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Standards for providing Internet Services over Wireless Networks

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Contents

Abstract

Wireless networking technologies are now an integral part of modern people's everyday activities. This evolution was the result of the contribution of a series of open standards, designed and implemented with the cooperation of many people in international organizations. In this paper we will make a summary of these standards.

Περίληψη

Οι τεχνολογίες ασύρματης δικτύωσης αποτελούν πλέον αναπόσπαστο τμήμα των καθημερινών δραστηριοτήτων του ανθρώπου. Αυτή η εξέλιξη προέκυψε ως αποτέλεσμα της συνεισφοράς μιας σειράς ανοικτών προτύπων, σχεδιασμένων και υλοποιημένων με τη συνεργασία πολλών ανθρώπων σε διεθνείς οργανισμούς. Στην εργασία αυτή θα προβούμε σε μια συνοπτική παρουσίαση των προτύπων αυτών.

Introduction[i]

It is common sense that the Internet "is built on technical standards, which allow devices, services, and applications to be interoperable across a wide and disperse network of networks" (Internet Society, 2009, p. 1). Most commonly, these standards are the results of the collaboration between people originating from both the private and public sector, who participate in international organizations including IETF[1], IAB[2], IESG[3], IRTF[4], W3C[5], IEEE-SA[6], ISO[7], ANSI[8], ETSI[9] and ITU-T[10]. On the other hand, certain private companies and company groups have developed their own standards that have been adopted by the industry on a de-facto basis. The former usually outcompete the latter, since they are free and accessible to anyone. Thus economy of scale is achieved, leading to lower manufacturing costs and finally, competitively priced products that also meet the users' increasing demand for interoperability (Milovanovic, Rao, & Bojkovic, 2008).

Internet and Wireless Networks

Since the early 90's, we have witnessed the rapid evolution of the *Internet* ("Internet", 2012) and *Wireless Communication Networks*, especially cellular telecommunication networks. Both technologies evolved primarily due to the development of a significant number of standards that have been adopted by companies. Eventually, these technologies have converged (Marks, Gifford, & O'Hara, 2001), resulting in the *Wireless Internet* which nowadays is in widespread use. This evolution, together with the rapid reduction of the acquirement and maintenance costs of the related products and services led to their large commercial success.

According to Wikipedia in ("Wireless Networks", 2012), the term *Wireless Network* is used to refer to "any type of computer network that is not connected by cables of any kind". However we believe that we should rephrase and extend this definition to state that a

[i] Throughout the whole extent of this work, we use acronyms to refer to terms, expanded in Appendix A. Each acronym is referenced by its integer index in the appendix, formatted as superscript.

Wireless Network is “any type of network formed by electronic devices connected with each other without the use of cables of any kind”. With this definition, membership in a Wireless Network is not limited to computers -in the narrow sense- but also extends to printers, modern smart-phones, tablets, media-streaming devices for radio and/or TV broadcasts, game consoles, set-top boxes, smart-TVs and so on.

Scope and Methodology

The purpose of this work is to briefly present and serve as an elementary source for information about the standards implemented for connecting devices to Wireless Networks and providing Internet Services to their users. We analyze these standards in the “Results” chapter that follows, to a limited extent due to restrictions on total word count.

In the process of conducting this survey, we used the Google Scholar, IEEE Xplore and Science Direct services, in order to find an adequate number of books, research papers and related articles. We also took advantage of subscriptions of the library of University of Macedonia in a number of publishers (IEEE, ACM, Wiley etc.) in order to acquire documents in electronic form. Information has also been obtained from the official web sites of related organizations and SIGs[11]. Wikipedia was used for certain encyclopedic information.

Results

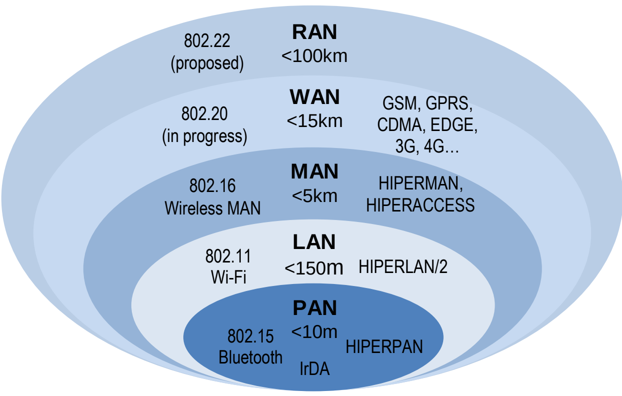

Figure 1 - Classification of Wireless Standards (Cordeiro, Challapali, Birru, & N, 2006)

We present the standards for providing wireless internet services, classified according to the scale of the network they primarily focus on. We use the typical PAN/LAN/MAN/WAN/RAN classification scheme, based on the range of the transmitted signal. The technological evolution in recent years, however, made it hard to restrain some of the standards in a single category. Hence the borders between the categories of this scheme tend to blur.

The majority of these standards cover the Physical layer (PHY) and the Media Access Control (MAC) and Logical Link Control (LLC) sub-layers of the Data Link layer of the Basic Reference Model[i] defined by OSI (we will refer to it as the "OSI Model" hereafter). In cases where providing internet services had not been a requirement from the beginning of a standard's design, support was eventually incorporated in subsequent releases, allowing the standard to become a part of the TCP/IP protocol stack.

Wireless transmission is inherently less secure than cable transmission, since the signal could be easily intercepted by unauthorized people. For this reason, these standards are, typically, also accompanied by a series of specialized technologies that deal with security and other issues related to the characteristics of the network and the underlying physical media.

