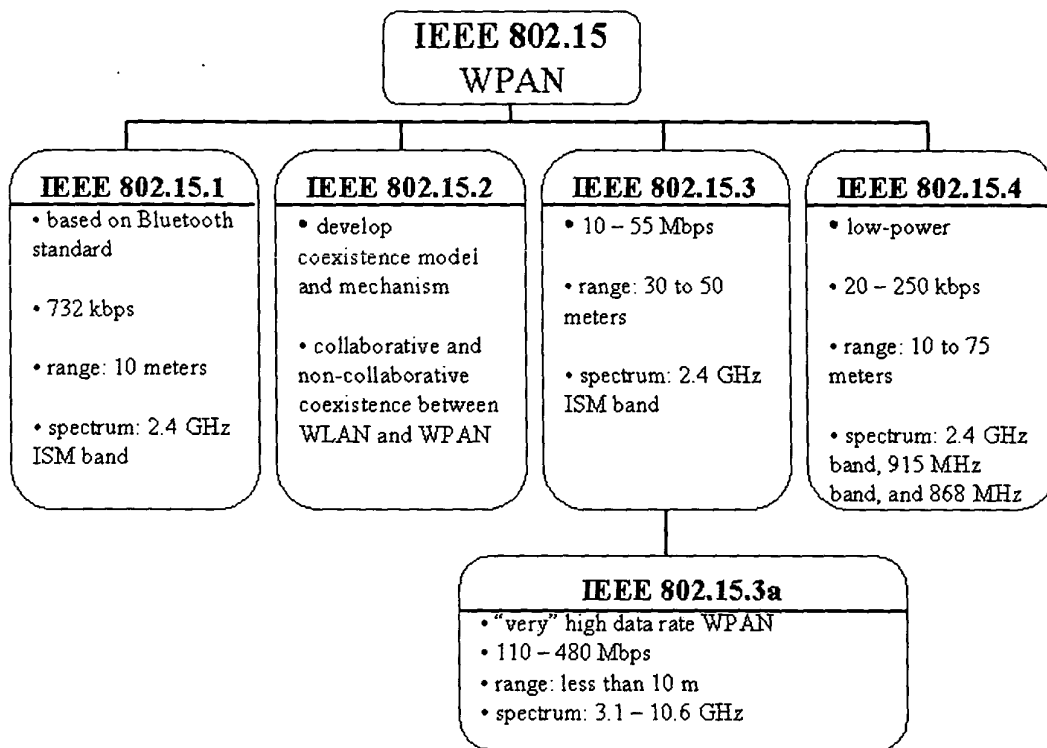


Figure 2 – Organization of IEEE 802.15.

The IEEE 802.15.1 task group was responsible for forging the standard based on Bluetooth v1.1 [2]. Bluetooth uses a short-range radio link (up to 10m) to transmit data between personal devices, forming an ad-hoc network in the unlicensed 2.4 GHz band. The Bluetooth standard uses frequency hopping spread spectrum (FH-SS) with up to 1600 hops/s among 79 frequencies separated by 1 MHz intervals, and transmits 1 Msymbol/s using Gaussian shaped BFSK symbols (BT=0.5). Data traffic can reach a maximum of 732 kbps (unidirectional) and 64 kbps (bi-directional). The 802.15.1 standard includes an adaptation of the Bluetooth Media Access Control (MAC) and physical (PHY) layers as well as a Logical Link Control/MAC (LLC/MAC) interface. In addition, it includes a high-level behavioral specification and description language (SDL) model for an integrated MAC sublayer. The 802.15.1 standard will eventually allow data transfers between a WPAN device and an 802.11 device. The IEEE Standards Association (IEEE-SA) approved this standard on April 15, 2002 and it was published on June 14, 2002.

