WiMAX

General information about the standard 802.16

Application Note

This Application Note is one of three papers dealing with the WiMAX standard, covering the theoretical aspects of WiMAX. It gives a detailed overview of the basic concepts of WiMAX (FFT, OFDM, frame structures, etc) and explains the physical standard parts of IEEE 802.16 standards 802.16-2004, corr1 and 802.16e.

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1 Overview

The new WiMAX radio technology – worldwide interoperability for microwave access – is based on wireless transmission methods defined by the IEEE 802.16 standard. WiMAX has been developed to replace broadband cable networks such as DSL and to enable mobile broadband wireless access.

Rohde & Schwarz offers an all-in-one test solution for WiMAX applications by combining its R&S SMU200, R&S SMJ100A or R&S SMATE200A signal generator and R&S FSQ signal analyzer plus the appropriate options.

This Application Note is one of three papers dealing with the WiMAX standard, covering the theoretical aspects of WiMAX.

Chapter 2 Standard Overview gives an overview of the WiMAX standard and describes them in the context of 802 and 802.16. Also, some basic overview tables are provided.

Chapter 3 OFDM − Basic Terms is an introduction to OFDM, providing explanations of all necessary key words and figures you need in order to understand the WiMAX physical transmission concept.

Chapter 4 802.16 OFDM contains the most important facts regarding the 802.16-2004 OFDM standard (key parameters, frequencies, basic transmitter structure, etc).

Chapter 5 802.16-2004 OFDMA describes the OFDMA extension of the WiMAX system with all the important facts (bursts, zone types, etc).

Chapter 6 802.16e focuses on the important changes made in the evolution from the previous standard 802.16-2004 to 802.16e.

Chapters 7 to 9 summarize the WiMAX standard parameters and list all measurement requirements.

The Application Note

WiMAX − Generate and Analyze 802.16-2004 and 802.16e Signals

[B] will give detailed guidelines on how to perform measurements on WiMAX signals in accordance with the WiMAX standard.

The Application Note

WiMAX − 802.16-2004, 802.16e, WiBRO − Introduction to WiMAX Measurements

[C] will give an overview of both standards and measurement, and also provides a short video sequence showing the operation of the R&S SMU and R&S FSQ for WiMAX measurement.

Introduction

The IEEE 802.16-2004 standard specified OFDM as the transmission method for NLOS connections. The OFDM signal is made up of many orthogonal carriers, and each individual carrier is digitally modulated with a relatively slow symbol rate. This method has distinct advantages in multipath propagation because, in comparison with the single carrier method at the same transmission rate, more time is needed to transmit a symbol. The BPSK, QPSK, 16QAM, and 64QAM modulation modes are used, and the modulation is adapted to the specific transmission requirements. Transmission rates of up to 75 Mbit/s are possible. Unlike WiMAX's "little brother" WLAN, the bandwidth is not constant and can vary between 1.25 MHz and 28 MHz. In IEEE 802.16-2004, a distinction is made between two methods: OFDM and OFDMA. In the normal OFDM mode, 200 carriers are available for data transmission and both TDD and FDD methods are used. In the OFDMA mode, various subscribers can be served simultaneously by assigning each subscriber a specific carrier group (subchannelization) that carries the data intended for that subscriber. The number of carriers is also significantly increased. The 802.16e [2] standard is a further expansion of WiMAX in the frequency range up to 6 GHz with the objective of allowing mobile applications and even roaming. In addition, the number of carriers can vary over a wide range depending on permutation zones and FFT base (128, 512, 1024, 2048). The Korean standard WiBRO is a special case of 802.16e.

2 Standard Overview

From 802.11b to 802.16e

This brief introduction chapter shows the evolution of the Wireless Local Area Network (WLAN) standard 802.11 and the Wireless Metropolitan Area Network (WMAN) standard 802.16 over the last seven years.

- The evolution of wireless LAN started with the introduction of the **802.11b** standard in 1999. This standard used a single carrier (SC) modulation at an RF frequency of 2.4 GHz with BPSK and QPSK modulation and had a maximum transfer rate of 11 Mbit/s.
- In the same year, the **802.11a** standard introduced the Orthogonal Frequency Division Multiplexing (OFDM) method to transmit up to 54 Mbit/s at a RF frequency of 5 GHz to 6 GHz by spreading the information over several OFDM carriers that can have modulation orders from BPSK to 64QAM.
- In 2003, "the best" of both standards (low RF frequency of 802.11b and 54 Mbit/s of 802.11a) were joined to the **802.11g** standard. This standard uses the RF frequency of 2.4 GHz and supports both 802.11 modulation types (SC and OFDM).
  Additionally, "turbo modes" with up to 108 Mbit/s were introduced.
- While all former standards were used for "small networks" with no network operator required (small office & home office, SOHO), the first **802.16** standard, which was introduced at the end of 2001, provided an operator-based standard for e.g. Internet access over long distances as they occur in urban areas.

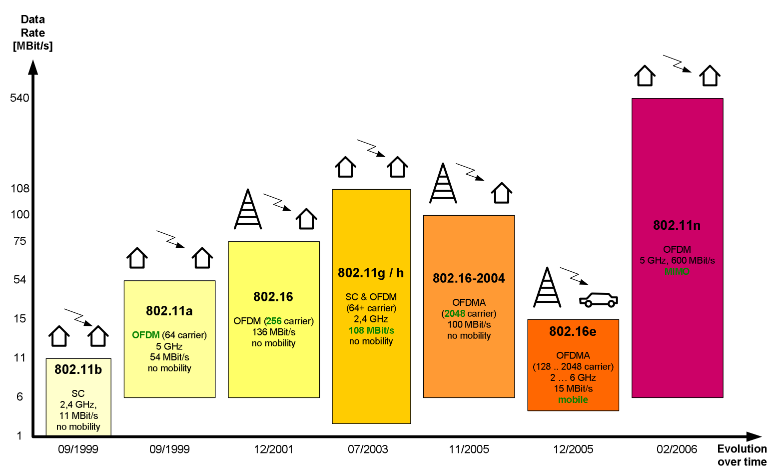

Fig. 1: From 802.11b to 802.16e

Standards 802 and 802.16

802.16 includes several parts that describe different functions and features of 802.16.

The table below provides an overview of the currently available 802 and 802.16 standards. Standards marked in green are covered by this Application Note.

Standard	Name / Description
802.1	Higher Layer LAN Protocols (Management of 802.x)
802.2	Logical Link Control (LLC)
802.3	Ethernet (CSMA/CD − carrier sense multiple access / collision detection)
802.4	Token Passing / Token Bus
802.5	Token Ring / FDDI (Fiber Distributed Data Interface)
802.6	DQDB WAN (Distributed Queue Dual Bus WAN)
802.7	Recommended practices for broadband LANs (BBTAG)
802.8	Recommended practices for fiber optics (FOTAG)
802.9	IsoEnet (Isochronous Ethernet) (ISLAN)
802.10	Protocol for security LAN
802.11	Protocol for wireless LAN
802.12	100VG AnyLAN (demand priority access method)
802.13	unused
802.14	Protocol for cable TV and cable modem
802.15	Wireless Personal Area Network (WPAN)
802.16	Wireless Metropolitan Area Networks (MAN)
802.17	Resilient Packet Ring Working Group (RPRWG)
802.18	Radio Regulatory TAG
802.19	Coexistence TAG
802.20	Mobile Broadband Wireless Access (MBWA)
802.21	Media Independent Handoff
802.22	Wireless Regional Area Networks (WRAN)
Legend: INACTIVE / DISBANDED	

Table 1: Different 802 standards

Standard	Name / Description
802.16	WiMAX, frequency range 10 GHz to 66 GHz
802.16a	WiMAX for stationary SS, frequency range <11 GHz
802.16b	Licensed Exempt Frequencies; frequency range 5 GHz to 6 GHz ("Wireless HUMAN" = High Speed Unlicensed MAN)
802.16c	Detailed System Profiles for 10 GHz to 66 GHz
802.16d	WiMAX standard with additions in accordance with WiMAX Forum
802.16-2004	Replaces 802.16/.16a/.16d (including OFDMA)
802.16e	WiMAX for moving SS (speed up to 120 km/h; FFT size 128, 512, 1024 and 2048)
802.16f	MIB Management
802.16g	Management Plane
802.16-1	Air Interface; frequency range 10 GHz to 66 GHz
802.16.2	Coexistence of Broadband Wireless Access Systems Replaced by 802.16.2-2004
802.16.2-2004	Coexistence
802.16.2a	Recommended Practice for Coexistence of Fixed Broadband Wireless Access Systems
802.16.3	Air Interface for Fixed Broadband Wireless Access Systems; frequency range <11 GHz (e.g. ISM, PCS, MMDS, UNII Band)

Table 2: 802.16 standards

The figure below illustrates the most important evolutionary steps of the 802.16 standard (regarding the PHY = physical layer).