Wireless Personal Area Network (WPAN) Standards

We begin our survey of wireless internet standards with those related to PANs. A PAN is usually defined as a "computer network used for communication among computerized devices, including telephones and personal digital assistants (PDAs)" in various texts, including ("Wireless Standards", ca. 2006) and ("Personal Area Network", 2012). PANs are typically interconnecting a person's devices, either for intrapersonal communication (between the devices themselves) or for connecting them to a higher level network, or even the internet. By definition, Wireless PANs are small-sized and operate in a short range. In such a restricted usage scenario, low-cost equipment, consuming low amounts of power can be used.

Infra-Red Data Association (IrDA). Infra-Red Data Association[12] was founded in June 1993 as an interest group driven by the industry ("Infrared Data Association", 2012). The group has defined a complete set of protocols for wireless optical communications,

[i] The interested reader can download and use a single copy of the OSI Basic Reference Model (International Organization for Standardization [ISO], 1994) from ISO at no charge.

according to which light is emitted in a straight line (Line-of-Sight, LOS), on a point & shoot basis, within a very small operating range. The name IrDA is also used to refer to these protocols. The main characteristics of IrDA communication are: physical security (enforced by the operating mode described above), half-duplex mode of operation and very low bit error rate.

IrDA protocols are organized hierarchically, similar to that of the OSI Model. These protocols are explained in detail in (Megowan, Suvak, & Knutson, n.d., pp. 6-16). On the bottom there is IrPHY[13] layer, defining the optical link, modulation, coding, error correction and framing mechanism (SIR, MIR etc.). On top of it lies IrLAP[14], representing the Data Link layer. A method similar to Poll/Select (Diakonikolaou, Agiakatsika, & Bouras, 2007, p. 150) is used for controlling access to the media between a Primary and a set of Secondary devices. This link is managed by the subsequent IrLMP[15], on top of which lies TinyTP[16], a protocol responsible for the segmentation and reassembly of large messages and flow control. These protocols are accepted to define the core of the IrDA 1.x platform (Williams, 2000, p. 12). Albeit being an optional protocol, TinyTP is included in the core components, since it provides the necessary functionality for the implementation of IrOBEX[17], Serial/Parallel port emulation (IrCOMM) and last but not least, IrLAN[18] which enables wireless access to Ethernet networks.

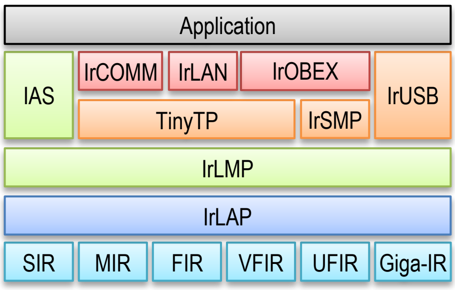

Figure 2 - IrDA protocol stack

The initial implementation supported a transfer rate up to 115 kb/s (SIR) in a range of 0-1m and an angular coverage of 15-30^{o}. Subsequent improvements in protocol layers and transceiver designs as well as the IrSimple extension allowed for higher transfer rates (MIR: 1.152 Mb/s, FIR: 4 Mb/s, VFIR: 16 Mb/s, UFIR: 96 Mb/s, Giga-IR: 1 Gb/s), extended the operating range to 3m and enabled much wider angles (IrDA, 2012). Currently the group is working on even extending the transfer rate to 5/10 Gb/s.

Bluetooth. Bluetooth is a wireless technology that uses short wavelength radio transmissions for exchanging data between personal digital assistants (PDAs), mobile phones, laptops, PCs, printers, digital cameras and video game consoles over short distances ("Bluetooth", 2012) with low power consumption. It was originally created by Ericsson and is currently maintained by the Bluetooth SIG incorporating over 17,000 companies including Intel, Lenovo, Microsoft, Motorola, Nokia and Toshiba to name but a few. The SIG is responsible for all the aspects of the standard, from development to marketing.

Class	*Power (mW)*	*Range (m)*
Class 1	100	~100
Class 2	2.5	~10
Class 3	1	~1

Table 1 - Bluetooth classes

Version	*Rate*	*Throughput*
1.x	1 Mb/s	723.1 Kb/s
2.x+EDR	3 Mb/s	2.1 Mb/s
3.x, 4.x	* uses Wi-Fi IEEE802.11	

Table 2 - Bluetooth transmission & actual transfer rates

The standard utilizes FHSS[19] modulation in the unlicensed Industrial, Scientific & Medical (ISM) 2.4-2.485 GHz range, split into 79 1-MHz bands. Data is split into chunks transmitted on some of these bands in full-duplex mode (Bluetooth SIG, 2012). The standard defines 3 *Classes* of operation, which determine the maximum permitted power and the resulting range of operation. Transmission rates, on the other hand, depend on the modulation types used among the different versions. Devices are organized in *Piconets*, where a collection of *Slave* devices are communicating with a single *Master* device using TDD[20] mode (Zussman, Segall, & Yechiali, 2004).

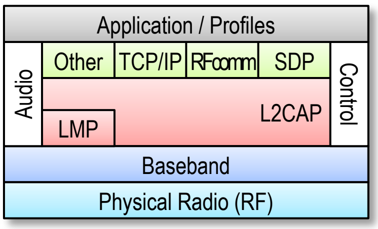

Figure 3 - Bluetooth protocol stack

Bluetooth defines a set of hierarchically organized protocols consistent with the OSI Model. Physical Radio and Baseband lie on the Physical Layer. LMP[21] which controls the radio link and L2CAP[22] offering packet segmentation and reassembly, implement the Data Link layer. RFCOMM[23] provides serial data stream support, while SDP[24] allows devices to share information about the implemented services with each other. The Profile concept encapsulates this information by defining possible applications and general communication behaviors ("Bluetooth Wireless Technology Profiles", n.d.).