IEEE 802.15.2 is concerned with coexistence issues that arise when two wireless systems share an environment of operation [3]. The IEEE 802.15.2 task group has two goals: 1) to quantify the effects of mutual interference between WPAN and WLAN devices; and 2) to establish mechanisms for coexistence of WPAN and WLAN (e.g. IEEE 802.15.1 and IEEE 802.11b) at both the MAC and PHY layer. These mechanisms can be broadly categorized as collaborative or non-collaborative. Some of the metrics for evaluating the

performance of a coexistence method include the receiver sensitivity degradation (in dB) and the reduction of throughput in the presence of an interferer. A collaborative mechanism that facilitates coexistence needs to have coordinated scheduling efforts, such as TDMA or CSMA. Adaptive frequency hopping, MAC scheduling, and transmit power control schemes are non-collaborative mechanisms for coexistence [4]. The task group is establishing recommended practices for coexistence between WLAN and WPAN

The IEEE 802.15.3 task group is developing WPANs up to 55 Mbps. The draft standard operates on five 15 MHz channels in the 2.4 GHz ISM band, two of which interfere with IEEE 802.11b traffic. Modulation (QPSK, DQPSK, 16/32/64-QAM) and coding (trellis-coded modulation) are varied to provide five data rates (11 Mbps, 22 Mbps, 33 Mbps, 44 Mbps, and 55 Mbps) [5]. The MAC layer described by this standard allows for the coordination of WPAN devices to form piconets. The MAC layer also allows for multimedia quality of service (QoS), power management, and 'ad-hoc' networking support. IEEE 802.15.3 gained sponsor ballot approval in May 2003. The focus of UWB occurs in IEEE 802.15.3.a, which is a separate task group discussed below.

The IEEE 802.15.4 task group is focused on low data rate, low power WPAN (LP-WPAN). IEEE 802.15.4 investigates low data rate WPAN solutions with a battery life ranging from months to several years and a very low complexity. The IEEE 802.15.4 standard is intended to operate in unlicensed and international frequency bands. The spectrum allocation for this standard is as follows: 1 channel at 868 MHz, 10 channels in the 915 MHz band, and 16 channels in the 2.4 GHz band [6]. Using either MSK or BPSK (depending on the data rate), this standard transmits a spread spectrum signal. The range is 10 to 75 meters nominally, depending on the consumption for a given application. The MAC layer included in this standard supports various ad-hoc topologies and guaranteed packet delivery. IEEE-SA approved the draft proposed by IEEE 802.15.4 on May 12, 2003.

The remainder of this article focuses on the up-to-the minute standardization activities of IEEE 802.15.3a, concerned with very high data rate WPAN, where UWB is employed. IEEE 802.15 Task Group 3a was formed in late 2001 to identify a higher speed physical layer alternative to 802.15.3. The IEEE 802.15.3a task group is aimed at developing physical layer standards to support data rates between 110 Mbps and 480 Mbps over short ranges of less than 10 meters (i.e. alternatives for the original IEEE 802.15.3 physical layer). It should be noted that 802.15.3.a is only concerned with physical layer alternatives and uses the same MAC layer as IEEE 802.15.3, which is described in [8].

IEEE 802.15.3a: Current Status

The IEEE 802.15.3a task group (also called "TG3a"), established technical requirements and selection criteria (see Table 2) for a WPAN physical layer in December 2002, and is currently debating proposals submitted by various companies (including Intel, Texas Instruments, Motorola and Xtreme Spectrum). The IEEE 802.15.3a task group set forth goals for low power consumption and low cost to ensure that the WPAN standard is amenable to implementation in CMOS technology. These requirements will ensure that

the high data rate physical layer drafted by 802.15.3a can be easily integrated into WPAN devices which have MAC and network layers already implemented in CMOS technology [8].

The flexible standard to be developed by TG3a will enable data rates of 110 – 480 Mbps (data rates necessary for wireless USB), WPAN over a cost effective architecture, and will operate on the IEEE 802.15.3 MAC layer which is already well defined [8]. The new TG3a standard will enable a broad range of applications, including multimedia requiring in excess of 100 Mbps (e.g. wireless video conferencing).

Parameter	Value
Data Rates (measured at PHY-SAP)	110, 200 and (optional) 480 Mbps
Range	10 m, 4 m, and below
Power Consumption	100 mW and 250 mW
Power management modes	Capabilities such as power save, wake up etc
Co-located piconets	4
Interference susceptibility	Robust to IEEE systems, PER < 8% for a 1024 byte packet length
Co-existence capability	Reduced interference to IEEE systems, interfering average power at least 6dB below the minimum sensitivity level of non-802.15.3a device
Cost	Similar to Bluetooth
Location awareness	Location information to be propagated to a suitable management entity
Scalability	Backwards compatibility with 802.15, adaptable to various regulatory regions (such as the US, European countries, or Japan).
Signal Acquisition	<20 μ s for acquisition from the beginning of the preamble to the beginning of the header
Antenna practicality	Size and form factor consistent with original device

Table 2 – Summary of Tech. Requirements and Selection Criteria for 802.15.3a [19, 20].

