Technical overview and performance of HSPA and Mobile WiMAX

June 2007

Technology Paper

ERICSSON

TAKING YOU FORWARD

Contents

1 Executive summary

In just a few years, the Internet has transformed the way we access information, communication and entertainment services at home and at work. Broadband connections have made the Internet experience richer for millions of people and, in the coming years, millions more will turn to wireless technology to deliver their broadband experience.

This technology paper aims to cut through the confusion surrounding the relative merits of the various wireless broadband technologies. While there are a host of technologies competing to deliver commercial mobile broadband services – the most recent being Mobile WiMAX – 3G networks based on well established WCDMA (Wideband Code Division Multiple Access) and HSPA (High Speed Packet Access) technologies offer the best way forward in terms of global acceptance, economies of scale and spectrum efficiency.

The capabilities of HSPA evolution and Mobile WiMAX are broadly similar: their peak data rates and spectral efficiency are comparable, as are their network architectures, although HSPA offers superior coverage. In short, Mobile WiMAX does not offer any technology advantage over HSPA.

However, HSPA is built on the firm foundations of the 3GPP family – offering the broadband speeds users desire and the carrier-grade voice services they expect. HSPA can be built out using the existing GSM radio network sites and is a software upgrade of the installed WCDMA networks. Together with dual-mode terminals, this ensures nationwide coverage in most countries both for voice (GSM/WCDMA) and data (HSPA/EDGE).

Thanks to its heritage, HSPA operators have a single network – which offers multiple services – with a sound business case built on revenues from voice, SMS, MMS, roaming customers and mobile broadband.

HSPA offers an ecosystem of unrivalled breadth and depth, as well as unmatched economies of scale that benefit all players in the ecosystem. This ecosystem is uniquely available to a technology that is part of the 3GPP family of standards, currently serving over two billion subscribers.

Low-cost HSPA-capable embedded modules are already available and, with over 100 commercial networks in operation, HSPA is the clear and undisputed choice for mobile broadband services.

2 Introduction

The Internet continues to grow in importance in our daily lives: in just a few years, we have seen dramatic changes in how it can support us in our private and professional lives. To fully enjoy the benefits of the Internet, users need a broadband connection and in the coming years, millions of people will turn to wireless technology to deliver their broadband experience.

There are a host of technologies competing to deliver commercial mobile broadband services. By far the most successful is HSPA, which has been commercially deployed by over 100 operators in more than 50 countries, with an additional 50 operators committed to rolling out commercial services[1] (and counting). HSPA is a state-of-the art technology that is able to provide mobile and wireless broadband services for the vast majority of the market, with unsurpassed performance and economies of scale. By 2010, when the number of wireless broadband connections is estimated to exceed 600 million, HSPA will be delivering more than 70 per cent of all mobile broadband connections.

A good mobile broadband system must fulfill certain criteria, including high data rate, high capacity, low cost per bit, low latency, good Quality of Service (QoS) and good coverage. There are a number of techniques that can be used to meet these criteria in a wireless system, including:

- for higher data rates (and capacity)
  - higher-order modulation schemes, such as 16 Quadrature Amplitude Modulation (16QAM) and 64QAM
  - Multi-Input Multi-Output (MIMO) advanced antenna systems, which rely on multiple antennas at both the transmitter and the receiver, effectively multiplying the peak rate
- for improved Quality of Service and low latency
  - dynamic scheduling, with end-user traffic streams prioritized according to their service agreements
  - short Transmission Time Interval (TTI), allowing for round-trip times approaching wired equivalents (such as DSL)
- for higher capacity

[1] Source: Global mobile Suppliers Association (GSA), April 2007

    - shared-channel transmission to make efficient use of available time/frequency/code, as well as power resources
    - link adaptation to dynamically optimize transmission parameters, depending on actual radio conditions
    - channel-dependent scheduling to assign radio resources to users with instantaneously favorable radio conditions
    - Hybrid Automatic Repeat reQuest (H-ARQ) to enable rapid retransmission of missing data, and soft-combining to significantly improve performance and provide robustness

- for greater coverage
    - Advanced antenna systems and advanced receivers to enhance the radio link and improve cell range.

Both HSPA and Mobile WiMAX employ most of these techniques, and therefore their performance is broadly similar. However, there are differences, for example in areas such as the duplex scheme (FDD versus TDD), frequency bands, multiple access technology and control channel design – leading to differences mainly in uplink data rates and coverage.

2.1 HSPA

The 3rd Generation Partnership Project (3GPP) is a collaboration agreement that brings together a number of telecommunications standards bodies. The USA, Europe, Japan, South Korea and China jointly formed the 3rd Generation Partnership Project and there are currently over 400 3GPP member companies and institutions. 3GPP defines GSM and WCDMA specifications for a complete mobile system, including terminal aspects, radio access networks, core networks and parts of the service network. Standardization bodies in each region have a mandate to take the output from the 3GPP and publish it in their region as formal standards.

3GPP specifications are structured in releases and discussions of 3GPP technologies normally refers to the functionality in one release or another. It is worth noting that all later releases are backward-compatible with previous releases.