The PAN Profile (Bluetooth SIG, 2003) provides internet services through the NAP[25] and GN[26] services. Beyond the mandatory protocols -LMP, L2CAP & SDP- the PAN profile also includes the Bluetooth Network Encapsulation Protocol (BNEP) protocol, used for transferring IP packets and Management Entity (ME) which handles connection management.

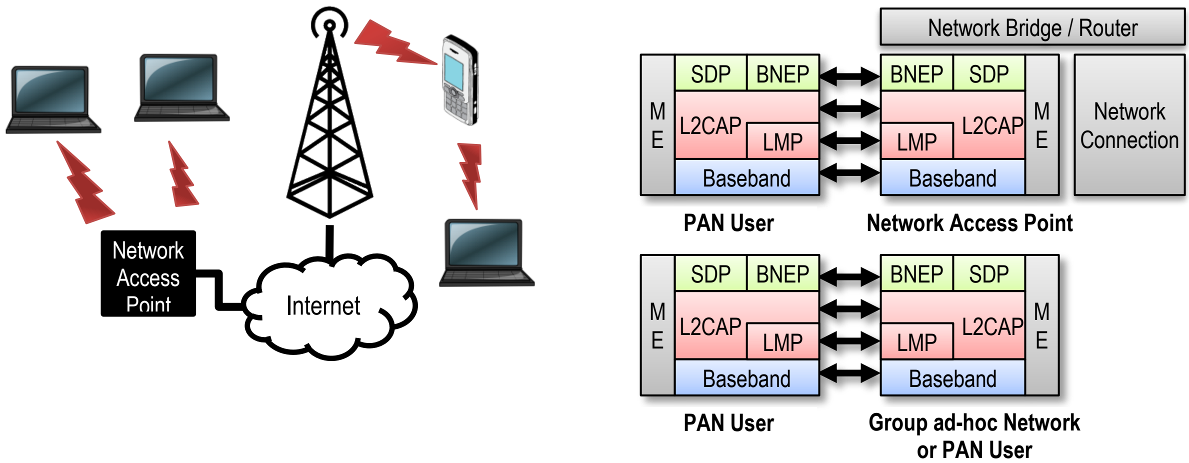

Figure 4 - Left: Types of Network Access Points, Right: PAN User, NAP and GN (Bluetooth SIG, 2003, pp. 14, 17)

IEEE 802.15. The 802.15 Working Group (http://ieee802.org/15/) of the IEEE LAN/MAN Standards Committee includes seven task groups -TG1: 802.15.1 to TG7: 802.15.7- dealing with WPAN standards. Each individual standard is named after the corresponding task group.

TG1 directly adapted v1.1 of the Bluetooth standard as IEEE 802.15.1 (IEEE, 2005). TG2 deals with the coexistence of WPAN with other radio technologies sharing the same frequency bands, such as **IEEE 802.11.** , which will be analyzed in the next chapter. TG3 defines PHY and MAC layers for Hi-Rate WPANs (IEEE, 2003), supporting data transfer rates from 11 to 55 Mb/s. TG4 also defines various PHY and MAC layer implementations for Lo-Rate WPANs (IEEE, 2011a), which focus on flexibility, low cost, low data rates using extremely low power consumption, in order to be used in ad-hoc sensor networks for home and business applications (Callaway, et al., 2002). It is the basis for the ZigBee and MiWi (Microchip, 2012), ISA100.11a and WirelessHART specifications, each of which extends the standard by developing the upper layers of the OSI Model. TG5 deals with mesh networks of Hi-Rate (TG3) and Low-Rate (TG4) WPANs. TG6 has approved a draft standard for Body Area Networks (BAN). Finally, TG7 defined a draft standard for PHY and MAC layers for Visible Light Communications.

ETSI HiperPAN. HiperPAN is yet another wireless technology, designed by ETSI. It is a stripped-down version of HiperLAN[i] for complying with PAN requirements. Its name comes from HIgh PERformance PAN and focuses on coexistence with other radio technologies and provides Quality of Service (QoS) control. However, since only a draft specification is available (ETSI, 2000a) and no other actual references of it have been found, it is considered an abandoned standard.

Wireless Local Area Network (WLAN) Standards

We continue our survey with the standards related to LANs. This type is typically used in SOHO[27] environments, SMEs and homes, yet recently it has been adapted by larger enterprises and organizations. The majority of the characteristics of WLANs -such as size, range, cost and power consumption- lie in the small to medium range.

IEEE 802.11. 802.11 is a family of standards designed and maintained by the 802.11 Working Group (http://ieee802.org/11/) of the IEEE LAN/MAN Standards Committee. Several amendments (namely 802.11a, 802.11b etc.) have been published, defining extensions and corrections of the original 1997 specification (“802.11”, 2012). Products based on this standard using the brand-name Wi-Fi[28], a trademark owned by the Wi-Fi Alliance (http://www.wi-fi.com), have dominated the market of WLANs equipment.

[i] HiperLAN will be covered in the following chapter.

802.11	*Release*	*Freq. (GHz)*	*Bandwidth (MHz)*	*Throughput per stream (Mb/s)*	*MIMO streams*	*Modulation*	*Approximate range (m)*	
							Indoor	Outdoor
-	6/1997	2.4	20	1, 2	1	DSSS, FHSS	20	100
a	9/1999	5/3.7	20	6…54	1	OFDM	35	120
b	9/1999	2.4	20	1…11	1	DSSS	35	140
g	6/2003	2.4	20	6…54	1	OFDM, DSSS	38	140
n	10/2009	2.4/5	20	7.2…72.2	4	OFDM, QAM	70	250
			40	15…150				
ac (under development)	11/2011 (final: 2013 est.)	5	20	< 87.6	8			
			40	< 200				
			80	< 433.3				
			160	< 866.7				
ad (draft)	6/2011	2.4/5/60		< 7.000				

Table 3 - IEEE 802.11 characteristics summary ("802.11", 2012)

The standard defines a MAC and a series of PHY layers (IEEE, 2012) introduced by the standard's amendments. Most of these PHY layers specify different modulation techniques for radio transmissions: FHSS, Standard DSSS[29], Hi-Rate DSSS, Extended-Rate DSSS, Standard OFDM[30] and Hi-Throughput OFDM/QAM[31]. An Infrared (IR) PHY layer is also defined, allowing transmission without requiring a clear line-of-sight. Radio transmissions are operating in the ranges of 2.4, 3.7, 5 and 60 GHz in half-duplex mode. Since the 802.11n amendment, MIMO[32] technology has been incorporated to improve performance. The characteristics of these standards are summarized in Table 3.

