UWB (WPAN)

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***Abstract*— An unprecedented transformation in the design, deployment, and application of short range wireless devices and services is in progress today. A key driver in this transition is the steep growth in both demand and deployment of WLANs/WPANs based on the wireless standards within the IEEE 802 suites [1]. UWB technology has the potential to become a viable and competitive wireless technology for short range high-rate WPANs as well as lower-rate and low-power-consuming low-cost devices and networks, with the capability to support a truly pervasive user-centric and thus personal wireless world. Here, in this paper we present the main issues of UWB for WPANs: definitions, features, advantages, standards, development, applications, and technologies.**

***Index Terms*— UWB (Ultra Wide Band), WPAN (Wireless Personal Area Network).**

I. Introduction

THE UWB is a technique that has received a lot of attention recently, in particular in the US. The FCC has licensed its use and a number of new companies have staked their future on its success. In Europe there is more of an air of caution, with some concern about the interference it could cause.

The UWB technology is already used in military applications and it may see increased use in the future for wireless communications and ranging. The technology offers many advantages over conventional narrowband and wide-band systems. Due to the very wide bandwidth a fine time resolution can be achieved. The UWB signal penetrates many materials providing a functionality that would not be present in a system of comparable bandwidth at a significantly higher center frequency. High processing gains can be obtained that allow a large number of users to access the system [2] [3].

II. UWB technology basics

A. What is UWB

Ultra Wideband is an innovative wireless technology which can transmit digital data over a wide frequency spectrum with very low power and at very high data rates [4]. UWB can be defined as a radio technology that modulates impulse based waveforms instead of continuous carrier waves. Figure1 illustrates the difference of the UWB communication system

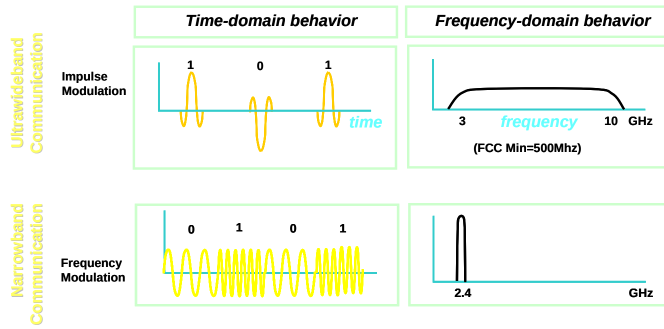

Fig. 1. Time & frequency behaviors for UWB & narrow band systems [5].

compared to the narrow band communication system in both time and frequency behaviors.

Under FCC regulation, the UWB mean the systems with occupied fractional bandwidth more than 0.2 or absolute

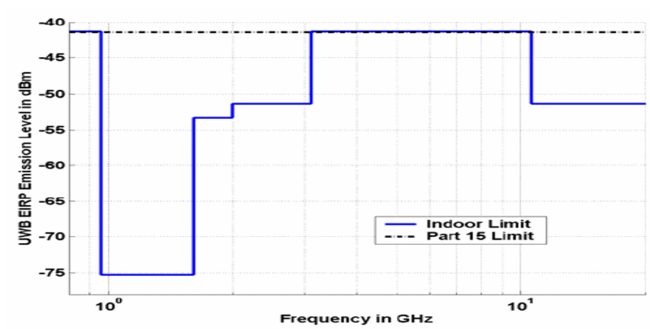

Fig. 2. FCC mask for UWB systems [6].

bandwidth more than 500 MHz under the mask as illustrated in Figure2.

B. UWB signals & modulations

UWB Signals can be generated from an impulse followed by shaping filter and Chirp signals which is suitable for non-coherent pulse transmissions. Another method to generate UWB signals is using synchronous pulse synthesis which is best suited for frequency/time-agile systems and synchronous systems. Moreover, OFDM and COFM techniques can be also used to generate UWB signals that best suited for fine PSD