Version	Released	Info
Release 99	2000 Q1	Specified the first UMTS 3G networks, incorporating a WCDMA air interface
Release 4	2001 Q2	Added features, including an all-IP core network
Release 5	2002 Q1	Added IMS and HSDPA

Release 6	2004 Q4	Integrated operation with Wireless LAN networks, added enhanced uplink, MBMS and enhancements to IMS such as Push to Talk over Cellular (PoC)
Release 7	2007 Q2	Added downlink MIMO, further reduced latency, improved QoS and improvements to real-time applications like VoIP
Release 8	In progress	Includes E-UTRA (LTE) and the Evolved Packet Core (SAE) architecture and further enhancements of HSPA

Table 1 Progressive enhancements to 3GPP specifications

The development of the 3GPP technology track (GSM/WCDMA/HSPA) has been spectacular. Within a decade, there has been a 1,000-fold increase in the supported data rates, for example. What is more, 3GPP technologies will continue to evolve and enhance their capability.

WCDMA 3GPP Release 99 provides data rates of 384kbit/s for wide-area coverage. However, as the use of packet data services increases, and new services are introduced, higher speed and greater capacity are required – at lower production cost.

WCDMA 3GPP Release 5 extended the specification with, among other things, a new downlink transport channel, the High Speed Downlink Shared Channel, which enhances support for high-performance packet data applications. The production cost per bit is reduced, since the enhanced downlink provides a considerable increase in capacity compared with Release 99. It also significantly reduces latency and provides downlink data rates of up to 14Mbit/s.

This enhancement, which commonly goes under the abbreviation HSDPA (High Speed Downlink Packet Access), is the first step in the evolution of WCDMA.

There are quite a number of applications that benefit from an improved uplink, although a lot of traffic is downlink-oriented. These include the sending of large e-mail attachments, pictures, video clips and blogs. The key enhancement in WCDMA 3GPP Release 6 was a new transport channel in the uplink, Enhanced Uplink – also referred to as HSUPA (High Speed Uplink Packet Access) – which provides higher throughputs, reduced latency and increased capacity. Data rates of up to 5.8Mbit/s can be provided with Enhanced Uplink.

Together, HSDPA and Enhanced Uplink are known as High Speed Packet Access (HSPA). HSPA evolution (also referred to as HSPA+) is being introduced in 3GPP Release 7 and supports MIMO, 64QAM (downlink) and 16QAM (uplink) to further boost the peak data rate and capacity. HSPA evolution supports data rates up to 42Mbit/s in the downlink and 11.5Mbit/s in the uplink.

The Long Term Evolution (LTE), currently being specified by 3GPP for Release 8 (expected to be ready at the end of 2007), introduces OFDM/OFDMA in the downlink and Single Carrier FDMA (SC-FDMA) in the uplink. LTE supports very high data rates, exceeding 300Mbit/s in the downlink and 80Mbit/s in the uplink. LTE will support channel bandwidths from approximately 1.25MHz up to at least 20MHz and operation in both paired and unpaired spectrum (FDD and TDD).

2.2 Mobile WiMAX

The IEEE 802.16 Working Group on Broadband Wireless Access Standards, which was established by IEEE Standards Board in 1999, prepares the formal specifications for broadband Wireless Metropolitan Area Networks. The 802.16 family of standards is officially called WirelessMAN and is the basis of Mobile WiMAX.

Version	Released	Info
IEEE 802.16d IEEE 802.16-2004	2004 Q2	Replaced all previous 802.16 specifications. Support for non-line of sight operation
IEEE 802.16e IEEE 802.16e-2005	2005 Q4	Enhanced 802.16-2004 with support for data mobility
WiMAX Forum Network Architecture Specification Release 1.0	2007 Q1	Networking specifications for fixed, nomadic, portable and mobile WiMAX systems. Release 1.0 covers Internet applications and data mobility
WiMAX Forum Network Architecture Specification Release 1.5	In progress	Enhancements to the Release 1.0 specification for carrier-grade VoIP, location-based services, MBMS, full IMS interworking and over-the-air client provisioning

Table 2 Evolution of WirelessMAN (802.16 family of standards)

The IEEE 802.16-2004 specification (also referred to as 802.16d) provides support for non-line of sight (NLOS) and indoor end user terminals for fixed wireless broadband. In 2005, an amended standard – IEEE 802.16e-2005 (also referred to as 802.16e) – which added support for data mobility was approved.

IEEE 802.16e-2005 (as it is formally known, but is best known as 802.16e or Mobile WiMAX) provides an improvement on the modulation schemes used in the original (Fixed) WiMAX standard by introducing SOFDMA (Scalable Orthogonal Frequency Division Multiple Access).

The Mobile WiMAX system profile based on the OFDMA mode in IEEE 802.16e-2005 is not backward-compatible with the Fixed WiMAX system profile based on the OFDM mode in IEEE 802-16-2004.

The WiMAX Forum is an organization of more than 400 members. The WiMAX Forum's charter is to promote and certify the compatibility and interoperability of broadband wireless access equipment that conforms to the Institute for Electrical and Electronics Engineers (IEEE) 802.16 and ETSI HiperMAN standards.