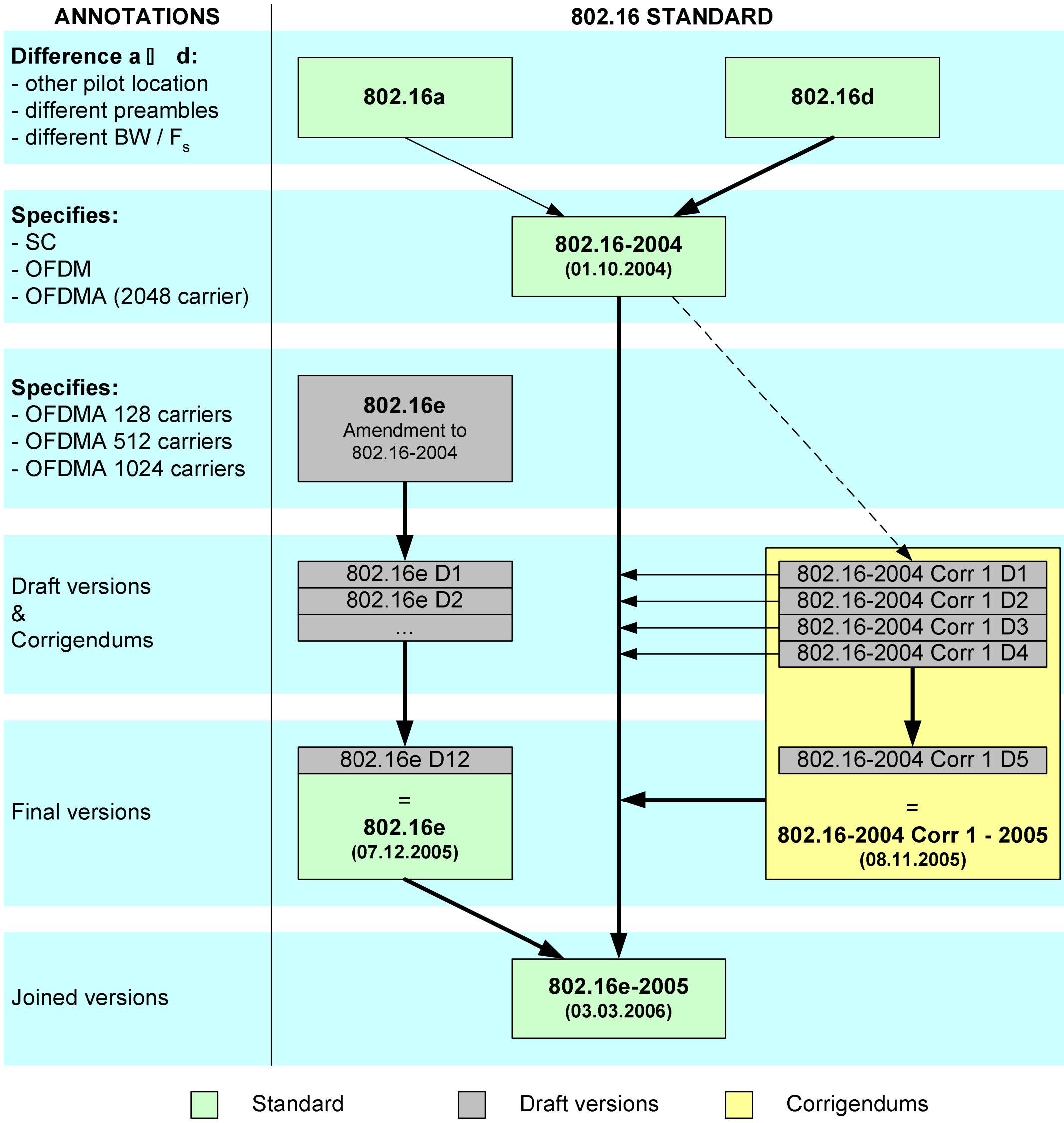

Fig. 2: Evolution of 802.16 PHY standard

3 OFDM − Basic Terms

The WiMAX standard describes different modes of operation:

- **Single Carrier** (SC / SCa) and
- Orthogonal Frequency Division Multiplex (**OFDM** / OFDMA).

The following chapter provides a brief introduction to OFDM − the concept, some basic terms, etc.

OFDM

OFDM is one step in the evolution of transmitting information over a physical media:

- The easiest way to send information is ***bit-by-bit*** in time at one particular carrier frequency. With this method, you start with the first bit, transmit it, send the second bit, transmit it, and so on. This is done by means of ASK modulation, for example.
- A more complex method is to group a certain number of bits together to form a symbol and then to transmit such symbols ***symbol-by-symbol***. QPSK (two bits form 1 QPSK symbol) or 16QAM (four bits form one 16QAM symbol) are examples of this modulation.
- OFDM is an even more complex method of transmitting information over a physical channel. The basic concept is to use ***multiple carriers*** (e.g. 256 carriers) to transmit a large number of symbols at the same time, and distributing information blocks containing a certain number of bits to a certain number of carriers.

Using OFDM has many advantages, including high spectrum efficiency, resistance against multipath interference (particularly in wireless communications), and ease of filtering out noise (if a particular range of frequencies is affected by interference, the carriers within that range can be disabled or made to run slower). Also, the upstream and downstream speeds can be varied by allocating a higher or lower number of carriers for each purpose.

An extremely important benefit from using multiple subcarriers is that because each carrier operates at a relatively low bit rate, the duration of each symbol is relatively long. For example, if you send a million bits per second over a single baseband channel, then the duration of each bit must be under a microsecond. This imposes severe constraints on synchronization and removal of ***multipath interference***. If the same million bits per second are spread among N subcarriers, the duration of each bit can be extended by a factor of N, and the constraints of timing and multipath sensitivity are greatly relaxed. For moving vehicles, the Doppler effect on signal timing is another constraint that causes difficulties for some other modulation schemes.

The more complex the technique and the greater the information bandwidth (one parameter is "bit/Hz", which indicates how many useful bits can be transmitted when using 1 Hz bandwidth), the more sensitive the systems are to ***disturbing effects*** (such as fading, noise, transmitter and receiver imperfections).

To overcome these problems, more sophisticated techniques to ***recover errors*** have to be introduced (advanced protocols, multipath receivers such as Rake receivers, high-performance receiver frontends, advanced error coding and error recovery methods such as turbo codes, Viterbi decoders, etc).

The following figure shows the evolutionary steps from ASK to OFDM.

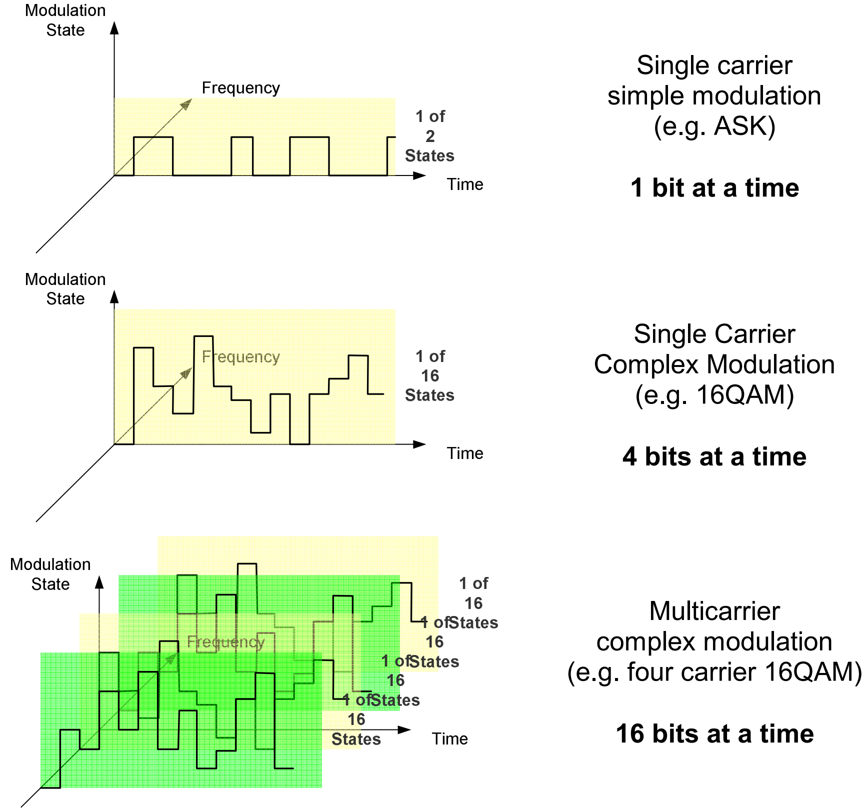

Fig. 3: Evolution from ASK to OFDM

Basic Terms

In order to describe an OFDM system, a number of terms are used to specify the parameters of the physical properties.

The following table and the figure explain and illustrate the basic terms of OFDM.

