Chapter 2

A Plethora of BFWA Standards

BFWA Standard Technologies

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2.1 INTRODUCTION

This chapter takes a closer look at the available standards for Broadband Fixed Wireless Access (BFWA). As pointed out in Chapter 1, standardization is critical to align the market, and to allow the development of interoperable equipment. In contrast to popular belief, we are convinced that standardization does not inhibit creativity but rather enables a flourishing market, in which innovative products can thrive. As standardization is an important market creation tool, it should also be pointed out that market forums, like WiMax and WiFi, play an essential role in promoting and certifying interoperable products based on standards.

Several standards are used by BFWA equipment manufacturers, although not all were originally developed with BFWA as their primary target application. The IEEE 802.11 standard was originally developed for indoor Wireless Local Area Networks (WLANs), although also frequently used for point-to-point bridging of wireline local area networks. Recently, it also has emerged as a wireless access technology for (local area) hot spots. The European Telecommunication Standardization Institute (ETSI) has defined an alternative standard, namely High-Performance Local Area Networks (HIPERLAN). However, it did not receive market acceptance, and, hence, will not be considered further. The IMT-2000 standard contains both a Frequency-Division Duplex (FDD) and a Time-Division Duplex (TDD) mode. Where the former is based on pure Wideband Code-Division Multiple Access (WCDMA), the latter includes an additional Time-Division Multiple Access (TDMA) component, called TD-CDMA. Although the main focus of

IMT-2000 is on the FDD/WCDMA mode for moving users, there is a growing interest in the TDD/TD-CDMA mode, which is intended for broadband access for stationary users. Recently, the IEEE started a standardization effort for high-rate mobile access in the 802.20 Working Group. Nevertheless, the primary standards for BFWA have been realized by the IEEE 802.16 Broadband Wireless Access Working Group. The line-of-sight (LOS) systems in the frequency bands above 11 GHz have been defined in the baseline IEEE 802.16 standard. An alternative system has been defined in the ETSI High-Performance Access (HIPERACCESS) standard. Non-line-of-sight (NLOS) systems below 11 GHz follow the IEEE 802.16a standard. Due to a close collaboration between ETSI and IEEE, the High-Performance Metropolitan Area Network (HIPERMAN) standard is a subset of the IEEE 802.16a standard. In 2004, a consolidation of all 802.16 standards was realized, which resulted in the 802.16-2004 revision.

In the following sections, we will discuss each of these standards in more detail. Section 2.2 discusses the IEEE 802.11 WLAN standard, whereas Section 2.3 briefly reviews the IMT-2000 TDD/TD-CDMA standard. Section 2.4 introduces the IEEE 802.20 Mobile Broadband Wireless Access (MBWA) standard. Sections 2.5 and 2.6 briefly describe the true BFWA standards, with Section 2.5 focusing on the 10-66 GHz IEEE 802.16/HIPERACCESS standard, and with Section 2.6 focusing on the sub-11 GHz IEEE 802.16a/HIPERMAN standard. Finally, Section 2.7 comments on the convergence of different wireless access technologies towards a common wireless platform.

2.2 THE IEEE 802.11 WIRELESS LAN STANDARD

The IEEE 802.11 WLAN standard was originally developed for the 2.4 GHz unlicensed spectrum, and later on extended to the frequency bands between 5 and 6 GHz [1][2]. As illustrated in *Figure 2.1*, the standard supports both infrastructure-based networks as well as ad-hoc networking, with a maximum data rate of 54 Mbps per cell. The communication range is typically limited to 50 m for indoor use and to 300 m for outdoor applications. The price of 802.11-compliant equipment is eroding very fast, and the installation can easily be performed by an end user. Up till recently, no mechanism was available in the standard to provide Quality-of-Service (QoS) guarantees. A recently finalized effort in the 802.11e Task Group has tried to resolve this shortcoming. Moreover, Siemens has recently launched a product that offers proprietary QoS features for industrial applications [3]. Security is a recent enhancement of the 802.11 standard. Moreover, the Working Group is looking at extensions towards multi-hop or mesh networking, and towards higher speeds, targeting more than 100 Mbps effective data rate. Multi-antenna techniques will be most likely an essential part of this high data rate extension. Several companies have already demonstrated the capabilities of multi-antenna techniques for increasing both the capacity and the range of a network.

