

1

Introduction to Broadband Wireless Access

1.1 The Need for Wireless Data Transmission

Since the final decades of the twentieth century, data networks have known steadily growing success. After the installation of fixed Internet networks in many places all over the planet and their now large expansion, the need is now becoming more important for wireless access. There is no doubt that by the end of the first decade of the twenty-first century, high-speed wireless data access, i.e. in Mb/s, will be largely deployed worldwide.

Wireless communication dates back to the end of the nineteenth century when the Maxwell equations showed that the transmission of information could be achieved without the need for a wire. A few years later, experimentations such as those of Marconi proved that wireless transmission may be a reality and for rather long distances. Through the twentieth century, great electronic and propagation discoveries and inventions gave way to many wireless transmission systems.

In the 1970s, the Bell Labs proposed the cellular concept, a magic idea that allowed the coverage of a zone as large as needed using a fixed frequency bandwidth. Since then, many wireless technologies had large utilisation, the most successful until now being GSM, the Global System for Mobile communication (previously Groupe Spécial Mobile), originally European second generation cellular system. GSM is a technology mainly used for voice transmission in addition to low-speed data transmission such as the Short Message Service (SMS).

The GSM has evolutions that are already used in many countries. These evolutions are destined to facilitate relatively high-speed data communication in GSM-based networks. The most important evolutions are:

- GPRS (General Packet Radio Service), the packet-switched evolution of GSM;
- EDGE (Enhanced Data rates for GSM Evolution), which includes link or digital modulation efficiency adaptation, i.e. adaptation of transmission properties to the (quickly varying) radio channel state.

In addition to GSM, third-generation (3G) cellular systems, originally European and Japanese UMTS (Universal Mobile Telecommunication System) technology and originally American cdma2000 technology, are already deployed and are promising wireless communication systems.

Cellular systems have to cover wide areas, as large as countries. Another approach is to use wireless access networks, which were initially proposed for Local Area Networks (LANs) but can also be used for wide area networks.

1.2 Wireless Networks and Broadband Wireless Access (BWA)

1.2.1 Different Types of Data Networks

A large number of wireless transmission technologies exist, other systems still being under design. These technologies can be distributed over different network families, based on a network scale. In Figure 1.1, a now-classical representation (sometimes called the ‘eggs figure’) is shown of wireless network categories, with the most famous technologies for each type of network.

A *Personal Area Network* (PAN) is a (generally wireless) data network used for communication among data devices close to one person. The scope of a PAN is then of the order of a few metres, generally assumed to be less than 10m, although some WPAN technologies may have a greater reach. Examples of WPAN technologies are Bluetooth, UWB and Zigbee.

A *Local Area Network* (LAN) is a data network used for communication among data devices: computer, telephones, printer and personal digital assistants (PDAs). This network covers a relatively small area, like a home, an office or a small campus (or part of a campus). The scope of a LAN is of the order of 100 metres. The most (by far) presently used LANs are Ethernet (fixed LAN) and WiFi (Wireless LAN, or WLAN).

A *Metropolitan Area Network* (MAN) is a data network that may cover up to several kilometres, typically a large campus or a city. For instance, a university may have a MAN that joins together many of its LANs situated around the site, each LAN being of the order

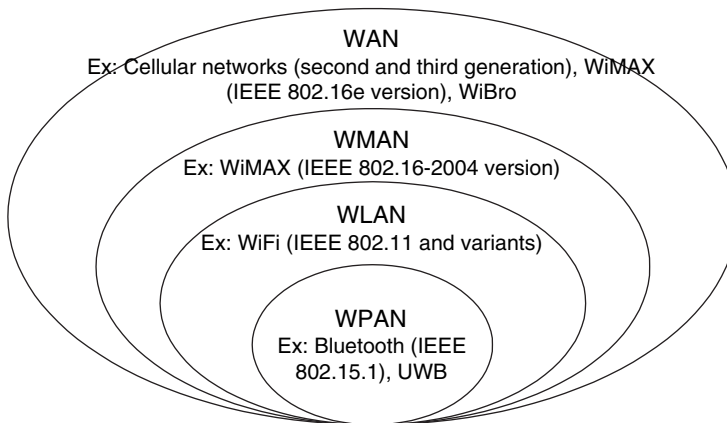


Figure 1.1 Illustration of network types. For each category, the most well known technologies are given. To this figure, some people add a smaller ‘egg’ in the WPAN (Wireless Personal Area Network), representing the WBAN (Wireless Body Area Network), with a coverage of the magnitude of a few metres, i.e. the proximity of a given person