To achieve this goal, the WiMAX Forum defines and conducts conformance and interoperability testing to ensure that different vendor systems work seamlessly with each other. WiMAX certification profiles specify characteristics including spectrum band, duplexing and channelization, and several different profiles exist for both Fixed and Mobile WiMAX.

Currently there are two waves of certification planned for Mobile WiMAX equipment:

- Wave 1: Mobile WiMAX system profile with Single Input Single Output (SISO) terminals for the 2.3GHz and 3.5GHz bands
- Wave 2: Mobile WiMAX system profile with Multiple Input Multiple Output (MIMO) terminals and beam-forming support for the 2.6GHz band (sometimes referred to as the 2.5GHz band).

As the IEEE 802.16 standardization only covers basic connectivity up to Media Access (MAC) level, the WiMAX Forum also addresses network architecture issues for Mobile WiMAX networks. The first network architecture specification (Release 1.0) is focused on delivering a Wireless Internet service, with mobility, as the first step.

Release 1.5 will add support for telecom-grade mobile services, supporting full IMS interworking, carrier-grade VoIP, broadcast applications like mobile TV, and over-the-air provisioning.

While Mobile WiMAX offers the promise of high-speed wireless broadband services, it is still very much in its infancy and real-life performance has yet to be proved.

3 Technical comparison

As both HSPA and Mobile WiMAX technologies are designed for high-speed packet data services, they share similar technology enablers – including dynamic scheduling, link adaptation, H-ARQ with soft combining, multiple-level QoS and advanced antenna systems.

Performance differences between HSPA and Mobile WiMAX result from differences in the physical layer signal format, duplex scheme, handover mechanism and operating frequency bands.

This chapter provides a high-level description of the similarities and differences between HSPA and Mobile WiMAX. Technical details of HSPA can be found in the 3GPP specifications, and details of Mobile WiMAX can be found in the IEEE 802.16e-2005 standard and the WiMAX Forum Mobile System Profile.

3.1 Similarities

3.1.1 Dynamic scheduling

In traditional circuit-switched telephone systems, a connection is set up as a dedicated link during the entire session. The drawback of this approach for packet data is that the dedicated link is tied up even during idle periods – wasting communication resources. For high-speed packet data systems with bursty traffic, it makes sense to allocate the radio resource only during active periods, to ensure that radio resources are fully utilized.

Radio links often experience fluctuations in signal strength, because of the volatile nature of wireless channels. This means it is more effective to schedule the base station and terminal to communicate only when there are good radio conditions.

Channel-dependent scheduling (as shown in Figure 1) is used in both HSPA and Mobile WiMAX systems for efficient and effective resource utilization for packet data.

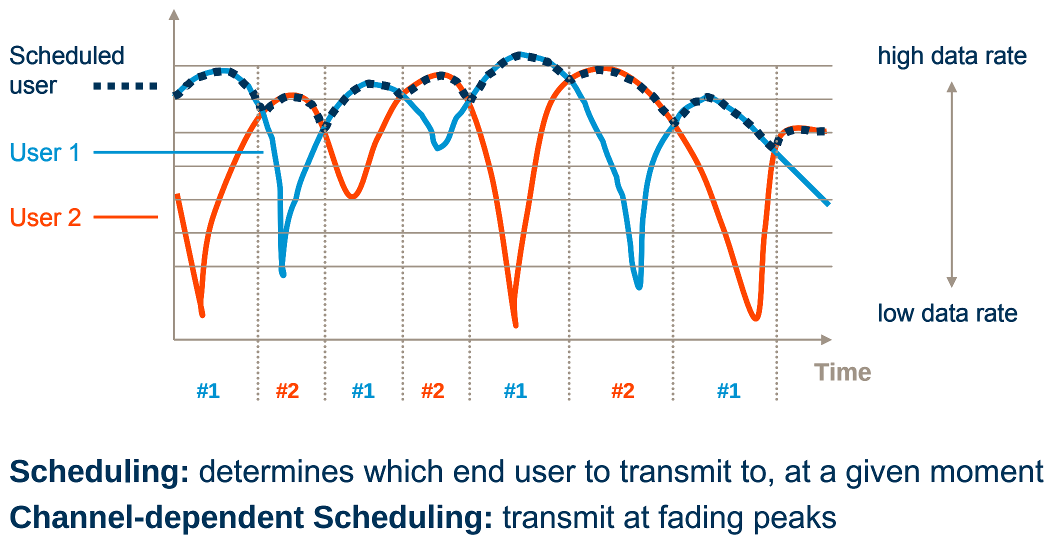

Figure 1 Channel-dependent scheduling

3.1.2 Link adaptation

When a mobile device is scheduled for transmission, the quality of its radio link will vary in time. The modulation scheme and channel-coding rate used for a scheduled link can be adapted to minimize errors under a variety of radio conditions. Link adaptation (illustrated in Figure 2) enables full utilization of channel capacity for each communication link in the wireless environment and so maximizes the throughput of scheduling-based systems.

