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Understanding the Radio Technologies of Mobile WiMAX

And their effect on network deployment optimization

White Paper

Introduction

The merits of various radio technologies, and specifically mobile WiMAX, is an on-going debate as these technologies have a direct bearing on the capacity, coverage, quality of service (QoS), and, most importantly, the types of broadband applications that can be supported. Ultimately, the performance of the radios has a direct impact on the service and financial success of a service provider. Ranging from OFDM and OFDMA to deployment trade-offs, smart antennas, radio resource management and handoffs; there are many advanced algorithms and technologies available to meet the challenges of providing carrier-class mobile broadband services and ensuring a winning business model for the service provider.

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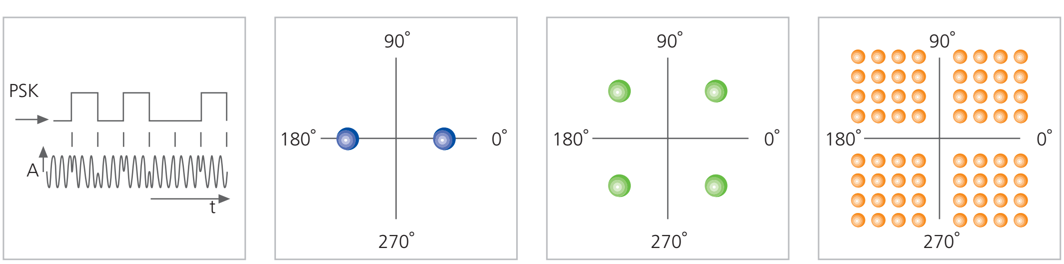
For around 15 years, Alvarion has been at the forefront of the development and deployment of advanced radio and smart-antenna technologies for broadband wireless systems including mobile WiMAX. In this paper Alvarion examines the benefits of the newest radio and related technologies and describes how these benefits impact the deployment of mobile WiMAX networks.

Modulation and Multiple Access Technologies

Higher-Order Modulation

In contrast to existing analog (AM, FM) and low efficiency digital modulation schemes (PSK, BPSK, and QPSK) widely used in today's networks, broadband wireless requires the use of higher order modulation schemes with better spectral efficiency. These higher order modulation schemes however, are more sensitive to interference and multi-path, both of which are prevalent in wireless deployments where ubiquity is required and large numbers of users are present.



Phase Shift Keying (PSK) Modulation | Binary Phase Shift Keying (BPSK) with 2 symbols constellation diagram | Quadrature Phase Shift Keying (QPSK) with 4 symbols constellation diagram | Quadrature Amplitude Modulation (QAM) with 64 symbols constellation diagram

Figure 1: Examples of different order modulation schemes

To counter these effects, OFDM, OFDMA, and S-OFDMA are new advanced access technologies that provide the necessary channel robustness for the support of higher spectral efficiency and higher channel throughput. These new access technologies are the basis for mobile WiMAX and other next generation mobile broadband systems.

OFDM

The need for reliable broadband services in a non-line-of-sight (NLOS) wireless environment, typically riddled by severe multi-path, and interference from other wireless service providers, has driven the wireless industry to the widespread adoption of Orthogonal Frequency Division Multiplexing (OFDM) in standards[1] and products.