of half a square kilometre. Then from this MAN the university could have several links to other MANs that make up a WAN. Examples of MAN technologies are FDDI (Fiber-Distributed Data Interface), DQDB (Distributed Queue Dual Bus) and Ethernet-based MAN. Fixed WiMAX can be considered as a Wireless MAN (WMAN).

A *Wide Area Network* (WAN) is a data network covering a wide geographical area, as big as the Planet. WANs are based on the connection of LANs, allowing users in one location to communicate with users in other locations. Typically, a WAN consists of a number of interconnected switching nodes. These connections are made using leased lines and circuit-switched and packet-switched methods. The most (by far) presently used WAN is the Internet network. Other examples are 3G and mobile WiMAX networks, which are Wireless WANs. The WANs often have much smaller data rates than LANs (consider, for example, the Internet and Ethernet).

To this figure, some people add a smaller ‘egg’ in the WPAN, representing the WBAN, *Wireless Body Area Network*, with a coverage of the magnitude of a few metres, i.e. the near proximity of a given person. A WBAN may connect, for example, the handset to the ear-phone, to the ‘intelligent’ cloth, etc.

1.2.2 Some IEEE 802 Data Network Standards

WiMAX is based on the IEEE 802.16 standard [1,2]. Standardisation efforts for local area data networks started in 1979 in the IEEE, the Institute of Electrical and Electronics Engineers. In February 1980 (80/2), the IEEE 802 working group (or committee) was founded, dedicated to the definition of IEEE standards for LANs and MANs. The protocols and services specified in IEEE 802 map to the lower two layers (Data Link and Physical) of the seven-layer OSI networking reference model [3,4]. IEEE 802 splits the OSI Data Link Layer into two sublayers named Logical Link Control (LLC) and Media Access Control (MAC) (see Chapter 3).

Many subcommittees of IEEE 802 have since been created. The most widely used network technologies based on IEEE 802 subcommittees are the following:

- IEEE 802.2, Logical Link Control (LLC). The LLC sublayer presents a uniform interface to the user of the data link service, usually the network layer (Layer 3 of the OSI model).
- IEEE 802.3, Ethernet. The Ethernet, standardised by IEEE 802.3, is a family of network technologies for LANs, standardized by IEEE 802.3. It quickly became the most widespread LAN technology until the present time. Possible data rates are 100 Mb/s, 1 Gb/s and 10 Gb/s.
- IEEE 802.5, Token Ring. The Token Ring LAN technology was promoted by IBM in the early 1980s and standardised by IEEE 802.5. Initially rather successful, Token Ring lost ground after the introduction of the 10BASE-T evolution of Ethernet in the 1990s.
- IEEE 802.11, WLAN. IEEE 802.11 is the subcommittee that created what is now known as WiFi Technology. A Wireless Local Area Network (WLAN) system and many variants were proposed by the IEEE 802.11 working group (and subcommittees), founded in 1990. A WLAN covers an area whose radius is of the magnitude of 100 metres (300 feet). First, IEEE 802.11 (www.ieee802.org/11/) and its two physical radio link variants, 802.11a and 802.11b standards, were proposed by the end of the 1990s. IEEE 802.11b products, certified by WiFi (Wireless Fidelity) Consortium, were available soon after. These products have nearly always been known as being of WiFi Technology. These WiFi products

quickly encountered a large success, mainly due to their simplicity but also the robustness of the technology, in addition to the relative low cost and the use of unlicensed 2.4 GHz and 5 GHz frequency bands. Other variants of the basic 802.11 standard are available (802.11e, 802.11g, 802.11h, 802.11i, etc.) or are at the draft stage (802.11n, etc.).