HSPA and Mobile WiMAX both support dynamic selection between QPSK, 16QAM and 64QAM modulation schemes, as well as of the channel-coding rate, where the lowest coding rate without repetition is 1/2 for Mobile WIMAX and 1/3 (that is, additional coding gain) for HSPA. Overall, HSPA has a finer granularity of modulation and coding formats than Mobile WiMAX.

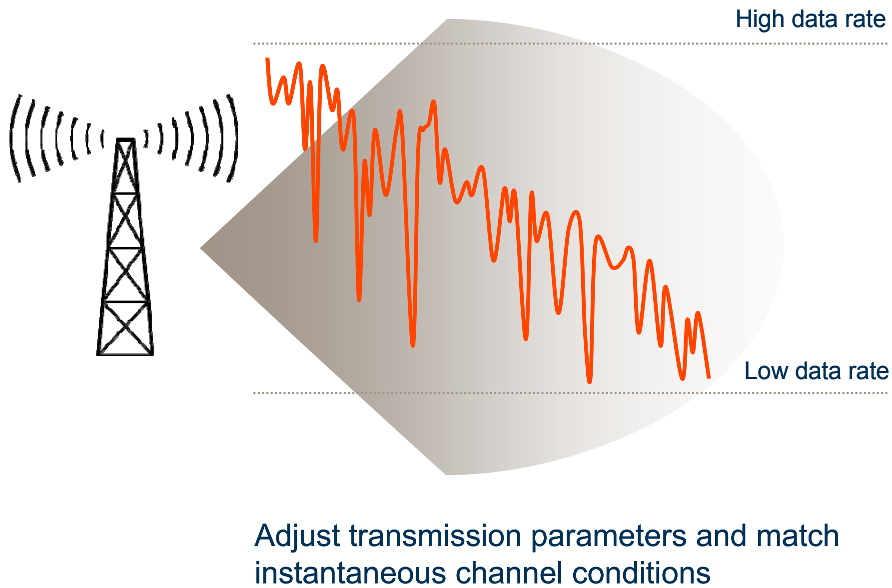

Figure 2 Link adaptation

3.1.3 Hybrid Automatic Repeat reQuest (H-ARQ) with soft combining

Because of delays in channel quality feedback, link adaptation may suffer from errors incurred between time instances of reporting and scheduling. Using H-ARQ with soft combining on downlink and uplink, these error packets can be quickly corrected without having to rely on higher-layer ARQ. H-ARQ with soft combining provides an effective remedy to link adaptation errors and reduces retransmission delays that are vital for higher-layer throughput.

On the uplink, H-ARQ with soft combining also reduces transmission power and improves system capacity, as a result of the lower interference and better power control stability. In HSPA, incremental redundancy is used for extra coding gain of a lower coding rate which goes along with the retransmission. In Mobile WiMAX, only Chase combining is available for energy gain and the coding rate is not adjusted after retransmission.

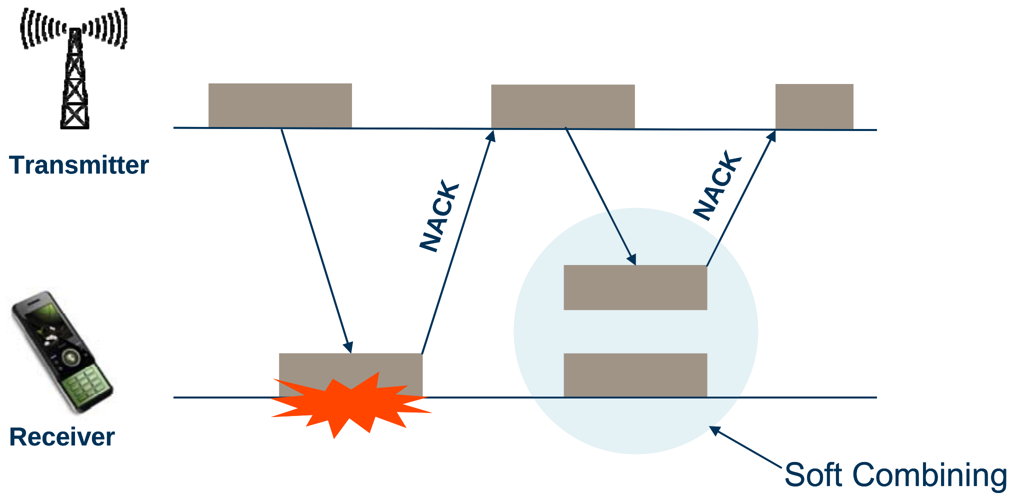

Figure 3 Hybrid Acknowledgement Request (H-ARQ) with soft combining

3.1.4 Multi-level Quality of Service

HSPA and Mobile WiMAX both support multiple QoS levels. In HSPA, QoS levels are divided into four categories: conversational, streaming, interactive, and background. In Mobile WiMAX uplink, there are five scheduling mechanisms defined for different QoS levels: unsolicited grant service (UGS), extended real-time polling service (ertPS), real-time polling service (rtPS), non-real-time polling service (nrtPS), and best-effort.