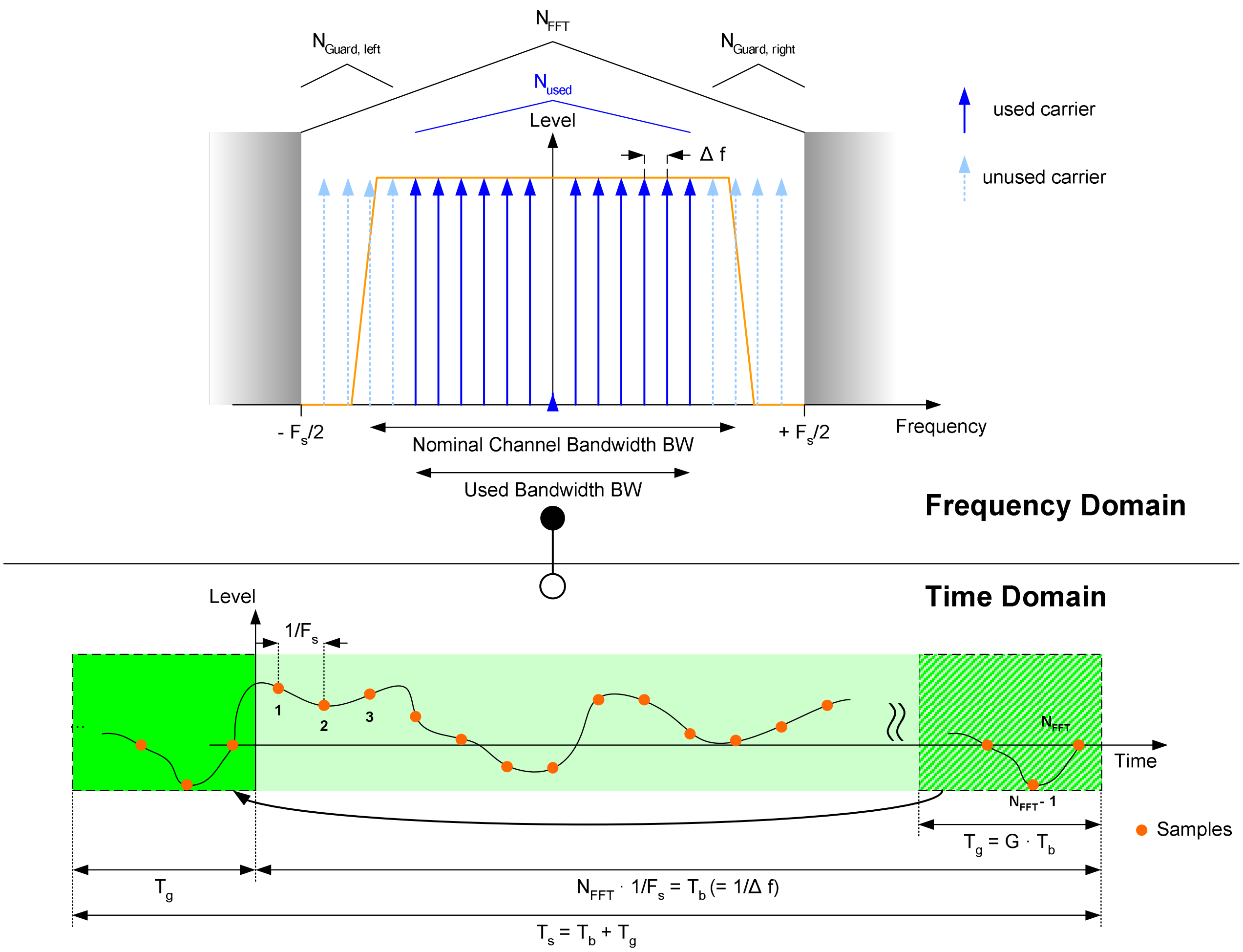

Fig. 4: Definitions of OFDM terms

Nominal channel bandwidth BW [Hz]

The bandwidth which is allocated e.g. by the governmental authorities. BW = F_s / n.
Values are e.g. 1.5 MHz, 5 MHz or 20 MHz.

Used bandwidth BW [Hz]

The bandwidth is the area which is physically occupied by the WiMAX signal in frequency domain. BW = $N_{used\ (max)} \cdot \Delta f$.
The used bandwidth must be smaller than the nominal BW.

Sampling frequency F_S [Hz]

The sampling frequency is the "core" frequency of the transmission system, i.e. the frequency at which e.g. the D/A converter generates new samples. F_s = floor(n · BW/8000) · 8000
F_S is always greater than BW.

Sampling factor n [1]

The sampling factor is equal to the ratio of sampling frequency to channel bandwidth. n = F_S / BW.
Typical factors are $^{8}/_{7}$ (very common), $^{28}/_{25}$, $^{86}/_{75}$, …

FFT size N_{FFT} [1]

In OFDM, signals are very often processed using fast Fourier transformation (FFT). N_{FFT} specifies the number of samples for this processing step and is always a power of 2.
Typical values are 256 (for OFDM) or 2048 (for OFDMA).

(Sub-)carrier spacing Δf [Hz]

The distance between two adjacent physical OFDM carriers. The value is calculated by $\Delta f = F_S / N_{FFT}$.
For OFDMA, this value is e.g. 11.1607 kHz.

Useful symbol time T_b [s]

The time a symbol is "valid", which means the correct and undisturbed carrier modulation state (also called the "orthogonality interval") is present. $T_b = 1 / \Delta f$.
For FFT analysis, this is the analyzed interval length.

Guard period ratio / interval G [1], cyclic prefix (CP) time T_g [s]

In order to collect multipath information, a particular ratio of the useful symbol is added to the OFDM symbol.
The ratio is called guard period (typical values of G: $^1/_4$, $^1/_8$, $^1/_{16}$ or $^1/_{32}$), the absolute time is called cyclic prefix ($T_g = G \cdot T_b$).

(Overall) OFDM symbol time T_s [s]

The duration of the complete OFDM symbol with useful symbol time and cyclic prefix time ($T_s = T_b + T_g$).

Number of used subcarriers N_{used} [1]

Due to e.g. the shape of the transmission filter, the outer carriers of an OFDM signal may be attenuated and thus be disturbed. Also, the DC carrier cannot be used.
Consequently, the outer carriers do not carry any modulation data. N_{used} may vary, e.g. depending on special transfer modes.
For OFDM, N_{FFT} = 256 and N_{used} = 200.

DC subcarrier [1]

The DC subcarrier is the carrier at the transmission frequency and is not used for data transmission (set to 0).

Pilot carriers [1]

Pilot carriers are used to synchronize the receiver to the transmitter by means of phase, frequency and timing.
For OFDM, eight pilot carriers are used.

Guard subcarriers $N_{Guard, left}$ / $N_{Guard, right}$ [1]

The guard subcarriers are the outer carriers, which are not used for transmission.
$N_{FFT} = N_{used\ (max)} + N_{Guard,\ left} + N_{Guard,\ right}$ + 1 (DC subcarrier)

Table 3: Definitions of OFDM terms

Guard Period, Fading

In a real-world scenario, a transmitted signal reaches the receiver inside a communication device not only via the direct path (e.g. the line-of-sight), but also via other paths (e.g. by a reflection of the signal on buildings, etc). This scenario is called a multi-path scenario.

As the different transmitted signals reach the receiver at different times, they are added up at the receiver site to form a combined signal.

This scenario is illustrated in the following figure:

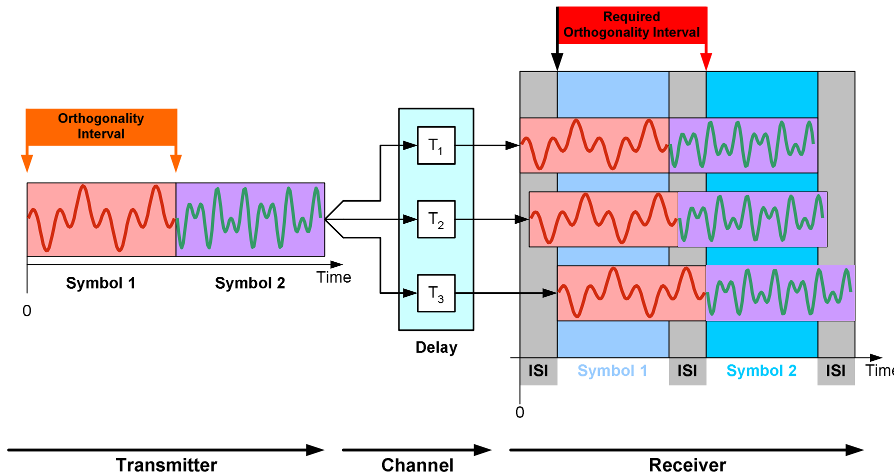

Fig. 5: Intersymbol interference

As you can see from the figure, there are two separate regions in the received signal:

- Only time-shifted version of the signal of ***the same symbol*** (symbol 1 OR symbol 2) are added (blue region). This effect is called **self-symbol interference** (SSI).
- Regions where ***different symbols*** (symbol 1 AND symbol 2) are added up together (gray region). This effect is called **intersymbol interference** (ISI).

Thus, there are basically two "disturbing" effects that must be considered when designing the receiver:

1. Self-symbol interference
2. Intersymbol interference

Self-Symbol Interference

OFDM was introduced because of its resistance to self-symbol interference.

OFDM uses orthogonal transmitter frequencies. Orthogonality means that the product of two carriers with different frequencies (the "cross-correlation function") is zero if samples at the sampling frequency $F_S = \Delta f \cdot N_{FFT}$.

One of the major benefits of OFDM is that this SSI (in contrast to other transmission techniques) improves the performance of the receiver. Mathematical calculations show that SSI in OFDM systems is not "destructive" (i.e. transmission is disturbed), but "constructive" (i.e. the SSI parts add up to form a higher amplitude of the single FFT carriers).

Remove Intersymbol Interference

The ISI part of an OFDM transmission cannot be corrected by any means of signal processing because the receiver has no knowledge of the next symbol being transmitted. This means that the receiver needs an interval with a definite length equal to the useful symbol time to determine the OFDM symbol. This interval is called the **Orthogonality Interval**.

To overcome this problem, a **Guard Period** (GP) is introduced. This is done by just adding the last part of an OFDM symbol to its front.

With this extension, the receiver is able to receive the undisturbed signal for a longer time and demodulate it without any errors.

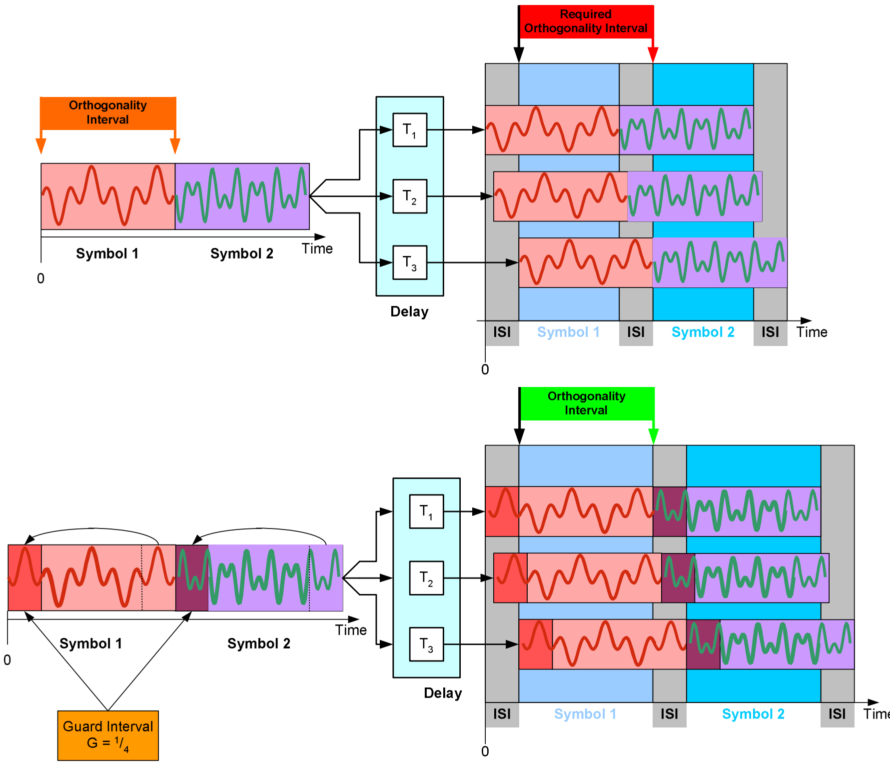

Fig. 6: OFDM transmission with and without guard interval

Length of the Guard Interval

The length of the guard interval is variable and depends on the maximum expected length of the separate delay paths. This length is calculated by simulating the typical environment in which the system will be operated.

