WiMAX Technology Notes V1.0, Draft

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1 Key Points About WiMAX

WiMAX is a consortium of companies that promote the IEEE 802.16 standard. The technology is defined by the 802.16-2004 standard (published October, 2004), and was updated for mobility by the 802.15e-2005 addendum (approved Dec. 7, 2005, published Feb 28, 2006). The original 802.16 issue specified line-of-sight (LOS) conditions, and 10 to 66 GHz frequency range. The later issues added non-line-of-sight (NLOS) and the 2-11 GHz range.

1.1 Techniques Used in 802.16

The wireless transmission channel has numerous characteristics that make data transmission a challenge. Suffering from time varying propagation conditions, signal dispersion and time-varying frequency selective fading due to multi-path signal scattering, and frequency shift due to the Doppler effect (in mobile applications), the wireless transmission medium is constantly changing. 802.16 gathers a number of powerful techniques in order to increase the reliability and speed of data transmission under difficult channel conditions.

1.1.1 Orthogonal Frequency Division Multiplexing (OFDM)

OFDM uses a large number of overlapping orthogonal frequency subcarriers (up to 256 mandatory, 2048 optional in 802.16) to carry numerous subchannels of data. This has the following advantages:

- Multiple bits are carried in a single OFDM symbol. A wireless channel suffers from *delay spread* due to the existence of multiple propagation paths (especially in NLOS conditions). When the data symbol is longer, the delay spread is a small and insignificant fraction of the symbol length, so the effect due to delay spread is minimized.
- Numerous frequency subcarriers are employed. Due to *multipath propagation*, the wireless channel is often non-flat in the frequency domain. With ordinary modulation techniques using a single carrier the signal is significantly distorted due to multipath, and so higher signal levels are required to achieve a good connection. With multiple carriers, each frequency subcarrier carries a few bits of information, and bit assignment is adapted to the channel condition at each particular subcarrier frequency.
- Modulation of all the carriers is done by fast fourier transform (FFT) using digital signal processing (DSP) hardware and software algorithms. This method allows the subcarriers to maintain orthogonality thus allowing them to be densely packed compared to ordinary frequency division multiplexing (FDM). The result is very efficient use of radio spectrum. Also, there is the capability to update the modulation scheme by software upgrades.

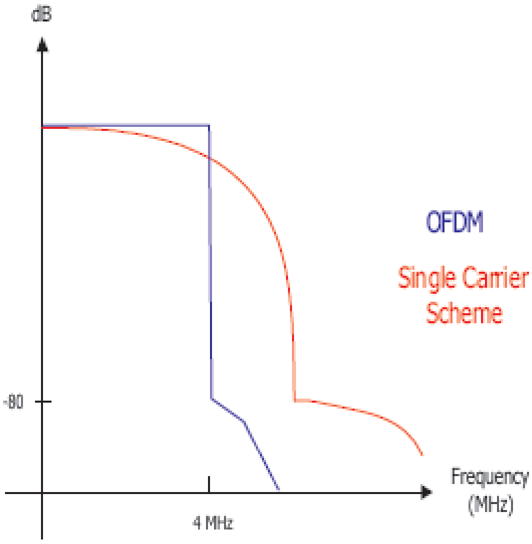

Figure 1: Comparison of OFDM spectrum and single carrier spectrum.

- Power is better contained within the channel bandwidth compared to single carrier techniques (see Fig. 1 for an illustration).

To summarize, OFDM has high spectral efficiency (more b/s per Hz of bandwidth), high resistance to multipath propagation (thus it works well in NLOS wireless channels), and better control of inter-channel interference.

802.11a and 802.11g use 64 OFDM (56 data subcarriers), while 802.16 has 256 (mandatory, which has 200 data subcarriers) to 2048 (optional) subcarriers. In addition, 802.16 uses more advanced peak-to-average power ratio (PAPR) reduction techniques, which improves the linearity, and increases average transmit power capability of the radio frequency power amps.

A variant of OFDM is orthogonal frequency division multiple access (OFDMA). The underlying ideas are the same, but it is used as a multiple access technique, allowing transmission in subchannels to multiple users. This allows the system to flexibly transmit data to multiple users, adjusting continuously as each user's channel changes with radio propagation conditions.

1.1.2 Powerful Error Control Coding

- 256 Reed-Solomon concatenated with convolutional coding (mandatory)
- Block turbo codes (optional) - high performance codes approaching the Shannon limit.
- Convolutional turbo codes (optional) - high performance codes approaching the Shannon limit.
- Low density parity check (LDPC) codes (optional in 802.16e) - high performance codes approaching the Shannon limit.