The allocated operation frequency range is divided into a number of bands called *Channels*. The 2.4-2.4835 GHz range is split into 13 channels spaced at 5 MHz intervals: ch.1 is centered at 2.412 and ch.13 at 2.472 GHz. These channels may overlap, according to the bandwidth required by the modulation being used, narrowing down the number of available channels. National regulations exist in some countries, reducing this number even more.

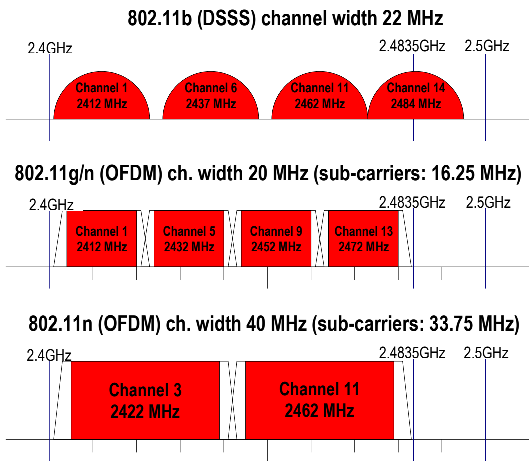

Figure 5 - Non-Overlapping channels for 2.4GHz WLAN ("802.11", 2012)

As far as security is concerned, the initial standard defined the WEP[33] algorithm, which proved easy to crack due to inherent flaws (Wong, 2003). WPA[34] was introduced (Wi-Fi Alliance, 2003) as WEP's replacement, which in turn was superseded by the more complete WPA2, issued as 802.11i in 2004.

The increasing demand and commercial success effectively pushed the standard's evolution and products to the market prior to final ratification by the IEEE Committee in some cases (g, n). Current work in progress, branded as Wi-Gig[35], promises to reach 7 Gb/s transfer rates in a 10m range, in order to handle HDTV[36] video streams in home networks.

ETSI HiperLAN. HiperLAN is one of the standards defined in ETSI's BRAN[37] project along with HiperPAN, HiperMAN[i] and HiperACCESS.

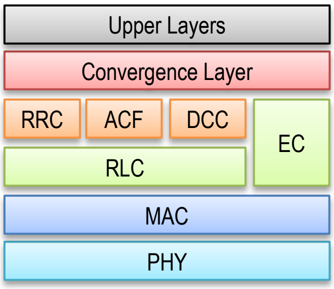

Figure 6 - HiperLAN protocol stack

The standard defines PHY and Data Link Control (DLC) layers -Radio Link Control, Error Control and MAC- for radio transmissions in the unlicensed 5 GHz range. The air interface is based on TDD and Dynamic TDMA[38] using OFDM modulation (Johnsson, 1999). The standard achieves maximum transmission rates of 54 Mb/s on the PHY layer and up to 25 Mb/s on layer 3. Two versions of the standard exist: HiperLAN/1 and its successor HiperLAN/2, which introduced QoS support. It should be noted that the specification of IEEE 802.11 -with an initial transmission speed of only 2 Mb/s- began while HiperLAN/2 was in progress (Khun-Jush, Malmgren, Schramm, & Torsner, 2000). Among the advantages of HiperLAN we consider QoS support, automatic frequency allocation and security.

Wireless Metropolitan Area Network (MAN) Standards

The next category of standards we are going to deal with refers to MANs. The IEEE 802 standard for LAN/MAN (IEEE, 2001, p. 1) defines MAN as:

[i] HiperMAN & HiperACCESS will be covered in the next chapter

"A MAN is optimized for a larger geographical area than is a LAN, ranging from several blocks of buildings to entire cities. As with local networks, MANs can also depend on communications channels of moderate-to-high data rates. A MAN might be owned and operated by a single organization, but it usually will be used by many individuals and organizations. MANs might also be owned and operated as public utilities."

IEEE 802.16. IEEE 802.16 is a family of standards designed and maintained by the 802.16 Working Group (http://ieee802.org/16/) of the IEEE LAN/MAN Standards Committee. The standards in this family are divided into two sets, supporting both *Fixed*[i] and *Mobile*[ii] BWA[39]. They form a low-cost alternative and competitive technology to cable modem, DSL[40], T1 and FTTx[41] for "last mile" broadband access, especially applicable in rural areas where other technologies are too expensive to deploy (Vaughan-Nichols, 2004). Initially the two sets were issued as separate documents: 802.16-2004 dealt with f.a and 802.16e-2005 (IEEE, 2006) with m.a. More recent revisions (IEEE, 2009) and (IEEE, 2011b) combine the two sets in a single document.