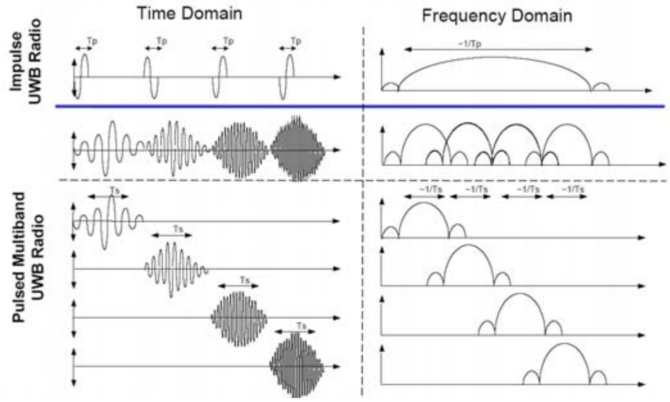

Fig. 3. The multiband UWB idea [9].

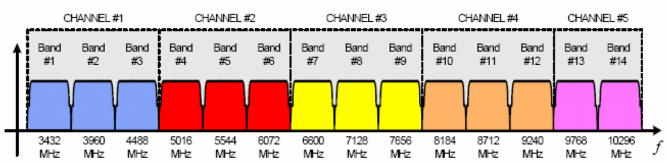

Fig. 4. Multiband UWB OFDM band plan [9].

tailoring. UWB-OFDM signal has the capability to be implemented by different multiple access schemes. Figure3 illustrate the idea of multiband UWB OFDM and Figure4 demonstrates an example of multiband UWB OFDM band plan.

UWB basic impulse information modulation may be: Pulse Position Modulation (PPM), Pulse Amplitude Modulation (PAM), On-Off Keying (OOK), and Bi-Phase Modulation (BPSK). However, nowadays the favor is to OFDM technology [7] [8].

C. UWB spectrum

FCC ruling permits UWB spectrum overlay. UWB spectrum is shown in Figure5. FCC ruling was issued in 2002 after about four years of study and public debate. FCC believes that the current ruling is conservative.

UWB is a unique and new usage of a recently legalized frequency spectrum. UWB radios can use frequencies from 3.1 GHz to 10.6 GHz—a band more than 7 GHz wide. Each radio channel can have a bandwidth of more than 500 MHz, depending on its center frequency. To allow for such a large signal bandwidth, the FCC put in place severe broadcast power restrictions, see Figure2. By doing so, UWB devices can make use of an extremely wide frequency band while not emitting enough energy to be noticed by narrower band

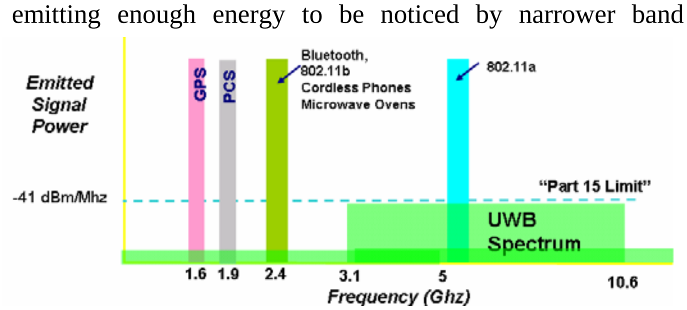

Fig. 5. FCC UWB spectrum [5].

devices nearby, such as 802.11a/g radios. This sharing of spectrum allows devices to obtain very high data throughput, but they must be within close proximity [5] [10].

D. UWB channel model

The UWB channel can be described by its time-variant impulse response, which can be expressed as:

TABLE I
OVERVIEW OF REPORTED UWB MEASUREMENTS IN FREQUENCY AND TIME DOMAINS

	UWB channel measurements	Frequency range [GHz]	Environment	Distance [m]
Frequency domain	Keignart (LETI) [2]	2-6	lab/office	up to 20
	Intel [4]	2-8	residential	1-20
	Ghassemzadeh (AT&T) [3]	4.375-5.625	residential	1-15
	Kunisch (IMST) [1]	1-11	office	3-10
Time domain	Yano (TDC) [6]	1.25-2.75	office	2-17
	Intel [4]	2-8	residential	1-20
	Win (TDC) [5]	0-1.3	lab/office	1-15

$$h(t,\tau) = \sum_{n=1}^{N(t)} a_n(t)\delta(t-\tau_n(t))e^{j\theta_n(t)}$$

where the parameters of the nth path: α_n ,θ_n , and τ_n are amplitude, delay, phase, and number of relevant multipath components, respectively. Another approach to characterize the UWB channel is to use the frequency domain autoregressive (AR) model. The basic idea of AR modeling is that the frequency response of the UWB channel at each point can be modeled by an AR process. Table I presents some UWB channel measurements in both time & frequency domain in different environments [11].