Since IEEE 802.15.3a began hearing proposals in March 2003, many companies have merged their ideas and collaborated to form coalitions which support a single proposal. Before TG3a's May 2003 meeting, The UWB Multiband-Coalition was (<http://www.uwbmultiband.org>) led by Intel and includes several other major companies ([33], [34], [35], [36], [37], [38]) who support a multiband approach which employed pulsed modulation. On July 14, 2003, industry titans Intel and Texas Instruments merged their proposals to form a united approach that employs multiple bands and uses OFDM modulation. The newly formed Multiband-OFDM Coalition (<http://www.multibandofdm.org>), whose membership includes TI and the membership of the UWB Multiband-Coalition, endorses a proposal which is essentially the same as the original TI proposal, with an optional operating mode which uses seven bands (as opposed to three) [43]. TG3a heard its final round of proposals at their July 21-25, 2003 meeting and now faces the task of selecting one or more approaches to draft a standard from.

After its July 2003 meeting, TG3a is now left with two primary contenders: (1) The Texas Instruments OFDM-based multiband approach which uses 528 MHz channels (three mandatory lower band channels and four optional upper band channels) supported by the Multiband-OFDM Coalition, and (2) the Xtreme Spectrum - Motorola dual-band Impulse Radio spread spectrum approach, where there is a high band (above the 5.2 - 5.8 GHz unlicensed band) and a low band (from 3.1 GHz to just below the 5.2 - 5.8 GHz unlicensed band), and which exploits all of the UWB spectrum allocation.

If the standardization process finishes according to the TG3a timeline (see Figure 3), high data rate WPAN devices with IEEE 802.15.3a will be available well before 2005.

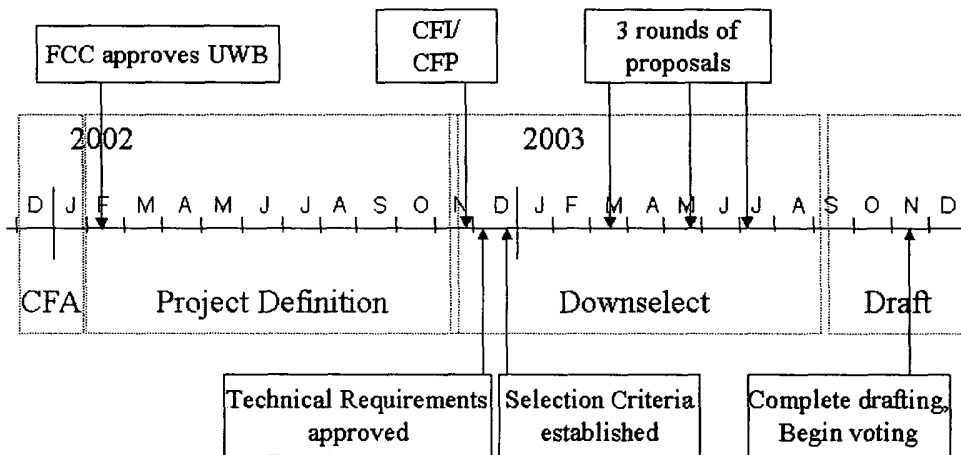


Figure 3 – IEEE 802.15.3a Timeline [7].

Company	Multiband-OFDM Coalition (presented by TI)
Spectrum Allocation:	
# of bands	3 (1 st generation bands), 10 optional bands
Bandwidths	528 MHz
Frequency ranges	Group A: 3.168 – 4.752 GHz, Group B: 4.752 – 6.072 GHz, Group C: 6.072 – 8.184 GHz, Group D: 8.184 – 10.296 GHz
Modulation Scheme	TFI-OFDM (with 128-point FFT), QPSK
Coexistence method	null band for WLAN (~5 GHz)
Multiple access method	Time frequency interleaving (TFI)
# of simultaneous piconets	4
Error correction codes	Convolutional code
Code rates	11/32 @ 110 Mbps, 5/8 @ 200 Mbps, 3/4 @ 480 Mbps
Link margin	5.3 dB @ 10 m @ 110 Mbps, 10.0 dB @ 4 m @ 200 Mbps, 11.5 dB @ 2 m @ 480 Mbps
Symbol period	312.5 ns OFDM symbol
Multipath mitigation method	1-tap (robust to 60.6 ns delay spread)

Table 3: Overview of the TI Multiband-OFDM Physical Layer Proposal supported by the newly formed Multiband-OFDM Coalition [28], [43].