1.1.3 Adaptive Modulation and Coding (AMC)

High order modulation techniques - 64 quadrature amplitude modulation (QAM) for example - use radio spectrum more efficiently since more data bits are packaged into each transmitted symbol. However, when the signal to noise ratio (SNR) is poor, higher order modulation suffers from poor bit error rate, which can greatly reduce the effective throughput of the channel. A lower order scheme, like binary phase shift keying (BPSK), may be required to maintain a lower throughput with an acceptable bit error rate. With adaptive modulation, the modulation scheme changes continuously with the SNR of the channel. The highest modulation that can support a good bit error rate will be used. In 802.16, up to 64QAM is mandatory, with 256QAM being optional.

With error control coding, stronger error control is obtained with more bit redundancy. Redundancy, however, wastes radio spectrum by reducing the *code rate*, i.e. percentage of information bits to total bits transmitted. For example, a rate $1/2$ code will transmit 2 bits for every 1 data bit, so the spectral efficiency is cut in half. This is often necessary to achieve an acceptable bit error rate, but if a OFDM subcarrier SNR is good, less error control may be required. A rate $5/6$ code will transmit 6 bits for every 5 data bits, so the spectral efficiency is much better. With adaptive coding, the strength of the code is adjusted to obtain good error performance while wasting as few bits as possible on error control.

A combination of modulation adaptation and coding adaptation is done for each OFDM subcarrier, allowing the system to adapt to SNR conditions on each subcarrier.

1.1.4 Hybrid Automatic Repeat Request (HARQ)

HARQ is an option for Orthogonal Frequency Division Multiple Access (OFDMA). Ordinary automatic repeat request (ARQ) is used to request the retransmission of a protocol data unit (PDU - a MAC layer data packet) if the packet was found to be corrupted (according to the cyclic redundancy check - CRC). With hybrid ARQ (HARQ), the physical layer error control coding (such as Reed-Solomon, or turbo codes) is used to determine whether the packet is recoverable. If not, the HARQ mechanism requests a retransmission. This gives better error control performance in wireless channels.

To save data transmission bandwidth while obtaining powerful error correction, incremental redundancy (IR) HARQ can be used. With IR HARQ, a powerful, but low rate (e.g. $1/5$ rate - in which there are 5 bits encoded for every 1 data bit) code is used. Not all of the redundant bits are transmitted in the first transmission of a HARQ packet because that may not be necessary. Only when the receiver determines that a packet is errored are additional bits transmitted. The original errored packet is retained by the receiver, and the additional bits are used to reattempt decoding the data. In this way, good error control is obtained, but transmission bandwidth is not wasted as additional redundant bits are sent only as needed.

Stop and wait HARQ is used in 802.16, in which the transmitter waits for acknowledgement of the transmitted packet before continuing. In order to speed up the HARQ system, a separate ARQ channel is reserved just for ARQ packet retransmissions.

1.1.5 Smart Antenna Techniques

There are a number of smart antenna techniques available as options in the 802.16 standard. Three techniques based on multiple antennas are beamforming, space time coding, and spatial multiplexing.

Beamforming By changing the phases of the signals in multiple transmit antennas, the main lobe of the antenna pattern can be dynamically steered towards the intended receiver. This results in greater gain towards the receiver, and minimization of interference to other terminals.

Space time coding (STC) STC is a means of coding the transmit signals so that transmit diversity is achieved. As described earlier, radio signals suffer from fading due to multipath propagation. With STC diversity, more than one spatial channel is created. Not all spatial channels will experience fading simultaneously, so combining the information from the channels results in greater resistance to fading, and thus higher link reliability.

Spatial multiplexing With special coding and decoding techniques, the use of multiple antennas at the transit and receive ends can result in the creation of numerous spatial channels. Data can be split up and sent on each of these spatial channels, which greatly increases the data rate on the link.

1.1.6 Flexible Channel Sizes

In 802.1-2004, numerous channel sizes have been defined in order to adapt to different regulations in different countries, and to allocate bandwidth as needed. Channel sizes defined in the standard are 1.25 MHz to 28 MHz. Equipment currently available general implement the 3.5, 5.0, 7.0 and 10.0 MHz channel sizes. This gives maximum over-the-air rates of 17.5 to 50 Mb/s.

1.1.7 Flexible Quality of Service

Different types of data applications often require differing forms of quality. For example, voice over IP (VOIP) requires low latency (delay), while file downloading is more delay tolerant, but benefits from high data transfer rates. 802.16 defines four different quality of service (QoS) types: unsolicited grant service (UGS), real-time polling service (rtPS), non-real time polling service (nrtPS), and best effort (BE), which can be set on each individual connection. With UGS, traffic rates, maximum latency and jitter can be set on a connection. This is suitable for real-time applications lime VOIP. BE QoS parameters include maximum sustained traffic rate, and traffic priority, and is suitable for file transfer and web browsing.

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