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Introduction to 60 GHz[1]

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1.1 What is 60 GHz?

Since the first wireless transatlantic radio wave transmission demonstration by Marconi from Cornwall, England, to Newfoundland, Canada, in 1901 (based on long wave), wireless communications have undergone tremendous growth. They were first used mainly by military and shipping companies and later quickly expanded into commercial use such as commercial broadcasting services (such as shortwave, AM and FM radio, terrestrial TV), cellular telephony, and global positioning service (GPS), wireless local area network (WLAN), and wireless personal area network (WPAN) technologies. Today, these wireless communications systems have become an integral part of daily life and continue to evolve in providing better quality and user experience. One of the recent emerging wireless technologies is millimeter-wave (mm-wave) technology. It is important to note that mm-wave technology has been known for many decades, but has mainly been deployed for military applications. Over the past 5–6 years, advances in process technologies and low cost integration solutions have made mm-wave a technology to watch and begun to attract a great deal of interest from academia, industry and standardization bodies. In very broad terms, mm-wave technology is concerned with that part of the electromagnetic spectrum between 30 and 300 GHz, corresponding to wavelengths from 10 mm to 1 mm [1], as shown in Figure 1.1. In this book, however, we will focus

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[1] This work was done when the author was affiliated with Samsung Electronics.

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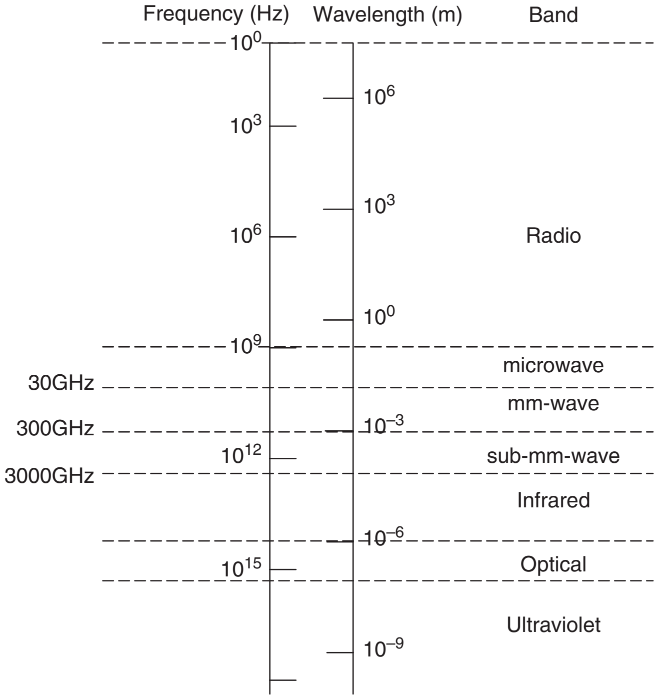

Figure 1.1 Electromagnetic spectrum allocation.

specifically on 60 GHz radio[2] which enables many new applications that are difficult if not impossible to offer by wireless systems at lower frequencies, as discussed in Section 1.3.

1.2 Comparison with other Unlicensed Systems

60 GHz technology offers various advantages over current or existing communications systems [2]. One major reason for the recent interest in 60 GHz technology is the huge unlicensed bandwidth. As shown in Figure 1.2, at least 5 GHz of continuous bandwidth is available in many countries worldwide. While this is comparable to the unlicensed bandwidth allocated for ultra-wideband (UWB) purposes [3], the 60 GHz bandwidth is continuous and less restricted in terms of power limits. This is due to the fact that UWB system is an overlay system and thus subject to very strict

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[2] Unless otherwise specified, the terms 60 GHz and millimeter-wave are used interchangeably in this book.