E. UWB system model & performance evaluation

Figure6 shows the block diagram of a pulse-based UWB transceiver. Built using 0.18µm CMOS technology, the UWB transceiver comprises of the transmitter and receiver integrated circuits (ICs). The transmitter IC contains modules like pulse generator, analog pulse modulator (APM) and driver amplifier (DA) whereas the receiver IC consists of modules such as low noise amplifier (LNA), variable gain amplifier (VGA), integrator, analog pulse demodulator (APD) and analog-to-digital converter (ADC). The transceiver meets the requirements, as illustrated in Table II.

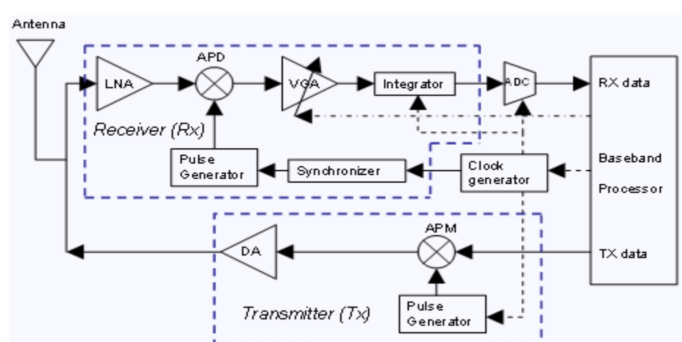

Fig. 6. UWB Transceiver System Diagram [12].

TABLE II
TRANSCEIVER'S PERFORMANCE TO IEEE 802.15.3A REQUIREMENTS [12]

IEEE 802.15.3A Requirements	IME Transceiver
Bit rate (PHY-SAP) 480, 200, 110Mbps	~100Mbps to 400Mbps
Range 1m, 2m, 10m	~2m
Power consumption 250mW, 100mW	~84mW (Tx+Rx)
Co-located piconets 4	4
Interference capability Robust to IEEE systems	YES
Co-existence capability Reduced interference to IEEE systems	YES

UWB shows significant throughput potential at short range as shown in Figure7, which represents the theoretical data rates over range for the UWB compared with IEEE802.11a. Also, Figure8 shows the UWB performance for different encoding rules. An example of UWB link analysis is illustrated in Figure9. The high capacity achieved by UWB is very clear in Figure10 when compared with other wireless technologies.

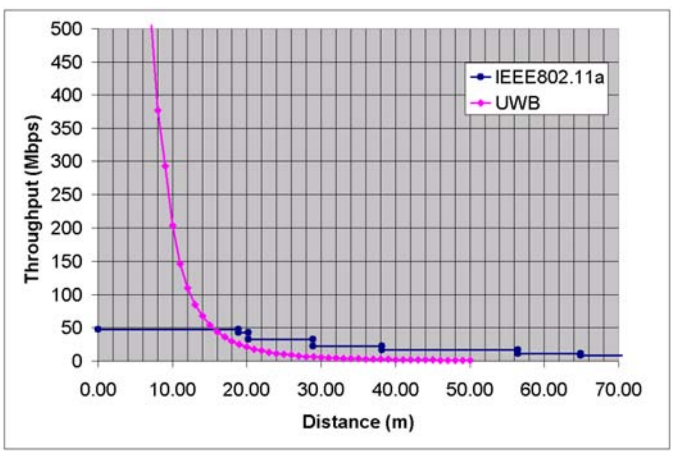

Fig. 7. Theoretical Data Rates over Range.