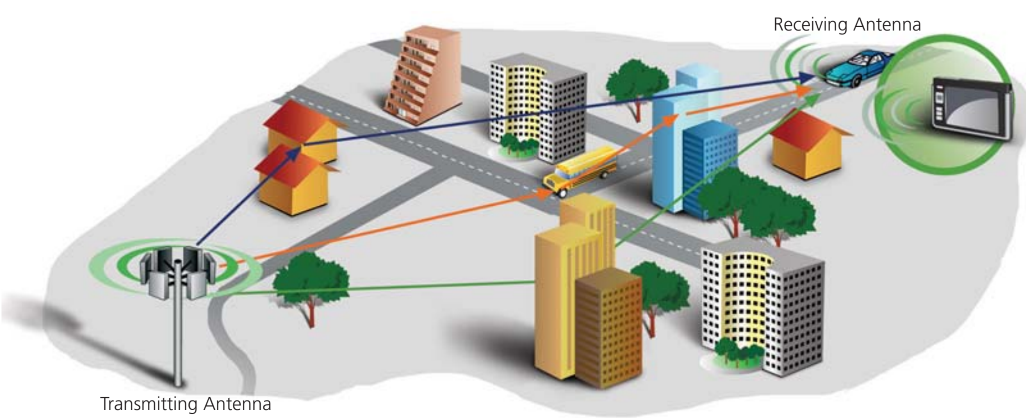
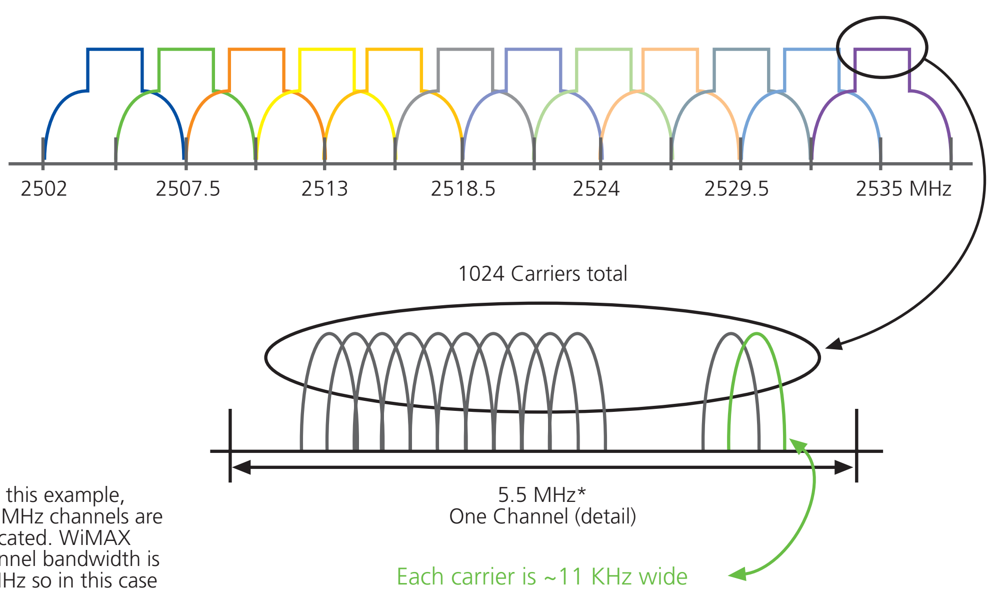


Figure 2: Typical Example of Multi-path Problem

For robustness, OFDM partitions the data stream into multiple narrowband transmissions in the frequency domain using subcarriers that are orthogonal to one another.

These subcarriers are then assembled into frequency channels for over the air transmission.



* In this example, 5.5 MHz channels are allocated. WiMAX channel bandwidth is 5 MHz so in this case there is a guard band of 0.5 MHz.

Figure 3: Example of OFDM Carriers

[1] Examples include 802.11a and 802.11g WLAN standards, the 802.16-2004 wireless MAN standard, and the 802.15.3a ultra wide band (UWB) personal area network (PAN) standard.

These narrowband transmissions use long-duration symbols in the time-domain to make them less subject to distortion due to multi-path. In an urban environment, multi-path reflections are spread a few microseconds apart[2]. By employing symbol durations of approximately 100 microseconds with a 'guard interval' of about 10 microseconds, OFDM enables the effects of multi-path to be overcome with very low overhead.

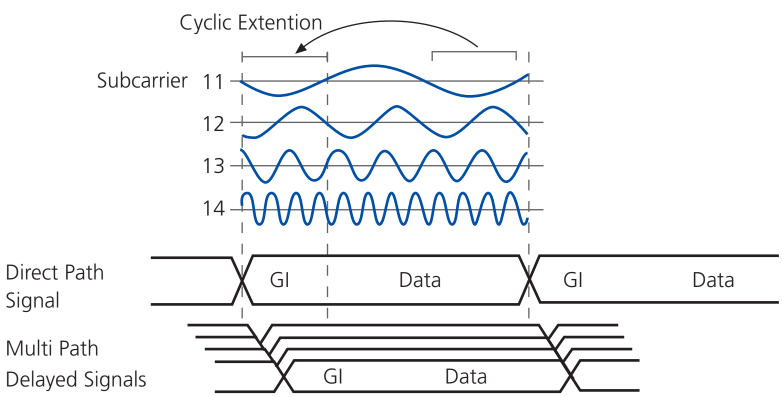


Figure 4: Symbol integrity is kept for multi-path delays up to the guard interval (GI) time

To ensure orthogonality, the subcarriers spacing is selected to be the inverse of the symbol duration.