3.1.5 Advanced antenna technologies

Advanced multi-antenna technologies are key to the performance and capability of modern mobile communication systems. In general, multi-antenna technologies rely on the use of multiple transmit and/or receiver antennas to achieve:

- *diversity* against fading on the radio channel
- *beam-forming* to improve the radio link signal-to-noise/interference ratio
- *spatial multiplexing*, often referred to as *MIMO* (Multi-Input-Multi-Output) antenna processing, to increase the peak data rates and utilize high radio-link signal-to-noise/interference ratios more efficiently.

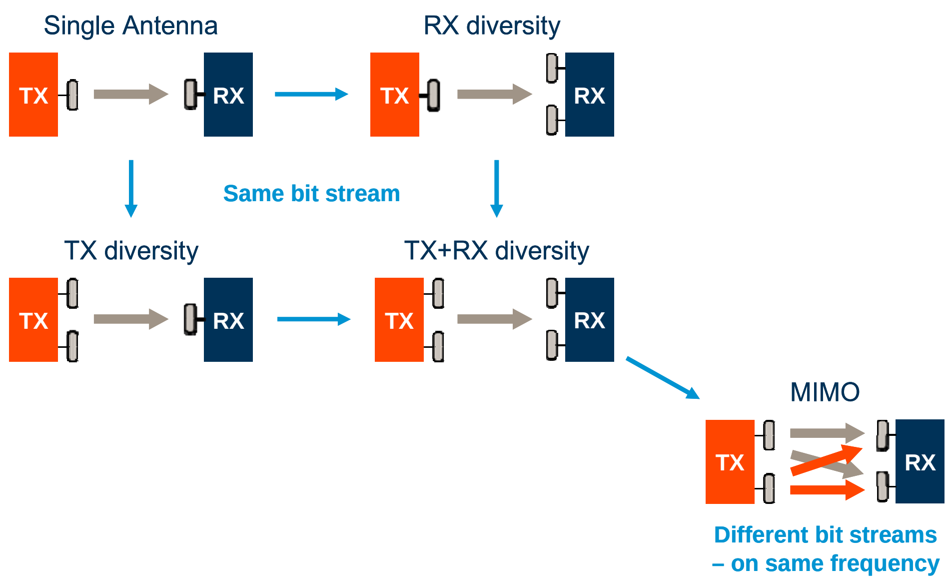

Figure 4 Overview of the different antenna transmission scheme

WCDMA supports two multi-antenna transmission schemes: open-loop transmit diversity and closed-loop transmit diversity

WCDMA open-loop transmit diversity uses modified Alamouti coding and can be applied to dedicated as well as common channels. Open-loop transmit diversity provides diversity against radio-channel fading.

WCDMA closed-loop transmit diversity allows for adjustment of transmission phase and amplitude, based on feedback of the instantaneous downlink channel conditions. This means that, in addition to diversity, WCDMA closed-loop transmit diversity allows for beam-forming gains.

Both WCDMA open-loop and closed-loop transmit diversity are also available for HSPA. In addition, in HSPA Release 7, 2x2 spatial multiplexing effectively doubles downlink peak data rates.

In the Mobile WiMAX system profile, there are two types of multi-antenna transmission schemes specified: transmit diversity using the Alamouti space-time code (STC), similar to WCDMA/HSPA open-loop transmit diversity and spatial multiplexing (MIMO).

Mobile WiMAX also allows for beam-forming, which is enabled by uplink sounding. This aims to take advantage of TDD channel reciprocity; that is, the spatial characteristics measured at the base station can be used to form downlink beams. In practice, however, the performance is limited by asymmetry of interference and different antenna settings at the terminal and the base station.

3.2 Differences

3.2.1 Physical signal format

The main differences between Mobile WiMAX and HSPA in the physical layer lie in the signal format. Mobile WiMAX is based on orthogonal frequency domain multiplexing (OFDM), while HSPA is a direct-sequence spread spectrum system. One of the most important features of OFDM is its robustness to multi-path propagation. The key enabler for this feature is the use of narrowband tones in combination with a cyclic prefix. The cyclic prefix serves two purposes: to provide a guard time against inter-symbol interference; and to ensure the multi-path channel only imposes a scalar distortion on each tone, making equalization both simple and effective. When properly synchronized and protected by cyclic prefix, tones of an OFDM signal remain mutually orthogonal even after going through multi-path channels. The disadvantage of using cyclic prefix is that it introduces overhead, which effectively reduces bandwidth efficiency.

The ability of an OFDM signal to maintain orthogonality under multi-path conditions helps ensure an intra-cell interference-free system that is well suited to high-speed data transmission. However, when there are large Doppler spreads in OFDM, inter-tone interference arises and the performance degrades. Using an OFDM signal for uplink multiple accesses, a Mobile WiMAX base station needs to fine-tune the frequency errors of each terminal within tolerable ranges, and minimize the total interference level through power control.

An OFDM signal also has a relatively large peak-to-average power ratio (PAPR). This means that for a given average power, the power amplifier must be able to handle significantly higher power peaks, while avoiding distortion of the transmitted signal.

