



Understanding WiMAX and 3G for Portable/Mobile Broadband Wireless

Technical White Paper

*A Technical Overview and Comparison of
WiMAX and 3G Technologies*

December 2004



Abstract

New and increasingly advanced data services are driving up wireless traffic, which is being further boosted by growth in voice applications in advanced market segments as the migration from fixed to mobile voice continues. Meanwhile, difficult market conditions have caused a number of operators to delay making substantial investments in upgrading their networks to higher capacity technology. In today's commercially challenging climate, all capital investments must be well justified. This is already putting pressure on some networks and may be leading to difficulties in maintaining acceptable levels of service to subscribers. This white paper focuses on the major technical comparisons between WiMAX/OFDMA (IEEE 802.16e) and 3G/WCDMA/HSDPA for mobile/portable broadband data services; this paper also describes where each technology best serves operators' needs for networks capable of delivering high speed portable and mobile data services in a cost efficient manner.

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Executive Summary

Attenuation

Since WiMAX* is slated to operate in the 2.5, 3.5, or 5.8 GHz bands, it may require more cells than 3G (which typically has frequencies < 2 GHz) due to the higher frequencies. The main impact will be to operators planning to deploy in the unlicensed 5.8 GHz spectrum. However, the costs associated with the licensed spectrum for 3G and 2.5/3.5 GHz spectrum may offset the cost for additional cell sites, so this cost impact must be considered as well.

Multipath

OFDM/OFDMA performs much better than CDMA* in a multipath environment since it is better at overcoming Inter Symbol Interference (ISI), which happens when reflected signals overlap with the transmitted signal.

Frequency Selective Fading

OFDMA is more resistant to frequency selective fading since its parallel nature allows errors in sub-carriers to be corrected.

Frequency Offset and Phase Noise

OFDMA is more sensitive to frequency offset and phase noise which results in Inter Carrier Interference (ICI), although this is somewhat mitigated by the use of guard bands.

Impulse Noise Rejection

Since OFDMA symbols are longer in duration than CDMA symbols, an impulse noise may not cause an increase in the error rate. For CDMA, a few CDMA symbols may be lost, and that could lead to an increase in the coded Bit Error Rate (BER).

Adaptive Modulation and Coding (AMC)

OFDMA better utilizes AMC, so it achieves higher throughput (9.6 Mbps) when compared to WCDMA (3 Mbps). This test was performed using textbook OFDM and only up to 16 QAM (IEEE 802.16e supports 64 QAM). In addition, OFDMA may be able to utilize higher order modulation (higher data rates) at greater ranges.

AMC and OFDMA

OFDMA may be able to further improve its advantage over CDMA by applying AMC at the sub-channel level. This is known as Space Division Multiple Access (SDMA) and could allow the optimization of sub-channel selection based on geographical location.

Frequency Reuse

CDMA employs interference averaging, which allows it to maintain a frequency re-use of 1. OFDMA typically needs a frequency reuse of 1 to 3, which means the achievable throughput per cell for a specific bandwidth must be divided by 3. Advanced Antenna Systems (AAS) may allow OFDMA to overcome this limitation, although AAS may be expensive.

Code Limitation

Due to the limitations of code availability and client complexity, most HSDPA clients will be limited to 5 of the maximum 15 codes. Furthermore, since each user will need at least one code for voice or data, this could have a significant impact on the number of users supported by each system, especially when compared to the high number of sub-carriers employable by OFDMA.

Quality of Service

WiMAX has a data oriented MAC compared to the essentially circuit-switched MACs of HSDPA and WCDMA. WiMAX can also take advantage of multiple duplexing modes, including TDD dynamic asymmetry; this allows the uplink/downlink bandwidth to be allocated according to current traffic conditions.

Voice

CDMA systems are much better suited to handle mobile voice calls because they support multiple voice coding schemes, seamless handoffs and roaming.

Equipment Cost

OFDMA-based systems may be easier to implement since they don't require the higher complexity of a RAKE receiver needed in CDMA. It may also be simpler to implement equalization, interference cancellation and adaptive antenna array algorithms with OFDMA, where the algorithms are done in the frequency domain.

Standards Based

WiMAX (OFDMA) is based on IEEE 802.16e, an upcoming industry standard, allowing it to avoid the costly proprietary interfaces found in 3G networks. This also allows it to take advantage of other standardized technologies, including work being done in the proposed 802.21 IEEE Handoff Group.

Advanced Radio Techniques

WiMAX (OFDMA) may be able to better take advantage of diversity techniques (Space Time Coding, Maximum Ratio Combining), MIMO and smart antenna technology.

Introduction

Although the broadband data market segment has been rather anemic for the past couple decades, declining average revenue per user has caused carriers to look at wireless broadband data as a means to drive revenue growth. While growth of low-bandwidth applications such as downloading ring tones and SMS are experiencing sharp growth, the growth of broadband data applications such as email and downloading/uploading files with a laptop computer or PDA has been slow. Primary inhibitors of portable broadband services have included service price, slow data speed and spotty coverage.