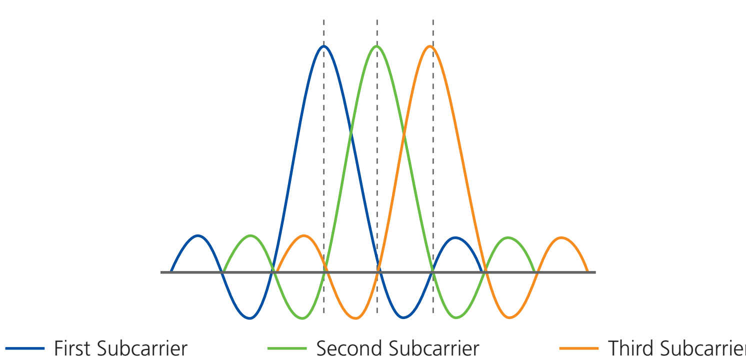


Figure 5: Subcarrier spacing is carefully selected so that each subcarrier is orthogonal to the other subcarriers. Subcarrier spacing is equal to the reciprocal of the (useful) symbol duration

The specific number of subcarriers is a power of two (2) and is engineered based on numerous factors including the channel bandwidth and the degree of interference tolerance desired. This number corresponds to the fast fourier transform (FFT) size. The 802.16-2004 Air Interface Standard specifies 256 subcarriers, corresponding to a FFT size of 256 independent of channel bandwidth. The 802.16e-2005 amendment on the other hand, provides for FFT sizes ranging from 512 to 2048 corresponding to channel bandwidths ranging from 5 to 20 MHz to maintain relatively constant[3] symbol duration and subcarrier spacing independent of channel bandwidth. With OFDM therefore, the combination of multiple orthogonal subcarriers transmitted in parallel with long duration symbols ensures that the overall broadband throughput is immune to constraints due to NLOS environments and multi-path interference.

[2] Typical multi-path behavior in MAN environment (e.g. 802.16 doc 04/29r4).

[3] The mobile WiMAX Release-1 system profiles include channel bandwidths of 7.0 and 8.75 MHz with a specified FFT size of 1024 resulting in slightly longer symbol durations than the 10 MHz channel bandwidth which also specifies a 1024 FFT size.

OFDMA

Orthogonal frequency division multiple access (OFDMA) is a multi-carrier technology that extends OFDM for use as a multiple access technology. As shown in the following diagram, OFDMA supports the assignment of individual groups of subcarriers to specific subscribers. Each subcarrier group is denoted as a 'subchannel', and each subscriber is assigned one or more subchannels for transmission based on each subscriber's specific traffic requirements.

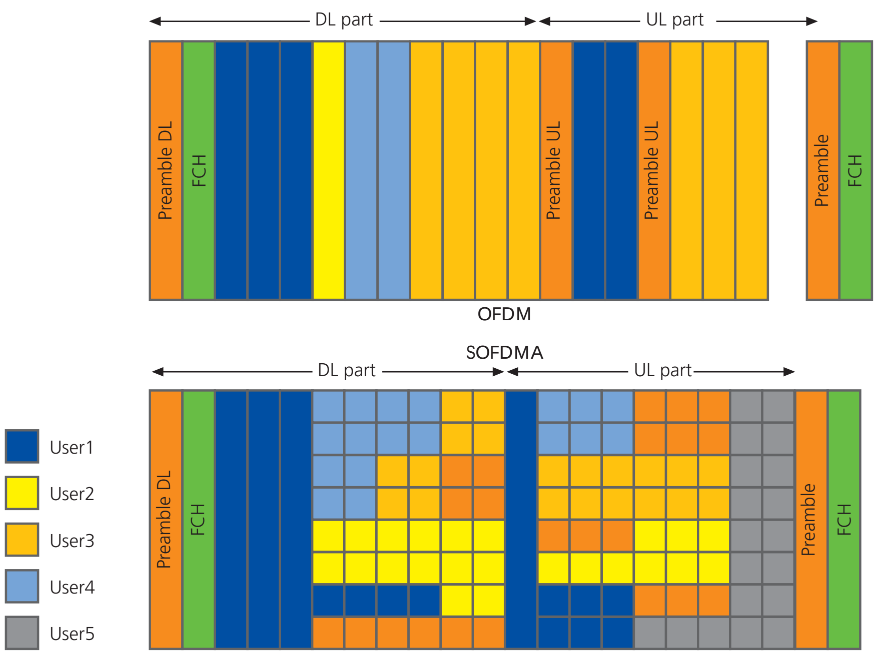


Figure 6: OFDM Vs. SOFDMA Channelization

OFDMA has several benefits ranging from increased flexibility to improved throughput and robustness. By assigning subchannels to specific subscribers, transmissions from several subscribers can occur simultaneously without interfering, thus minimizing an effect known as multiple access interference (MAI). Furthermore, subchannelization enables the concentration of transmit power over a reduced number of subcarriers. This results in increased link margins which in turn, lead to improved range and coverage.