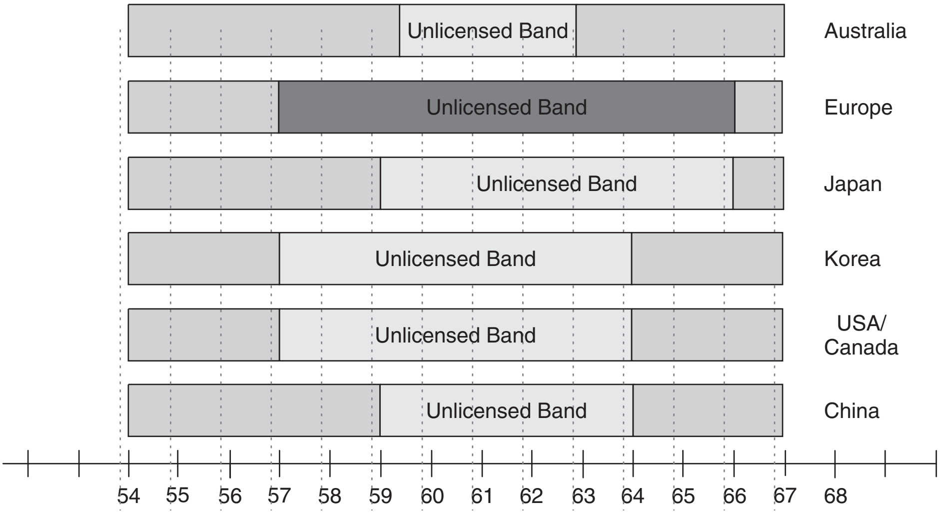

Figure 1.2 Worldwide frequency allocation for 60 GHz band and operation.

Table 1.1 Comparison of the typical implementation of 60 GHz, UWB and 802.11n systems in terms of their output power, antenna gain and EIRP output

Technology	Frequency (GHz)	PA output (dBm)	Antenna gain (dBi)	EIRP output (dBm)
60 GHz	57.0–66.0	10.0	25.0	35.0
UWB	3.1–10.6	−11.5	1.5	−10.0
IEEE 802.11n	2.4/5.0	22.0	3.0	25.0

and different regulations [4]. The large bandwidth at 60 GHz is one of the largest unlicensed bandwidths ever to be allocated. This huge bandwidth represents great potential in terms of capacity and flexibility, making 60 GHz technology particularly attractive for gigabit wireless applications (see Section 1.3).

Furthermore, 60 GHz regulation allows much higher transmit power – equivalent isotropic radiated power (EIRP) – compared to other existing WLAN and WPAN systems. Table 1.1 shows examples of typical 60 GHz, UWB and IEEE 802.11 systems that operate near the US Federal Communications Commission (FCC) regulatory limit.

The output power of a power amplifier for 60 GHz is typically limited to 10 dBm because the implementation of efficient power amplifiers at this frequency is very challenging (see Chapter 3 for more discussion) though FCC regulations allow up to 27 dBm. However, the huge antenna gain up to 40 dBi has significantly boosted the allowable EIRP limits. On the other hand, UWB systems which are required to meet the strict power spectrum mask of −41.3 dBm/MHz based on FCC regulations, thus offer only very limited EIRP of the order of −10 dBm. This makes the UWB system a very short-range and low-power device. In contrast, the design of power amplifiers for 2.4/5.0 GHz is simpler and can deliver much higher power than the 60 GHz system. However, the EIRP limit is typically confined to 30 dBm due to the crowded Industrial, Scientific and Medical band. It can be seen from Table 1.1 that the EIRP of the 60 GHz system is approximately 10 times larger than the IEEE 802.11n and 30 000 times larger than the UWB system.

The higher transmit power is necessary to overcome the higher path loss at 60 GHz. While the high path loss seems to be a disadvantage at 60 GHz, it confines the 60 GHz operation to within a room in an indoor environment. Hence, the effective interference levels for 60 GHz are less severe than those systems located in the congested 2.0–2.5 GHz and 5.0–5.8 GHz regions.