Early Wide Area Network Technologies (WAN) such as General Packet Radio Service (GPRS) offered average throughput speeds of 10 Kbps, which was far too slow for user satisfaction. In 2003, carriers began deploying services such as Enhanced Data rates for Global Evolution (EDGE), which delivers average speeds of 100-130 Kbps and bursty traffic up to 200 Kbps. Code Division Multiple Access (CDMA) technologies such as 1xEvDO provide average speeds of ~300-400 Kbps with bursts up to 700 Kbps; EVDV boosts these speeds even higher.^[5]

Recent research from In-Stat/MDR* (4/04)^[5] indicates that laptop computers are becoming the access devices of choice for broadband wireless data. Personal productivity applications such as email, address books, calendars, and internet browsers, are among the top applications used.

While many service providers and operators may be somewhat familiar with the previously mentioned 2.5G services, they are now hearing about newer 3G technologies such as UMTS and HSDPA, and other technologies such as WiMAX (IEEE 802.16e), which offer substantial improvements in data rate and spectral efficiency. This paper focuses on the technical differences between these technologies by comparing the differences between the modulation techniques used in CDMA and OFDMA.

Technology Overview

WCDMA

Wideband Code Division Multiple Access uses Direct Sequence Spread Spectrum (DSSS) to spread the signal over a 5 MHz spectrum. It is based on 3GPP Release 99 and provides data rates of 384 Kbps for wide area coverage and up to 2 Mbps for hot-spot areas. In addition to the use of orthogonal spreading codes, it uses Quadrature Phase Shift Keying (QPSK) for its modulation.

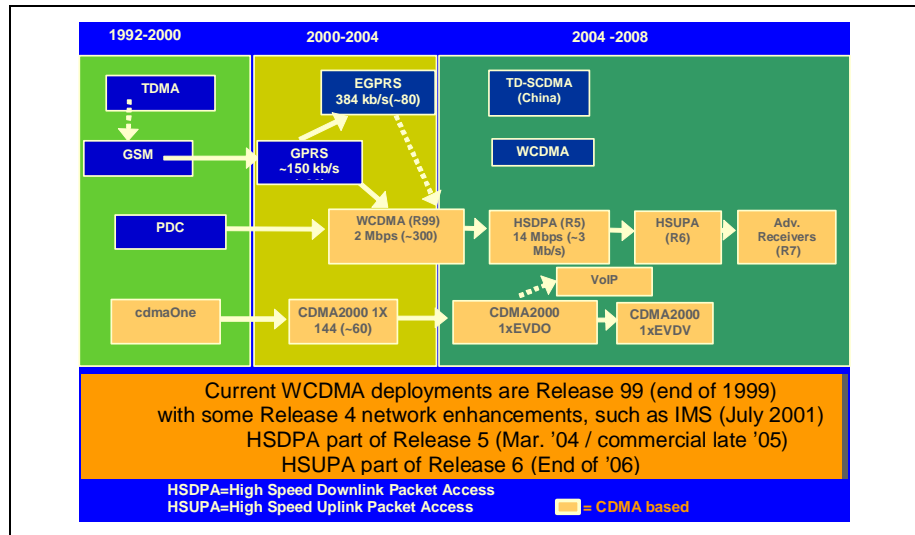
High Speed Downlink Packet Access (HSDPA) Overview

WCDMA 3GPP Release 5 extends the WCDMA specification with High Speed Downlink Packet Access (HSDPA). HSDPA adds a new transport channel, the high-speed downlink shared channel (HS-DSCH), which is optimized for shared data. It also provides higher-order modulation (Quadrature Amplitude Modulation or QAM), short transmission time interval (TTI), fast link adaptation, fast scheduling, and fast hybrid automatic-repeat-request (ARQ).

WiMAX (IEEE 802.16e)

The portable version of WiMAX, IEEE 802.16e utilizes Orthogonal Frequency Division Multiplexing Access (OFDM/OFDMA) where the spectrum is divided into many sub-carriers. Each sub-carrier then uses QPSK or QAM for modulation. For more on the basics of OFDM, refer to [Orthogonal Frequency Division Multiplexing](#).

Figure 1. Cellular Network Evolution



Overview of the Wireless Environment

While all of the previously mentioned technologies enhance spectral efficiency, they each have some inherent strengths and weaknesses due to the unpredictability of the wireless environment. The wireless environment provides significant challenges including attenuation, multipath interference and cell planning. It is also important to consider the client complexity (and costs associated) and cell deployment scenarios. The following sections compare the impact of the wireless environment on CDMA-based technologies and OFDMA-based technologies.

Attenuation

Attenuation, which is the reduction in the strength of the received signal, is caused by a number of factors, including transmission path length, obstructions in the path of the signal, and multipath effects. Even as the RF signal passes through the air, some of the energy is absorbed, which causes attenuation. Although RF can penetrate obstructions like walls (unlike light waves), this will result in attenuation of the signal, since some of the energy will be absorbed. This is also known as shadowing, which can be extremely severe in metropolitan areas due to buildings, hills, trees, etc. Some of the signal can be diffracted in this case, so that the signal “bends” around corners. As seen in Figure 2, as the distance increases, attenuation is increased significantly.