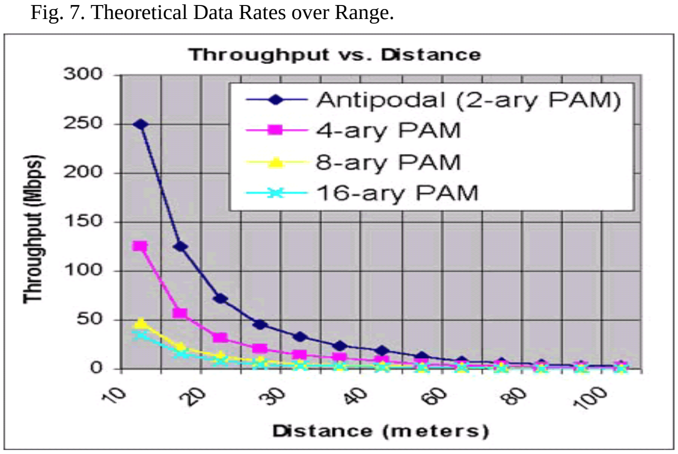

Fig. 8. Performance analysis with encoding rules.

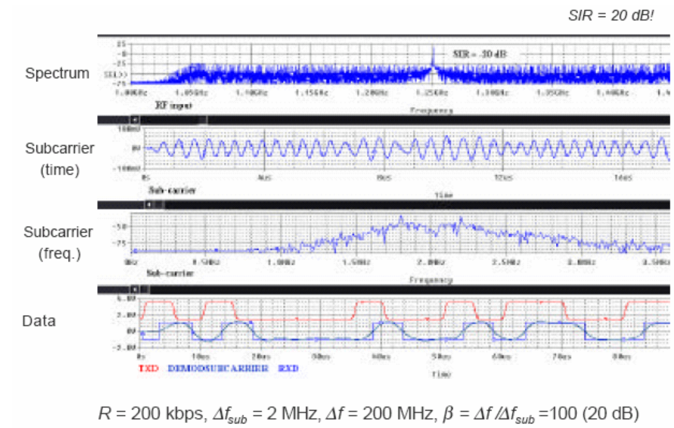

Fig. 9. UWB link analysis example [13].

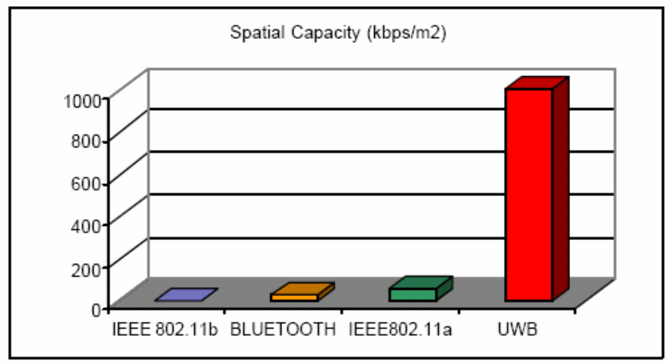

Fig. 10. Capacity of UWB compared with other wireless technologies [13].

F. *UWB motivation*

The followings lead to adopt UWB technology:

- There is 7.5 GHz of free spectrum in the U.S. FCC recently legalized UWB for commercial use. Spectrum allocation overlays existing users, but its allowed power level is very low to minimize interference.
- The very high data rates possible. 500 Mbps can be achieved at distances of 10 feet under current regulations.
- Based on Moore's Law Radio, data rate scales with the shorter pulse widths made possible with ever faster CMOS circuits.
- Simple CMOS transmitters at very low power. Suitable for battery-operated devices and low power CMOS technology.

G. *UWB characteristics*

The main characteristics of UWB are:

1) *Extremely low transmission energy:* (less than 1mW).

2) *Very high bandwidth within short range:* (200Mbps within 10m).

3) *Extremely difficult to intercept:* Short pulse excitation generates wideband spectra and low energy density also minimizes interference to other services.

4) *Multipath immunity*.

5) Commonality of signal generation and processing architectures.

6) Radar: Inherent high precision with sub-centimeter ranging and wideband excitation for detection of complex, low RCS targets.

7) Geolocation/Positioning: Sub-centimeter resolution using pulse leading edge detection and LOS is not required.

8) Low Cost: Nearly all of the UWB architecture is digital and ideal for microminiaturization into a chipset.

9) In UWB the frequency diversity is possible with minimal hardware modifications.