The huge bandwidth available for 60 GHz and UWB systems also simplifies the system design of these technologies. A system with much lower spectral efficiency can be designed to deliver a Gbps transmission to provide low cost and simple implementation. Table 1.2 shows the spectral efficiency required by the 60 GHz, UWB and IEEE 802.11 systems to achieve 1 Gbps transmission as well as spectral efficiency of the actual deployment of such systems. A typical 60 GHz system requires only 0.4 bps/Hz to achieve 1 Gbps, making it an ideal candidate to support very high data rate applications using simple modulation. Though the UWB system only requires 2 bps/Hz to achieve 1 Gbps, its actual deployment is limited to 400 Mbps at 1 m operating range. IEEE 802.11n-alike systems will require 25 bps/Hz in order to achieve 1 Gbps, making the extension of such system to beyond 1 Gbps unappealing in terms of cost and implementation. A more detailed discussion on the modulation choice for 60 GHz is presented in Chapter 4.

Table 1.2 Spectral efficiency comparison between 60 GHz, UWB and IEEE 802.11n technology

Technology	Bandwidth (MHz)	Efficiency@ 1 Gbps (bps/Hz)	Target data rate (Mbps)	Efficiency required (bps/Hz)
60 GHz	2000	0.5	4000	2.0
UWB	528	2.0	480	1.0
IEEE 802.11n	40	25.0	600	15.0

In addition, the huge path loss at 60 GHz enables higher-frequency reuse in each indoor environment, thus allowing a very high-throughput network. The compact size of 60 GHz radio also permits multiple-antenna solutions at the user terminal that are otherwise difficult if not impossible at lower frequencies. Compared to 5 GHz systems, the form factor of 60 GHz systems is approximately 140 times smaller and thus can be conveniently integrated into consumer electronic products.

Despite of the various advantages offered, 60 GHz based communications suffer a number of critical problems that must be solved. Figure 1.3 shows the data rates and range requirements for a number of WLAN and WPAN systems.

Since there is a need to distinguish between different standards for broader market exploitation, the 60 GHz related standards are positioned to provide gigabit rates and longer operating range than the UWB systems but shorter than that of IEEE 802.11n systems. Typically, 60 GHz systems are designed to provide multi-gigabit data rates with operating range below 20 m to support various applications as described in Section 1.3. At such rate and range, it will be a non-trivial task for 60 GHz systems to provide sufficient power margin to ensure a reliable communication link. Furthermore, the delay spread of the channel under study is another limiting factor for high-speed transmissions. Large delay spread values can easily increase the complexity of the system beyond the practical limit for equalization (see Chapter 2 for more discussion on the impact of channel on the 60 GHz design as well as choice of modulation in Chapter 5).

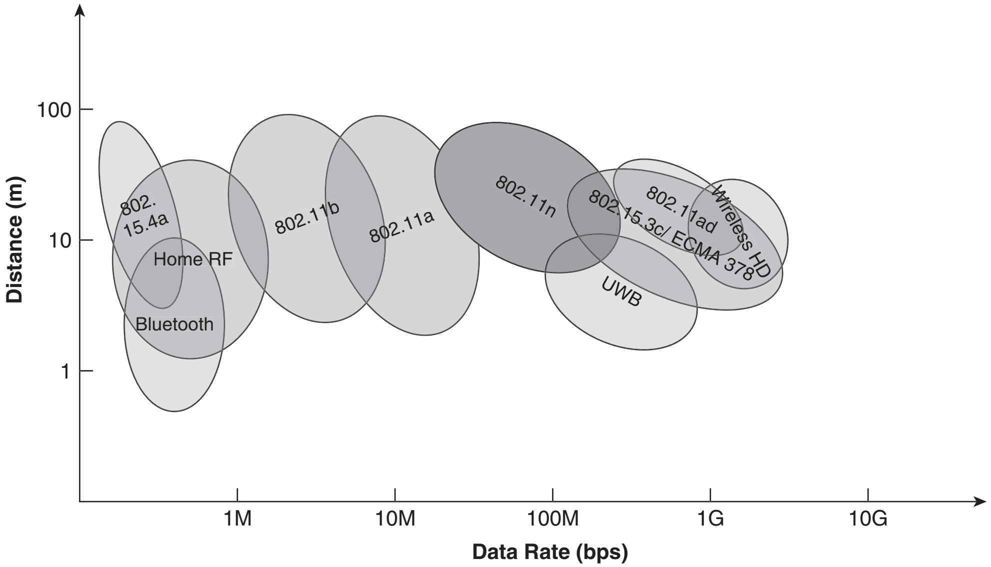

Figure 1.3 Rate versus range for WLAN and WPAN standards.