Figure 2. Free Space Path Attenuation^[1]

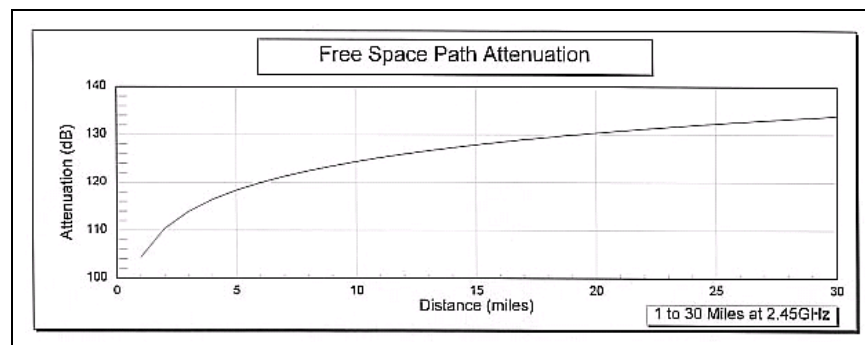


Table 1 shows the impact different types of environment can have on the relative strength of the signal.

Table 1. Attenuation in the Wireless Environment

| Description | Typical Attenuation Due to Shadowing |
|--|--|
| Heavily built-up urban center | 20 dB variation from street to street |
| Suburban area (fewer large buildings) center | 10 dB greater signal power than built-up urban |
| Open rural area | 20 dB greater signal power than suburban areas |
| Terrain irregularities and tree foliage | 3-12 dB signal power variation |

Source: <http://www.skydsp.com/publications/4thyrthesis/index.htm>

WiMAX Frequency Attenuation Impact on Coverage

It is also important to consider the operating frequency of your network. Higher frequency transmissions do not travel as far due to higher attenuation. In tests^[1] comparing the ISM (2.4 GHz) and UNII bands (5.8 GHz) (see Figure 3 and Table 2), the difference in free space path loss at 10 m is theoretically around 7 dB in favor of the ISM band, although tests reveal results closer to 4 dB. The difference goes up to 10 dB for non line of sight (NLOS) paths. Since WiMAX is slated to operate in the 2.5, 3.5, or 5.8 GHz bands it may require more cells than 3G (which typically has frequencies < 2 GHz) due to the higher frequencies. The main impact will be to operators planning to deploy in the unlicensed 5.8 GHz spectrum. However, the costs associated with licensed spectrum for 3G and 2.5/3.5 GHz spectrum may offset the cost for additional cell sites.

Figure 3. Best Fit NLOS Path Gain for ISM and UNII Average UNII as a Function of Distance^[1]

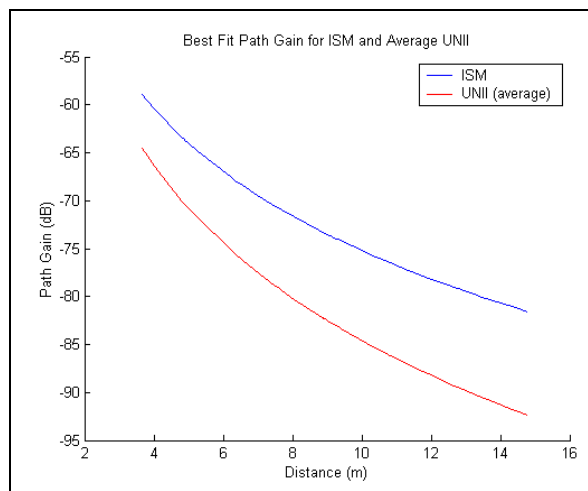


Table 2. Summary of Path Loss and Path Loss Exponents

Path Loss in dB^[1]

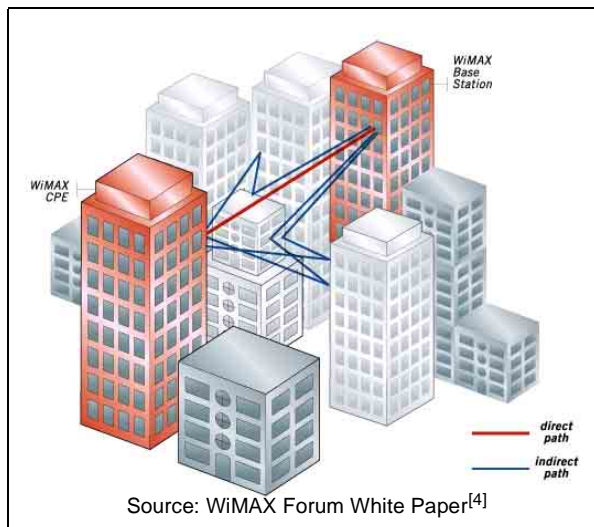
| | ISM | UNII Mean | ISM – UNII |
|-------------------------|------|-----------|------------|
| Free space (3m, ideal) | 49.8 | 56.7 | -6.9 |
| LOS (3m, measured) | 55.1 | 59.0 | -3.9 |
| NLOS (3m, measured) | 55.7 | 60.6 | -4.9 |
| Free space (10m, ideal) | 60.2 | 67.1 | -6.9 |
| LOS (10m, measured) | 65.1 | 68.9 | -3.8 |
| NLOS (10m, measured) | 75.2 | 84.6 | -9.4 |
| Wall | 10.7 | 14.9 | -4.2 |
| Floor | 5.5 | 7.0 | -1.5 |
| Water | 3.8 | 14.2 | -10.4 |
| LOS Path Loss Exponent | 1.9 | 1.9 | |
| NLOS Path Loss Exponent | 3.7 | 4.6 | |

Multipath Interference

Multipath interference occurs when multiple reflected signals arrive at the wireless receiver. These signals may have been reflected off buildings, walls, trees, hills or other solid object. When the mobile user is indoors, there is no line of sight signal at all. Since each of the signals is reflected from different objects, each has traveled a different distance, causing some signals to arrive earlier than others. This results in each signal arriving at random phase offsets of one another. The

signals then experience fading through destructive (and constructive) interference when the signals become superimposed on one another. This interference is often referred to as Inter Symbol Interference (ISI). The amount of fading depends on the delay spread of the signal as well as the power level of each signal (some multipath signals may have weaker signals due to attenuation, possibly caused by an object like a tree).