- IEEE 802.15, WPAN. Different WPAN technologies were or are defined in IEEE 802.15. IEEE 802.15.1 included Bluetooth, initially proposed by a consortium of manufacturers, and now studies the evolution of Bluetooth. Bluetooth is now a widely used (data) cable-replacement technology with a theoretical scope of up to 20 m. IEEE 802.15.3a studied an Ultra-Wide Band (UWB) System, very high-speed and very low-distance network. The IEEE 802.15.3a draft has not yet been approved. IEEE 802.15.4 is about ZigBee, a low-complexity technology for automatic application and an industrial environment.
- IEEE 802.16, BWA. IEEE 802.16 is the working group of IEEE 802 dedicated to BWA. Its aim is to propose standards for (high data rate) WMAN. IEEE 802.16 standards are detailed in Section 2.2. As for 802.11 products a certification forum was created for IEEE 802.16 products, the WiMAX (Worldwide Interoperability for Microwave Access) forum, also described in Chapter 2. It can already be said that WiMAX is the name normally used for IEEE 802.16 products.

BWA networks have a much greater range than WLAN WiFi. In fact, IEEE 802.16 BWA has two variants: IEEE 802.16-2004, which defines a fixed wireless access WMAN technology, and IEEE 802.16e, which is an amendment of 802.16-2004 approved in December 2005. It included mobility and then fast handover, then becoming a Wireless WAN (see Figure 1.1).

- IEEE 802.20, Mobile Broadband Wireless Access (MBWA). The aim of this group is to define a technology for a packet-based air interface designed for IP (Internet Protocol)-based services. This technology is destined for high-speed mobile devices. It was reported that MBWA will be based on the so-called Flash OFDM technology proposed by Flarion Company.

A draft 802.20 specification was balloted and approved on 18 January 2006. On 8 June 2006, the IEEE Standards Board directed that all activities of the 802.20 working group be temporarily suspended [3].

- IEEE 802.21, Media Independent Handover (MIH). IEEE 802.21 is a new IEEE standard. It is definitely interesting for a telecommunication equipment to have the possibility of realising a handover between two different wireless technologies. A handover is the operation of changing the corresponding base station (the cell), the communication channel, the technology, etc., without interruption of an ongoing telecommunication session (conversation or other). IEEE 802.21 studies standards enabling handover and interoperability between different network types, which is called MIH. These network types can be of the IEEE 802 family or not. For example, the 802.21 standard would provide information to allow a handover between 3G and 802.11/WiFi networks.

1.2.3 Cordless WLL Phone Systems

Along with progress in cellular (or mobile) systems and wireless data networks, wireless phone systems have begun to appear. An important budget for a phone operator or carrier has always been the local loop, also called the ‘last mile’, which connects the phone

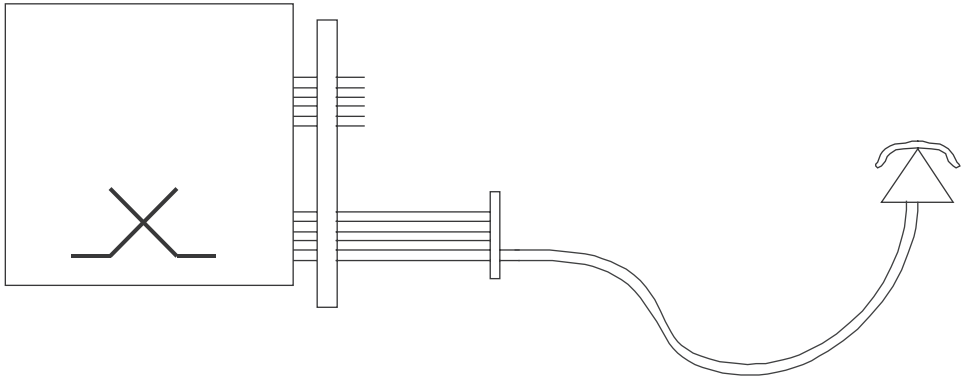


Figure 1.2 Local loop of a classical (voice) phone system

subscriber to the network last elements. It was seen for some configurations that a (radio) Wireless Local Loop (WLL) can be an interesting replacement solution for a fixed (mainly copper) local loop. These WLL systems had to provide a communication circuit, initially for voice, and some low-rate data services. The general principle of a local loop is shown in Figure 1.2.