1.3 Potential Applications

With the allocated bandwidth of 7 GHz in most countries, 60 GHz radio has become the technology enabler for many gigabit transmission applications that are technically constrained at lower frequency. A number of indoor applications are envisioned, such as:

(i) cable replacement or uncompressed high definition (HD) video streaming that enables users to wirelessly display content to a remote screen with wired equivalent quality/experience;
(ii) ‘synch and go’ file transfer that enables gigabytes of file transfer in a few seconds;
(iii) wireless docking stations that allow multiple peripherals (including an external monitor) to be connected without the need for frequent plugging and unplugging;
(iv) wireless gigabit Ethernet that permits bidirectional multi-gigabit Ethernet traffic;
(v) wireless gaming that ensures high-quality performance and low latency for exceptional user experience.

All these applications have been discussed in various standards and industry alliances [5–9]. Uncompressed video streaming is emerging as one of the most attractive applications and related products based on the WirelessHD specification are currently available on the market from companies such as Panasonic, LG Electronics and Toshiba [5, 10]. In the following, we will briefly describe the technical requirements for proper uncompressed video streaming operation.

Depending on the progressive scan resolution and number of pixels per line, the data rate required varies from several hundred Mbps to a few Gbps. The latest commercially available high-definition television (HDTV) resolution is 1920 × 1080, with a refresh rate of 60 Hz. Considering RGB video formats with 8 bits per channel per pixel, the required data rate turns out to be approximately 3 Gbps, which is currently supported by the HDMI 1.1 specification. In the future, higher numbers of bits per channel (10 and 12 bits per color) as well as higher refresh rates (90 Hz, 120 Hz) are expected to improve the quality of next-generation HDTV. This easily scales the data rate to well beyond 5 Gbps. Table 1.3 summarizes data rate requirements for some current and future HDTV specifications. Furthermore, uncompressed HD streaming is an asymmetric transmission with significantly different data flow in both uplink and downlink directions. This application also requires very low latency of tens of microseconds and very low bit error probability (down to 10^{-12}) to ensure high-quality video.

Table 1.3 Data rate requirements for different resolutions, frame rates, and numbers of bits per channel per pixel for HDTV standard

Pixel per line	Active line	Frame rate per picture	Number of bits per channel per pixel	Data rate (Gbps)
1280	720	24	24	0.53
1280	720	30	24	0.66
1440	480	60	24	1.00
1280	720	50	24	1.11
1280	720	60	24	1.33
1920	1080	50	24	2.49
1920	1080	60	24	2.99
1920	1080	60	30	3.73
1920	1080	60	36	4.48
1920	1080	60	42	5.23
1920	1080	90	24	4.48
1920	1080	90	30	5.60

1.4 Worldwide Regulation and Frequency Allocation

This section discusses the current status of worldwide regulation and standardization efforts for the 60 GHz band. The regulatory bodies in the United States, Japan, Canada and Australia have already set frequency bands and regulations for 60 GHz operation, while in Korea and Europe intense efforts are currently under way. A summary of the issued and proposed frequency allocations and main specifications for radio regulation in a number of countries is given in Table 1.4. It is important to note that even though a maximum transmit power of 27 dBm is allowed in the USA, the actual transmit power may be limited by the capability of power amplifiers (PAs), especially in the case of single antennas. Typically, the maximum output of the 60 GHz PA is limited to around 10 dBm.

1.4.1 North America

In 2001, the FCC allocated 7 GHz in the 54–66 GHz band for unlicensed use [11]. In terms of the power limits, FCC rules allow emission with average power density of 9 μW/cm^2 at 3 meters and maximum power density of 18 μW/cm^2 at 3 meters, from the radiating source. These values translate to average EIRP and maximum EIRP of 40 dBm and 43 dBm, respectively. The FCC also specified the total maximum transmit power of 500 mW for an emission bandwidth greater than 100 MHz.