Figure 4. Multipath Environment



Technologies using DSSS (802.11b, CDMA) and other wide band technologies are very susceptible to multipath fading, since the delay time can easily exceed the symbol duration, which causes the symbols to completely overlap (ISI).

The use of several parallel sub-carriers for OFDMA enables much longer symbol duration, which makes the signal more robust to multipath time dispersion.

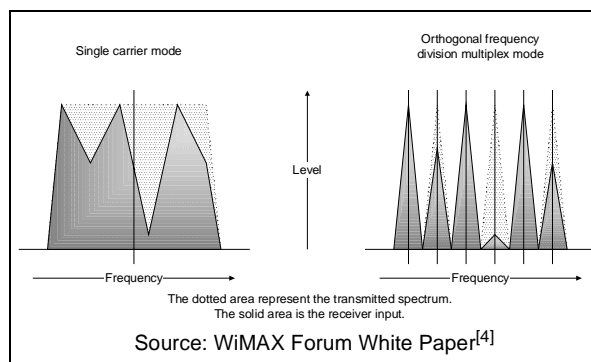
If for example we wanted to send 1000 bits/second, we could do this serially where each bit would take $1/1000^{\text{th}}$ of a second. Any delays longer than $1/1000^{\text{th}}$ second would overlap the next bit. By sending 1000 bits in 1000 parallel streams, each bit would take 1 second to transmit and a $1/1000^{\text{th}}$ second delay would only overlap by $1/1000^{\text{th}}$ of the transmission interval for any given bit, basically eliminating any interference. By adding a small guard time, the ISI can effectively be mitigated.

Multipath: Frequency Selective Fading

This type of fading affects certain frequencies of a transmission and can result in deep fading at certain frequencies. One reason this occurs is because of the wide band nature of the signals. When a signal is reflected off a surface, different frequencies will reflect in different ways. In Figure 5 below, both CDMA (left)

and OFDMA (right) experience selective fading near the center of the band. With optimal channel coding and interleaving, these errors can be corrected (the coded Bit Error Rate (BER) does not increase at all). CDMA tries to overcome this by spreading the signal out and then equalizing the whole signal (the coded BER increases proportionally to the increase in the raw BER). OFDMA is therefore much more resilient to frequency selective fading when compared to CDMA.

Figure 5. Frequency Selective Fading: CDMA vs. OFDMA



Frequency Offset and Phase Noise

In a mobile environment, the receiver will likely be moving relative to the source. When moving toward each other, the frequency is higher than the source, and when moving away from each other the frequency is lower. This is known as Doppler shift and can affect transmissions that are sensitive to carrier frequency offsets like OFDMA.

So while CDMA is more susceptible to Inter Symbol Interference, OFDMA has to deal with frequency offset. This results in the sub-carriers no longer being orthogonal, and is known as Inter Carrier Interference (ICI). However, this can be mitigated by adding guard bands between frequencies. These guard bands allow OFDMA to dynamically calibrate to the proper frequency, although some bandwidth is sacrificed.

Impulse Noise Rejection

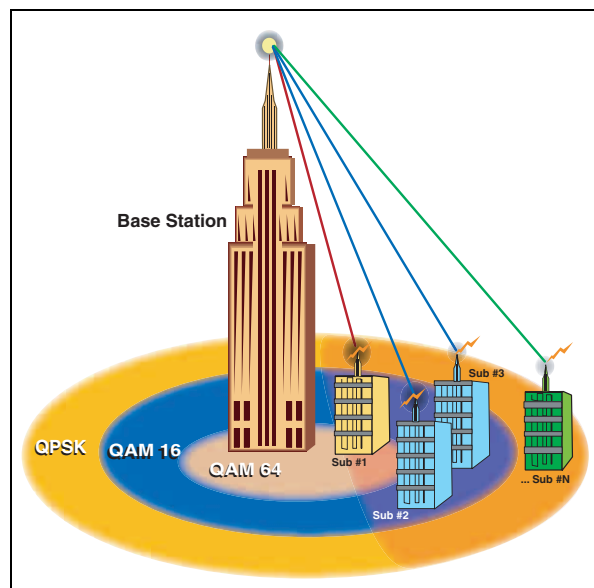
OFDMA spreads the energy of an impulse noise over a WiMAX-OFDMA burst. This means that instead of a few symbols being lost, the noise level slightly increases over a burst, which may not cause an increase in the error-rate.

On the other hand, CDMA absorbs the energy of an impulse noise over a few CDMA symbols that will be lost. For low data rates, coding and interleaving will correct the errors, but for high data rates this can translate into an increase in the coded BER.

Adaptive Modulation and Coding (AMC)

Both W-CDMA (HSDPA) and OFDM utilize Quadrature Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM). It should be noted here that for WCDMA, AMC is only used on the downlink (HSDPA), since the uplink still relies on WCDMA 3GPP release 99, which uses QPSK but not QAM. Modulation and coding rates can be changed to achieve higher throughput, but higher order modulation will require better channel conditions (i.e., Signal to Noise Ratio). [Figure 6](#) below illustrates how higher order modulations like QAM 64 are used closer to the base station, while lower order modulations like QPSK are used to extend the range of the base station. To find out more about Adaptive Modulation, refer to: [Adaptive Modulation \(QPSK, QAM\)](#).