The standards define a MAC and a series of PHY layers for radio transmissions in both licensed and unlicensed frequency ranges, from 2 to 66 GHz. OFDM, OFDMA[42], QAM or even BPSK[43] modulation may be used, together with TDD (f.a, m.a) and FDD[44] duplexing (f.a only), allowing for bandwidths varying from 1.5 to 28 MHz and raw transmission speeds up to 1 Gb/s (f.a) and 100 Mb/s (m.a) per channel. MIMO technology has been incorporated to improve signal quality and transmission speed, via multiple concurrent channels. Improved security is provided by

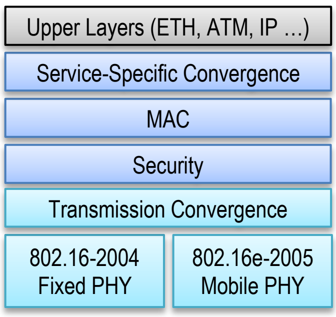

Figure 7 - 802.16 protocol stack

[i] For the rest of the chapter, f.a will be used as an abbreviation for fixed access and m.a for mobile access.
[ii] The mobile variation is a WAN rather than a MAN technology, yet we analyze it here for the sake of unity.

utilizing AES[45] and DES[46] encryption algorithms. Finally, QoS is supported since the 802.16e amendment, strongly backed by the connection-oriented nature of the technology.

ETSI HiperMAN and HiperACCESS. HiperMAN and HiperACCESS complete the ETSI family of standards defined in the BRAN project together with HiperPAN and HiperLAN. HiperACCESS provides fixed access in urban and rural areas (Haine, 1998), supporting transfer rates from 25 to 100 Mb/s using the 40.5-43.5 GHz frequency range (ETSI, 2000b). HiperMAN on the other hand, operates at frequencies between 2 and 11 GHz and has similar characteristics to IEEE 802.16 upon which it was based (Hoymann, Puttner, & Forkel, 2002).

WiMAX. The name WiMAX[47] has initially been used as a brand-name for products conforming to the 802.16 standard ("802.16", 2012). However, WiMAX also incorporates ETSI HiperMAN. IEEE and ETSI have officially co-operated (IEEE, n.d) in order to incorporate features from one's standard to the other's (Vaughan-Nichols, 2004). The WiMAX Forum (http://www.wimaxforum.org) owns the WiMAX trademark and operates the product certification process.

WiBro. WiBro[48] is a PIS[49] technology developed by an alliance formed by the largest Korean telecommunication companies[i]. The Korean government has allocated a bandwidth of 100 MHz in the 2.3-2.4 GHz area for exclusive WiBro usage in order to support its evolution (Nam, Kim, & Lee, 2008). It was the first implementation of the mobile 802.16e-based standard and promised to fill the gaps between WLAN and 3G technologies - covered in the next chapter. However it was superseded by mobile WiMAX, which may be considered identical to WiBro (WiBro Technical Overview, ca. 2007). It is currently deployed in most major Korean cities, reaching population coverage of about 85% ("WiBro", 2012).

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[i] Including Hyundai, LG, Samsung etc., see: http://www.wibro.or.kr

Wireless Wide Area Network (WAN) Standards

In this chapter we will analyze standards for providing internet services to outspread networks using highly mobile devices, such as phones and tablets. Users of these *Mobile* networks consider mobility as the most important characteristic, yet recent efforts focus on increasing transfer rates and lowering service fees. The vast majority of these networks are based on cellular technology. Cellular networks and related standards are classified in four major “generations”, 1G to 4G, a scheme that we use in this chapter. International organizations such as 3GPP[50], ETSI and IEEE define the major characteristics of these and forth-coming generations. Some of the standards are considered over-qualified for one generation but under-qualified for the next one and have been assigned to a mid-generation.

1G Mobile Networks. 1G mobile network technologies appeared as early as 1978 in the US (AMPS[51]) and early 80’s in Europe (NMT[52], TACS[53], ETACS[54]) and the rest of the world, as stated in (“AMPS”, 2012), (“NMT”, 2012) and (“TACS”, 2012). These proprietary standards utilized analog modulation for radio transmission of voice in a variety of bands (150, 450 and 800-960 MHz), using early implementations of FDMA[55]. Data transmission in low data rates of a few Kb/s could be achieved via FFSK[56] modems. Major disadvantages include the lack of interoperability and security, as well as low capacity and transfer rates, yielding a low overall QoS level. Consumer terminals also suffered from low autonomy -battery life- and mobility.

2G Mobile Networks. Increasing demand for wireless mobile services led to the evolution of these standards. The first step to address disadvantages of 1G was the utilization of digitally encoded transmission.

During the 80’s, Groupe Spécial Mobile committee was formed by CEPT[57] -and later transferred to ETSI- to work on the implementation of a new, open, pan-European standard for voice transmission, focusing in interoperability, security and product affordability

(Seurre, Savelli, & Pietri, 2003a). The standard named GSM[58] was initially publicized in 1990. The GSM trademark is owned by the GSM Association (http://www.gsma.com).

GSM operates in licensed bands: 900/1800 MHz in the EU, 850/1900 MHz in the US & Canada and 400/450 MHz in other countries where the former bands had already been allocated ("GSM", 2012). FDMA is utilized to separate different cell transmissions, while TDMA is used by a single cell for multiplexing digitally encoded user voice data of up to 8 concurrent time-slots (channels), with a combined transfer rate of 270 Kb/s.

IS-95[59] is a competitive de-facto standard owned by the Qualcomm company. User data is multiplexed using CDMA[60], which improves bandwidth utilization by supporting more users per MHz. GSM's widespread use in addition to the proprietary nature of the standard, limits its' usage in the US.