Table 1.4 Frequency band plan and limits on transmit power, EIRP, and antenna gain for various countries

Region	Unlicensed bandwidth (GHz)	Transmit power	EIRP (dBm)	Maximum antenna gain (dBi)
USA/Canada	7.0	500 mW or 27 dBm (max)[*]	40.0 (ave)[+] 43.0 (max)[#]	33.0 (max) when 10.0 dBm TX power is used
Japan	7.0[†]	10 mW or 10 dBm (max)	58.0 (max)	47.0
Korea	7.0	10 mW or 10 dBm (max)	27.0 (max)	17.0[‡]
Australia	3.5	10 mW or 10 dBm (max)	51.7 (max)	41.8
Europe[◇]	9.0	20 mW	57.0 (max)	30.0

Note:

[*] For bandwidth >100 MHz.

[+] Translate from average power density of $9\ \mu\text{W/cm}^2$ at 3 m.

[#] Translate from average power density of $18\ \mu\text{W/cm}^2$ at 3 m.

[†] Maximum bandwidth allowed is 2.5 GHz.

[‡] All devices shall transmit the Tx ID code per se. Statement is needed in user manual for antenna gain 17 dBi.

[◇] Recommendation by the European Telecommunications Standards Institute; minimum bandwidth is 500 MHz.

Devices must also comply with the radio frequency (RF) radiation exposure requirements specified in §1.307(b), §2.1091 and §2.1093 of [11]. After taking RF safety issues into account, the maximum transmit power is limited to 10 dBm. Furthermore, each transmitter must transmit transmitter identification at least once, within 1 second interval of the signal transmission. It is important to note that 60 GHz regulations in Canada, enforced by Industry Canada Spectrum Management and Telecommunications (IC-SMT) [12], are harmonized with those of the USA.

1.4.2 Japan

In 2000, the Ministry of Public Management, Home Affairs, Posts and Telecommunications (MPHPT) of Japan issued 60 GHz radio regulations for unlicensed utilization in the 59–66 GHz band [13]. The 54.25–59 GHz band is allocated for licensed use. The maximum transmit power for unlicensed use is limited to 10 dBm [14] with maximum allowable antenna gain of 47 dBi [15]. Unlike in North America, Japanese regulations specify that the maximum transmission bandwidth must not exceed 2.5 GHz. There is no specification for RF radiation exposure and transmitter identification requirements. For further information and latest regulation updates in Japan, interested readers are referred to [16].

1.4.3 Australia

Following the released of regulations in Japan and North America, the Australian Communications and Media Authority (ACMA) took similar steps to regulate the 60 GHz band in 2005 [17]. However, only 3.5 GHz bandwidth (59.4–62.9 GHz) is allocated for unlicensed use. The maximum transmit power and maximum EIRP are limited to 10 dBm and 51.7 dBm, respectively. The data communication transmitters that operate in this frequency band are limited to land and maritime deployments. For further information and latest regulation updates in Australia, interested readers are referred to [18].

1.4.4 Korea

In June 2005, the Millimeter-wave Frequency Study Group (MFSG) was formed under the auspices of the Korean Radio Promotion Association [19]. The MFSG has recommended a 7 GHz unlicensed spectrum (57–64 GHz) without limitations on the types of application to be used. For indoor applications, the maximum transmit power is 10 dBm, the same as in Japan and Australia, while the maximum allowable antenna gain is 17 dBi. For outdoor applications, the transmitted power is limited to −20 dBm and 10 dBm for frequency bands 57–58 GHz and 58–64 GHz, respectively, while the maximum antenna gain is 47 dBi [20]. In addition, any device using frequencies in the 57–64 GHz band shall transmit the transmitter identification code *per se*, to enable other devices to fully detect and protect against malfunctions from occurring, with the exception of any fixed point-to-point system. For further information and latest regulation updates in Korea, interested readers are referred to [21].

