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BROADBAND WIRELESS ACCESS AND MOBILITY SOLUTION USING IEEE 802.16: CONCEPTS AND ARCHITECTURE

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Abstract: **WiMAX (Worldwide Interoperability for Microwave Access) is a wireless broadband access solution, developed according with the IEEE 802.16 standard specifications with the purpose of delivering high speed radio access, most commonly Internet access, especially for those areas where a conventional solution, based on cable or DSL, proves to be ineffective. The early WiMAX solutions were based on IEEE 802.16-2004 and targeted fixed applications. In December 2005, the IEEE group completed and approved IFEE 802.16e-2005, an amendment to the IEEE 802.16-2004 standard that added mobility support.**

Key words: *WiMAX, IEEE 802.16-2004, IEEE 802.16e-2005, BS, SS.*

I. INTRODUCTION

Over the last several years, the area of broadband data communications has experienced a very high growth. Traditional solutions that provide high speed broadband access use wired access technologies, such as traditional cable, digital subscriber line (DSL), Ethernet, and fiber optics. It is extremely difficult and expensive to build and maintain wired networks, especially in rural and remote areas. Also, most providers, are unwilling to install the necessary equipment in these areas because of little profit and potential. For these areas, the broadband wireless access technique proves to be an optimal solution [5].

Generally, a *broadband connection* is defined as a high capacity, bidirectional connection, between the user and the network, established through the access network that is capable of sustaining interactive multimedia applications. According to the ITU terminology, the term "broadband" refers to transmission rates greater than 1.5 Mb/s, although it is estimated that in the near future, the modern user will require data rates up to 20 Mb/s in order to satisfy his needs [2][5]. There are several wireless broadband access techniques. Some of them are proprietary solutions (such as Flash-OFDM from Flarion and I-Burst from ArrayComm), and so are incompatible with one another, others are based on standards and are being developed by different task groups.

The standard developed by IEEE for broadband wireless communications, is called IEEE 802.16, and is suited for fixed and mobile topologies, in point-to-point, point-to-multipoint, and mesh connectivity. As this standard covers only the Physical (PHY) and the Medium Access Control (MAC) layers, from the OSI model, the specifications for the above layers being established by the vendors, the WiMAX forum was created with the purpose of providing the testing and certification necessary to assure vendor equipment interoperability for 802.16 hardware. Because of that, this technology began to be known under the commercial name of ***WiMAX (Worldwide Interoperability for Microwave Access).***

II. SYSTEM DESCRIPTION

II.1. ARCHITECTURE

The WiMAX network is in fact a WMAN (Wireless Metropolitan Area Network), its core components being the Subscriber Station (SS) and the Base Station (BS). A BS and one or more SS's can form a cell, where a BS is able to cover an area up to 50 km [4]. There are two main versions of this technology, one that is suited for fixed and nomadic applications, and is based on the IEEE 802.16-2004 standard (called Fixed WiMAX), and one that is suited for mobile users that travel with a speed up to 120 km/h and is based on the IEEE 802.16e-2005 standard (called Mobile WiMAX).

One big advantage of this technology is that it supports a wide range of frequencies, from 2-66 GHz. As the electromagnetic propagation in this range is not uniform, multiple physical layers exist in order to deal with this issue. For the licensed frequencies between 10-66 GHz, suited for LOS application, the PHY layer specification that was developed is called WirelessMAN-SC, and is based on a single carrier modulation technique. For the licensed and unlicensed frequencies between 2-11 GHZ, four specifications for the PHY layer exist: WirelessMAN-SCa, which is similar to WirelessMAN-SC, but includes some additional elements regarding the equalization and estimation of the wireless channel, WirelessMAN-OFDM, which is based on the OFDM modulation with a FFT in 256 points, WirelessMAN-OFDMA, based on a variable length FFT, of maximum 2048 points and WirelessHUMAN, specification issued in order to assure the functionality in the unlicensed bands, especially for the 5 GHz band [5].