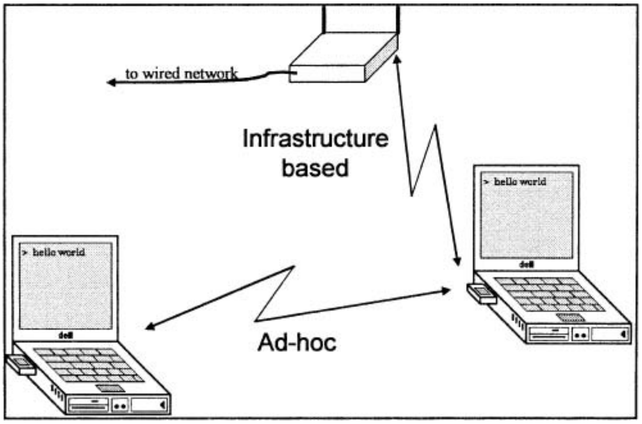

Figure 2.1. Infrastructure-based versus ad-hoc networking scenario.

The extensions of the base standard, which originally provided 1 and 2 Mbps in the 2.4 GHz band, are indicated with a letter. This resulted in the following confusing "letter soup":

- 802.11a is the extension of the standard towards 54 Mbps communications in the frequency bands between 5 and 6 GHz.
- 802.11b extends the base standard with a 5.5 Mbps and an 11 Mbps mode.
- 802.11c defines the bridging operation with other local area networks.
- 802.11d added features to the hopping pattern and the management information base, to support the use of the standard outside the United States (US).
- 802.11e is a currently finalized Task Group that has been working on the definition of mechanisms to guarantee QoS.
- 802.11f defines recommended practices for implementing a protocol between 802.11 access points. As such, it is guaranteed that access points of multiple vendors will interoperate in a WLAN.
- The 802.11g Task Group extended the data rate of WLANs in the 2.4 GHz band towards 54 Mbps.

- 802.11h defined the dynamic frequency selection for the 5 to 6 GHz bands. This was crucial for Europe, where WLANs are only the secondary service in this frequency band.
- The 802.11i standard provided enhanced security mechanisms. These have become a major requirement after it was demontrated that the initial Wired Equivalent Privacy (WEP) algorithm could be broken.
- The 802.11j group provided channel selection for the 4.9 GHz band, which is available in Japan.
- 802.11k extends the radio resource measurements of an entity, and provides the mechanisms to communicate those measurements to other entities and higher layers.
- 802.11m is an active Task Group to maintain and correct the original baseline standard.
- The 802.11n Task Group aims at defining an additional physical layer (PHY) by the end of 2006, to increase the effective data rate to at least 100 Mbps.
- 802.11r is working towards provisioning fast roaming between access points.
- 802.11s has started mid 2004, to study mesh networking.
- 802.11t is discussing the definition of standardized methods to evaluate the wireless performance of an 802.11 system.

As pointed out in *Table 2.1*, four of these standard extensions define additional physical communication modes with increasing data rates and bandwidth efficiencies. The base standard defined 1 and 2 Mbps modes based on Direct-Sequence Spread-Spectrum (DSSS). The 802.11b enhancement added 5.5 and 11 Mbps modes, which use Complementary Code Keying (CCK). The 802.11a extension defines an Orthogonal Frequency Division Multiplexing (OFDM) mode in the 5 GHz band that provides up to 54 Mbps. In the 802.11g standard, this OFDM mode was also made available for the 2.4 GHz band. Finally, the 802.11n standard is still under construction and aims at increasing the effective data rate, measured at the MAC Service Access Point (SAP), i.e. on top of the MAC layer, above 100 Mbps. This minimum throughput requirement represents a four times leap in throughput performance compared to existing 802.11a/g WLANs, as the 54 Mbps mode only results in an effective data rate of 25 Mbps. Since May 2005, there are only two surviving candidate proposals, namely WWiSE [4] and TgnSync [5], both of which share the idea of using Multi-Input Multi-Output (MIMO) OFDM communications, through the deployment of multiple antennas at both the transmitting and receiving side. Although both proposals rely on MIMO technology to reach the required high throughputs, they resort to different MIMO processing techniques. On the one hand, the WWiSE proposal follows a cautious and evolutionary approach, based on simple Alamouti Space-Time Block Coding. On the other hand, TgnSync supports more audacious and future-proof spatial multiplexing solutions, including joint transmit and receive processing techniques. The final IEEE 802.11n draft standard is expected to be finalized by September 2006.