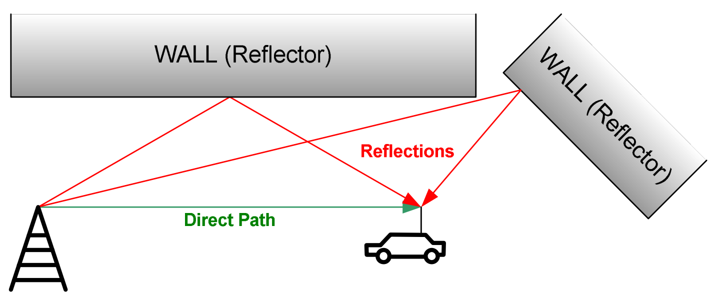

Fig. 7: Multipath environment: direct path and reflection paths

The following tradeoffs are considered when determining the guard interval length. Longer reflection paths require larger guard intervals to successfully overcome intersymbol Interference. However, as the guard interval size increases, the data throughput decreases (as the same amount of bits takes a longer time to be transmitted).

Doppler Shift

Since transmitter and receiver may move (e.g. when operating in a vehicle), a Doppler shift may occur because the distance between the transmitter and the receiver changes over time. This Doppler shift causes a change in frequency of the signal. Reducing the distance between the transmitter and the receiver increases the frequency, whereas increasing the distance reduces the frequency.

Within an OFDM system, a Doppler shift causes a change in carrier location, which means that the carriers move to lower frequencies when the distance between the transmitter and receiver is increased and vice versa. The picture below shows a scenario without fading (blue) and with fading in accordance with the following example below (black).

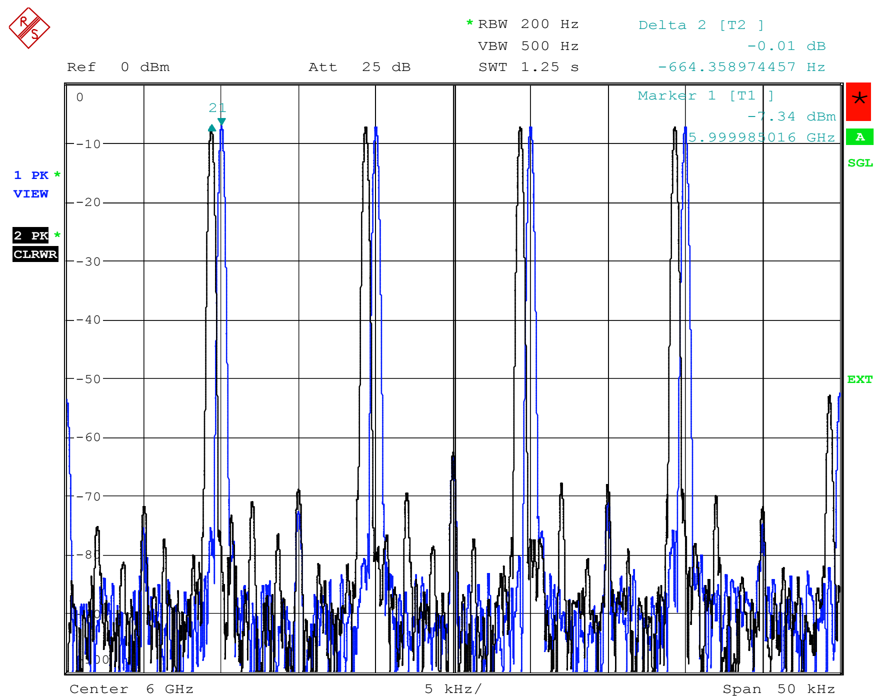

Fig. 8: Effect of Doppler shift

The frequency shift Δf for a vehicle moving with the velocity v and operating at the nominal radio frequency f_0 can be calculated using the formula

$$\Delta f \approx {}^{v}/_{c} \cdot f_0$$

where c is the speed of light (300,000 km/s or 1,080,000,000 km/h).

(The formula assumes that v << c, which is true for any transmitter-receiver environment.)

Assuming

- a vehicle velocity of **v = 120 km/h** and
- a transmitter frequency **f_0 = 6 GHz**,

the Doppler shift can be calculated to **Δf ≈ 670 Hz**.

For OFDM, the minimum possible carrier spacing is ≈ 6.7 kHz, which is ten times greater than the Doppler shift at 120 km/h. The receiver must be able to perform the demodulation for such a subcarrier frequency error or provide correction methods for this type of error.

OFDM Calculation Example

The following example shows how to calculate the main factors of an OFDM system signal.

Assume a WiMAX OFDM signal with the following parameters:

- **FFT size N_{FFT}** = 256 carriers
- **User carriers N_{used}** = 200
- **Pilot carriers N_{Pilot}** = 8
- **System bandwidth BW** = 7 MHz
- **Sampling factor n** = $^{8}/_{7}$

These parameters can be used to calculate the following:

- **Sampling frequency F_S** = n · BW = $^{8}/_{7}$ · 7 MHz = 8 MHz
- **Carrier spacing Δf** = F_S /N_{FFT} = 8 MHz/256 = 31.25 kHz
- **Useful symbol time T_b** = 1 / Δf = 1 / 31.25 kHz = 32 µs

For the calculation of the guard interval length, it is important to estimate the maximum difference between the length of the line-of-sight path and the longest delay path.

- **Assuming G is $^{1}/_{4}$**, then the cyclic prefix time T_g calculates to $T_g = G \cdot T_b = {}^{1}/_{4} \cdot 32$ µs = 8 µs.
  Within 8 µs, the electric wave travels (at the speed of light c = 300000 km/s) a distance of
  $d_{delay} = c \cdot T_g$ = 300 m/µs · 8 µs = 2.4 km.
- **If assuming G is $^{1}/_{32}$**, then the Cyclic Prefix Time T_g calculates to $T_g = G \cdot T_b = {}^{1}/_{32} \cdot 32$ µs = 1 µs.
  Within 1 µs, the electric wave travels (with the speed of light c = 300000 km/s) a distance of
  $d_{delay} = c \cdot T_g$ = 300 m/µs · 1 µs = 0.3 km.

If we assume G to be $^{1}/_{4}$, we can continue our calculation with

- **Overall symbol time T_s** = 32 µs + 8 µs = 40 µs
- For e.g. $N_{symbols}$ = 20 symbols,
  the subframe length **T_{SubF}** = 20 · 40 µs = 800 µs
- For e.g. QPSK modulation, the number of
  bits in this subframe **N_{bit}** = (200 − 8) · 20 · 2 = 7680 bit.
  = (N_{used} − N_{pilots}) · $N_{symbols}$ · (bits / modulation state)
- The raw transfer rate (without coding, puncturing, etc) calculates to 7680 bit / 800 µs = 9.6 Mbit/s.

OFDMA

OFDMA uses the same techniques as OFDM, but adds the functionality to divide the total number of carriers used by the OFDM signal into groups of non-adjacent carriers where different users are allocated to different carriers. This makes it possible to assign the total number of OFDM carriers to more than one user at a time.

The relation between the logical carrier and the physical carrier(s) is defined by tables and calculation rules, and depends on different parameters (type of transmission, base station and/or user equipment ID's, etc).

Details can be found in Chapter 5 "802.16-2004 OFDMA".

4 802.16 OFDM

802.16 uses an OFDM access technique that is already used in other systems such as 802.11a.

The main new features on the PHY layer − relative to 802.11a − are:

- Higher number of FFT carriers (from 64-FFT to 256-FFT)
- Variable channel bandwidth and sampling frequency, and variable ratio between these two values
- Multiple users within one Tx burst (infrastructure-oriented)
- Modulation type (QPSK, 16QAM, etc) can change over time within the frame
- Four instead of two possible guard interval values

Key Parameters

The basic characteristics of the 802.16-2004 system are listed below (see also [1], Table 213):

Channel bandwidth BW 1)	1.25 MHz to 28 MHz
Sampling frequency F_S 1)	1.72 MHz to 32 MHz
Sampling factor n	$^{8}/_{7}$, $^{86}/_{75}$, $^{144}/_{125}$ ($^{316}/_{275}$, $^{57}/_{50}$)
FFT size N_{FFT}	256
Subcarrier spacing Δf	F_S / N_{FFT}
Useful symbol time T_b	1 / Δf
Cyclic prefix (CP) time T_g	$G \cdot T_b$
Guard period ratio G	¼, $^{1}/_{8}$, $^{1}/_{16}$, $^{1}/_{32}$
OFDM symbol time T_s	$T_b + T_g$
Number of used subcarriers N_{used}	200
Pilot carriers	8 (fixed location 2))
Guard subcarriers $N_{Guard, left}$ / $N_{Guard, right}$	28 left, 27 right

1) Discrete values
2) ±13, ±38, ±63, ±88 − see also [1], Table 213

Frequency Bands

Channel bandwidth and sampling factor may differ depending on the frequency band.