Regarding MAC layer, a scheduling algorithm is used for the allocation of the available resources, for which the SS need to compete once. After an access slot is allocated by the base station, this time slot can enlarge and contract, but remains assigned to the SS which means that other subscribers cannot use it. The communication path between a SS and the BS has two directions: uplink and downlink. Both uplink and downlink can operate on different

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frequencies using *Frequency Division Duplexing (FDD)* or share the same frequencies using *Time Division Duplexing (TDD).*

In both FDD and TDD systems, the uplink and downlink channels are structured into frames. In TDD, the frame is divided into two subframes, uplink and downlink subframes, where the uplink subframe follows the downlink subframe. In FDD, the uplink and downlink subframes are concurrent in time but are carried on separate frequencies. All SSs and the BS have to be synchronized and transmit data bursts into predetermined time slots. In figure 1, the structure of a TDD frame is represented, for the case of the *WirelessMAN-SC* physical interface. The TDD framing is adaptive in the sense that the link capacity allocated to the downlink versus the uplink may vary.

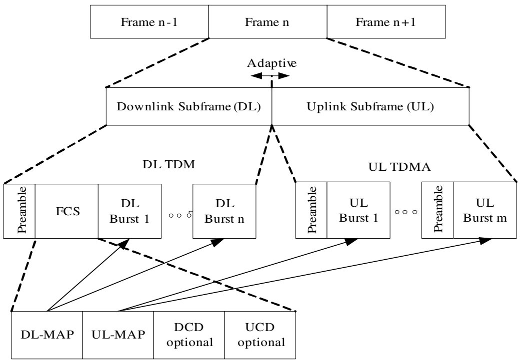

Figure 1. TDD frame and subframe structure in case of WirelessMAN-SC physical interface

In uplink transmissions (SSs to BS), several SSs share the channel in a TDMA fashion, each burst starting with a preamble, which is used for synchronization purposes. The Uplink Map Message (UL-MAP) is used to provide the channel access assignment to the subscriber stations. The UL-MAP which is transmitted by the base station at the beginning of the frame defines the uplink channel access as well as the uplink data burst profiles, with the help of UIUC (Uplink Interval Usage Code) in the current uplink subframe. The SSs are allowed to transmit data bursts at predetermined time slots as indicated in the UL-MAP [2]. Also, in uplink, a number of slots are assigned for various uses, such as registration, contention or guard periods. These slots are allocated according to the MAC layer specifications in the BS, and may vary over time for optimal performance.

In downlink transmissions (BS to SSs), due to the fact that there is only one station (BS) transmitting the data, the channel access is rather simple. The downlink channel is time division multiplexed (TDM), with the information for each SS multiplexed onto a single stream of data and received by all SSs within the same sector. A SS will only pick up the packets that are destined to it. The downlink frame starts with a preamble that is used for synchronization and equalization and a frame control section (FCS) that contains downlink and uplink maps stating the physical slots at which bursts begin. The Downlink Map Message (DL-MAP) contains information about the downlink data burst profiles, which are defined with the help of DIUC (Downlink Interval Usage Code) and about the physical slots at which the burst profile changes. In addition, the FCS may contain DCD (Downlink Channel Descriptor) and UCD (Uplink Channel Descriptor) messages that are used for describing the physical channel's parameters, such as the modulation type and FEC code type, and have the role of associating these parameters with the DIUC and UIUC codes. The bursts will be transmitted in the order of coding and modulation decreasing robustness [2].

In case of FDD systems, both full duplex SSs as well as half duplex SSs, which do not transmit and receive simultaneously, are supported. To support half duplex FDD subscriber stations, the FDD downlink subframe will contain, besides the TDM portion, also a TDMA portion.

For the physical layer between 10-66 GHz adaptive data burst profiling is allowed, in which transmission parameters, such as modulation and Forward Error Correction (FEC) coding schemes, can be adjusted individually to each SS on a frame-by-frame basis in both uplink and downlink transmissions. The incoming data is first randomized, then FEC encoded and after that modulated. Regarding the FEC coding, concatenated coding schemes are used formed from an inner code (which is usually a convolutional or a parity check code) and an outer code (which is a Reed-Solomon code). The reason for using two types of codes is that in general there are two types of errors that might appear: random errors and burst errors [1].