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The IEEE 802.16e-2005 amendment was developed to extend the 802.16 Air Interface Standard to cover mobile applications. This amendment adopted OFDMA to provide the flexibility to deal with varied usage scenarios and the challenges associated with rapidly moving mobile users in a NLOS environment. The 802.16e-2005 standard provides three subchannel allocation alternatives that can be selected based on the usage scenario as follows:

- Subcarriers can be scattered throughout the frequency channel range. This is referred to as fully used sub-channelization or FUSC.
- Several scattered clusters of subcarriers can be used to form a subchannel. This is referred to as partially used sub-channelization or PUSC.
- Subchannels can be composed of contiguous groups of subcarriers. This is referred to as adaptive modulation and coding or AMC.

With FUSC and PUSC, the allocation of subcarriers to subchannels is done in a pseudorandom fashion such that the subcarriers for a given subchannel in a certain cell are different than subcarriers for that same subchannel in another cell (for example the subcarriers in subchannel 1 in cell 1 will be different than the subcarriers in subchannel 1 in cell 2). This pseudorandom permutation provides an interference averaging effect further reducing the adverse effects of cell to cell interference. In general, FUSC and PUSC are the best alternatives for mobile applications, whereas AMC is well suited for stationary, portable, and low mobility applications.

S-OFDMA

Scalable OFDMA (S-OFDMA) provides the ability to adjust OFDMA in accordance with the bandwidth of the channel being used. As regulators assign varying amounts of spectrum to different service providers, the OFDMA parameters can be optimized in proportion to the bandwidth granted to a specific service provider. With S-OFDMA, the FFT size varies with the channel bandwidth based on parameters called out in 802.16e-2005. In a 5 MHz channel an FFT size of 512 subcarriers is specified, whereas in a 10 MHz channel an FFT size of 1024 is specified. This ensures that both the 5 MHz and 10 MHz systems have the same symbol duration and hence similar robustness to multi-path distortion even though they vary in size.

Smart Antenna Systems

Smart antenna systems refer to a class of antenna technologies designed to improve the received signal strength in a wireless access network. The intent is to improve the carrier-to-interference plus noise ratio (CINR). The use of ‘smart’ antenna technologies can both increase received signal strength and decrease interference levels to greatly enhance performance in a mobile communication network.

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Received signal strengths fluctuate as subscribers move throughout the coverage area and the use of multiple or ‘smart’ antennas to improve the link quality have been studied since the days of early cellular systems. The first step was to use multiple antennas to provide ‘receive diversity’. These systems either select the one antenna with the strongest signal or optimally combine the multiple signals received from all antennas. The WiMAX standard supports several smart antenna technologies, including multiple-input, multiple-output (MIMO) and advanced (or adaptive) antenna systems (AAS) on both subscriber terminals and base stations. While MIMO refers to the use of multiple antennas, and the resulting processing required for the additional signals; AAS refers to either ‘space-time coding’ techniques or ‘beam-forming’.

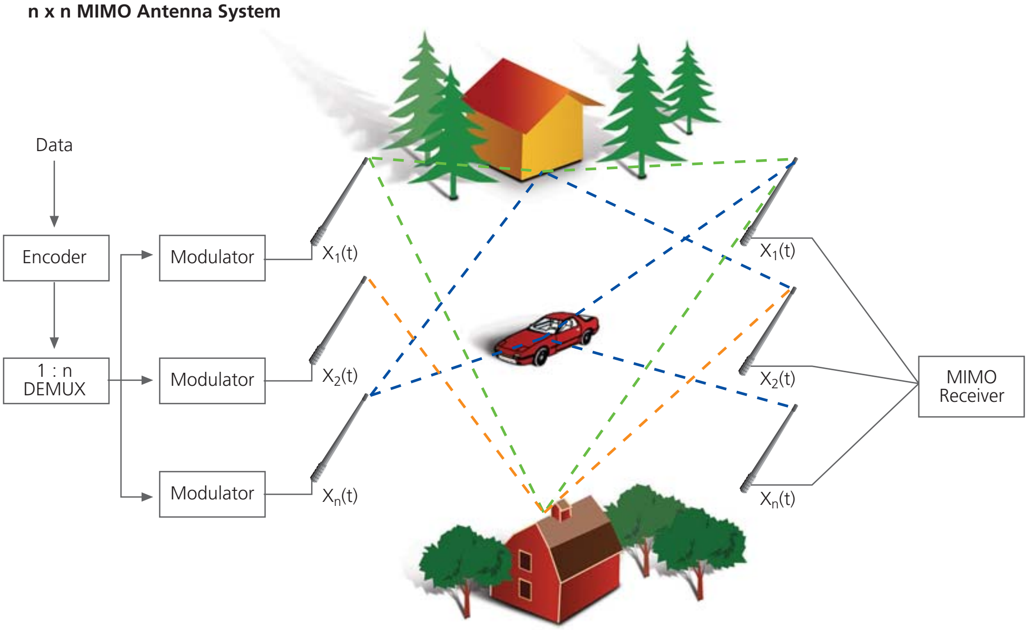
With beam-forming, the signal with its transmitted energy, is physically formed and directed to a particular subscriber resulting in higher gain, higher throughput, and more robustness to interference. Since OFDMA converts a wide bandwidth channel into numerous flat, narrowband subcarriers, AAS can be supported with far less complexity than would be required with other broadband wireless systems.