1.4.5 Europe

The European Telecommunications Standards Institute (ETSI) and European Conference of Postal and Telecommunications Administrations (CEPT) have been working closely to establish a legal framework for the deployment of unlicensed 60 GHz devices. In general, the 59–66 GHz band has been allocated for mobile services without specific decisions having been made as to the regulations. The CEPT Recommendation T/R 22-03 provisionally allocated (and later withdrew) the 54.25–66 GHz band for terrestrial and fixed mobile systems [22].

In 2004, the European Radiocommunications Committee (ERC) considered the used of the 57–59 GHz band for fixed services without requiring frequency planning [23]. Later, the Electronic Communications Committee (ECC) within CEPT recommended the use of point-to-point fixed services in the 64–66 GHz band [24]. Later, ETSI proposed 60 GHz regulations to be considered by the ECC for WPAN applications [25]. Under this proposal, 9 GHz of unlicensed spectrum is allocated for 60 GHz operation. This band represents the union of the bands currently approved and proposed among the major countries as shown in Figure 1.2. In addition, a minimum spectrum of 500 MHz is required for the transmitted signal with maximum EIRP of 57 dBm. No specification is given for the maximum transmit power and maximum antenna gain.

In October 2009, the CEPT recommended a maximum EIRP of 25 dBm with a maximum spectral power density of −2 dBm/MHz for outdoor applications, though a fixed outdoor installation is not allowed [26]. For indoor applications a maximum EIRP of 40 dBm with a maximum spectral power density of 13 dBm/MHz is specified [26]. It is unclear when the final regulation will be in place, but the current trend seems encouraging for the deployment of 60 GHz technology. For further information and latest regulation updates in the Europe, interested readers are referred to [27].

1.5 Industry Standardization Effort

The first international industry standard that covers the 60 GHz band is the IEEE 802.16 standard for local and metropolitan area networks [28]. However, this is a licensed band and is used for line-of-sight (LOS) outdoor communications for last mile connectivity. In Japan, two standards related to the 60 GHz band were issued by Association of Radio Industries and Business (ARIB): the ARIB-STD T69 [29] and ARIB-STD T74 [30]. The former is the standard for mm-wave video transmission equipment for specified low-power radio stations (point-to-point systems), while the latter is the standard for mm-wave ultra high-speed WLANs for specified low power radio stations (point-to-multipoint systems). Both standards cover the 59–66 GHz band defined in Japan.

Interest in 60 GHz radio continued to grow with the formation of multiple international mm-wave standards groups and industry alliances. In March 2005, the IEEE 802.15.3c Task Group (TG3c) was formed to develop a mm-wave based alternative physical layer (PHY) for the existing IEEE 802.15.3 WPAN standard 802.15.3-2003 [31]. In August 2006, ECMA TC-48 (formerly known as TC32-TG20) began an effort to standardize medium access control (MAC) and PHY for high-speed, short-range communications using the 60 GHz unlicensed frequency band for bulk data applications and for multimedia streaming applications [7]. In October 2006, the formation of the WirelessHD consortium was announced with a number of key consumer electronics companies to deliver a specification for high-speed, high-quality uncompressed audio/video (A/V) streaming using 60 GHz technology [5]. In the latest development, the Wireless Gigabit Alliance (WiGig) was formed in May 2009 to establish a unified specification for 60 GHz wireless technology in order to create a truly global ecosystem of interoperable products for a diverse range of applications [9]. In this section we briefly describe a number of standardization efforts.

1.5.1 IEEE 802.15.3c

The alternative PHY of IEEE 802.15.3c is aimed at supporting a minimum data rate of 2 Gbps over a few meters with optional data rates in excess of 3 Gbps. This is the first standard that addresses multi-gigabit short-range wireless systems. The IEEE 802.15.3c standard was ratified in September 2009 [31]. Three PHYs are defined in the specification, namely single carrier (SC) PHY, high speed interface (HSI) orthogonal frequency division multiplexing (OFDM) PHY and audio video (AV) OFDM PHY. The need for three PHYs is due to the inherent advantages of each PHY in supporting specific applications. SC PHY is designed to support low-cost and low-power mobile devices; HSI PHY is used for low-latency, high-speed bidirectional data transmission, while AV PHY is optimized for AV specific applications. The key PHY features of IEEE 802.15.3c are summarized in Table 1.5.