Scheme	*Data rate (Kb/s)*
CS-1	9.05
CS-2	13.4
CS-3	15.6
CS-4	21.4

Table 4 - GPRS coding schemes (Seurre et al., 2003a)

2G to 3G Evolution Mobile Networks. A very important extension to the GSM standard, often referred to as *2.5G*, was the ability to transfer data as well as voice in the same time. This was achieved by the introduction of GPRS[61] a packet-switching technology -in contrast to the circuit-switching GSM- which enabled internet access from mobile phones. GPRS defines PHY and MAC layers supporting IP, PPP and X.25 protocols. Three *Classes* of handsets are defined, allowing for simultaneous (A) or non-simultaneous use of GSM and GPRS with automatic (B) or manual (C) switching. Duplexing is offered using FDD. One out of four *Coding Schemes* (Seurre et al., 2003a) may be selected, depending on the relative location of the user to the active cell, offering a variety of transfer rates. Multiple TDMA time-slots may be allocated, according to the device's *Multi-slot Class*[i]. The actual Data Transmission speed[ii] is obtained by multiplying the active time-slots by the Coding Scheme data rate.

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[i] The devices' *Multi-slot Class* is a number (1 to 45) determining the maximum simultaneous time-slots supported for downlink (DL) or uplink (UL). The notation DL+UL designates the per link time-slots in use.

[ii] For a 4+1 class device, CS-4 scheme allows for 85.6 Kb/s DL and 21.4 Kb/s UL speed.

Another pre-3G evolution standard -often described as 2.75G- is EDGE[62]. EDGE extends GPRS' PHY layer by incorporating GMSK[63] and 8PSK[64] modulation (Seurre, Savelli, & Pietri, 2003b). It also defines nine Modulation and Coding Schemes with varying data rates, supporting up to 59.2 Kb/s per time-slot, or 296 Kb/s total with a 5+1 Multi-slot Class device.

Scheme	*Modulation*	*Data rate (Kb/s)*
MCS-1	GMSK	8.8
MCS-2	GMSK	11.2
MCS-3	GMSK	14.8
MCS-4	GMSK	17.6
MCS-5	8PSK	22.4
MCS-6	8PSK	29.6
MCS-7	8PSK	44.8
MCS-8	8PSK	54.4
MCS-9	8PSK	59.2

Table 5 – EDGE modulation & coding schemes ("EDGE", 2012)

3G Mobile Networks. 3G is a term used to define a set of standards complying with the ITU specifications for 3rd generation of mobile networks, which require a peak data rate of at least 200 Kb/s.

The first standard to fulfill ITU requirements for 3G was UMTS[65] developed by 3GPP based on GSM, in 2001 ("UMTS", 2012). It utilizes W-CDMA[66] to improve performance in terms of spectrum use and transfer rate, which reaches 384 Kb/s. It operates in separate frequency ranges, one for uplink (UL) and one for downlink (DL). EU ranges differ from US ones due to pre-existing allocation. Duplexing is offered using FDD.

Direction	*MHz EU*	*MHz US*
Uplink	1885-2025	1710-1755
Downlink	2110-2200	2110-2155

Table 6 – UMTS operating frequencies

HSPA[67] designates W-CDMA evolution, combining HSDPA[68] and HSUPA[69] ("HSPA", 2012). It further extends transmission rates to 14 Mb/s and 5.7 Mb/s respectively, by introducing new PHY and MAC layers (Dahlman, Parkvall, Skold, & Beming, 2007).

The competitive CDMA2000 standard appeared in 2001 from the evolution of IS-95, promising transfer rates of up to 153 Kb/s ("CDMA2000", 2012). CDMA2000 1xEV-DO further improved transfer rates for data only.

3G Evolution Mobile Networks. As we have seen in the years before the deployment of 3G technologies, there also exist standards considered to be “near 4G” but not 4G compliant, as defined in the next section.

One such technology is HSPA+[70] (Evolved HSPA). This extension of the HSPA standard utilizes higher order modulation (64QAM) and MIMO technology, enabling a *theoretical* maximum transfer rate of 168 Mb/s (DL) and 22 Mb/s (UL), achieved when the client is very closely located to the cell.

On the other side, the data optimized Revisions A, B and C of CDMA2000 1xEV-DO are also considered as mid-g technologies.

The 802.20 Working Group (http://ieee802.org/20/) of the IEEE LAN/MAN Standards Committee has designed IEEE 802.20 the family of standards, also known as Mobile Broadband Wireless Access (MBWA). The group’s goal is to “enable worldwide deployment of affordable, ubiquitous, always-on and interoperable multi-vendor mobile broadband wireless access networks that meet the needs of business and residential end user markets”. It defines PHY and MAC layers operating in frequencies below 3.5 GHz, optimized for IP data. Data rates of at least 1 Mb/s per user are supported utilizing OFDMA and both FDD and TDD duplexing (Ergen, 2009). Users may move at vehicular speeds of up to 250 Km/h.

4G Mobile Networks. 4G is a term used to define a set of standards complying with the ITU specifications for 4th generation of mobile networks, which require a peak data rate of at least 100 Mb/s. Some common characteristics among these standards are the abandonment of circuit-switched telephony in favor of IP-based telephony and spread-spectrum modulation in favor of OFDM (familiar from 802.11) and similar technologies.

LTE[71] is the most well-known 4G standard, developed by 3GPP extending UMTS technology (“LTE”, 2012). The standard defines new PHY and MAC layers promising transfer rates of up to 299.6 Mb/s (DL) and 75.4 Mb/s (UL). Radio transmissions use the same bands as 3G and support both FDD and TDD for duplexing (Dahlman et al., 2007). Backward compatibility is somewhat sacrificed for improved transfer rates.

Mobile WiMAX -especially v2- based on the 802.16m amendment[i] of the standard is also considered a 4G technology, focusing on users moving with high vehicular speeds. There is an obvious overlap between the goals of the IEEE 802.16 and 802.20 standards, with the former focusing on a broader operating frequency band and higher data rates. This causes a debate on the potential future of 802.20.

At the time of writing 4G networks are under deployment throughout the world. The actual transfer rates of these networks do not reach the promised levels and the functionality is mostly limited to urban areas (Varshney, 2012).