Three types of modulation schemes can be used: QPSK, 16 QAM, and 64 QAM, for WirelessMAN-SC. The mandatory modulation formats are QPSK and 16 QAM for the downlink, and only QPSK for the uplink. For the frequencies between 10-66 GHz, the channel's bandwidth is of 20 or 25 MHz for the USA, and of 28 MHz, for Europe. In Table 1, the bit rate that can be obtained using different modulation schemes and different channel bandwidths is represented, taking into consideration a frame duration of 1 ms, which represents a compromise between transport efficiency and latency, and a roll-off factor of 0.25. The symbol rates were chosen such that to provide an integer number of physical slots per frame.

Channel size [MHz]	Symbol rate [Mbaud]	Bit rate [Mb/s] QPSK	Bit rate [Mb/s] 16 QAM	Bit rate [Mb/s] 64 QAM
20	16	32	64	96
25	20	40	80	120
28	22.4	44.8	89.6	134.4

Table 1. WiMAX characteristic bit rates that can be obtained for different modulation schemes and channel bandwidths, for the 10-66 GHz band [2]

As operating in high frequency bands requires a license, which is very expensive, if at all possible to obtain, physical layers were also defined for operation in the 2-11 GHz band, which also includes unlicensed bands. In this environment, due to the longer wavelength, line of sight is not necessary and multipath may be significant. The channel bandwidths used typically vary from 1.25 to 20 MHz, and the data rates that can be achieved are up to 75 Mb/s at a distance of 50 km, for a 20 MHz channel [4].

WirelessMAN-SCa is the first specification established for this band, and is very similar to WirelessMAN-SC. It is also based on a single carrier modulation technique, but it requires an equalizer at the receiver to compensate for the distortions resulting from the channel, because due to multipath, intersymbol interference might appear among the received symbols. Regarding the transmitter signal processing, a concatenated FEC scheme will be used, based on the serial concatenation of a Reed-Solomon outer code and a rate-compatible TCM inner code. Between the inner and the outer code, byte interleaving can be used as an option, for spreading consecutive bits into separate symbols after modulation, in this way preventing a series of consecutive bad symbols, which may occur due to multipath [5]. The modulation types that are supported, on both the uplink and downlink are: BPSK, QPSK, 16 QAM, 64 QAM and 256 QAM, the usage of the last being optional. For improving performances and coverage area, antenna diversity can be used. Usually a two-way transmit diversity is employed by using two transmit antennas, where the output of the first antenna will be delayed with respect to the first. The second and the third physical layer specifications developed for the 2-11 GHz band are *WirelessMAN-OFDM* and *WirelessMAN-OFDMA*, both of them employing orthogonal frequency division multiplexing (OFDM), which is a multi-carrier transmission technique suitable for high speed NLOS. This technique is based on the idea of dividing the given high bit-rate data stream, into several parallel lower bit-rate streams, and after that modulating each stream on separate carriers, called subcarriers. The subcarriers are selected such that they are all orthogonal to one another over the symbol duration, thereby avoiding the need to have non-overlapping subcarrier channels to eliminate inter-carrier interference. The symbol period will be large enough so that the channel induced delays are insignificant, typically less than 10% of the symbol duration.

An OFDM symbol structure is shown in figure 2. As it can be seen, three types of subcarriers are used: data subcarriers for handling the transmission of data, pilot subcarriers, for synchronization and channel estimation purposes, and null subcarriers, on which no transmission takes place, these null subcarriers being intended for guard bands and Direct Current (DC) carriers.

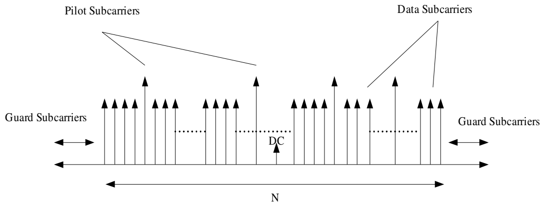

Figure 2. OFDM Symbol Structure [2]