In a WLL system, terminal stations are connected to a Base Station (BS) through the radio channel (see Figure 1.3). The main difference between WLL and cellular systems is the fact that in a cellular system a subscriber can be connected to one BS or another. A subscriber can also change the BS during a communication without causing an interruption, which is called the handover (or also handoff) procedure.

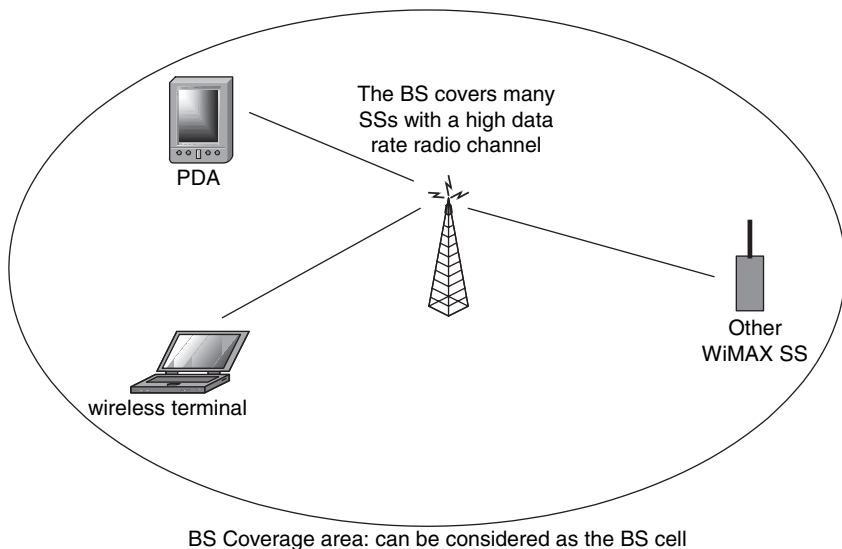


Figure 1.3 Coverage of a given zone by a BS

Several technologies have been proposed for WLL systems, also known as cordless phone systems (or also cordless systems). After analogue systems, mainly proprietary, a digital system was proposed, CT2/CAI (Cordless Telephone 2/Common Air Interface), in 1991. With CT2/CAI, the occupation of one (voice) user is 100kHz.

The European Telecommunications Standards Institute (ETSI) published a WLL cordless system in 1992 named DECT (Digital Enhanced Cordless Telecommunications). The range of DECT equipments is up to a few hundred metres. DECT works in the 1.9GHz bandwidth.

DECT is a digital TDMA (Time Division Multiple Access) suited for voice and low data rate applications, in the order of tens of kb/s. Some evolutions of DECT, featuring many slots per user, propose higher data rates up to hundreds of kb/s. DECT has a relatively high success rate nowadays, yet it is a capacity-limited system as TDMA-only systems do not use the bandwidth very efficiently (a user taking many slots leaves very few resources for other users). The wide use of WLL systems for phone communications and some other low data rate communications gave way to high data rate BWA systems, introduced in Section 1.2.2 above and described in further detail in the next section.

1.3 Applications of BWA

As already introduced above with IEEE 802.16, a BWA system is a high data rate (of the order of Mb/s) WMAN or WWAN. A BWA system can be seen as an evolution of WLL systems mainly featuring significantly higher data rates. While WLL systems are mainly destined for voice communications and low data rate (i.e. smaller than 50kb/s), BWAs' are intended to deliver data flows in Mb/s (or a little lower).