Figure 8 pictures the evolution and performance of radio modulation technologies used in the wireless broadband standards covered in this chapter.

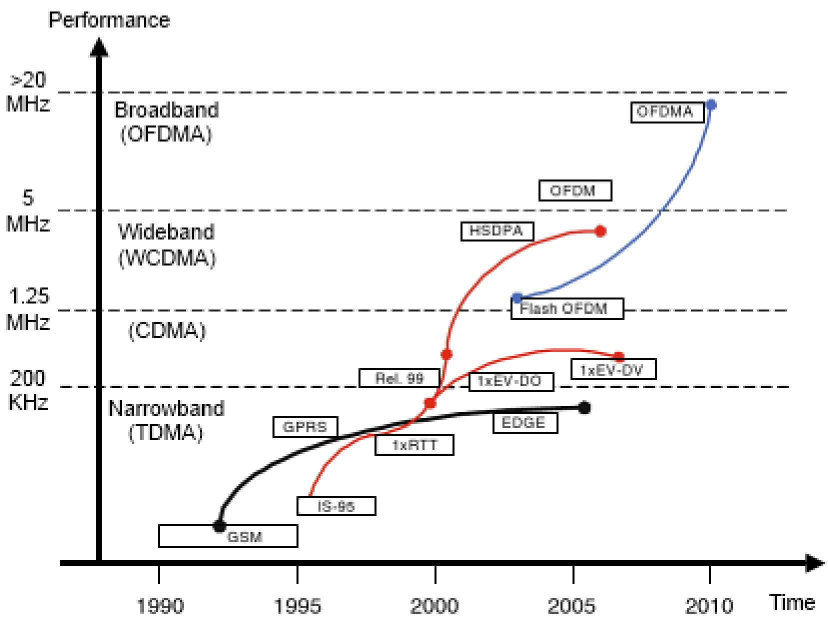

Figure 8 - Evolution of radio technologies; Source: Siemens (Ergen, 2009, p. 5)

[i] See also the related chapters, “IEEE 802.16” and “WiMAX”.

Wireless Regional Area Network (RAN) Standards

The term RAN was recently introduced to refer to geographically dispersed networks whose nodes cover a range up to 100 Km (Javvin Technologies Inc., n.d). This class is typically used in sparsely populated rural and non-metropolitan areas.

IEEE 802.22. IEEE 802.22 is another family of standards currently under development by the 802.22 Working Group (http://ieee802.org/22/) of the IEEE LAN/MAN Standards Committee. The group aims to "enable broadband wireless access" to rural areas. It defines PHY and MAC layers using *Cognitive Radio*[i] technology (IEEE, 2011c), operating in unused frequencies of the TV broadcast range[ii]. This is a very promising technology, especially for areas with either inadequate infrastructure or sparse population, a typical case for developing countries.

Conclusions

The standards developed in recent years that we presented in this work, have been widely adopted and posed a strong influence on the convergence of Wireless communication technologies and the Internet. This evolution of the Wireless Internet is two-fold, consisting of both a technological and a commercial aspect.

Wireless technology has been highly attractive from the very beginning of its appearance, due to ease of installation, use and low costs compared to cable networks. Nowadays, the increasingly popular social networks incorporating user generated content, created using the intuitive user interface of modern "smart" phones and tablets, are considered the "killer apps" leading the development and commercial success of mobile and fixed wireless networking products and services. Figure 9 illustrates the increasing trend in mobile vs. fixed telephony and internet subscriptions (ITU, 2012).

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[i] Cognitive Radio (CR) refers to software-enhanced "intelligent" radio transmitters, able to automatically detect and select unused frequencies.
[ii] In the US: 54-862 MHz, divided at 6-8 MHz channels (Cordeiro et al., 2006)

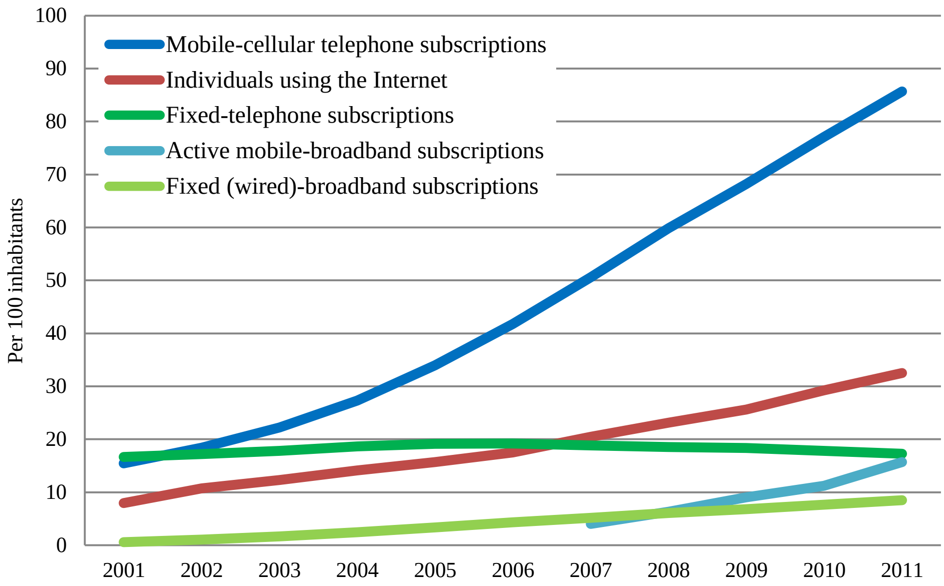

Figure 9 - Global ICT developments, 2001-2011; Source: ITU World Telecommunication / ICT Indicators DB (ITU, 2012)

In addition, the explosively increasing use of mobile devices accessing cloud based data and applications within enterprises, opens up a market dominated by fixed-line technologies to wireless products (Mehra, 2011).