Table 2.1. The IEEE 802.11 standard physical communication modes.

Standard	Frequency band (GHz)	Data rate (Mbps)	BW efficiency (bits/s/Hz)
802.11	2.4	1-2	0.05-0.1 (DS-SS)
802.11a	5	6-54	0.3-2.7
802.11b	2.4	5.5-11	0.275-0.55
802.11g	2.4	1-54	0.05-2.7
802.11n	2.4 & 5	> 100 (effective)	> 3

2.3 THE IMT-2000 TDD/TD-CDMA STANDARD

The IMT-2000 standard for a third generation (3G) mobile radio system comprises both an FDD and a TDD mode. The FDD mode uses a minimum spectrum of 5 MHz in each communication direction in the paired frequency bands between 1920 – 1980 MHz and between 2110 – 2170 MHz. The TDD mode uses a minimum spectrum of 5 MHz for up- and downlink communication in the unpaired frequency band between 1885 – 1920 MHz. Hence, two times 60 MHz of licensed spectrum is available for FDD operation, while 35 MHz of licensed spectrum is available for TDD operation.

The FDD mode, which is based on pure WCDMA at a chip rate of 3.84 Mcps, is mainly intended for mobile users in public macro and micro cell environments, supporting data rates up to 384 Kbps [6]. The TDD mode, which is based on TD-CDMA (a combination of TDMA and CDMA) at the same chip rate, is mainly intended for stationary users in public micro and pico cell environments, and for broadband fixed wireless access applications, supporting data rates up to 2 Mbps [7]. Although not practically supported by the system, a maximum user data rate of 3.3 Mbps can be achieved, in case no spreading is performed.

The system is based on a point-to-multipoint network architecture, and supports communication with variable QoS requirements. Furthermore, the system entails several PHY procedures that are essential for system operation, for instance, to support seamless handover and roaming, such as handover measurements, initial cell search, and random access. Based on a classical rake receiver, which is depicted in *Figure 2.2*, combined with powerful Forward Error Correction (FEC) coding, the system can handle multipath propagation and multiuser interference, only to some extent. In this case, the capacity that can be achieved with a reasonable bit error rate (BER) performance will be very limited, with typical values up to 20 % of the maximum system load. Based on advanced multiuser receivers at the base station for uplink communication, and based on advanced chip equalizer receivers at the mobile station for downlink communication, the system can effectively handle intra-cell interference (interference between users residing in the same cell) as well as non-line-of-sight multipath communications [9]. In this case, the system capacity will be limited by the inter-cell interference, that is the interference originating from users residing in neighbouring cells.

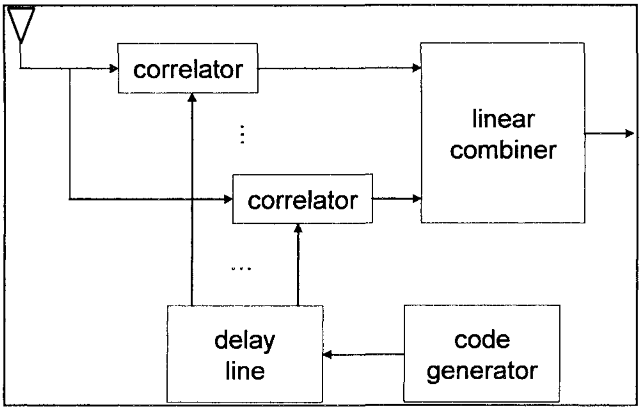

Figure 2.2. Classical rake receiver collects signal energy in different propagation paths.