The number of subcarriers that will be used is determined by the Fourier matrix size, which is chosen as a balance between the protection against multipath that can be achieved, the Doppler shift and the design cost and complexity. For WirelessMAN-OFDM, the number of FFT points is 256. From the total number of subcarriers, only 200 subcarriers will be used for the transmission of data and pilots, this representing the actual number of subchannels that can be obtained, the rest of 56 subcarriers being used for the transmission of the DC carrier and as guard intervals [1]. With respect to the channel coding, the same steps are applied as in WirelessMAN-SC and WirelessMAN-SCa. A randomization followed by FEC and interleaving are used. For encoding the data, besides the standard coding scheme that consists of the concatenation of a Reed-Solomon code and a convolutional code, two optionally coding schemes can be used, which are based on block turbo codes and convolutional codes. Interleaving is based on a two step permutation. One permutation has the role of spreading the adjacent coded bits on different subcarriers and the second permutation has the role of permuting the adjacent bits onto less and more significant bits of a constellation to spread possible errors. OFDM physical specification supports QPSK, 16 QAM and 64 QAM. Adaptive modulation and coding must be supported in the downlink per SS. In the uplink, each SS can use different modulation schemes based on the MAC burst configuration messages coming from the BS. Another physical interface designed for the 2-11 GHz band, is the WirelessMAN-OFDMA. Orthogonal frequency division multiple access (OFDMA) is a 2048 subcarrier OFDM scheme. In OFDM a channel is defined as consisting of all carriers residing within the full signaling bandwidth, so the basic resource allocation unit is an OFDM symbol. The amount of data that fits into an OFDM symbol depends on the constellation and the coding method used within this symbol, as well as the number of data carriers per symbol. In OFDMA, subchannels are defined as a fraction of the available carriers within the full signaling bandwidth, the basic resource allocation unit being the subchannel. As OFDMA organizes the time (the symbols) and the frequency (the subcarriers) resources into subchannels for allocation to individual receivers, is said to be a multiple access method simultaneously in time and frequency [3].

On the downlink, one subchannel can be allocated to one or many users, while on the uplink one transmitter can receive one or more subchannels, and more transmitters can send data in the same time. Subchannels may be formed using either contiguous subcarriers or subcarriers pseudo-randomly distributed across the frequency spectrum. Subchannels formed using distributed subcarriers provide more frequency diversity, which is particularly useful for mobile applications [1]. Signal coding and modulation are set separately for each subchannel based on channel conditions to optimize the utilization of network resources.

From the user perspective, subchannelization allows different subchannels to be allocated to different subscribers according to their requirements and channel conditions. One customer can be allocated two or more subchannels. For service providers, subchannelization provides a flexible and efficient bandwidth management solution and a flexible power transmission method. Higher power can be allocated to those subchannels with bad radio conditions. The advantage of the OFDMA technique over other techniques is that it facilitates the exploitation of frequency diversity and multi-user diversity to significantly improve the system capacity.

For the development of applications in the unlicensed bands, especially in the 5 GHz band, the WirelessHUMAN specification was issued. As operation in the unlicensed bands introduces additional interference and coexistence issues, mechanisms were developed to detect and avoid interference, such as DFS (Dynamic Frequency Selection). Once implemented, this mechanism allows for the system to switch to different RF channels, that are not occupied by users which have legal rights upon the transmission, based on channel measurement criteria [2]. Also, for operation in the license exempt bands, only the TDD mode is allowed.

Concerning the MAC layer, in order to assure the necessary support for multimedia applications, a number of QoS signaling mechanisms were included as well as five scheduling services. The QoS parameters, upon which a flow is included in one service category or another, include: traffic priority, maximum sustained traffic rate and maximum burst rate, minimum tolerable rate, scheduling type, maximum delay, tolerated jitter, service data unit type and size, bandwidth request mechanism to be used, and so on.

II.2. MOBILITY SUPPORT

The mobile WiMAX variant of the system has mechanisms to support secure seamless handovers for delay-tolerant full-mobility applications, such as VoIP. Also, support is offered for power saving mechanisms that extend the battery life of handheld subscriber devices.