H. UWB Advantages

In UWB, the capacity is high and it is possible to achieve high throughput. Also, the power consumption and the cost are low which means high capacity with lower transmit power levels. In addition to the high data rate capability of Ultra Wideband, its low transmit power also means it transmits negligible interference to existing systems. The low power properties of UWB communications can allow systems to operate across a range of frequency bands unlicensed. The power is so low in fact, that it is below the levels associated with the emission limits for unintentional transmitters such as televisions and washing machines. In addition, UWB has the fading robustness duet to the wideband nature of the signal that reduces time varying amplitude fluctuations and the relative immune to multipath cancellation effects. Moreover, UWB enjoys the position location capability since it was developed first as radar technology. Consequently, UWB is a flexible technology it can can dynamically trade-off throughput for distance.

III. UWB FOR WPAN

A. What is WPAN

The WPAN is basically an ad-hoc network configuration. Although there is piconet controller, main communication is peer-to-peer transmission. The WPAN is a new standard under development, which will be part of the IEEE802.15 standard. The main objective of the WPAN is to replace wires between electronic and/or computing equipment in close proximity and provide connectivity to larger networks through a convenient transmission medium.

B. Where UWB fits

With the characteristics of low power, low cost, and very high data rates at limited range, UWB is positioned to address the market for a high-speed WPAN. This trend is enhanced when considering Figure11 that shows WPAN suites the short range communications. However, UWB comes to fit WPAN offer high data rates for it as shown in Figure12.

C. WPAN requirements

The essential requirements of WPAN include:

- Wireless - without line-of-sight limitations.
- Low power consumption.
- Optimized for power management and QoS.
- Ad-hoc networking support.
- Multi-device networks.
- Cross-network interference tolerance.
- Small size and easy integration into variety of devices.
- Low cost & complexity.

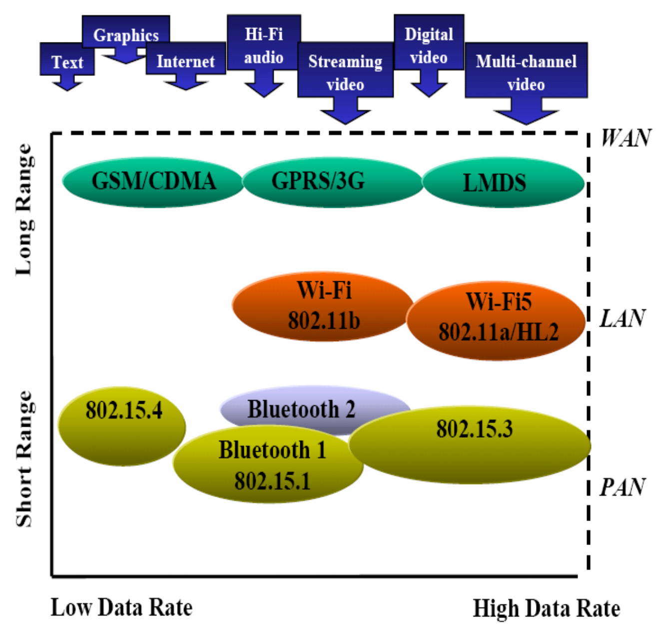

Fig. 11. WPAN location among technologies. [15].

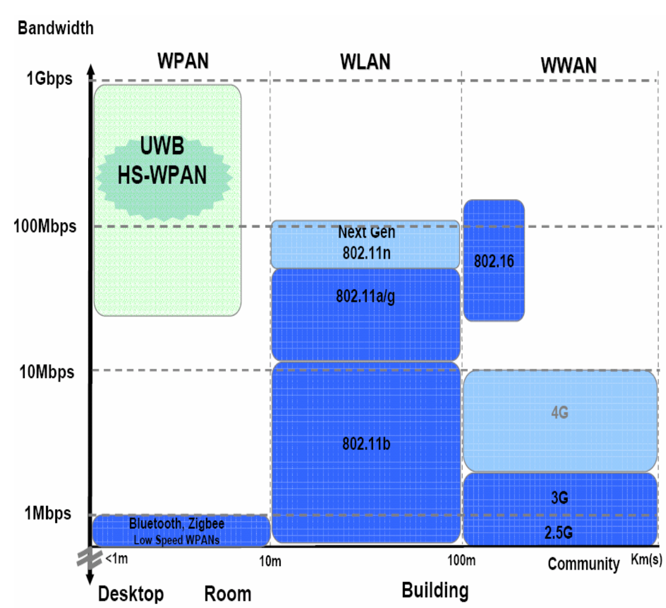

Fig. 12. Where UWB fits. [15].