As shown in Table 3, Texas Instruments prefers a channelized UWB system. There are 3 Group A bands which are used for standard operation. The 4 Group C bands are allocated for optional use in areas where simultaneous operating piconets are in close proximity (this is only used at close proximity since propagation loss severely limits signals at these higher frequencies). Group B and D bands are reserved for future expansion. Each band uses frequency hopping orthogonal frequency division multiplexing (TFI-OFDM), which allows for each UWB band to be divided into a set of orthogonal narrowband channels (with much larger symbol period duration). Because of the increased length of the OFDM symbol period, this modulation method can successfully reduce the effects of ISI. However, this robust multipath tolerance comes at the price of increased transceiver complexity, the need to combat inter-carrier interference (ICI), and tighter linear constraint on amplifying circuit elements. The University of Minnesota also proposed a similar OFDM approach [29].

Company	XtremeSpectrum
Spectrum Allocation:	
# of bands	2
Bandwidths	1.368 GHz, 2.736 GHz
Frequency ranges	3.1 GHz – 5.15 GHz, 5.825 GHz – 10.6 GHz
Modulation Scheme	BPSK, QPSK, DS-SS
Coexistence method	null band for WLAN (~5 GHz)
Multiple access method	Ternary CDMA
# of simultaneous piconets	8
Error correction codes	Convolutional code, Reed-Soloman code
Code rates	$\frac{1}{2}$ @ 110 Mbps, RS(255,223) @ 200 Mbps, RS(255,223) @ 480 Mbps
Link margin	6.7 dB @ 10 m @ 114 Mbps, 11.9 dB @ 4 m @ 200 Mbps, 1.7 dB @ 4 m @ 600 Mbps
Chip time	731 ps (Low band), 365.5 ps (High band)
Multipath mitigation method	Decision feedback equalizer and RAKE

Table 4: Overview of the Xtreme Spectrum CFP Document [30].

The Xtreme Spectrum - Motorola proposal uses a dual band approach, as shown in Table 4, which employs short duration pulses to transmit over each band, having bandwidth in excess of 1 GHz (this is often referred to as *impulse radio*). Xtreme Spectrum's design benefits from a coding-gain achieved through the use of direct sequence spread spectrum (DS-SS) with 24 chips/symbol, and exploits the Hartley Shannon principals to a greater degree than the Multiband-OFDM approach, has greater precision for position location, and realizes better spectrum efficiency. However, it has less flexibility with regard to foreign spectral regulation and may be too broadband if foreign governments choose to limit their UWB spectral allocations to smaller ranges than authorized by the FCC. Sony [31] and Parthus Ceva [32] also have offered similar proposals which employ DS-SS over very wide bandwidths. A comparison of the trade-offs between impulse radio and multibanded UWB is presented next to emphasize the primary differences between the Xtreme Spectrum - Motorola and the Multiband-OFDM Coalition proposals.

Impulse Radio (IR) vs. Multibanded UWB

The two major approaches being considered by IEEE 802.15.3a primarily differ with regard to their allocation of UWB spectrum. Impulse Radio (IR), the traditional approach to UWB communication, involves the use of very short-duration pulses that occupy a single band of several GHz. Data is commonly modulated using pulse-position modulation (PPM); and multiple users could be supported using a time-hopping scheme

[21]. Xtreme Spectrum's proposals, similar to two independent IR bands, uses a high chip rate direct sequence spread spectrum (DS-SS) signal to occupy its bandwidth.

The other approach to UWB spectrum allocation is a multibanded system where the UWB frequency band from 3.1 – 10.6 GHz is divided into several smaller bands. Each of these bands has to have bandwidth greater than 500MHz, to comply with the FCC definition of UWB. Frequency hopping between these bands can be used to facilitate multiples access. Companies in the newly formed Multiband-OFDM coalition support this approach primarily because it has greater flexibility in adapting to the spectral regulation of different countries and avoids transmitting in already occupied bands. Figure 4 illustrates the division of the UWB spectrum into sub-bands.