All frequency bands and the corresponding settings for the physical parameters are shown below:

ETSI (European Telecommunications Standards Institute)		
	RF frequency	3410 MHz to 4200 / 10000 MHz to 10680 MHz
	Channel bandwidth (BW)	1.75 MHz, 3.5 MHz, 7 MHz, 14 MHz, 28 MHz
	Sampling factor n	$^{8}/_{7}$
MMDS (Multichannel Multipoint Distribution Service)		
	RF frequency	2150 MHz to 2162 MHz / 2500 MHz to 2690 MHz
	Channel bandwidth (BW)	1.5 MHz, 3 MHz, 6 MHz, 12 MHz, 24 MHz
	Sampling factor n	$^{86}/_{75}$
WCS (Wireless Communication Service)		
	RF frequency	2305 MHz to 2320 MHz / 2345 MHz to 2360 MHz
	Channel bandwidth (BW)	2.5 MHz, 5 MHz, 10 MHz, 15 MHz
	Sampling factor n	$^{144}/_{125}$
U-NII (Unlicensed National Information Infrastructure)		
	RF frequency	5250 MHz to 5360 MHz / 5725 MHz to 5825 MHz
	Channel bandwidth (BW)	unspecified MHz
	Sampling factor n	depends on BW

Subchannelization

As WiMAX is designed to operate as an infrastructure network, resource allocation is also an important topic.

Within WiMAX (OFDM and OFDMA), subchannelization allows you to group the complete number of OFDM carriers into blocks and assign each block e.g. to a different segment of a base station. The blocks are spread over the complete frequency range and contain a number of adjacent carriers. The ***subchannel index*** controls the use of the different blocks over the entire spectrum.

The complete number of data subcarriers (192) can be divided into 2, 4, 8 or 16 subchannels. All subcarriers are spread in four different "regions" of the available frequency range.

If, four subchannels are used (as in the example below), there will be $^{16}/_{4} = 4$ different subchannel indices and $^{192}/_{4} = 48$ subcarriers per subchannel, which are distributed over four different "regions", thus yielding $^{48}/_{4} = 12$ adjacent subcarriers per subchannel block.

Details on subchannelization can be found e.g. in [1], Table 213 for OFDM.

The figure below shows the concept of subchannelization with the example of four used subchannels. Subchannel index 12 (green) is used as an example.

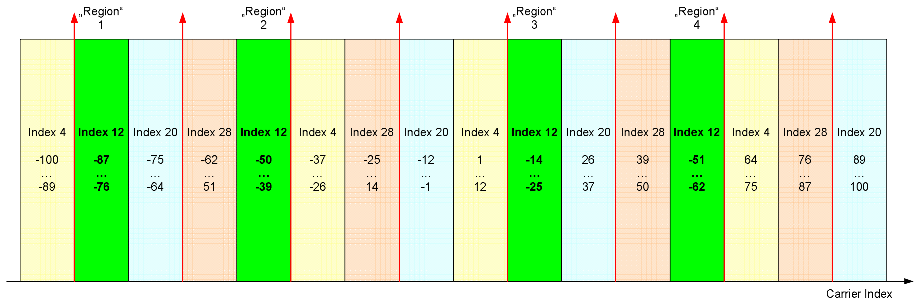

Fig. 9: Subchannelization with 4 used subchannels

Frame Structure

The figure below shows the frame structure of an WiMAX OFDM transmission.

A frame is divided into a DL and a UL subframe. The DL and UL subframes start with the preamble − a known symbol with a limited number of carriers − to recover information about the transmission channel and allow the receiver to recover the channel response. The FCH and DL MAP contains information about the frame content (location and modulation of the individual bursts) and is BPSK-modulated.

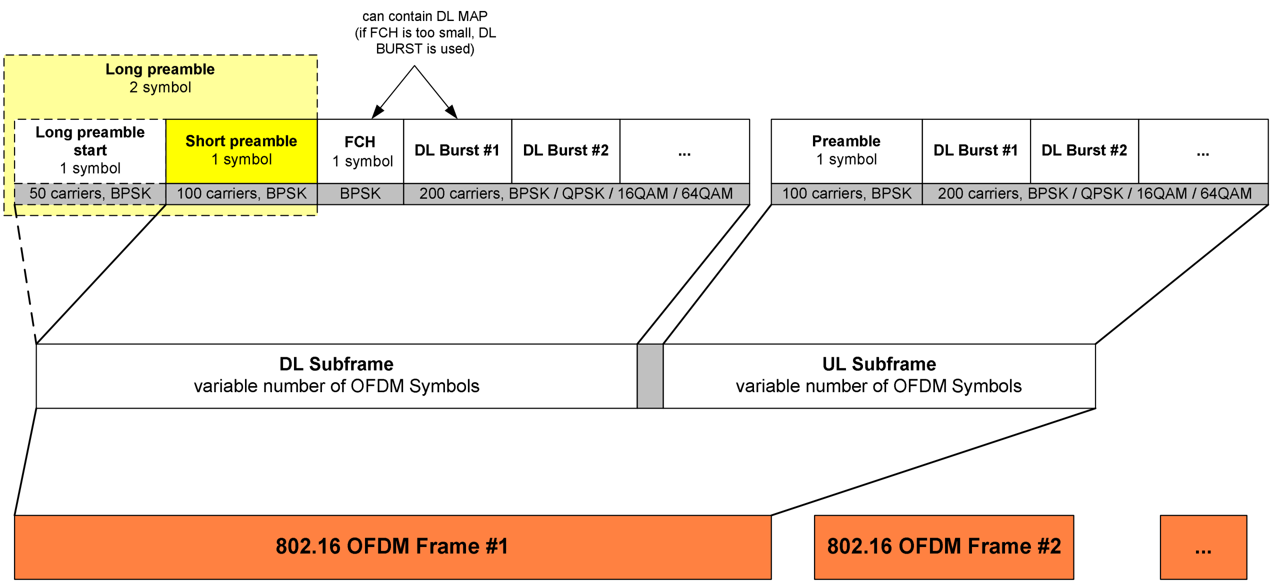

Fig. 10: 802.16 OFDM frame structure

From Bits to Carrier

To get a basic impression of how OFDM / OFDMA transmission works, the path from bits to the carrier is described below.

This image shows a 802.16-2004 OFDM transmitter (with parts of the OFDMA transmitter) and is just an overview; the detailed implementation may vary.

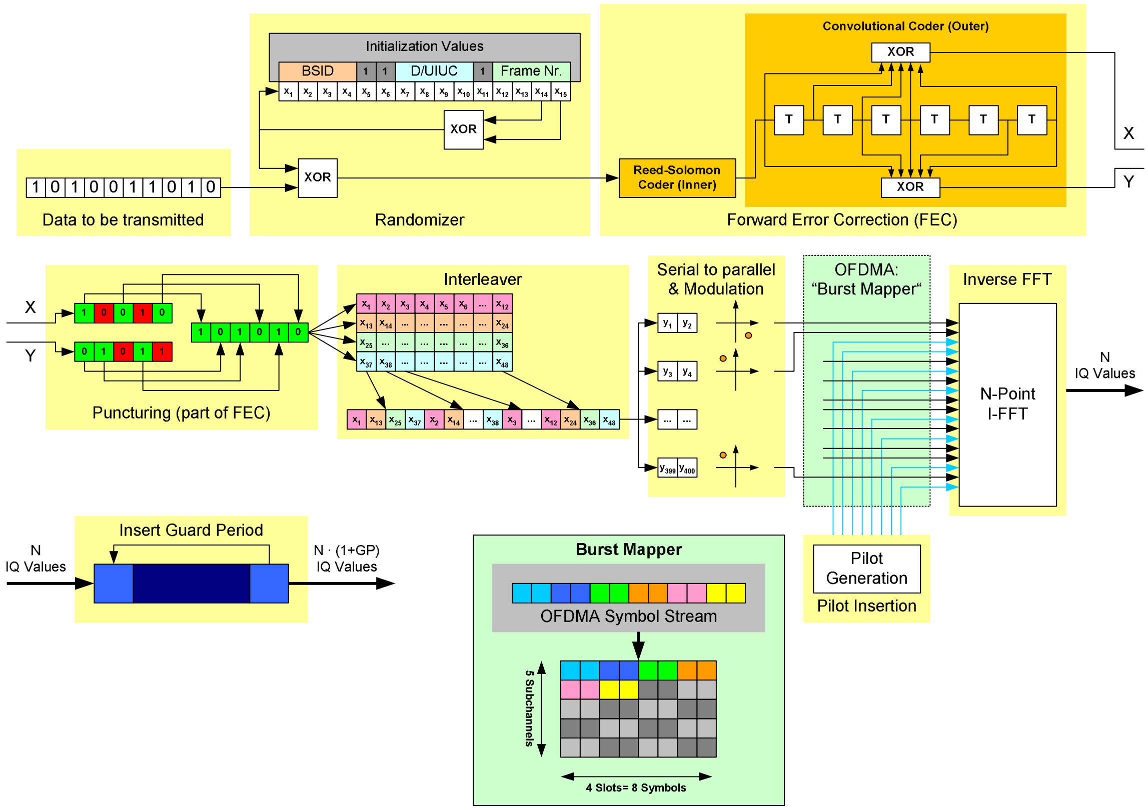

Fig. 11: OFDM / OFDMA transmitter architecture (simplified)

First, data from upper layers pass the **randomizer,** which converts long 0's or 1's sequences into randomly scrambled data, showing better coding performance in the next steps of transmission. The initialization value consists of the base station ID, DL or UL interval usage code (DIUC/UIUC) and frame number. The randomizer is implemented as a feedback register.