IEEE 802.16e operation is limited to licensed bands suited for mobility below 6 GHz. Concerning the physical layer, a new radio interface is defined called *scalable-OFDMA (SOFDMA)*, besides those that have been previously defined. S-OFDMA uses a FFT size of 128, 512, 1024, or 2048 subcarriers, depending on whether the channel bandwidth is 1.25MHz, 5MHz, 10MHz, or 20 MHz respectively. This scaling may be done dynamically to support user roaming across different networks that may have different bandwidth allocations [4]. The FFT size is increased such that the subcarrier spacing is always 10.94 kHz. This keeps the OFDM symbol duration, which is the basic resource unit, fixed and therefore makes scaling have a minimal impact on the higher layers. The subcarrier spacing of 10.94 kHz was chosen as a good balance between satisfying the delay spread and Doppler spread requirements for operating in mixed fixed and mobile environments.

With respect to the MAC layer, two important mechanisms were introduced for supporting mobility: handovers, which are needed for maintaining an ongoing session without interruption while on the move, even at vehicular speeds of up to 120 km/h and power saving mechanisms, which are needed for reducing the battery power consumption on portable subscriber terminals. Power saving is achieved by turning off parts of the SS in a controlled manner when it is not actively transmitting or receiving data. Mobile WiMAX defines signaling methods that allow the SS to retreat into a sleep mode or idle mode when inactive.

Sleep mode is a state in which the SS effectively turns itself off and becomes unavailable for predetermined periods. The periods of absence are negotiated with the serving BS. In addition to minimizing SS power consumption, the sleep mode conserves the BS's radio resources. To facilitate handoff while in sleep mode, the SS is allowed to scan other base stations to collect handoff related information. *Idle mode* allows even greater power savings, but support for it is optional in WiMAX. Also, it allows the SS to completely turn off and not to register with any BS and yet receive downlink broadcast traffic. The benefit of this mode is that it eliminates the handover traffic from inactive SSs [1].

Considering the handover procedure, this may be triggered for two reasons. One is due to fading of the signal or interference level within the current cell or sector, which may lead to a break of the radio link. The other one is due to the fact that another cell can provide a higher level of QoS for the mobile station (MS). Three handover methods are supported for mobile WiMAX; one is mandatory and the other two are optional. The mandatory handover method is the *hard handover* (HHO) and this was the only type required to be implemented by mobile WiMAX initially. HHO implies an abrupt transfer of connection from one BS to another.

The two optional handover methods that are supported are the *fast base station switching* (FBSS) and *macro diversity handover* (MDHO). In these two methods, the MS maintains a valid connection simultaneously with more than one BS. In the FBSS case, the MS maintains a list of the BSs involved, called the *active set*. The MS continuously monitors the active set, does ranging, and maintains a valid connection ID with each of them. The MS, however, communicates with only one BS, called the *anchor BS*. When a change of anchor BS is required, the connection is switched from one base station to another without having to explicitly perform handover signaling. Macro diversity handover is similar to FBSS, except that the MS communicates on the downlink and the uplink with all the base stations in the active set simultaneously. In the downlink, multiple copies received at the MS are combined using diversity combining techniques, while in the uplink, where the MS sends data to multiple base stations, selection diversity is performed to pick up the best signal [1].

III. CONCLUSIONS

WiMAX is a wireless broadband solution that offers a rich set of features with a lot of flexibility in terms of deployment options and potential service offerings. Data rates of up to 134 Mb/s can be obtained for a 28 MHz channel in case of LOS, when using 64 QAM, and up to 75 Mb/s can be obtained for a 20 MHz channel, in case of NLOS conditions. Compared with the fixed version, mobile WiMAX can offer lower data rates, of up to 15 Mb/s. Under very good signal conditions, even higher peak rates can be achieved using multiple antennas and spatial multiplexing. Also, user scaling can be done dynamically to support user roaming across different networks, that may have different bandwidth allocations, from 1.25 MHz to 20 MHz, in case of mobile WiMAX.

Besides that, a number of modulation and FEC coding schemes can be employed on a per user and per frame basis, based on channel conditions, in order to maximize the throughput in a time-varying channel. Also, for assuring the user's security, WiMAX supports strong encryption, using Advanced Encryption Standard (AES), and has a robust privacy and key-management protocol.

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