Multiple-Input Multiple-Output

Multiple-Input, Multiple-Output (MIMO) describes systems that use more than one radio and antenna system at each end of the wireless link. In the past it was too costly to incorporate multiple antennas and radios in a subscriber terminal. Recent advances in radio miniaturization and integration technology now makes it feasible and cost effective. Combining two or more received signals has the most immediate benefit of improving received signal strength, but MIMO also enables transmission of parallel data streams for greater throughput. For example, in a 2 x 2 MIMO (two transmit and two receive elements), dual polarization point-to-point system, the carrier's allocated frequency can be used twice, effectively doubling the throughput data rate.

In point-to-multipoint systems employing MIMO, each base station antenna transmits a different data stream and each subscriber terminal receives various components of the transmitted signals with each of its subscriber antennas as illustrated in the figure below. By using appropriate algorithms, the subscriber terminal is able to separate and decode the parallel simultaneously received data streams. The mobile WiMAX standard covers a suite of MIMO encoding techniques for up to four antennas at each end of the link, (4 x 4 MIMO).

n x n MIMO Antenna System



Where: $r_n(t)=h_{n1}x_1(t)+h_{n2}x_2(t)+ \ldots +h_{nn}x_n(t)$

Figure 7: MIMO Antenna System

Space-Time Coding

Space-time coding (STC) is a family of techniques for implementing transmission diversity. Mobile WiMAX uses transmit diversity in the downlink direction to provide spatial diversity that enhance the signal quality to a specific subscriber located anywhere within the range of the antenna beam. Although providing less signal gain than beam-forming, transmit diversity is more robust for mobile users since it does not require prior knowledge of the path characteristics of a subscriber's particular frequency channel. One such STC technique, known as the Alamouti Code, was published in 1998[4] and has been incorporated in the WiMAX standard.

Beam-Forming

The transmission of signals from several antennas at specific relative phases can be used to create a much narrower antenna beam giving rise to the name 'beam-forming'. Beam-forming provides substantial improvement in the link budget in both the downlink and uplink directions by increasing the effective antenna gain in addition to reducing fade margin requirements due to interference. Beam-forming does require knowledge of a subscriber's location making it more challenging to implement for subscribers moving at high speeds. According to cellular network statistics however, the majority of subscribers are either stationary or only moving at pedestrian speeds thus enabling beam-forming to provide significant benefits for most usage models.

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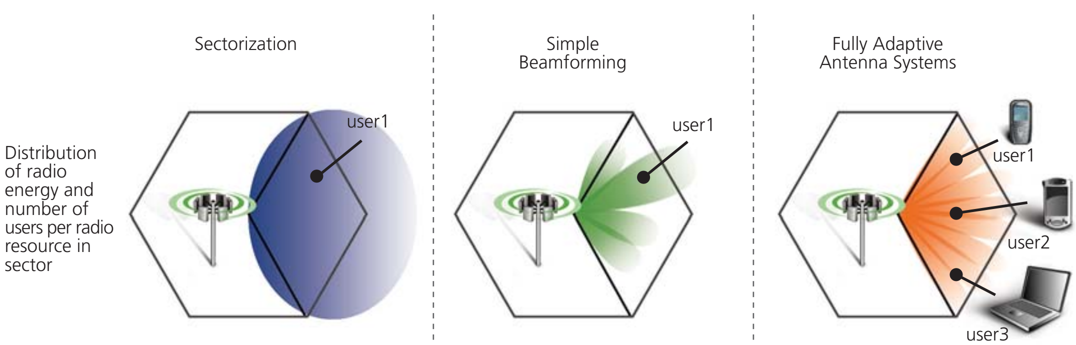

Figure 8: Beam Forming

A 4-antenna beam-forming configuration for example, can provide a 6 dB signal enhancement while significantly improving the transmission fade margin. As a result, beam-forming delivers more range, higher throughput, and improved indoor coverage. With the potential for fewer base stations to achieve a specific system-wide capacity, beam-forming can provide a savings of as much as 50% on capital expenses (CAPEX) and 30% on operating expenses (OPEX). Beam-forming is the third 'smart antenna' technology that has been incorporated in the WiMAX specification to improve system capacity and performance in broadband mobile networks.