Figure 6. Adaptive Modulation and Coding



Performance results conducted for one of the 3GPP Working Groups^[2], show that while OFDM is able to achieve the maximum throughput of 9.6 Mbps (16QAM), WCDMA (HSDPA) does not exceed 3 Mbps. From these results, it appears that even higher discrepancy may be found when utilizing higher modulation and code rates to yield even higher throughput for OFDM.

[Table 3](#) shows some system-level performance results comparing OFDM and WCDMA (HSDPA). Even with more advanced receivers (MMSE), OFDM is found to perform better in this environment. *Furthermore, these results were found using textbook OFDM up to 16QAM. Using more advanced OFDM and modulation techniques (like those included in 802.16e), the gap would likely widen. WiMAX (802.16e) in fact supports a higher order modulation of 64QAM (optional 256QAM).*

It is important to note that while both of these technologies offer higher throughput, it appears that OFDM may provide a greater range of higher throughput when compared to HSDPA (where the highest speeds – 16QAM – may only be provided within hot spot size coverage). It should also again be noted that while AMC can be utilized in both the downlink and uplink for WiMAX, AMC has only been defined for the downlink portion of WCDMA (HSDPA).

Table 3. System-level Performance Results for FTP Traffic in Ped B with Maximum Throughput Scheduling^[3]

| Technology | Users Per Sector | Average OTA Throughput (Mbps) | Ave. Packet Call Throughput (kbps) | Average Residual BLER | Average Packet Delay (s) |
|--------------|------------------|-------------------------------|------------------------------------|-----------------------|--------------------------|
| OFDM | 40 | 4.45 | 1802 | 0.002 | 2.33 |
| WCDMA (MMSE) | 40 | 3.83 | 1170 | 0.002 | 3.56 |
| WCDMA (Rake) | 40 | 3.03 | 490 | 0.000 | 8.54 |

Coding: Forward Error Correction (FEC)

Error control coding allows the system to recover from bit errors. The coding rate directly affects bandwidth and can be dynamically changed depending on the channel conditions.

A CDMA system uses convolutional codes with $k=9$ in order to increase the multipath immunity, while OFDMA uses convolutional codes with $k=8$. However, OFDMA can utilize coding and interleaving across sub-carriers, where the strong sub-carriers can help the weak ones (see "Multipath: Frequency Selective Fading" on page 7).

OFDMA

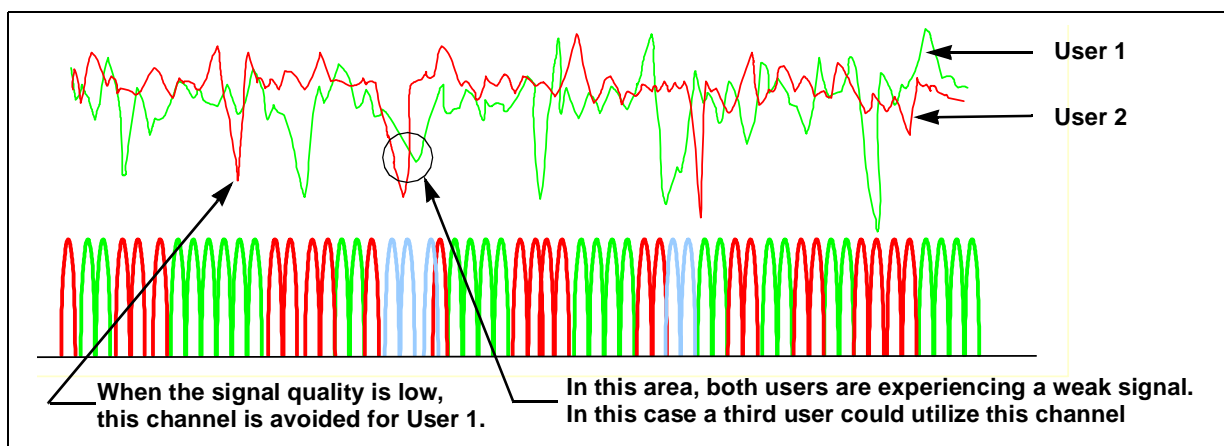
Adaptive Modulation and Coding (AMC) in a multipath environment may give OFDMA further advantages since the flexibility to change the modulation for specific sub-channels allows you to optimize at the frequency level. Another alternative would be to assign those sub-

channels to a different user who may have better channel conditions for that particular sub-channel. This could allow users to concentrate transmit power on specific sub-channels, resulting in improvements to the uplink budget and providing greater range. This technique is known as Space Division Multiple Access (SDMA).

In Figure 7, you can see how sub-channels could be chosen depending on the received signal strength. The sub-channels on which the user is experiencing significant fading are avoided and power is concentrated on channels with better channel conditions. The signals on the top indicate the received signal strength, while the bottom part of the figure indicates which sub-carriers are then chosen for each signal.

With OFDMA, the client device could choose sub-channels based on geographical locations with the potential of eliminating the impact of deep fades. CDMA-based technologies utilize the same frequency band regardless of where the user is.