Implementations of the TDD/TD-CDMA mode are available on the market, for instance from IP Wireless [8]. Because they follow the principle of a direct coverage from the base station towards the computer, even indoor, they can be easily installed by the end user. However, the main shortcoming of this technology is the relatively low data rate. Consequently, this is one of the major areas for future improvements. More specifically, the High-Speed Downlink Packet Access (HSDPA) standard evolution, which is currently under investigation, aims to significantly reduce the end-to-end delay as well as to increase the effective data rate up to 10 Mbps for downlink packet data, by resorting to higher modulation formats and code rates, combined with a low spreading factor, and multiple parallel codes per user.

2.4 THE IEEE 802.20 MBWA STANDARD

In December 2002, the IEEE 802.20 Mobile Broadband Wireless Access (MBWA) Working Group was established with the mission of specifying a broadband packet-based air interface for mobile users with speeds up to 250 km/h [10]. The 802.20 MBWA system should operate in licensed bands below 3.5 GHz, supporting both FDD and TDD operation. Furthermore, it should support deployment in at least one of the following frequency arrangements: 1.25 MHz, 5 MHz, 10 MHz, 15 MHz, or 20 MHz in each direction for FDD operation, and 2.5 MHz, 5 MHz, 10 MHz, 20 MHz, 30 MHz, or 40 MHz for TDD operation. Targeting a sustained spectral efficiency well beyond 1 bps/Hz/cell, the peak user data rate should exceed 1 Mbps in the downlink and 300 Kbps in the uplink. Furthermore, the peak aggregate data rate per cell should exceed 4 Mbps in the downlink and 800 Kbps in the uplink. It should be emphasized that these targets are for a 1.25 MHz channel bandwidth, which corresponds to two 1.25 MHz paired frequency bands for FDD or a 2.5 MHz unpaired frequency band for TDD. For other channel bandwidths, the data rates should be scaled in proportion to the channel bandwidth.

Although the Working Group has experienced a difficult start, it has finalized a system requirements document in July 2004 [11]. Currently, the Working Group is coming to an agreement on channel models for system simulations [12] and evaluation criteria [13]. Furthermore, it is finalizing the discussions on the technology selection process, such that a call for proposals can be issued in 2006. Although Flarion with their Flash OFDM system [14] were the main promoters of this Working Group, all options for the Medium Access Control (MAC) layer and the PHY of the system are still open. Block-spread CDMA transmission techniques, which judiciously combine CDMA and OFDM concepts, seem very appealing for the IEEE 802.20 MBWA system, since they inherit the attractive features of both worlds [9]. They can be divided into two main families.

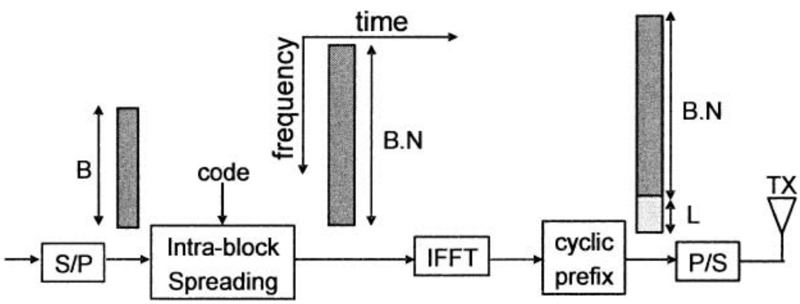

Figure 2.3. Intra-block-spread CDMA techniques spread information along frequency axis.

On the one hand, so-called intra-block-spread CDMA techniques that perform spreading of the information blocks along the frequency axis, such as Multi-Carrier CDMA (MC–CDMA) and Single-Carrier CDMA (SC-CDMA) are well suited for high mobility users in macro and micro cell environments. A general transmitter block diagram of these intra-block-spread CDMA techniques is shown in *Figure 2.3*.