After that, the **Forward Error Correction** (FEC) coder adds redundancy to the signal. This is a means of correcting errors that may occur during signal transmission. The coder is implemented as a ***Reed-Solomon coder*** as inner coding and a ***Convolutional Coder*** as outer coder. The total number of bits after encoding is higher than the number of bits before encoding. Alternatively, ***turbo coding*** can be added as a block turbo coder or convolutional turbo coder, which performs better but is also more complex.

The signal's number of bits must now be reduced. This is done within the ***puncturing*** device. It removes parts of the two output streams of the FEC and joins them in a defined way depending on the selected coding rate.

The ***interleaver*** now takes the bit stream and rearranges the data in a different order. This is done to protect against burst (or block) errors that can occur due to fading, signal level drops or other RF conditions.

The bit sequence leaving the interleaver is converted from **serial to parallel** (width depends on the FFT size) and applied to a **modulator** that performs a specific modulation scheme on the data (BPSK, 16QAM, etc).

For OFDMA, the data from one user occupies a certain amount of frequency and time resource. This mapping depends on different parameters such as amount of data to transmit, zone type, segment, subchannel group, etc. A logical carrier can be built up from more than one physical carrier, which are normally non-adjacent physical carriers. This mapping is done by a **burst mapper,** which arranges the data in accordance with the rules defined in the standard.

All operations up to now lead to a complex-value and symbol-based representation of the data in frequency domain. This frequency domain data is now transformed to the time domain by means of an **FFT** block, which takes a certain number of ***data carriers***, maps them to the FFT inputs (where the mapping rule may depend on complex rules) and adds a certain number of ***pilot carriers***. The pilot carriers are used to recover the absolute phase and phase response of the transmission channel, and allow the receiver to recover information about the transmission channel. The output data is now complex values in the time domain.

After the FFT block, the **Guard Period** is inserted into the IQ stream to overcome the problem of multipath effects on the OFDM signal, is then filtered by a baseband filter and passed to the D/A converter section, where it is converted to the transmission frequency and finally transmitted.

5 802.16-2004 OFDMA

Basic Terms

This chapter describes OFDMA.

To understand this mode of PHY channel access, the following table gives an overview of the basic terms within OFDMA.

Frame (contains zones)

A frame is one complete set of downlink and uplink transmissions, meaning the time between two preambles of the downlink signal.

Zone (contains bursts)

A zone is one complete logical part of a frame. There are downlink and uplink zones, and there are different zone types that may use all subchannels of the OFDMA frequency range (full usage of subchannels = FUSC) or only parts of them (partial usage of subchannels = PUSC).

Burst (contains slots)

A burst is an area within a zone which is assigned to one dedicated user. It uses a certain number of subchannels (frequency) and a certain number of symbols (time).
Do not mix up a burst of OFDMA with a "power" burst (meaning the area "between the gaps" of a signal).

Slot

A slot is the minimum possible data allocation unit within OFDMA, defined in time and frequency. It always contains one subchannel and can contain one to three symbols (depending on the zone type).
A DL-PUSC slot is two symbols wide, a UL-PUSC slot three symbols wide.

Subchannel

A subchannel describes the smallest logical allocation unit in the frequency domain. It contains one or more physical carriers, which are normally non-adjacent carriers and whose order may change within a burst from symbol to symbol.
For 802.16-2004, the number of subchannels varies from 32 to 96, depending on the zone type.

Symbol

A symbol is the smallest allocation unit in the time domain. The duration depends on the guard time and the frequency spacing.

Segment

A segment is a set of OFDMA subchannel groups.
There are up to three segments for the downlink and three for the uplink.

Pilot carriers

Pilot carriers are physical carriers that have a known bit pattern and are used e.g. for phase synchronization.

The location (= carrier "index") and number of pilot carriers can be fixed or can change from symbol to symbol (depending on the zone type).

Subchannel group

1 or more Subchannel(s) (which may itself consist of 1 or more physical carriers) in the Downlink PUSC zone are grouped to a subchannel group.

There are 6 subchannel groups.

Overview

OFDMA extends the functionality of OFDM by adding additional multiple access features in the frequency domain. This means that the bandwidth can be divided into slots for the user in the time ***and*** the frequency domain.

The difference to e.g. a standard FDMA mode is that the OFDMA carriers for different users are very close together (e.g. 10 kHz) and that the order of the physical carriers may change from symbol to symbol.

As it is difficult to design a receiver with variable subcarrier spacing, manufacturers try to implement combinations of system bandwidth and FFT size that yield a fixed subcarrier spacing.

The following table shows one possible setting for different system bandwidths and FFT sizes.

<table>
<tr><th colspan="2">Parameter</th><th colspan="20">Mode</th></tr>
<tr><td>System bandwidth [MHz]</td><td>BW</td><td colspan="4">1.25</td><td colspan="4">2.5</td><td colspan="4">5</td><td colspan="4">10</td><td colspan="4">20</td></tr>
<tr><td>Sampling frequency [MHz]</td><td>$F_s = {}^8/_7 \cdot BW$</td><td colspan="4">1.429</td><td colspan="4">2.857</td><td colspan="4">5.714</td><td colspan="4">11.429</td><td colspan="4">22.857</td></tr>
<tr><td>Sample time [µs]</td><td>$T_s = 1 / F_s$</td><td colspan="4">0.7</td><td colspan="4">0.35</td><td colspan="4">0.175</td><td colspan="4">0.088</td><td colspan="4">0.044</td></tr>
<tr><td>FFT size</td><td>N</td><td colspan="4">128</td><td colspan="4">256</td><td colspan="4">512</td><td colspan="4">1024</td><td colspan="4">2048</td></tr>
<tr><td>Subcarrier spacing [kHz]</td><td>$\Delta f = F_s / N$</td><td colspan="20">11.16071429</td></tr>
<tr><td>Useful symbol time [µs]</td><td>$T_b = 1 / f$</td><td colspan="20">89.6 (exact)</td></tr>
<tr><td colspan="2">Available guard time settings T_g =</td><td colspan="5">T_b / 4</td><td colspan="5">T_b / 8</td><td colspan="5">T_b / 16</td><td colspan="5">T_b / 32</td></tr>
<tr><td>Guard time [µs]</td><td>T_g</td><td colspan="5">22.4</td><td colspan="5">11.2</td><td colspan="5">5.6</td><td colspan="5">2.8</td></tr>
<tr><td>OFDMA symbol time [µs]</td><td>$T_s = T_b + T_g$</td><td colspan="5">112</td><td colspan="5">100,8</td><td colspan="5">95.2</td><td colspan="5">92.4</td></tr>
</table>

Table 4: OFDMA key physical parameters (taken from [2], Table 1)

The table below shows all possible frame duration codes (according to [1], Table 274) and the exact durations for all T_g settings. Please note that RTG and TTG intervals must be included in a frame.

Duration [ms]	Symbols	Exact duration for T_g = … [ms]			
		$^1/_4 \cdot T_b$	$^1/_8 \cdot T_b$	$^1/_{16} \cdot T_b$	$^1/_{32} \cdot T_b$
2	19	2.128	1.9152	1.8088	1.7556
2.5	24	2.688	2.4192	2.2848	2.2176
4	39	4.368	3.9312	3.7128	3.6036
5	49	5.488	4.9392	4.6648	4.5276
8	79	8.848	7.9632	7.5208	7.2996
10	99	11.088	9.9792	9.4248	9.1476
12.5	124	13.888	12.4992	11.8048	11.4576
20	198	22.176	19.9584	18.8496	18.2952

Table 5: Frame durations (see [1], 8.4.5.2)

Frame Overview

The following figure is an overview of an OFDMA frame and gives you an idea of the structure of a frame. The terms used are explained in the chapters preceding and following this figure.