Figure 7. AMC for OFDMA Sub-Channels



Spectral Efficiency and Frequency Re-Use

Spectral Efficiency is important to an operator due to the limited spectrum available and the cost of a spectrum license. It is also important to consider frequency re-use in order to understand deployment of multiple cells.

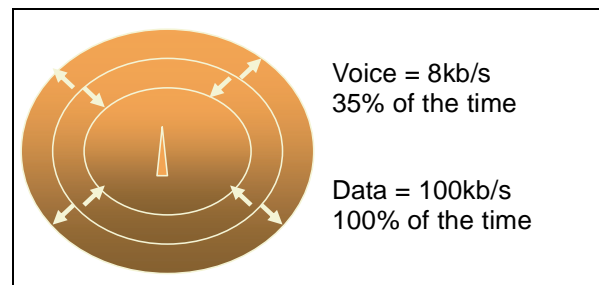
OFDMA typically needs a frequency reuse of 1 to 3; this means that the available spectrum must be split into a 3 cell formation. For example, if a carrier has 5 MHz of available spectrum, they need to divide it into 3 channels of 1.75 MHz each, so that adjacent cells utilize different frequencies to avoid interference. For WiMAX, this results in a maximum of ~6 Mb/s per cell compared to 14.4 Mb/s achievable by HSDPA. However, although the max throughput may be lower for WiMAX, it must be remembered that the 14.4 Mb/s achievable by HSDPA would be very limited in coverage. WiMAX also supports larger channel sizes of up to 20 MHz.

To overcome this limitation, OFDMA systems can maintain a frequency reuse of near 1 if there are location sensitive transmissions near the edge of the cell that use a subset of the carriers, and/or if using Advanced Antenna Systems (AAS), although AAS may be too expensive.

Cell Breathing

In CDMA systems the coverage of the cell expands and shrinks depending on the number of users. This is known as cell breathing and occurs because with CDMA, users transmit at the same time (and are identified by their unique code). The interference is averaged among the other users so as users are added to the cell, the coverage shrinks, and as users leave the cell, the coverage expands. A user downloading data can significantly reduce the coverage and forcing voice users to “soft” handoff to another cell. Such an increase in handoff rates would require that more cells be added to ensure coverage and eliminate any dead spots. This problem could be worsened with the deployment of HSDPA due to more bursty data and higher data rates. Another possible solution would be to deploy HSDPA on a separate 5 MHz channel.

Figure 8. Cell Breathing



Code Limitation (Cell User Capacity)

HSDPA aggregates up to 15 shared codes for highest capacity. Each user of the HSDPA channel requires a unique code for control access to the data channel. This limitation in code availability could lead to blocked voice calls. Because of this limitation and client complexity, most clients will initially be limited to 5 codes.

Furthermore, since each user will require at least one code or carrier set allocated to him, this can have a great impact on the number of users supported by each system. CDMA systems must also provide one code for each voice call, which implies that in order to support a broadband data pipe, service providers will need to deploy HSDPA on a separate 5 MHz channel.

Quality of Service

Data Oriented MAC

WiMAX has a data-oriented MAC while HSDPA and WCDMA have essentially circuit-switched MACs. HSDPA has added shared channel transmission. HSDPA is an improvement over WCDMA, since it allows time and code division multiplexing, although it can only be used in the downlink transmission.

Duplexing Modes (Asymmetric Links)

CDMA uses Frequency Division Duplexing (FDD) with 5 MHz for HSDPA downlink and 5 MHz for WCDMA uplink. WiMAX/OFDMA supports both FDD and Time Division Duplexing (TDD). The first thing to note here is the higher uplink data rate that will be attainable using WiMAX/OFDMA (at least until HUSPA is deployed). With WCDMA, because of its slower uplink capability, tasks such as sending email with large attachments may significantly degrade performance compared to

what is achievable by WiMAX. Symmetric data services (e.g., peer to peer) and asymmetric data (e.g., FTP) may also see dramatically reduced data efficiency.

Furthermore, WiMAX can utilize an adaptive TDD mode that allows for dynamic asymmetry of the uplink and downlink channels. TDD mode can more efficiently utilize the channel by expanding the downlink channel when uplink traffic is low and vice versa. With WCDMA, when you are not uploading anything, that channel goes unused.

Voice

While WiMAX provides a data-centric network, CDMA systems are designed to support voice and always-on data transmission. Features such as multiple voice coding schemes, user selectable Enhanced Variable Rate CODEC (EVRC), and seamless handoffs and roaming are integrated, which makes CDMA much better suited to handle mobile voice calls.

Base Station Assignment (Soft Handoff)

Because of universal frequency reuse, CDMA mobile stations can more easily communicate to multiple base stations simultaneously. This is actually only necessary in CDMA systems due to the power control algorithms that deal with near/far limitations. HSDPA utilizes code sharing (compared to voice which uses dedicated code channels) so it will be unable to utilize soft handoff.

Equipment Cost

While base stations support all data rates, HSDPA handheld devices are likely to be ALWAYS limited to 5 codes; this limits data rates to 3.6 Mbps. Initial deployments and coverage will probably be QPSK (1.8 Mbps), since 16QAM will not be available across the cell. OFDMA based systems require only the use of a FFT, while CDMA requires the higher complexity of a RAKE receiver. It may also be simpler to implement equalization, interference cancellation and adaptive antenna array algorithms with OFDMA, because the algorithms are done in the frequency domain. There are proposals to perform such operations for CDMA, but it would require transformation from time domain to frequency domain and back, making them more complex than OFDMA.