[4] S. M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications", IEEE J-SAC, vol. 16, pp 1451-1458, October 1998.

Deployment and Frequency Reuse

To maximize coverage and frequency reuse while minimizing interference, terrestrial wireless systems cover the service area with multiple cells, which are further subdivided into multiple sectors. Since some subscribers may be located at the boundaries between cells or sectors and potentially receive signals from multiple sources – thus creating interference – each sector is typically assigned a different frequency channel. Then, in accordance with an overall radio plan for the area, each channel is reused with a spatial separation in order to maximize the use of the limited spectrum while minimizing self-interference from the same channel being reused elsewhere in the network. This is commonly referred to as co-channel interference (CCI).

The 'reuse factor', a measure of how aggressively a given frequency is reused, is expressed as a fraction of the sectors or cells operating with the same frequency channel. Typical reuse factors for traditional cellular systems are 3 or 7 – resulting in the need for 3 or 7 different frequency channels to implement a specific multi-cellular radio plan.

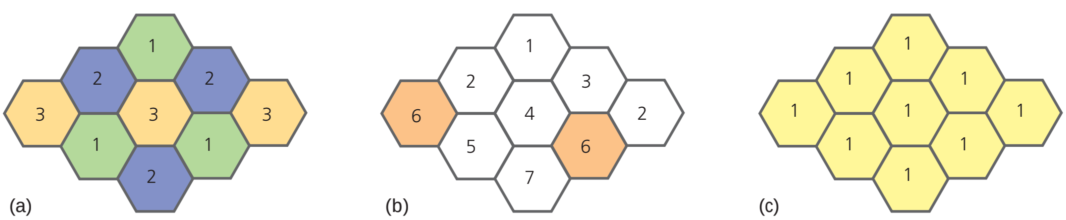

Figure 9: Frequency reuse patterns:
(a) 3 frequencies (Digital systems)
(b) 7 frequencies (Analog FDMA)
(c) OFDMA and CDMA

An alternative approach, used in both CDMA and OFDMA, is to use all available frequency channels within each sector and to use robust modulation schemes, such as OFDMA or CDMA, to deal with the high levels of interference from adjacent sectors or cells. This is referred to as having a reuse factor of 1 – sometimes called 'reuse-1' or 'universal frequency reuse' – and is very popular with today's carriers since it eliminates the need for detailed network radio planning. To support universal frequency reuse, these modulation schemes handle interference through the use of strong error correction codes such as convolutional turbo codes (CTC) and by using a subset of the available bandwidth through the use of access codes, in the case of CDMA, and subcarriers, in the case of OFDMA. The mobile WiMAX standard also provides the ability to orthogonally split resources within a cell while randomizing subcarrier allocations between cells. The orthogonal split within the cell assures that there is little or no interference between adjacent sectors, while the randomization of subcarrier allocations between cells assures that there is little overlap between subcarriers used for specific subscribers in adjacent cells. This mitigates the potential for cell-to-cell interference and enables the air link to operate at higher modulation efficiency, resulting in higher data throughput.

Quality of Service Support

Support for quality of service (QoS) is essential for broadband wireless systems with channels designed to simultaneously carry a combination of voice, video, and data services. QoS algorithms are required to ensure that the shared use of the channel does not result in service degradation or failure. Examples include jerky or abrupt video streams, latency levels in a voice call that interfere with natural conversation or the download of an Internet page that is unacceptably delayed or freezes. Despite the fact that subscribers are sharing the broadband link with others, they expect an acceptable level of performance from the service provider under all conditions.

The mobile WiMAX standard provides a suite of tools to support QoS for multiple applications. The WiMAX base station allocates all uplink and downlink airtime resources using a traffic scheduling procedure that reflects traffic demand and the subscription parameters of individual subscribers. Comprehensive algorithms are then employed to ensure that the application-specific QoS parameters are met. The following table provides a summary of the QoS categories, applications and QoS parameters to be controlled as delineated in the 802.16e-2005 standard.