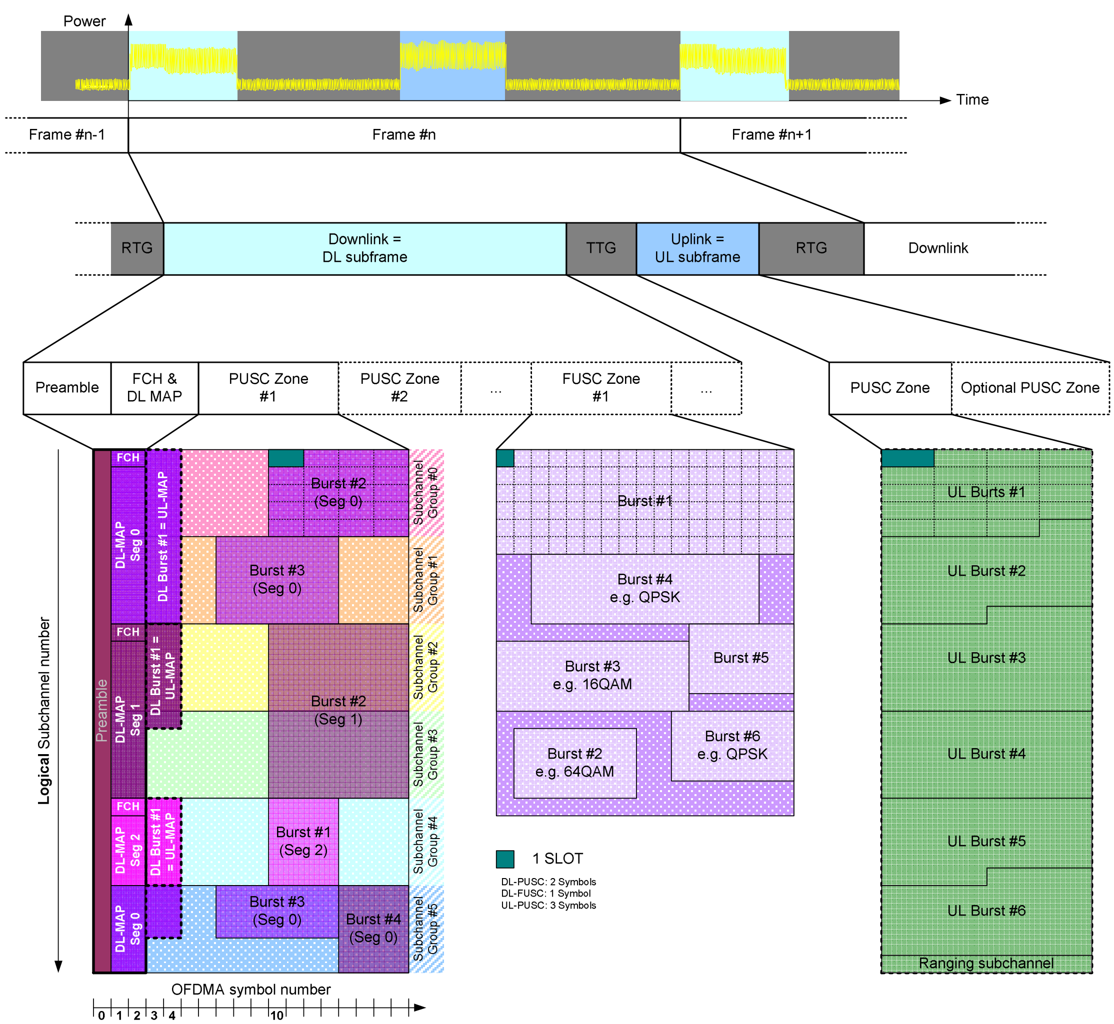

Fig. 12: OFDMA frame structure

Frame Parts & Zone Types

UL and DL are separated (when running TDD mode) by gaps, the transmit transition gap (TTG) after the DL subframe and the receive transition gap (RTG) after the UL subframe.

For OFDMA, different "modes" can be used for transmission in DL and UL. Areas over time where a certain mode is used are called ***zones***.
In the following chapters, the different zones will be defined.

Besides zones, there are four elements that carry information that enables the receiver to demodulate the signal: preamble, FCH, DL-MAP and UL-MAP.

These four elements in the 802.16-2004 structure are used for transmitting additional necessary "signaling" information on the OFDMA signal.

Preamble

The preamble is the start of every downlink frame. It contains BPSK-modulated carriers and is one OFDMA symbol long.

The preamble is used for two reasons:

- Fixed pilot sequences inside the preamble make it easy for the receiver to estimate frequency and phase errors and to synchronize to the transmitter. They are also used to estimate and equalize channels.
- The number of preamble carriers used indicates which of the three segments of the zone are used. Carriers 0, 3, 6,… indicate that segment 0 is to be used, carriers 1, 4, 7,… indicate that segment 1 is to be used, and carriers 2, 5, 8,… indicate that segment 3 is to be used.

FCH

Each segment contains a frame control header (FCH) field, which is QPSK-modulated and two OFDMA symbols long. The physical location (by means of physical carrier index) of the FCH field is fixed, as there is no information in the preamble that characterizes the location.

The content of the FCH describes the subchannels used, the length of the DL-MAP which will follow, and some other transmission parameters.

Element	Size [bit]	Explanation
Subchannel bitmap used	6	Each bit represents one subchannel group to be used or not to be used.
Reserved	1	Set to zero
DL-MAP repetition coding indication	2	00_2: repetition coding off 01_2: repetition coding 2 10_2: repetition coding 4 11_2: repetition coding 6

DL-MAP coding indication	3	000_2: CC encoding 001_2: BTC encoding 010_2: CTC encoding 011_2: ZT CC encoding 100_2: CC encoding with optional interleaver 101_2: LDPC encoding 110_2 .. 111_2: reserved
Length of DL MAP	8	Length in slots
Reserved	4	Set to zero

DL-MAP / UL-MAP

The DL-MAP (downlink map) describes the location of the bursts contained in the following downlink zones. It contains the number of downlink bursts and their offsets and lengths in both the time (= symbol) and the frequency (= subchannel) direction.

The DL-MAP is transmitted in every segment, so each segment contains at least one FCH and one DL-MAP.

The UL-MAP (uplink map) is transmitted as the first burst in the downlink and contains information about the location of the UL burst for the different users.

Zone Types

In the following, the most common zone types are described:

DL-PUSC

If a downlink zone can perform a partial usage of subchannelization, this zone is called a DL-PUSC zone. This type of zone does not use all the (logical) subchannels available to it, but only uses groups of subchannels

The DL-PUSC zone must be the first downlink zone type.

There are a total of six subchannel groups, which you can assign to up to three segments. Thus, a segment can contain one to six subchannels (see also Fig. 12 − segment 0 contains three subchannel groups, segment 1 contains two, and segment 2 contains one subchannel group).

DL-PUSC all SC

The DL-PUSC all SC (all subchannels) is a special form of a PUSC zone that uses all subchannels. The usage of this "all subchannel" mode is indicated by one bit in the DL-MAP field of the zone description.

DL-FUSC

A DL-FUSC (full usage of subchannelization) zone does not use any segments, but can distribute all bursts over the complete frequency range.

In addition, the number of (logical) subchannels is reduced (for FFT size = 2048, from 60 to 32). This results in a higher number of physical subcarriers per logical subchannel in contrast to the DL-PUSC zone.

UL-PUSC

Same as DL-PUSC (partial usage of subchannelization).

The DL-PUSC zone must be the first uplink zone type.

AAS

An AAS (adaptive antenna system) is part of a UL and/or DL frame. It is used for adaptive antenna systems (MIMO, phase array antennas, etc) to improve decoding and transmission performance.

Other Zone Types

Besides the zone types described above, there are other zone types (optional DL-FUSC, AMC, etc) which use e.g. different permutation algorithms or are used to meet special adaptive antenna scenarios. For further details, please refer to the standard.

Parameter	DL-FUSC	Optional DL-FUSC	DL-PUSC	UL-PUSC
In accordance with [1], 8.4.6.1.2.	2	3	1	1 / 5
FFT size	2048 = 2k	2048 = 2k	2048 = 2k	2048 = 2k
DC subcarriers	1 (index 1024)	1	1 (index 1024)	1 (index 1024)
Left guard subcarriers	173	159	184	184
Right guard subcarriers	172	160	183	183
Used subcarriers (N_{used}) without DC	1702	1728	1680	1680
Subcarriers per cluster	---		14	---
Clusters	---		120	---
Pilots	166 (2x12 + 2x71)	192	variant	variant
Data subcarriers	1536	1536	---	
Subcarriers per subchannel	48	48	---	
Subchannels	32	32	60	70
Bands	---	---	---	---
Bin per band	---	---	---	---
Slot size (subch. x symbols)	1 x 1	1 x 1	1 x 2	1 x 3

Table 6: OFDMA PHY overview table (Cor1 included)

6 802.16e

802.16e is a further development of 802.16-2004. This standard includes all the features of 802.16-2004 as well as additional functionality.

Most of the features have been added to higher layers (especially the MAC layer and a number of features, such as roaming), but there are also changes in the PHY layer:

- The main difference is that 802.16e supports not only the FFT size 2048 but also additional FFT sizes (1024, 512 and 128).
- All other parameters (N_{used}, number of subchannels, etc) get scaled with the FFT size.
- The number of subchannel groups has been reduced to three (numbered 0, 2 and 4) for the FFT sizes 128 and 512 (see [4], Table 268a).
- The FCH content has been shortened and modified for FFT size 128.
- The sampling factors $^{86}/_{75}$ $^{144}/_{125}$, $^{316}/_{275}$ and $^{57}/_{50}$ have been deleted and replaced by $^{28}/_{25}$, and also the selection rule has been changed (to make the sampling factors more "integer").

The tables below list the number of used carriers (N_{used}) excluding the DC carrier versus the FFT size (N_{FFT}) depending on the zone type, and the number of subchannels that can be assigned within the zone.

Zone type	2048	1024	512	128
DL-FUSC	1728	850	426	106
DL-PUSC	1680	850	420	84
DL-PUSC all SC	1680	840	420	84
DL-OPUSC	1728	864	432	108
DL-AMC	1728	864	432	108
UL-PUSC	1680	840	408	98
UL-PUSC all SC	1680	840	408	98
UL-OPUSC	1728	864	432	108
UL-AMC	1680	864	432	108

Table 7: N_{used}, depending on the zone type and N_{FFT}

Zone type	2048	1024	512	128
DL-FUSC	32	16	8	2
DL-PUSC	60	30	15	3
DL-PUSC all SC	60	30	15	3
DL-OPUSC	32	16	8	2
UL-PUSC	70	35	17	4
UL-PUSC all SC	70	35	17	4
UL-OPUSC	96	48	24	6

Table 8: Number of subchannels, depending on zone type and N_{FFT}

7 WiBRO

WiBRO (wireless broadband) is a wireless broadband Internet technology being developed by the Korean telecom industry.