The first application of BWA is fixed-position high data rate access. This access can then evidently be used for Internet, TV and other expected high data rate applications such as Video-on-Demand (VoD). It will also surely be used for other applications that are not really apparent yet. In one word, the first target of BWA is to be a wireless DSL (Digital Subscriber Line, originally called the Digital Subscriber Loop) or also a wireless alternative for the cable. Some business analysts consider that this type of BWA application is interesting only in countries and regions having relatively underdeveloped telecommunications infrastructure. Indeed, using WiMAX for the fixed-position wireless Internet in Paris or New York does not seem economically viable.

Another possible use of high data rate access with BWA is WiFi Backhauling. As shown in Figure 1.4, the Internet so-called backbone is linked to a BS which may be in Line-of-Sight (LOS) of another BS. This has a Non-Line-of-Sight (NLOS) coverage of Subscriber Stations (SSs). The distinction between IEEE 802.16 NLOS and LOS technologies will be detailed in Chapter 2.

The SS in Figure 1.4 is a Consumer Premises Equipment (CPE). The CPE is a radio-including equipment that realises the link between the BS and the terminal equipment(s) of the user. After the CPE, the user may install a terminal such as a Personal Computer (PC) or a TV and may also connect a WiFi Access Point and then a WLAN (the BWA then realizing the WiFi network backhauling). Hence the two main applications of fixed BWA are the wireless last-mile for high data rate and (more specifically) WiFi backhauling. As shown in this figure, a wireless terminal can then be fixed (geographically) or not. This may be the case of a laptop connected to the CPE with a WiFi connection (see the figure).

The fixed access is the first use of BWA, the next step being nomadicity (see Section 1.3.1 for the difference between nomadicity and mobility). A first evolution of the SS will be the

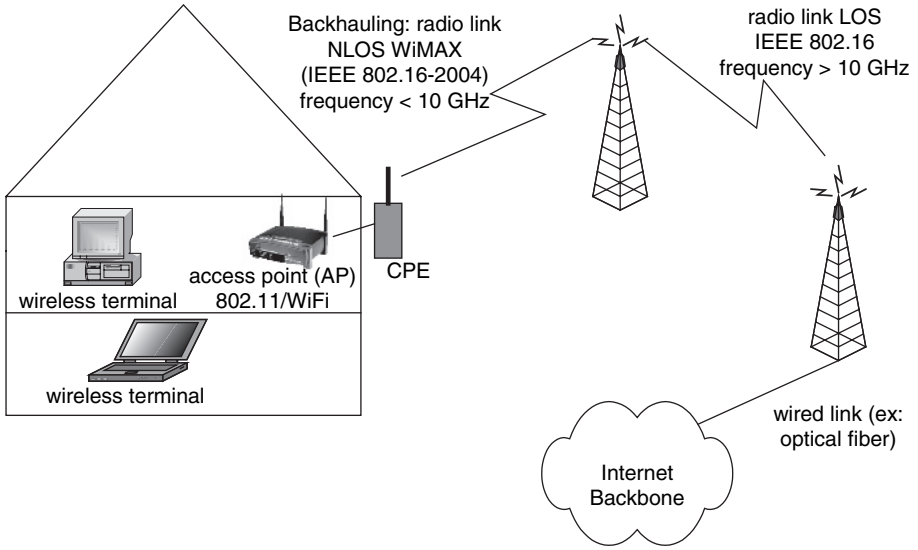


Figure 1.4 Broadband Wireless Access (BWA) applications with a fixed access. The two main applications of a fixed BWA are wireless last-mile for high data rate and (more specifically) WiFi backhauling

case when it is no longer a CPE but a card installed in some laptop. A nomadic access, shown in Figure 1.5, is an access where the user or the subscriber may move in a limited area, e.g. in an apartment or a small campus. This area is the one covered by a BS. Whenever the user moves out of the zone, the communication (or the session) is interrupted. A typical example