Products built upon OFDMA-based standards, like Wi-Fi, have already dominated the WLAN market, primarily due to their performance characteristics. This is also gradually becoming true in the extremely competitive mobile broadband market, fulfilling Ergen's prediction (2009) that "OFDMA-based mobile broadband will emerge as a successor to cellular systems". Currently deployed 4G networks are based on such technologies, like LTE and mobile WiMAX, among which Varshney (2012) estimates that LTE will eventually prevail.

Varshney (2012) also designates network reliability, speeds and coverage, infrastructure and spectrum license costs, access service pricing and finally, demand for sophisticated applications as the key factors to affect the future of the networking industry. These factors have significantly affected network technology evolution so far, hence they may as well continue to influence it in the years to come, unless a new "distracting" technology appears.

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Appendix A - Acronyms & Abbreviations

[1] IETF: Internet Engineering Task Force, http://www.ietf.org/

[2] IAB: Internet Architecture Board, http://www.iab.org/

[3] IESG: Internet Engineering Steering Group, http://www.ietf.orf/iesg/

[4] IRTF: Internet Research Task Force, http://irtf.org/

[5] W3C: World Wide Web Consortium, http://www.w3.org/

[6] IEEE-SA: Institute of Electrical and Electronics Engineers - Standards Association, http://standards.ieee.org/, http://www.ieee.org/

[7] ISO: International Organization for Standardization, http://www.iso.org/

[8] ANSI: American National Standards Institute, http://www.ansi.org/

[9] ETSI: European Telecommunications Standards Institute, http://www.etsi.org/

[10] ITU-T: International Telecommunication Union Standardization Sector

[11] SIG: Special Interest Group

[12] IrDA: Infrared Data Association, http://irda.org

[13] IrPHY: Infrared Physical (layer)

[14] IrLAP: Infrared Link Access Protocol

[15] IrLMP: Infrared Link Management Protocol

[16] TinyTP: Tiny Transfer Protocol

[17] IrOBEX: Infrared OBject EXchange

[18] IrLAN: Infrared Local Area Network

[19] FHSS: Frequency-Hopping Spread Spectrum

[20] TDD: Time Division Duplex

[21] LMP: Link Management Protocol

[22] L2CAP: Logical Link Control and Adaptation Protocol

[23] RFCOMM: Radio Frequency COMMunications

[24] SDP: Service Discovery Protocol

[25] NAP: Network Access Point

[26] GN: Group ad-hoc Network

[27] SOHO: Small Office/Home Office

[28] Wi-Fi: Wireless-Fidelity

[29] DSSS: Direct-Sequence Spread Spectrum

[30] OFDM: Orthogonal Frequency-Division Multiplexing

[31] QAM: Quadrature Amplitude Modulation

[32] MIMO: Multiple-Input Multiple-Output refers to the use of multiple antennas on both the transmitter and the receiver in order to improve communication performance.

[33] WEP: Wired Equivalent Privacy

[34] WPA: Wi-Fi Protected Access

[35] Wi-Gig: Wireless Gigabit Alliance, http://wirelessgigabitalliance.org/

[36] HDTV: High-Definition TV

[37] BRAN: Broadband Radio Access Networks

[38] TDMA: Time-Division Multiple Access

[39] BWA: Broadband Wireless Access

[40] DSL: Digital Subscriber Line

[41] FTTx: Fiber To The x, where x = { N: Node, C: curb/closet, B: building/business, H: home, P: premises, D: desk }

[42] OFDMA: Orthogonal Frequency-Division Multiple Access (multi-user OFDM)

[43] BPSK: Binary Phase Shift Keying (2-order PSK)

[44] FDD: Frequency Division Duplex

[45] AES: Advanced Encryption Standard

[46] DES: Data Encryption Standard

[47] WiMAX: Worldwide Interoperability for Microwave Access

[48] WiBro: Wireless Broadband

[49] PIS: Portable Internet Service

[50] 3GPP: 3rd Generation Partnership Project

[51] AMPS: Advanced Mobile Phone System

[52] NMT: Nordic Mobile Telephone

[53] TACS: Total Access Communication System

[54] ETACS: Extended Total Access Communication System

[55] FDMA: Frequency-Division Multiple Access

[56] FFSK: Fast Frequency Shift Keying

[57] CEPT: European Conference of Postal and Telecommunications Administrations

[58] GSM: Groupe Spécial Mobile (early), Global System for Mobile Communications (current)

[59] IS-95: Interim Standard 95

[60] CDMA: Code-Division Multiple Access

[61] GPRS: General Packet Radio Service

[62] EDGE: Enhanced Data rates for GSM Evolution

[63] GSMK: Gaussian Minimum Shift Keying

[64] 8-PSK: 8-order Phase Shift Keying

[65] UMTS: Universal Mobile Telecommunications System

[66] W-CDMA: Wideband Code Division Multiple Access

[67] HSPA: High-Speed Packet Access

[68] HSDPA: High-Speed Downlink Packet Access

[69] HSUPA: High-Speed Uplink Packet Access

[70] HSPA+: Evolved High-Speed Packet Access

[71] LTE: Long Term Evolution

Figure Captions

Notes

APA Style formatting was based on the "APA paper format" template obtained from http://bit.ly/TfkFNX with additional information obtained from the following sites and documents:

- http://blog.apastyle.org
- http://nyu.libguides.com/content.php?pid=27555&sid=200248
- http://www.aug.edu/elcse/2010APAGuidelineChanges.pdf

The Bibliography functionality of Microsoft Office 2010 was utilized for bibliography table and in-text references. This functionality was expanded according to information obtained from http://bit.ly/RMM8bQ in order to incorporate DOI information in the bibliography table.