QoS Category	Applications	QoS Parameters
UGS Unsolicited Grant Service	VoIP	• Maximum Sustained Rate • Maximum Latency Tolerance • Jitter Tolerance
rtPS Real-Time Polling Service	Streaming Audio or Video	• Minimum Reserved Rate • Maximum Sustained Rate • Maximum Latency Tolerance • Traffic Priority
ErtPS Extended Real-Time Polling Service	Voice with Activity Detection (VoIP)	• Minimum Reserved Rate • Maximum Sustained Rate • Maximum Latency Tolerance • Jitter Tolerance • Traffic Priority
nrtPS Non-Real-Time Polling Service	File Transfer Protocol (FTP)	• Minimum Reserved Rate • Maximum Sustained Rate • Traffic Priority
BE Best-Effort Service	Data Transfer, Web Browsing, etc.	• Maximum Sustained Rate • Traffic Priority

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Radio Resource Management

Advanced radio resource algorithms in broadband wireless systems enable service providers to maximize subscriber throughput and overall coverage while maintaining QoS. Techniques to optimize the use of available radio resources include power control, rate adaptation, automatic repeat requests, channel quality indication, scheduling, and admission control. WiMAX with its' OFDMA-based structure provides a means to balance the effects of these techniques to provide an optimal tradeoff between throughput and link quality.

Radio Resource management algorithms optimize the performance over the available radio resources.

Power Control

Adaptive power control is an important function for ensuring link quality. In the upstream direction, adaptive transmit power control is used to maximize the usable modulation level, which achieves the highest throughput, while at the same time controlling interference to adjacent cells. In the downstream direction, different power allocations for specific subchannels can be used to provide better service to subscribers at the edge of the cell while providing sufficient signal levels to subscribers in closer proximity to the base station.

Rate Adaptation

In any terrestrial multi-cellular network, mobile subscribers will experience transmission path conditions that vary with relative location and time. With OFDMA the specific modulation and coding scheme can be adapted on a per subscriber basis dependent on path conditions to maximize channel throughput while maintaining link quality to each subscriber. With OFDMA systems, the subcarriers are modulated with either the more robust QPSK or the higher order, more efficient QAM modulations – with the more sophisticated modulation schemes having higher throughput but being much more susceptible to interference and noise. This rate adaptation, through adaptive modulation and error coding schemes ensures that the number of bits conveyed by each subcarrier is optimized relative to the CINR required to ensure a reliable air link connection. OFDMA systems can also increase throughput to individual subscribers by increasing the number of allocated subchannels at any given time. Both of these concepts are included in the mobile WiMAX specification.

Hybrid Automatic Repeat Request

Automatic repeat request (ARQ) algorithms are well known in wireless, and wireline, networks for retransmitting failed transmissions. The effective use of ARQ however, requires precise selection of both transmit power and data rate for the retransmissions, otherwise the link becomes underutilized or experiences excessive packet errors. Since it is challenging to maintain these optimal settings in the time-varying environment of mobile broadband services, a significantly more robust mechanism called Hybrid-ARQ (H-ARQ) was developed. With H-ARQ, which is part of the mobile WiMAX specification, the receiver combines the information from a faulty packet with the re-transmissions of the same packet until enough information is gathered to retrieve the packet in its entirety.

Channel Quality Indication

Timely channel quality indication (CQI) messages at the receiver are essential for adaptive power and rate control and H-ARQ to be effective. The support of high mobility services requires that fast corrective actions be taken at the transmitter to ensure the link is operating optimally at all times. Mobile WiMAX specifies a compact size (4-6 bits each) CQI messages, resulting in lower delay and greater reliability than regular control messages. This ensures that the CQI messages provide fast and reliable feedback of path conditions to the base station while maintaining low overhead.

Scheduling Control

Scheduling control is a mechanism, located in the base station, for managing upstream and downstream packet allocations based on traffic requirements and channel conditions at any given moment. The scheduler allocates radio resources in frequency and time, based on considerations such as; QoS parameters for the specific traffic-type, individual subscriber service level agreements (SLA), and connection-by-connection path conditions. Since data-oriented traffic can vary considerably between uplink and downlink, asymmetric capacity allocation is also supported in time division duplex (TDD) implementations with appropriate radio resources and packet assignments done on a per-sector basis for a variable duration based on actual demand. These basic scheduling control mechanisms are part of the mobile WiMAX standard.

Admission Control

Admission control is the process of determining whether or not to allow a new connection to be established based on: current traffic conditions, available resources, and cumulative QoS requirements. Excessive traffic in a cell increases the amount of interference to adjacent cells thus reducing cell coverage. Admission control is used to accept or reject the connection requests so as to maintain the cell load within acceptable limits. The admission control function is located in either the WiMAX base station or the access service network (ASN) gateway where the load information for several base stations can be monitored.

Mobility Management

Power conservation in mobile handheld devices and the ability to support seamless handoffs are essential requirements for supporting mobile applications. For ease in portability and subscriber convenience, mobile subscriber terminals must be small and light thus limiting battery size. At the same time subscribers demand long battery life.