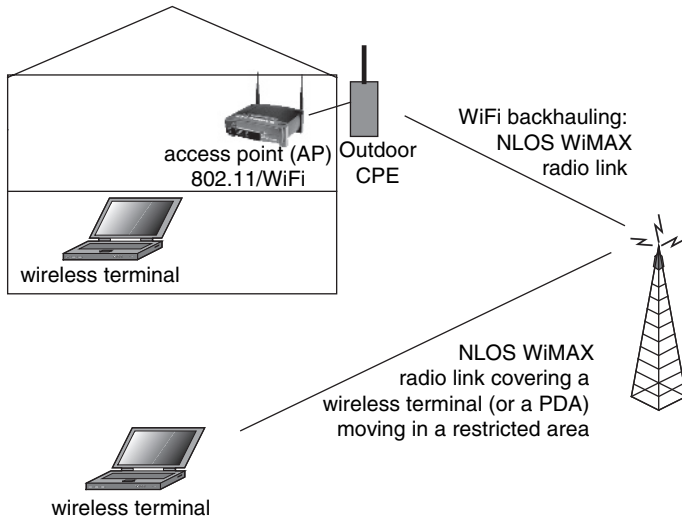


Figure 1.5 Nomadic or portable BWA

of a portable access is WLAN/WiFi use in its first versions (802.11, 802.11b and 802.11a) where a session is interrupted when the terminal gets out of a WLAN coverage even if it enters a zone covered by another WLAN, e.g. in two neighbouring companies.

The nomadic access is very useful in some cases, such as campuses, company areas, compounds, etc. It can be observed that due to this position, which is not fixed, the link between the BS and the SS has to be NLOS (it can be LOS only in the case of fixed CPEs, theoretically). A nomadic access is also sometimes known as a wireless access. The final expected step of WiMAX is a mobile access. The difference between wireless and mobile will now be discussed.

1.3.1 Wireless is Not Mobile!

Different scenarios of mobility can be considered. The most simple one is when two neighbouring BSs belong to the same operator. Hence, the same billing system and customer care apply to the two BSs. In this case, a user moving from one cell to a neighbouring one has to start the session again. This feature is nomadicity rather than mobility. Mobility (or full mobility) is the scenario where the session is not interrupted, whether this is a data session, a voice communication (over IP or not), a video transmission, etc.

The distinction is made between wireless (but yet geographically) fixed access, nomadicity, portability and mobility. Portability is when a user can move with a reasonable speed over a large area, covered by many BSs, without interruption of an possible open session or communication. The value considered as a reasonable speed is of the order of

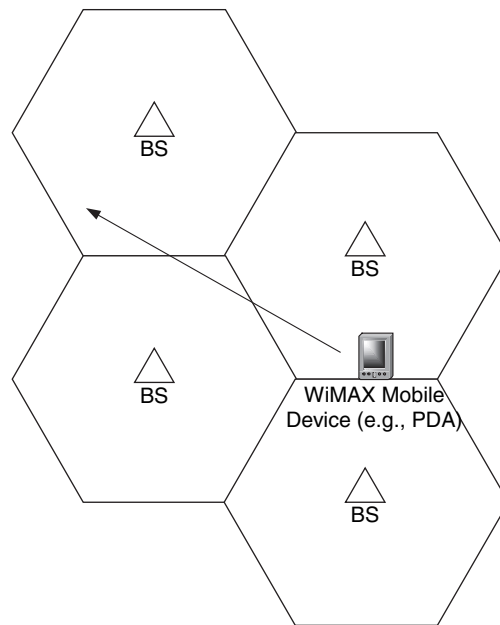


Figure 1.6 Mobile Broadband Wireless Access (BWA). A mobile WiMAX device can move over all the cells in a seamless session

120 km/h. Mobility is the same as portability but with no real limit for speed; i.e. if mobility is realised, a BWA can be used in some high-speed trains with speeds exceeding 350 km/h.

In cellular systems, second generation or later, a voice communication is not interrupted when a mobile moves from one cell to another. This is the so-called ‘handover’. The cellular systems are then real mobile networks. Is WiMAX a cellular mobile network? Considering that a cell is the area covered by one BS, the only condition would be a high-speed handover feature. This should be realised with 802.16e evolution of 802.16. However, a WiMAX handover is not expected to occur at very high speeds – to be precise, at speeds higher than a magnitude of 100 km/h. The final objective of WiMAX is to be a mobile system. In this case, part or all of a territory or country will be covered by contiguous cells with a seamless session handover between cells, as in a cellular system (see Figure 1.6). It is evident that WiMAX will then become a rival to 3G cellular systems.