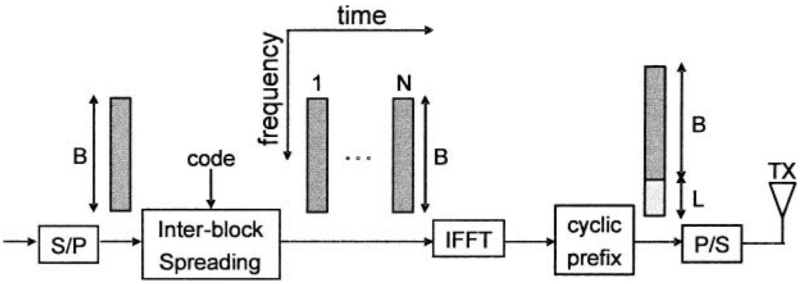

Figure 2.4. Inter-block-spread CDMA techniques spread information along time axis.

On the other hand, so-called inter-block-spread CDMA techniques that perform spreading of the information blocks along the time axis, such as Multi-Carrier Block-Spread CDMA (MCBS–CDMA) and Single-Carrier Block-Spread CDMA (SCBS–CDMA), are well suited for stationary to low mobility users in micro and pico cell environments. A general transmitter block diagram of these inter-block-spread CDMA techniques is shown in *Figure 2.4*.

Finally, multiple antenna techniques, both at the base and mobile station, are key to meet the data rate and QoS requirements.

2.5 THE IEEE 802.16/HIPERACCESS STANDARD

The dominant BFWA standard is the IEEE 802.16 standard, as it was specifically designed for this application. The base standard defines a point-to-multipoint network that operates in licensed frequency bands between 10 and 66 GHz [15] [3]. In Europe, ETSI specified HIPERACCESS, a similar yet different standard for the same application.

The high operating frequencies make that only line-of-sight operation with highly directive antennas is feasible. Because narrow-beam antennas need very careful installation, this normally requires the involvement of the operator. The high frequencies also increase the sensitivity of the system to weather conditions, or, in particular, to rain fading. They further increase the cost of the terminal because of the difficulty of integrating such high-frequency circuits.

The 802.16 and HIPERACCESS standards define communication in channel bandwidths of 25 to 28 MHz, and data rates exceeding 120 Mbps. The MAC layer is inspired on the cable modem standard DOCSIS, and, hence, has extensive features for managing the QoS of connections.

With its high data rates, but also with its high costs (with typical values between 500 and 15000 Euros), the 802.16 system is typically suited for business applications and backhaul of wireless networks.

To improve the reliability of the network, mesh networks have been, until now unsuccessfully, promoted [17]. For example, Radiant networks (sold to LamTech) developed a roof-mounted user terminal with four vertically stacked highly directional antennas that can be steered with full freedom of +/-360° rotation in the horizontal plane.

2.6 THE IEEE 802.16A/HIPERMAN STANDARD

The 802.16a standard inherits the MAC layer from the base standard, and adds PHY communication schemes that are suited for non-line-of-sight communication in frequency bands below 11 GHz [3]. Both licensed (mainly 2.5-2.69 GHz in the US and 3.4-3.6 GHz in Europe and the rest of the world) and unlicensed spectrum (5.725-5.850 GHz as the most important band) is supported. The ETSI HIPERMAN committee closely cooperated with the IEEE Working Group, and defined the OFDM subset of the 802.16a standard as a European standard [4].

The relatively low operating frequencies bring several advantages to the IEEE 802.16a system: non-line-of-sight operation, low terminal cost (with typical values less than 400 Euros), and ease of installation. Consequently, 802.16a is ideally suited for broadband fixed wireless access to small and medium enterprises, to small offices and home offices, and to residential customers. It can also be used for backhaul of 802.11 hot spots. The standard supports multiple bandwidths and data rates up to 104 Mbps in a 28 MHz channel bandwidth. However, a typical deployment would rather use a 3.5 MHz channel bandwidth, resulting in approximately 13 Mbps, or a 5 MHz channel bandwidth, resulting in just over 18 Mbps. Recent performance benchmarks have shown, however, that the total average downlink throughput can be expected to be between 3 and 7 Mbps over a 5 MHz bandwidth, with the lower rates corresponding to having a single receive antenna and three-sector cells, and the higher rates corresponding to having two receive antennas and six-sector cells [5].

Besides the centrally scheduled point-to-multipoint architecture of 802.16, the standard also adds a mesh mode. This mode allows extending the reach of the network, at the cost of the network capacity. A lot of research is still ongoing to optimize this range versus capacity trade off for mesh networks. Also guaranteed QoS in a mesh network is an active research topic. In addition, multiple antenna techniques, which are another means of improving range and capacity, are actively studied.