HSPA uses CDM code aggregation of orthogonal Walsh code to offer a high-speed downlink channel and direct sequence Code Division Multiple Access (CDMA) for the uplink. While it is less sensitive to Doppler spread, the loss of orthogonality in time-dispersive channels creates intra-cell interference that limits the use of high-order modulation. Generalized RAKE receivers can alleviate interference through advanced signal processing on the receiver side at the moderate cost of additional receiver complexity.

When compared with an OFDM signal, the HSPA uplink signal has a lower PAPR – which implies a less complex power amplifier. Alternatively, for a given complexity, a higher average power can be used, leading to a coverage advantage.

3.2.2 Duplex scheme

Another difference between HSPA and Mobile WiMAX is the duplex scheme. HSPA is an FDD technology, with uplink and downlink transmission taking place in separate frequency channels (usually denoted as 2x5MHz to indicate two separate 5MHz channels; one for the uplink and one for the downlink). Mobile WiMAX, as currently defined in the WiMAX Forum mobile WiMAX system profile, is a TDD technology, with just one frequency channel (10MHz for example) that is shared between the uplink and the downlink in the time domain. The ratio between the uplink and the downlink defines how the frequency channel is shared. A 2:1 ratio means the channel is used for the downlink two-thirds of the time and for the uplink one-third of the time (as shown in Figure 5)

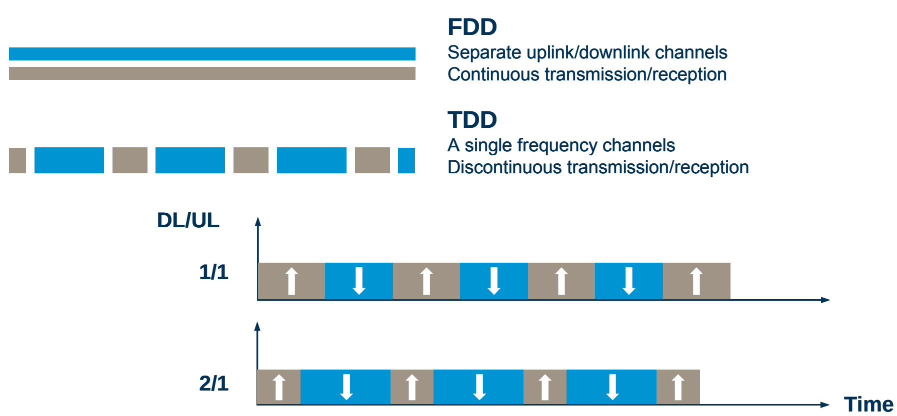

Figure 5 Overview of FDD and TDD

Although FDD operation is also possible within the IEEE 802.16 specification, TDD is the only duplex mode selected in the WiMAX Forum Mobile WiMAX system profile. TDD has the flexibility of changing downlink-to-uplink ratio to accommodate various traffic asymmetries, although in practice the ratio needs to be fixed system-wide (unless guard bands are used to limit interference effects). In addition, in a TDD system with a large downlink-to-uplink ratio, there will be a link budget penalty as the uplink average power is reduced for a given peak power.

The interference scenarios are different between FDD and TDD systems. In FDD systems, a frequency duplex gap is used between the uplink and the downlink to prevent interference between uplink and downlink transmissions. In TDD systems, a guard time is used between the uplink and the downlink. This results in different interference scenarios for FDD and TDD systems, as shown in Figure 6.

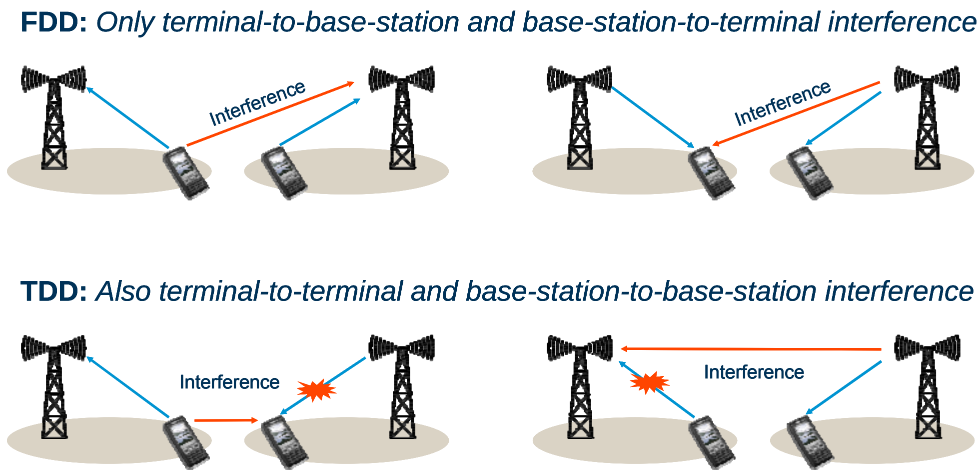

Figure 6 Overview of the interference scenarios for FDD and TDD systems

When building a TDD network, there are a number of interference scenarios, which must be handled in different ways:

- **Interference within a network** – interference between base stations as well as between terminals can occur. Therefore all base stations must be fully time-synchronized with each other (for example, using a GPS receiver at each base station).