Some service providers define triple play as the combination of data (Internet), voice (unlimited phone calls) and video (TV, video on demand). This evolves into quadruple play by adding mobility. In a first step, this mobility will in fact be only nomadism, e.g. using the WiMAX subscription to have an Internet access in a café far away from home.

Another application sometimes mentioned for BWA is telemetering: using the BWA for reporting electricity, gas, water, etc. This should represent a small but yet perhaps interesting market. WiMAX telemetering products have already been reported. Evidently, WiMAX is not the only technology that can be used for telemetering.

1.3.2 Synthesis of WiMAX BWA Applications

To sum up, the applications known or expected today of WiMAX as a BWA system are:

- Broadband fixed wireless access. WiMAX would be a competitor for fixed-line high data rate providers in urban and rural environments.
- WiFi backhauling.
- Telemetering. This should represent a small but yet perhaps interesting market.
- Nomadic Internet access.
- Mobile (seamless sessions) high data rate access.

1.4 History of BWA Technologies

1.4.1 Video Distribution: LMDS, MMDS and DVB

The Local Multipoint Distribution Service (LMDS) is a fixed wireless access system specified in the United States by the Digital Audio-Visual Council (Davic), a consortium of video equipment suppliers, network operators and other telecommunication industries. Davic was created in 1993. LMDS is a broadband wireless point-to-multipoint communication technology. Originally designed for wireless digital television transmission, the target applications were then video and Internet in addition to phone.

The standard is rather open and many algorithms used for LMDS are proprietary. Depending on the frequency bandwidth allocated, data rates are of the order of tens of Mb/s in the downlink and Mb/s in the uplink. Link distance can go up to a few km. LMDS operates in

the 28 GHz frequency band in the United States. This band is called the LMDS band. Higher frequencies can also be used.

The Multichannel Multipoint Distribution Service (MMDS), also known as wireless cable, is theoretically a BWA technology. It is mainly used as an alternative method of cable television. The MMDS operates on frequencies lower than the LMDS, 2.5 GHz, 2.7 GHz, etc., for lower data rates as channel frequency bandwidths are smaller.

Standardising for digital television started in Europe with the Digital Video Broadcasting (DVB) Project. This standardization was then continued by the European Telecommunications Standard Institute (ETSI). DVB systems distribute data by many mediums: terrestrial television (DVB-T), terrestrial television for handhelds (DVB-H), satellite (DVB-S) and cable (DVB-C). The DVB standards define the physical layer and data link layer of a television distribution system.

Many European countries aim to be fully covered with digital television by around 2010 and to switch off analogue television services by then. DVB will also be used in many places outside Europe, such as India and Australia.

1.4.2 Pre-WiMAX Systems

WiMAX and 802.16 systems will be described in detail in Chapter 2. In this subsection, the pre-WiMAX is introduced. The first version of the IEEE 802.16 standard appeared in 2001. The first complete version was published in 2004. There was evidently a need for wireless broadband much before these dates. Many companies had wireless broadband equipment using proprietary technology since the 1990s and even before. Evidently these products were not interoperable.

With the arrival of the 802.16 standard, many of these products claimed to be based on it. This was again not possible to verify as WiMAX/802.16 interoperability tests and plugfest started in 2006. These products were then known as pre-WiMAX products. Pre-WiMAX equipments were proposed by manufacturers often specialising in broadband wireless. Many of them had important markets in Mexico, Central Europe, China, Lebanon and elsewhere. Device prices were of the order of a few hundred euros. A nonexhaustive list of pre-WiMAX manufacturers contains the following: Airspan, Alvarion, Aperto, Motorola, Navini, NextNet, Proxim, Redline and SR Telecom. Intel and Sequans, among others, provide components.

The performances of pre-WiMAX systems are close to the expected ones of WiMAX, whose products should start to appear from the second part of 2006. Many of the pre-WiMAX equipments were later certified and more are in the process of being certified.