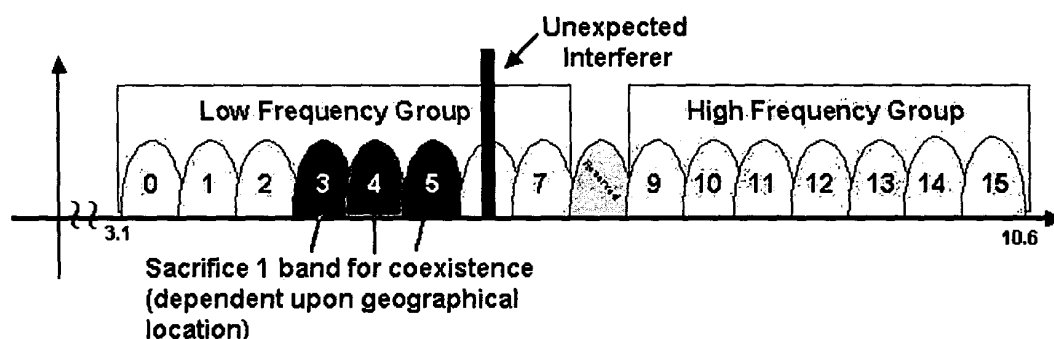


Figure 4 – Time Domain Corp.'s Multiband Spectrum Allocation [23].

Performance Comparison of Multiband OFDM vs. DS-SS IR

In the presence of a severe Narrow Band Interferer (NBI), as described in [25], a multiband system would drop the band under attack, thereby reducing its bandwidth efficiency and overall capacity. An impulse radio system (as employed by Xtreme Spectrum, also known as DS-CDMA) could mitigate these effects through the processing gain inherent in a DS-SS system with a RAKE receiver [24].

OFDM can be thought of as several, parallel, narrowband channels (subbands), and thus each subband undergoes parallel flat fading in the indoor channel. This means that OFDM does not require a digital equalizer in its receiver structure, whereas a CDMA IR receiver needs a RAKE equalizer to exploit multipath. The longer symbol period used in OFDM makes it less sensitive to timing jitter in the receiver as opposed to Impulse Radio which has much shorter time pulses. OFDM's resistance to frequency selective fading comes at the price of greater inter-carrier interference (ICI) from its own subband transmissions, and greater sensitivity to dynamic range (thus requiring a higher peak to average power ratio, and thus more battery drain). IR proponents argue that because of the long pulses used in the Multiband-OFDM approach, such a method cannot capture the benefits of signal processing techniques used to mitigate multipath and improve signal detection and ranging accuracy (techniques requiring high multipath resolution provided by wide signal bandwidth) [44].

In the presence of multipath, the wider bandwidth of impulse radio leads to more resolvable multipath components. The RMS delay spread of an indoor environment (~25 ns or less [27]) is larger than an IR pulse, but is much less than the OFDM multiband approach. Thus, the channel looks like a flat fading channel for the OFDM subband approach, which could cause fading and difficult propagation situations when multipath combines to provide a deep fade at a particular location; whereas the IR approach exploits multipath by its fine timing resolution, but requires signal processing to equalize or gate-time multipath to improve reception. In addition, the greater number of resolvable multipath components increases the number of rake fingers needed for the impulse-based approach for a given signal to interference ratio (SIR), leading to a more complex receiver.

Multibanded UWB, as proposed by the TI/Intel Multiband- OFDM coalition, has greater flexibility in coexisting with other international wireless systems and future government regulators, who may choose to limit UWB spectrum allocations to smaller contiguous bandwidths than the US allocation. OFDM is a new and complex multiple access method, but is gaining popularity in WLAN and IEEE 802.11a and 802.16 standards activities. DS-CDMA has better multipath resolution and bandwidth efficiency, and seems more in the spirit of the FCC's original UWB concept, but will likely need a RAKE receiver with considerably more fingers than today's popular CDMA cellphone RAKE which has only a few fingers. DS-CDMA Impulse Radio has already been implemented in working silicon, whereas OFDM has been proven in IEEE 802.11a. Both approaches represent an exciting modern approach to wireless high speed data. While the jury has not yet cast its ballot, it is possible that both standards may survive.

CONCLUSION

The FCC approval of UWB for commercial use has prompted the IEEE 802.15.3a standards committee to explore a new physical layer standard for consumer electronics applications. Two leading standards proposals have emerged, and the commercialization of UWB is just around the corner. Based on the selection criteria and technical requirements set forth by the task group, it is likely that a proposed method and drafting of the standard should be completed by November 2003.

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