D. WPAN standards

The main WPAN standards are: IEEE802.15.1 (Bluetooth), IEEE802.15.3 (High rate), and IEEE802.15.4 (Low rate). The essential IEEE802.15 project is summarized in Table III. Also, the main features of WPAN standards are compared in Table IV.

TABLE III
IEEE802.15 PROJECT [15]

Project	Data Rate	Range	Configuration	Other Features
802.15.1 (Bluetooth)	1 Mbps	10M (class 3) 100M (class 1)	8 active device Piconet/ Scatternet	Authentication, Encryption, Voice
802.15.3 High Rate	22, 33, 44, 55 Mbps	30-50M	256 active device Piconet/Mesh	QoS, Fast Join Multi-Media
802.15.4 Low Rate	up to 250Kbps	10M nominal 1M-100M based on settings	Master/Slave (256 Devices or more) Mesh	Battery Life: multi-month to infinite
802.15.SG3a Alternate 15.3 PHY	>100Mbps	10M nominal	256 active device Piconet/Mesh	
802.15.2 Coexistence	Develop a Coexistence Model and Mechanisms Document as a Recommended Practice			

E. UWB applications for WPAN

The UWB applications for WPAN covers: Personal Computing (PC), Consumer Electronic (CE), and Mobile devices, see Figure13. UWB technology can enable a wide variety of WPAN applications. Examples include:

- Replacing IEEE1394 cables between portable multimedia CE devices, such as camcorders, digital cameras, and portable MP3 players, with wireless connectivity.
- Enabling high-speed wireless universal serial bus (WUSB) connectivity for PCs and PC peripherals, including printers, scanners, and external storage devices.
- Replacing cables in next-generation Bluetooth Technology devices, such as 3G cell phones, as well as IP/UPnP-based connectivity for the next generation of IP-based PC/CE/ mobile devices.
- Creating ad-hoc high-bit-rate wireless connectivity for CE, PC, and mobile devices.

IV. CONCLUSION

UWB has the potential to become a viable and competitive wireless technology for short range high-rate WPANs as well as lower-rate and low-power-consuming low-cost devices and networks, with the capability to support a truly pervasive user-centric and thus personal *wireless world.* WPAN are expected to play significant role in the future wireless mobile communication systems.

HOMEWORK

- Define UWB, features, and benefits.
- Illustrate the potential application of UWB for WPAN.

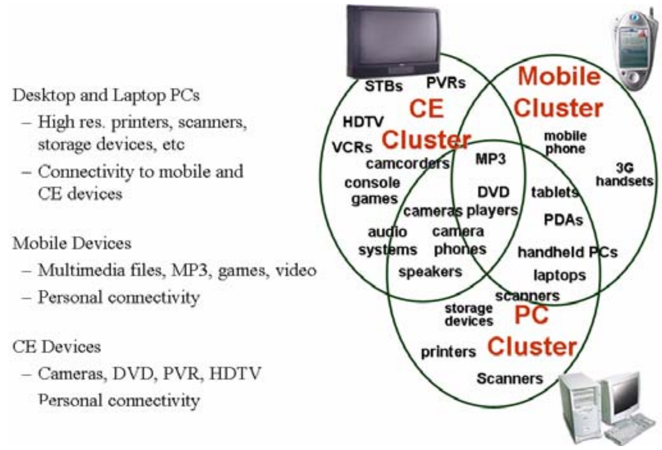

Fig. 13. UWB applications for WPAN.