- **Between a network and a geographically adjacent TDD network** – if another TDD network is using the same frequency band in the same geographical area, interference between the two networks can occur (just as it can occur within a network). Therefore, synchronization coordination between neighboring networks is required, or guard bands must be used to avoid interference. This can occur at national or state borders, especially where only local licenses have been issued.

- **Between a network and a spectrum-adjacent TDD network** – if another TDD network is using adjacent frequencies, base station-to-base station interference can occur if the base stations from the different networks are in close proximity. The uplink to one base station can suffer interference from the out-of-band leakage (ACLR) from another base station. This interference can be reduced by synchronizing the two networks, or by using guard bands.

- **FDD and TDD spectrum borders** – if an FDD network is using frequencies adjacent to the TDD network, base station-to-base station interference can occur if the base stations from the different networks are in close proximity. Such interference can only be resolved using suitable guard bands.

- **Duty cycle uplink/downlink settings in the TDD network in relation to adjacent networks** – in addition to synchronization in time, when setting the uplink/downlink ratio in a TDD network, coordination of this ratio within the network and with neighboring networks is required, to avoid all of the interference cases mentioned above. Alternatively, guard bands can be used.

Stringent requirements from existing satellite services in specific bands also make it more difficult to deploy TDD technologies in these frequencies. The tougher coexistence environment for TDD imposes requirements on the RF filters, which are just as complex as the duplex filter requirements for FDD.

In 3GPP, TDD has also been specified, although currently there have been no major deployments of TDD-based cellular systems.

3.2.3 Handover mechanism

HSPA supports soft handover in the uplink, which provides macro combining gain and improves the link budget (by 1.5dB on average). It also helps increase network capacity by reducing intra-cell interference. Hard handover is also supported in HSPA and is used for intra-frequency handover and inter-system handover to GSM.

In Mobile WiMAX, only hard handover is selected by the system profile.

3.2.4 Operating frequency bands

HSPA currently supports frequency bands ranging from 800MHz to 2,600MHz, including most of the existing 2G operating bands in Europe, Africa, the Americas and Asia-Pacific. The most common bands for HSPA are 2.1GHz, deployed worldwide, and the 850MHz band deployed in the Americas, Australia, New Zealand, and parts of Asia – enabling the delivery of mobile and fixed wireless broadband services over large areas.

Although a number of frequency bands are under discussion for Mobile WiMAX, current Mobile WiMAX certification profiles only cover the 2.3GHz, 2.6GHz and 3.3–3.8GHz frequency bands. Currently there are only a few deployments of Mobile WiMAX, mainly in the 2.3GHz band.

Approximately 90 per cent of all spectrum allocations worldwide are FDD.

3.3 Summary technical comparison

The technical similarities and differences between HSPA and Mobile WiMAX are summarized in Table 3.

	HSPA	Mobile WiMAX
Physical signal format	DL code aggregation, UL DS-CDMA	OFDMA for both DL and UL
Hybrid ARQ with soft combining	Adaptive IR + Chase combining	Chase combining
Multi-level QoS	√	√
Link adaptation	QPSK, 16QAM, 64QAM Lowest code rate: 1/3	QPSK, 16QAM, 64QAM Lowest code rate: 1/2
Duplex scheme	FDD	TDD
Frequency bands	850MHz to 2,600MHz	2.3GHz, 2.6GHz and 3.4–3.8GHz
Handover	Hard handover, Soft handover	Hard handover
Frequency reuse one	√	√
Advance antenna technologies	• Closed- and open-loop transmit diversity • Spatial multiplexing • Beam-forming	• Open-loop transmit diversity • Spatial multiplexing • Beam-forming

Table 3.Technical comparison of HSPA and Mobile WiMAX

4 Performance characteristics

System performance capabilities such as data rates, delays, spectrum efficiency and coverage are vital system characteristics. For the end-user, these determine what services are offered. For the operator, they define the number of users and the base station coverage area, which directly influences the cost of operating the system.

This chapter presents the performance characteristics of HSPA and Mobile WiMAX in terms of peak data rates, spectrum efficiency and coverage. Rather than cover just one version (or release) of each system family – which might give a misleading picture – the discussion covers a set of releases of both HSPA and Mobile WiMAX, to enable a fair comparison.

As many features are common to both system families – including antenna (MIMO) concepts, modulation and channel coding – their performance is similar in many respects. There are differences, however – such as the duplex scheme, frequency bands, multiple access technology and control channel design – leading to differences in uplink bit-rates and coverage, for example.

4.1 Peak data rates

The peak data rate indicates the bit-rate a user in good radio conditions can reach when not sharing the channel with other users, for example in a lightly loaded cell. Figure 7 shows the downlink and uplink peak data rates, measured above the MAC layer, for a set of system concepts. This shows how early releases of HSPA (Release 6) and Mobile WiMAX Wave 1 achieve comparable peak rates. The use of higher level modulation (64QAM in the downlink and 16QAM in uplink) for Mobile WiMAX is compensated for by lower overhead in HSPA, which uses 16QAM in the downlink and QPSK in the uplink.