In order to promote coexistence among these PHY modes, common mode signaling (CMS) is defined which is an SC-based $\pi/2$ binary phase shift key (BPSK)

Table 1.5 Summary of the PHY modes in the IEEE 802.15.3c standard

Feature	SC-FDE	HSI OFDM	AV OFDM
Constellation	BPSK, (G)MSK, QPSK, 8PSK, 16QAM	QPSK, 16 QAM 64QAM	QPSK, 16QAM
Data rate	25.3 Mbps–5.1 Gbps	31.5 Mbps–5.67 Gbps	0.95–3.8 Gbps
Coding	Reed Solomon, LDPC	LDPC	Reed Solomon and Convolutional Coding
UEP Support	Yes	Yes	Yes
Training sequence	Golay Code	Golay Code	M-Sequence Barker-13 chip
Beamforming	Yes	Yes	Yes
Occupied bandwidth	1.782 GHz	1.782 GHz	1.76 GHz (HRP) 92 MHz (LRP)

with low data rate (25 Mbps). CMS is used in piconet coordinator capable devices to send/receive a CMS synch frame in order to avoid interference between two or more operating piconets. Beamforming is supported by all the three PHY modes for heterogeneous antenna types. The beamfoming employs a two-level mechanism to find the optimum transmit and received beams that enable high data rate transmission. In addition, 15.3c specifies an unequal error protection (UEP) support for uncompressed video transmission. UEP can be achieved in both PHY and MAC layers. UEP at PHY protects the most significant bit (MSB) and least significant bit (LSB) in a subframe unequally by applying different coding and/or constellation mapping. On the other hand, UEP at MAC protects an aggregated frame which consists of MSB subframes, LSB subframes, or both MSB and LSB subframes, by using either different forward error corrections or different modulation and coding schemes. We will revisit the UEP PHY and MAC in more detail in Chapters 5 and 9, respectively.

1.5.2 ECMA 387

ECMA TC48 developed the ECMA 387 specification for high-rate 60 GHz PHY, MAC and HDMI PAL for short-range unlicensed communications. The first edition of the ECMA 387 was ratified in December 2008 and subsequently submitted to ISO/IEC JTC 1's fast-track procedure to turn ECMA-387 into ISO/IEC 13156 by the end of 2009 [32]. Three types of devices (i.e. Type A, Type B and Type C) are specified in ECMA 387 based on the complexity and power consumption. Type A represents the most complex and power-hungry device types, intended to deliver video/data even without LOS by employing beamforming. Type B represents devices of moderate complexity and power consumption and is designed to deliver video/data in LOS without using beamforming. Finally, Type C devices are the least complex and have lowest power consumption, and are used for data delivery over very short range (less than 1 meter). In addition, three mandatory PHYs are also defined in the specification, namely SC block transmission (SCBT), SC with differential binary phase shift keying (DBPSK) and SC with binary amplitude shift keying (BASK, also known as OOK). These mandatory PHYs are mapped into Type A, B and C devices as shown in Table 1.6.

In order to promote coexistence among these device types, during device discovery, which takes place in the discovery channel, Type A devices need to support SCBT, DBPSK and OOK modes while Type B devices need to support both DBPSK and OOK. While ECMA 378 specifies interoperability and coexistence among these three device types, the overall protocol and implementation complexity have dramatically increased, especially for Type A devices, as compared to IEEE 802.15.3c. Beamforming is mandatory for Type A devices while Type B devices may support beamforming training of Type A devices by feeding back the best adaptive weight