Other Considerations and Future Developments

Backwards Compatibility

HSDPA has the obvious advantage of being designed to be compatible with already deployed 3G infrastructure. By increasing the capacity and efficiency of the network, both data and voice performance can be improved. However, there is a trade-off here between voice and data. While HSDPA also upgrades voice capacity, data takes up significantly more bandwidth. Service providers will not jeopardize voice quality and capacity (revenue) for the sake of data. This implies that they must strongly consider having a separate data-centric network that is optimized for data rather than voice.

Spectrum Upgrade Path

OFDMA's scalability also makes future upgrades, such as increasing spectrum bandwidth from 5 MHz to 20 MHz easier. Expanding capacity would not affect existing 5 MHz clients.

Standards Based

WiMAX is based on IEEE 802.16, an industry standard. WiMAX networks can be implemented without the costly proprietary interfaces and royalties found in 3G networks (CDMA-based). Standardized technology also may provide easier upgrade paths to future technologies.

IEEE Handoff Group

WiMAX/OFDMA may also be able to take advantage of other IEEE work including the proposed 802.21 Handoff group, which will be able to leverage standardized handoff techniques defined by the IEEE for technologies such as Ethernet and Wi-Fi. The proposed scope of the group is to specify a common handoff framework applicable to 802 standards including wired and wireless (802.3, 802.11, 802.15, and 802.16).

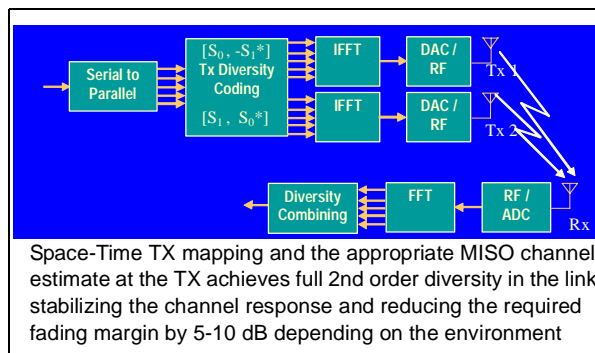
The Handoff Group also proposes to define the requirements and create handoff trigger abstractions for layer 3 and applications to reduce delays caused by PHY/MAC re-associations. This could lead to lower overall handoff latency, which could then enable real time applications.

Advanced Radio Techniques

Transmit and Receive Diversity

Diversity schemes are used to take advantage of multipath and reflected signals that occur in NLOS environments. By utilizing multiple antennas (transmit and/or receive), fading, interference and path loss can be reduced. The OFDMA transmit diversity option uses space time coding. For receive diversity, techniques such as maximum ratio combining (MRC) take advantage of two separate receive paths.

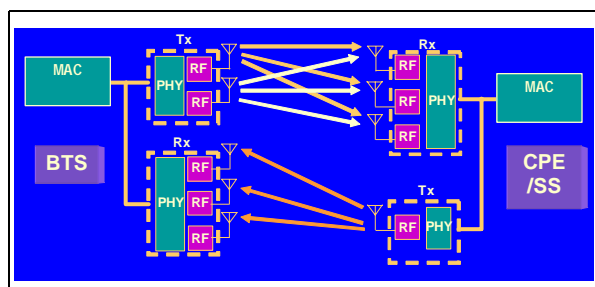
Figure 9. Space Time Coding



Extension to MIMO

The use of Multiple Input Multiple Output (MIMO) will also enhance throughput and increase signal paths. MIMO utilizes multiple receive and/or transmit antennas for spatial multiplexing. Each antenna could transmit different data which could then be decoded at the receiver. For OFDMA, since each of the sub-carriers are parallel narrowband channels, frequency selective fading appears as flat fading to each sub-carrier. This effect can then be modeled as a complex constant gain and may simplify the implementation of a MIMO receiver for OFDMA.

Figure 10. MIMO



Smart Antenna Technology

Adaptive antenna systems (AAS) are an optional part of the 802.16 standard. AAS equipped base stations can create beams that can be steered, focusing the transmit energy to achieve greater range. When receiving, they can focus in the particular direction of the receiver. This helps eliminate unwanted interference from other locations.

Figure 11. Beam Shaping

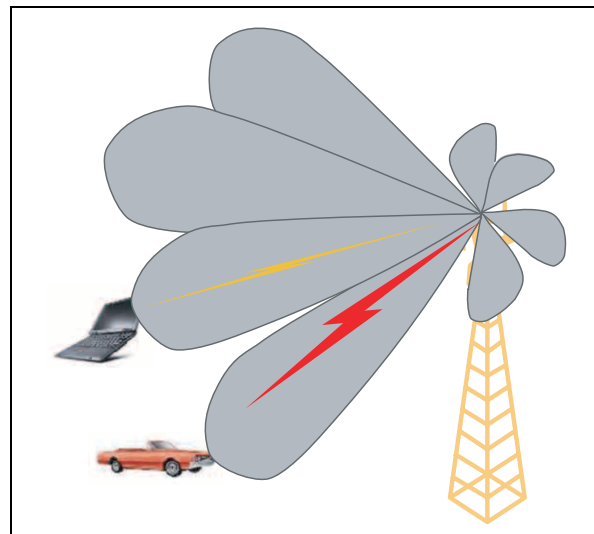
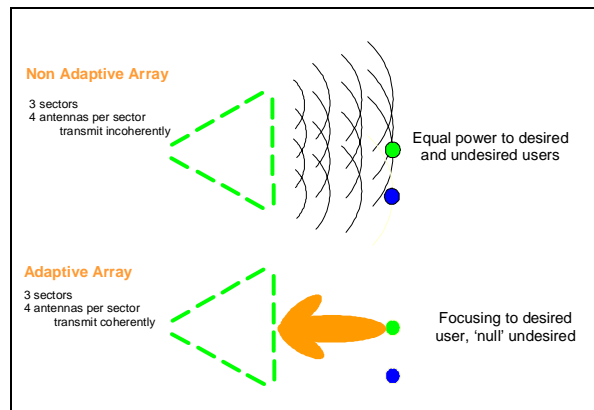