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Improved Power Consumption

The mobile WiMAX standard incorporates mechanisms that enable subscriber terminals to be active only at certain times as negotiated with the base station. When no data is to be transmitted or received, the subscriber terminal can move to ‘sleep’ or ‘idle’ modes to minimize power consumption. The base station scheduler is kept aware of every sleep or idle subscriber terminal and has the ability to switch the terminal to transmit or receive mode whenever required. In the subscriber terminal transmit mode the use of subchannels ensures that the transmit power is no greater than what is necessary to maintain sufficient link quality consistent with the traffic being transmitted, thus further reducing power consumption in the subscriber terminal.

Handoff Support

Using mobile subscriber terminals in terrestrial cellular networks require that some form of handoff mechanism be employed at the physical layer, and that other mobility management issues be addressed.

The mobile WiMAX standard supports three physical-layer handoff mechanisms:

- Hard Handoff – this is a 'break before make' handoff in which the subscriber terminal is disconnected from one base station before connecting to the next base station.
- Fast base station switching (FBSS) – the network hands-off the subscriber between base stations while the connection with the core network remains with the original base station,
- Macro-diversity handover (MDHO) – the subscriber maintains a simultaneous connection with two or more base stations for a seamless handoff to the base station with the highest quality connection.

Hard Handoff is the most bandwidth-efficient and is mandated by WiMAX Forum profiles, while FBSS and MDHO are optional handoff modes.

In addition to physical-layer handoffs, the overall end-to-end network infrastructure must support the processes of inter-network and inter-vendor handover to ensure the continuity of the ongoing session, security and authentication, QoS provisioning, and billing. The WiMAX Forum's networking working group (NWG) has defined the end-to-end network as an all IP network to make handoff and service continuity easy to implement and use.

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Alvarion and Mobile WiMAX

Alvarion has been a pioneer and major contributor in the creation and development of broadband wireless technologies for around 15 years. Additionally, Alvarion has made significant contributions to the IEEE 802.11, 802.11a, 802.16, and HiperMAN standards. In 1992, Alvarion was one of the founding companies in the IEEE 802.11 standards committee which is the basis for the Wi-Fi industry. Similarly, Alvarion was a founding member of the WiMAX Forum and the first company to have commercially available WiMAX solutions based on the 802.16-2004 standard. As a result, Alvarion engineers have consistently led the industry in the development of various radio technologies and innovations that have played a major role in the evolution of the wireless solutions discussed in this document.

Alvarion was a founding member of the WiMAX Forum and the first company to have commercially available WiMAX solutions based on the 802.16-2004 standard.

Continuing its longstanding involvement and commitment to standards' compliance and their respective organizations, Alvarion, as a proactive member of the WiMAX Forum, has been instrumental in driving WiMAX to its current place of global prominence. Since 2002, company representatives have served in two board positions of the Forum, and a member of Alvarion's CTO team is currently co-chairing the Forum's working group for developing performance profiles for IEEE 802.16e-2005. In addition, Alvarion chairs the ETSI BRAN HiperMAN Alliance and serves on the board of the Wireless Communication Association (WCA).

With the core technologies of OFDM, OFDMA, and S-OFDMA implemented across various products, customers can benefit from a full range of Alvarion products capable of operating in NLOS conditions with broadband throughput and wide coverage range. With the introduction of Alvarion's 4Motion™ WiMAX product incorporating adaptive beam-forming and MIMO technologies, customers enjoy further enhancements in spectral efficiency and peak throughput.

The radio resource management algorithms implemented in Alvarion's mobile WiMAX 4Motion solution addresses all layers of the wireless access network (PHY, MAC, power control, and networking), ensuring that all radio resources are optimized to deliver broadband services with maximum efficiency. Alvarion's 4Motion radio resource management goes beyond the basic scheduling control mechanisms in the mobile WiMAX standard taking advantage of many additional parameters to achieve the optimal balance of throughput and robustness to each and every subscriber. Alvarion's advanced schedulers control both downstream and upstream transmissions, with the upstream scheduler located at the base station for rapid response in providing transmission grants to active subscribers. Grants range from basic round-robin scheduling to the use of dynamic channel information for performance optimization on a connection-by-connection basis. The advanced scheduling function enables frame-by-frame capacity allocations to support a diverse set of subscribers, thus assuring that available radio resources are assigned in accordance with committed customer-by-customer service level agreements.

As a leader in mobile WiMAX, the Alvarion 4Motion solution implements the best of breed in all mobile WiMAX elements allowing service providers to easily and economically deploy mobile WiMAX systems and build a profitable next-generation service portfolio. With Alvarion expertise and leadership, mobile WiMAX will meet the new challenges of personal broadband services.

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