In June 2004, the IEEE 802.16 standard and the IEEE 802.16a standard were consolidated in a unified IEEE 802.16d standard, which was published as the IEEE 802.16-2004 in December, 2004 [1]. Currently, the IEEE 802.16e Task Group is defining extensions to this standard for moving terminals with mobile speeds up to 120 km/h [14].

2.7 TOWARDS A COMMON WIRELESS PLATFORM

The previous sections showed that multiple technologies compete to provide broadband wireless access. We do not believe that a single technology will emerge as a sole winner. Indeed, the technologies are all optimized for a particular operating environment, and are suboptimal in order situations. *Figure 2.5* illustrates this by providing an overview of current and future wireless data communication standards as a function of maximum data rate and typical cell range.

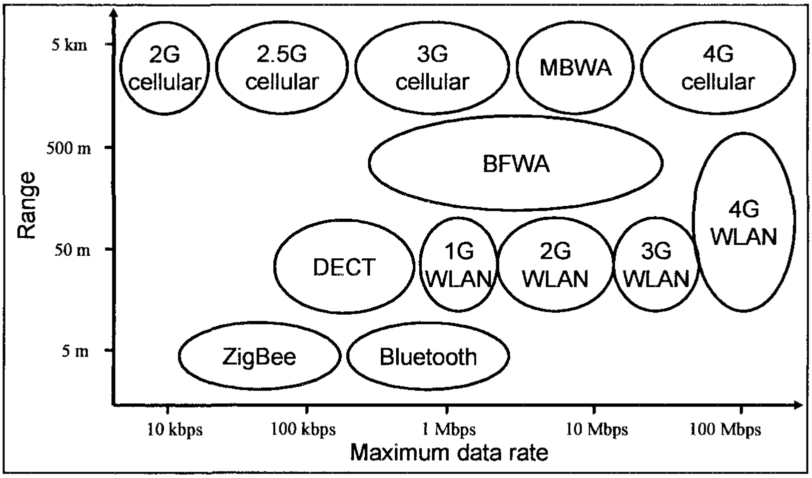

Figure 2.5. Different wireless data communication standards complement each other for maximum data rate versus cell range.

Hence, future-generation wireless systems will integrate different existing and new evolving wireless access systems on a common IP-based platform, to complement each other for different service requirements and radio environments [22]. To enable seamless and transparent interworking between these different wireless access modes, multistandard functionality is needed, especially at the terminal side. As such the different technologies can be combined to realize ubiquitous connectivity (see *Figure 2.6*): IMT-2000 or IEEE 802.20 when travelling at high speed, 802.11 at the office and a combination of 802.11 and 802.16 at home or within reach of a public hot spot.

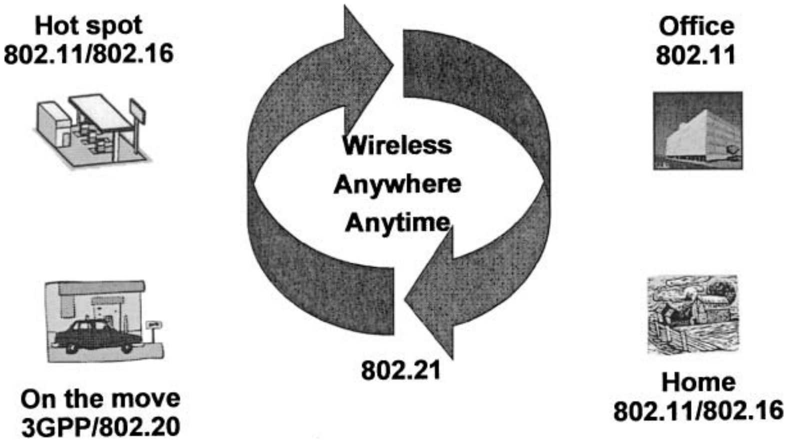

Figure 2.6. Wireless anywhere and anytime.

Since IEEE shares this vision, it has established the IEEE 802.21 Media Independent Handoff Working Group to study the handoff between these various technologies [23].

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