From the physical point of view, WiBro is the same as 802.16e with a special set of parameters and restrictions:

Basic modulation access mode	OFDMA
Sampling factor n	$^{8}/_{7}$
Sampling frequency F_S	10 MHz
Nominal channel bandwidth	8.75 MHz
FFT size N_{FFT}	1024
N_{used} (depends on zone type)	864 / 840
Channel bandwidth ($N_{used} \cdot \Delta f$)	8.4375 MHz
Cyclic prefix G	$^{1}/_{8}$
Subcarrier spacing Δf	9.765625 kHz (exact)
Useful symbol time T_b	102.4 µs (exact)
Cyclic prefix T_g	12.8 µs
OFDM symbol time T_S	115.2 µs
Symbols per frame	42
Duplexing mode	TDD
TDD frame length	5 ms, duty rate 1:1, 2:1, 5:1
TTG / RTG	87.2 µs / 74.4 µs

Table 9: WiBRO parameters

8 Comparison of the Different Standards

Parameter	802.11a	802.11b	802.16	802.16-2004	802.16e	WiBRO
FFT size	64	(1)	256	2048	2048, 1024, 512, 128	1024
User carriers	52	1	200	1680 / 1728	various	864 / 840
Pilot carriers	4	0	8	166 / 192	various	96
Bandwidth	20 MHz (Turbo: 40 MHz)	11 MHz	1.25 MHz to 28 MHz	1.25 MHz to 28 MHz	1.25 MHz to 28 MHz	8.75 MHz
Modulation	BPSK QPSK 16QAM 64QAM	BPSK QPSK DBPSK DQPSK	BPSK QPSK 16QAM 64QAM	QPSK 16QAM 64QAM	QPSK 16QAM 64QAM	QPSK 16QAM 64QAM
Duplex	TDD	TDD	TDD / FDD	TDD / FDD	TDD / FDD	TDD
Guard period	$^1/_4$	N/A	$^1/_4$, $^1/_8$, $^1/_{16}$, $^1/_{32}$	$^1/_4$, $^1/_8$, $^1/_{16}$, $^1/_{32}$	$^1/_4$, $^1/_8$, $^1/_{16}$, $^1/_{32}$	$^1/_8$
Multiple users over frequency (@ 1 symbol time)	NO	NO	NO	YES	YES	YES
Multiple users over time (@ 1 channel)	NO	NO	YES	YES	YES	YES
MIMO	NO	NO	YES	YES	YES	YES

9 Test & Measurement Requirements

The following table lists all measurement requirements and the corresponding paragraph in the standard. For details on how to perform the individual measurements, please refer to [B].

How to read the table:
TX, ***EVM*** measurement for ***OFDM*** can be found in Chapter **8.3.**10.1.2.

	Standard (Chapter …)	**SC (8.1…)**	**SCa (8.2…)**	**OFDM (8.3…)**	**RCT OFDM Requirement**		**OFDMA (8.4…)**
					SS (8.2…)	BS (8.3…)	
CQ	RSSI mean and standard deviation	.9.2	.2.2	.9.2	.6	---	.11.2
	CINR mean and standard deviation	.9.3	.2.3	.9.3	.7	---	.11.3
TX	Transmit power level control	Table 166	.3.5	.10.1	.16		.12.1
	Transmitter spectral flatness	---	---	.10.1.1	.17	.15	.12.2
	Transmitter constellation error (EVM)	.8.2.3 / Table 166	.3.4	.10.1.2	.18	.16	.12.3
	Transmitter channel bandwidth and RF carrier frequencies	Table 165 / 166	.3.1	.10.2			---
	Output power	.8.2.1	---	---			---
	Emission mask and adjacent channel performance	.8.2.2	.3.7 .3.8	---			---
	Maximum ramp up/down time	Table 165 / 166	.3.6	---			---
	RTG/TTG performance	---	---	---	.21 .22	---	---
	Frequency and timing requirements	Table 165 / 166	.3.3	.12		.18	.14.1
	Transmit spectral mask	Chapter 8.5.2	Chapter 8.5.2	HUMAN 8.5.2	.20	.17	Chapter 8.5.2
RX	Receiver sensitivity		.3.9	.11.1	.2	.2	.13.1
	Receiver adjacent and alternate channel rejection	Table 165 / 166	.3.11	.11.2	.8 / .9	.7 / .8	.13.2
	Receiver maximum input level	---	.3.10	.11.3	.10	.9	.13.3
	Receiver maximum tolerable signal	---	---	.11.4	.1	.1	.13.4
	Receiver image rejection	---	---	.11.5	.11	.10	---

10 Definitions and Abbreviations

AAS	***A**daptive **A**ntenna **S**ystem*
AMC	***A**dvanced **M**odulation and **C**oding*
BS	***B**ase **S**tation* The unit which communicates with one or more subscriber stations.
BSID	***B**ase **S**tation **I**dentifier* Number identifying the base station; used e.g. to initialize the randomizer in OFDM.
CQ	***C**hannel **Q**uality*
DIUC	**D**ownlink **I**nterval **U**sage **C**ode Value for initializing the scrambler for 802.16-2004 (OFDM).
DL	***D**own**l**ink* Link direction from the base station to the user.
FCH	***F**rame **C**ontrol **H**eader* Header within a WiMAX frame containing information such as frame lengths.
FFT	***F**ast **F**ourier **T**ransformation* A fast method to convert a signal from time to frequency domain and back again.
FUSC	***F**ull **U**sage of **S**ub**c**hannels* A zone mode within 802.16-2004 OFDMA.
MIMO	***M**ultiple **I**nput **M**ultiple **O**utput* A method for using multiple antennas for Tx and Rx to increase the performance.
NLOS	***N**on **L**ine **o**f **S**ight* No direct "shortest length" connection between e.g. BS and SS.
OFDMA	***O**rthogonal **F**requency **D**ivision **M**ultiple **A**ccess* An OFDM mode which combines users in both time and frequency domain.
O-FUSC	***O**ptional **FUSC*** A zone mode within 802.16-2004 OFDMA.
PUSC	***P**artial **U**sage of **S**ub**c**hannels* A zone mode within 802.16-2004 OFDMA.
RCT	***R**adio **C**onformance **T**est* Document describing how to test a WiMAX SS/BS.
RTG	***R**eceive **T**ransition **G**ap* The gap between UL and subsequent DL burst.
Rx	***R**eceive / **R**eceiver*
SC	***S**ingle **C**arrier* Modulation mode.
Slot	Minimum possible data allocation unit for OFDMA PHY Has a certain number of OFDMA symbols and a certain number of subchannels.
SS	***S**ubscriber **S**tation* Equivalent to a mobile for GSM end user equipment.
SUI	***S**tanford **U**niversity **I**nterim* Fading model used to describe WiMAX fading profiles.
TTG	***T**ransmit **T**ransition **G**ap* The gap between DL and subsequent UL burst.
Tx	***T**ransmit / **T**ransmitter*

UIUC	**U**plink **I**nterval **U**sage **C**ode Value for initializing the scrambler for 802.16-2004 (OFDM).
UL	***U***p***l***ink Link direction from the user to the base station.
WiMAX	***W***orldwide ***I***nteroperability for ***M***icrowave ***A***ccess
WirelessMAN	***Wireless M***etropolitan ***A***rea ***N***etwork
WLAN	***W***ireless ***L***ocal ***A***rea ***N***etwork

For additional information on definitions and abbreviations, see also [1], Chapters 3 and 4.

11 Literature

Besides the literature listed below, you can visit the official web pages of the following institutes for detailed information about 802.16:

- Official IEEE 802.16 homepage:
  http://www.ieee802.org/16/
- Official ETSI homepage:
  http://www.etsi.org

[B] **WiMAX - Generate and Analyze 802.16-2004 and 802.16e Signals**
Rohde & Schwarz, Application Note 1MA97
Available for free download:
http://www.rohde-schwarz.com/appnote/1MA97

[C] **WiMAX - 802.16-2004, 802.16e, WiBRO - Introduction to WiMAX Measurements**
Rohde & Schwarz, Application Note 1EF57
http://www.rohde-schwarz.com/appnote/1EF57

[1] **IEEE 802.16-2004**
IEEE Standard for Local and metropolitan area networks
Part 16: Air Interface for Fixed Broadband Wireless Access Systems
Available for free download:
http://standards.ieee.org/getieee802/download/802.16-2004.pdf

[1n] **IEEE 802.16e-2005**
IEEE Standard for Local and metropolitan area networks
Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems
Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands
and
Corrigendum 1

[2] **Scalable OFDMA Physical Layer in IEEE 802.16 WirelessMAN**
Intel Technology Journal, Volume 08, Issue 03, pp. 201 - 212
Available for free download:
http://www.intel.com/technology/itj/2004/volume08issue03

[3] **IEEE C802.16-02/05**
IEEE Standard 802.16: A Technical Overview of the WirelessMAN™ Air Interface for Broadband Wireless Access
Available for free download:
http://www.ieee802.org/16/docs/02/C80216-02_05.pdf

[4] **IEEE P802.16e/D12**
Draft IEEE Standard for Local and metropolitan area networks
Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems
Amendment for Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands

[5] **ETSI EN 301 021**
Fixed Radio Systems; Point-to-multipoint equipment; Time Division Multiple Access (TDMA); Point-to-multipoint digital radio systems in frequency bands in the range 3 GHz to 11 GHz
Available for free download:
http://pda.etsi.org/pda/queryform.asp

[6] **Vector Signal Generator R&S® SMU200A - Manual**
Rohde & Schwarz, 1007.9845.32
Available for free download:
http://www.rohde-schwarz.com/product/SMU (→Downloads)

[7] **Signal Analyzer R&S® FSQ3/8/26/31/40 - Operating Manual**
Rohde & Schwarz, 1155.5047.12
Available for free download:
http://www.rohde-schwarz.com/product/FSQ (→Downloads)

[8] **WiMAX IEEE 802.16-2004 TX Tests - Application Firmware R&S® FSQ-K92 - Software Manual**
Rohde & Schwarz, 1300.7462.42
Available for free download:
http://www.rohde-schwarz.com/product/FSQ-K92 (→Downloads)

[9] **PC Software for IEEE 802.16e OFDMA Signal Analysis - Manual**
Rohde & Schwarz
Available for free download:
http://www.rohde-schwarz.com/product/FSQ-K93 (→Download)

[10] **Fundamentals of Spectrum Analysis**
Rohde & Schwarz, 0002.6635.00
Published by the Rohde & Schwarz in-house publisher; available from Rohde & Schwarz sales offices.

12 Additional Information

This Application Note is updated from time to time. Please visit the website **1MA96** in order to download new versions.

Please contact TM-Applications@rsd.rohde-schwarz.com for comments and further suggestions.

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