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TABLE IV
WPAN STANDARFS FEATURES [1]

Characteristic	IEEE 802.15.4	Bluetooth	IEEE 802.11b	IEEE 802.11g+	IEEE 802.11a	IEEE 802.15.3+	UWB+ HDR
Standard version/status	IEEE approved	V 1.1 (Low-Rate)	IEEE approved	Draft	IEEE approved	Draft	Draft IEEE 802.15.3a
Max. data rate	250 kb/s; 40 kb/s; 20 kb/s	1 Mb/s	11 Mb/s	54 Mb/s	24 Mb/s mandatory; 54 Mb/s optional	11 Mb/s (QPSK) – 55 Mb/s (64 QAM) mandatory: ≥ 22 Mb/s	110 Mb/s (10m) 200 Mb/s (4m) (mandatory) (higher data-rate might optionally apply)
Max. distance	30 m	10 m	100 m	100 m	50 m	10 m	10 m
Frequency allocation	868–868.6 MHz; (ISM EU) 902–928 MHz; (ISM US) 2400–2483.5 MHz (ISM)	2.4 GHz (ISM)	2.4 GHz (ISM)	2.4 GHz (ISM)	5-GHz UNII (5.15 – 5.35 + 5.725 –5.825) GHz	2.4 GHz (ISM) 2.4–2.4835 GHZ	3.1–10.6 GHz
Channel bandwidth	0.3 MHz; 0.6 MHz (2 MHz spacing); 2 MHz (5 MHz spacing)	1 MHz	25 MHz	25 MHz	20 MHz	15 MHz	Min. 500 MHz Max. 7.5 GHz
Number of RF channels	1; 10; 16	79	3	3	12 U.S. 8 EU 4 Japan	5	(1–15)
Modulation type	BPSK; OQPSK	GFSK	11Mbaud QPSK (CCK coding)	OFDM 64 + CCK (legacy)	COFDM BPSK, QPSK, 16 QAM	DQPSK 16/32/64 QAM	BPSK, QPSK
Spreading	DS-SS	DS-FH	CCK	OFDM	OFDM	—	(Multiband)
Maximum allowed RF power	US 1W +6dB antenna gain; (FCC 15.247); EU (868 MHz) ERC70-03E: 25mW if duty cycle < 1% in 1 hour; (2400 MHz) ETSI 300-328: 20 mW¹ (2 MHz channels @ 10 mW/MHz) Japan 10 mW/MHz	0 dBm 20 dBm	US 30 dBm (PC needed for emissions> 20 dBm) EU 20 dBm Japan 10 dBm	US 30 dBm (PC needed for emissions >20 dBm) EU 20 dBm Japan 10 dBm	50 mW; 250 mW; 1-watt (depending on the used channels within the band)	US 50 mV/m (@3m, 1 MHz res. bandwidth) (47 CFR 15.249) EU 100 mW² EIRP (ETS 300–328) Jap 10 mW (ARIB STD-T66)	–41.3 dBm/MHz (max. average EIRP over entire band = 0.562 mW) (FCC First Report and Order; Part 15 ET Docket 98-153)
Required receiver sensitivity	–85 dBm PER<1%	–70 dBm BER < 10^{-3}	–76 dBm BER<10^{-5} FER = 8×10^{-2}	From –76 dBm (22 Mb/s) to –74 dBm (33 Mb/s) FER = 8×10^{-2}	From –82 dBm (6 Mb/s) to –65 dBm (54 Mb/s) BER < 10^{-5}	From –82 dBm (DQPSK) to –68 dBm (64 QAM)	—
Approx # PHY power consumption	< BT	BT (~ 40–100 mW)	~4BT	~4BT	~6BT	—	(~2–3BT)
Approx cost#	~0.5 BT	BT (~ 5$)	~4BT	~4BT	~5BT	—	(~1–2BT)

• Acronyms used: BT = reference Bluetooth device, CCK = complementary code keying (CCK), orthogonal frequency-division multiplexing (OFDM), COFDM = coded OFDM, ISM = industrial, scientific, medical, PC = power control, PSDU = PHY service data unit (payload), UNII = unlicensed national information infrastructure.
+ These specifications are currently (April 2003) under drafting. All parameters mentioned are speculative, in particular some of those referring to IEEE 802.15.3a, which is in its early stages of discussion.
# Parameters referring to power consumption and cost can vary dramatically from design to design; these numbers are only to be considered as rough indications.
¹ IEEE 802.15.4 EU general equipment plans to use 1–10 mW. ² IEEE 802.15.3 EU general equipment plans to use 8 dBm.