Table 1.6 Summary of device types and associated PHY modes in ECMA 378

	Type A	Type B	Type C
Mandatory modes	SCBT, DBPSK, OOK	DBPSK, OOK	OOK
Optional modes	25.3 Mbps–5.1 Gbps OFDM, DQPSK, 4ASK	31.5 Mbps–5.67 Gbps DQPSK, Dual-AMI 4ASK	0.95–3.8 Gbps 4ASK
Coding	Reed Solomon and Convolutional Coding	Reed Solomon	Reed Solomon
UEP support	Yes	Yes	No
Beamforming	Yes	No+	No
Beacon transmission	SCBT	DBPSK, SCBT*	N/A
DRP transmission	SCBT, OFDM, DBPSK, OOK, 4ASK	DBPSK, DQPSK, Dual AMI, OOK, 4ASK	OOK/4ASK

Note:
**SCBT is used for transmit only
+Assist in feeding back the transmit beamforming information and/or sending antenna training sequences for receive beamforming of Type A devices.

vector (AWV) for transmit beamforming and/or sending antenna training sequences for receive Beamforming. Similar to IEEE 802.15.3c, UEP is also supported at both PHY and MAC layers.

1.5.3 WirelessHD

The WirelessHD consortium developed the WirelessHD 1.0 specification released in January 2008 [5]. An overview of the WirelessHD specification 1.0 can be found in [33]. Unlike 15.3c and ECMA-378, WirelessHD only uses OFDM modulation with a smaller number of modes. A close comparison between the WirelessHD 1.0 specification [33] and AV OFDM PHY in 15.3c [31] reveals a lot of similarities. Both consist of OFDM based high-rate PHY (HRP) and low-rate PHY (LRP) that share the same frequency band plan, baseband and general parameters. Two types of beamforming are specified, namely, explicit beamforming and implicit beamforming. Explicit beamforming is mandatory and involves a beam search phase, which is used to estimate the AWV at both the transmitter and receiver, and a beam tracking phase, which is used to track the changes of the existing AWVs over time as a result of slow variation of the channel. On the other hand, implicit beamforming employs a beambook approach whereby a set of common beam vectors are maintained at both the transmitter and receiver. WirelessHD 1.0 also supports UEP for uncompressed video streaming applications. WirelessHD has gained some support from the consumer electronics industry. Companies such as LG Electronics, Panasonic, Toshiba and Gefen have already brought WirelessHD products to the market [10, 34], which represents a major milestone in commercializing 60 GHz technology. Recently, WirelessHD announced a next-generation WirelessHD specification that can support data rates up to 28 Gbps for 3D TV and 4K resolution support [35]. In addition, the next generation will also support data for low-power portable devices at a data rate of 1 Gbps.

1.5.4 IEEE 802.11.ad

IEEE 802.11ad was formed in January 2009 as an amendment to the existing IEEE 802.11-2007. This amendment defines standardized modifications to both the 802.11 PHY and the 802.11 MAC to enable very high-throughput operation in the 60 GHz frequency band [36]. This amendment specifies a maximum MAC service access point throughput of at least 1 Gbps while maintaining the network architecture of the 802.11 system as well as backward compatibility with the 802.11 management plane. In addition, IEEE 802.11ad is intended to define a mechanism for fast session transfer between 2.4/5 GHz and 60 GHz operation bands, while coexisting with other systems in the 60 GHz band such as IEEE 802.15.3c and ECMA-378. IEEE 802.11ad is expected to be completed by 2012.

1.5.5 Wireless Gigabit Alliance

The Wireless Gigabit Alliance (WiGig) was formed in May 2009 with broad support from the personal computer, consumer electronics, semiconductor and mobile handheld industries. The key objective of WGA is to establish a unified specification for 60 GHz wireless technologies that can support diverse applications as specified in Section 1.3. The WGA specification was released in May 2010.

1.6 Summary

The combination of high EIRP limit, huge bandwidth, and harmonized regulation and frequency allocation globally has positioned 60 GHz in the forefront of Gbps wireless communications. This can be demonstrated by the immense standardization effort and industry alliance formation to promote 60 GHz technology. Despite the tremendous progress made in 60 GHz technology in the past decade, the challenges of full-scale commercialization still remain, particularly in providing low-cost, low-power and robust 60 GHz products. It is the aim of this book to highlight and address some of the key issues related to 60 GHz technology from propagation, to PHY and MAC design as well as integrated circuit implementation of 60 GHz.

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