Figure 12. AAS Downlink



Summary and Conclusion

From this comparison of OFDMA and CDMA based technologies, we can conclude that WiMAX systems for portable/nomadic use will have better performance (interference rejection, spectral efficiency, multipath tolerance), high data quality of service support (data oriented MAC, symmetric link) and lower future equipment costs (low chipset complexity, high spectral efficiencies).

While it is clear that WCDMA has the advantage when referring to voice and soft handoff of voice, these advantages disappear for data-centric applications. There are some additional advantages of WCDMA in equipment performances; however these advantages are not sufficient to overcome the advantages of OFDMA stated above.

As data traffic continues to grow, there will be an increasing need to offload data from 3G to and OFDMA-based network optimized for data. WiMAX (upcoming 802.16e) provides the only standards-based OFDMA WAN technology; wireless carriers should work with equipment providers to ensure that their 3G infrastructure can easily be migrated to adopt OFDMA technologies in the near future.

References

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- [4] WiMAX Forum Whitepaper, <http://www.wimaxforum.org/news/downloads/WiMAXNLOSgeneral-versionaug04.pdf>
- [5] "Demand for Wireless High-Speed Data Services and Applications", In-Stat MDR, April, 2004.

Additional Resources

White Papers

Intel Corp., *IEEE 802.16* and WiMAX: Broadband Wireless Access for Everyone*, 2003, www.intel.com/ebusiness/pdf/wireless/intel/80216_wimax.pdf

WiMAX Forum, *WiMAX's Technical Advantage for Coverage in LOS and NLOS Conditions*, Aug 2004, www.wimaxforum.org/news/downloads/WiMAXNLOSgeneral-versionaug04.pdf

General Resources

WiMAX Forum:
www.wimaxforum.org

Note: The 802.16e standard is scheduled to be ratified in early 2005.

Key Terminology

| | | | |
|---------|--|-------------|---|
| 3GPP | Third Generation Partnership Project | MAC address | Media access control address. This address is a computer's unique hardware number. |
| AAS | Adaptive Antenna Systems or Advanced Antenna Systems | MAN | Metropolitan area network |
| AMC | Adaptive Modulation and Coding | MIMO | Multiple Input Multiple Output |
| AP | Access point. An AP operates within a specific frequency spectrum and uses an 802.11 standard specified modulation technique. It informs the wireless clients of its availability, authenticates and associates wireless clients to the wireless network and coordinates the wireless clients' use of wired resources. | OFDM | Orthogonal frequency division multiplexing |
| ARQ | Automatic-Repeat-Request | OFDMA | Orthogonal Frequency Division Multiplexing Access |
| BER | Bit Error Rate | PAN | Personal area network |
| BTS | Base station | PHY | Physical layer |
| CDMA | Code-Division Multiple Access | PoP | Point to point |
| CSMA | Carrier-sense multiple access | QAM | Quadrature Amplitude Modulation |
| DSSS | Direct sequence spread spectrum | QoS | Quality of service |
| EDGE | Enhanced Data rates for Global Evolution | QPSK | Quadrature Phase Shift Keying |
| ETSI | European Telecommunications Standards Union | RF | Radio frequency |
| EvDO | Evolution Data Only or Evolution Data Optimized | SDMA | Space Division Multiple Access |
| EVDV | Evolution Data/Voice | SS | Subscriber station |
| FCC | Federal Communications Commission | TDD | Time Division Duplexing |
| FDD | Frequency Division Duplexing | TTI | Transmission Time Interval |
| FFT | Fast Fourier Transform | UMTS | Universal Mobile Telecommunications System |
| GPRS | General Packet Radio Service | UWB | Ultra-wide band |
| HSDPA | High Speed Downlink Packet Access | VoIP | Voice over Internet protocol |
| HS-DSCH | High-Speed Downlink Shared Channel | WAN | Wide area network |
| ICI | Inter Carrier Interference | WCDMA | Wideband Code-Division Multiple Access |
| IEEE | Institute of Electrical and Electronics Engineers | Wi-Fi | Wireless fidelity. Used generically when referring of any type of 802.11 network, whether 802.11b, 802.11a, dual-band, and so on. |
| IP | Internet protocol | WiMAX | Worldwide Interoperability for Microwave Access |
| LAN | Local area network | WISP | Wireless Internet service provider |
| | | WLAN | Wireless local area network |
| | | WMAN | Wireless metropolitan area network |
| | | WWAN | Wireless wide area networks |