HSPA Release 7 introduces 64QAM and two-stream MIMO in the downlink (but not for simultaneous use) and offers comparable performance to Mobile WiMAX Wave 2. HSPA Release 8 has a peak data rate advantage over Mobile WiMAX Wave 2. In this case, the same modulation formats (64QAM and 16QAM) and comparable MIMO schemes (two streams in the downlink) are used, but the overhead is lower for HSPA. Further enhancements for HSPA Release 8 are under evaluation.

For Mobile WiMAX, TDD asymmetries may be used to increase downlink peak data rates, but this comes at the cost of reduced uplink peak data rates.

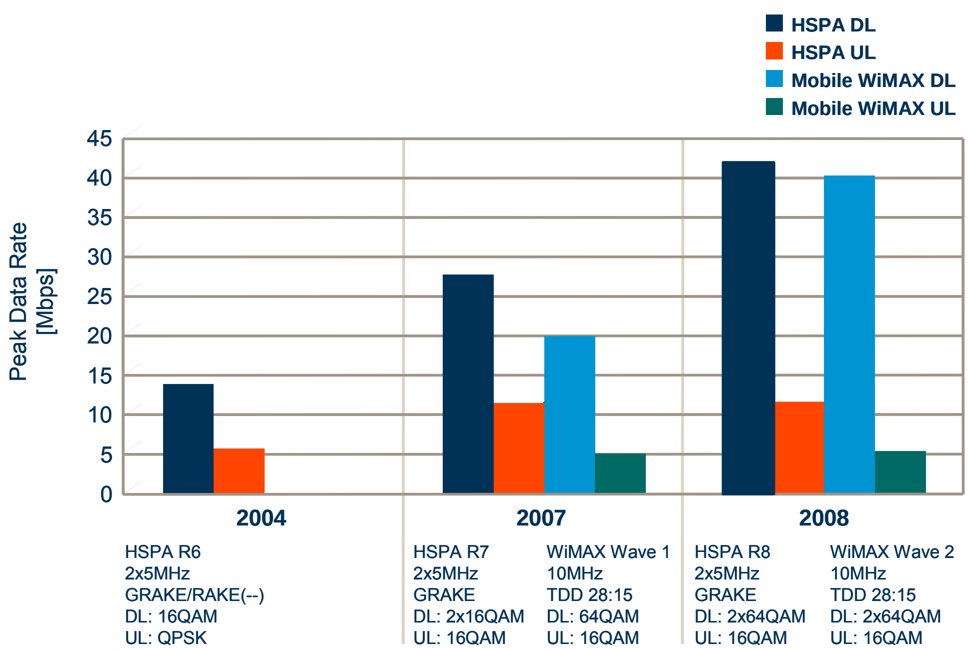

Figure 7 Peak data rates for a set of HSPA releases and WiMAX waves. For WiMAX, the TDD symmetry is expressed in terms of the number of downlink and uplink slots for data (that is, 28:15). Use of multi-stream MIMO is indicated by a factor in front of the modulation scheme. The HSPA Release 8 results are based on preliminary features.

4.2 Spectrum efficiency

Spectrum efficiency measures the maximum total amount of data that can be carried by a cell per unit time, normalized with the occupied system bandwidth. For any given traffic load per user, spectral efficiency can be used to determine the number of users that each cell can support.

The spectrum efficiency figures have been evaluated using models, assumptions and methodology aligned with 3GPP standards [1] (in this case, a system with 19 three-sector sites, placed on a regular grid with 500m inter-site distance). Users are uniformly distributed and of 'full buffer' type. Propagation models, including modeling of spatial correlation between antennas to enable accurate MIMO evaluations, are selected to simulate an urban environment.

System models, such as antenna solutions and output powers, are aligned with the capabilities of the studied systems. Similar assumptions have been made for all systems, with the aim of achieving fair comparisons. The figures should be used for comparative purposes and not as absolute values.

The spectrum efficiency achieved by HSPA Release 6 depends on the receiver type used. Mobile WiMAX Wave 1 reaches higher spectrum efficiency figures than the much earlier available HSPA Release 6 with basic RAKE receivers (indicated by the dotted line in Figure 8). With more advanced receivers, such as the GRAKE with receive diversity, a substantially higher spectrum efficiency is achieved than with basic RAKE receivers. A comparison of HSPA Release 6 with more advanced receivers (which is also available earlier than Mobile WiMAX Wave 1 devices) shows the spectrum efficiency to be better with HSPA.

HSPA Release 7 is modeled with two-stream MIMO in the downlink and 16QAM in the uplink. Mobile WiMAX Wave 2 (which has approximately the same availability as HSPA Release 7) yields performance figures comparable to HSPA Release 7.

HSPA Release 8 is modeled with preliminary features and shows better spectrum efficiency than Mobile WiMAX Wave 2.

Results similar to those presented here have been achieved by 3G Americas [2]. The figures for Mobile WiMAX are somewhat lower than those presented by WiMAX Forum [4], probably because of differences in modeling. The WiMAX Forum does not present results for HSPA Release 7 or 8. Its HSPA Release 6 results are however similar to those presented here, assuming simple receivers.

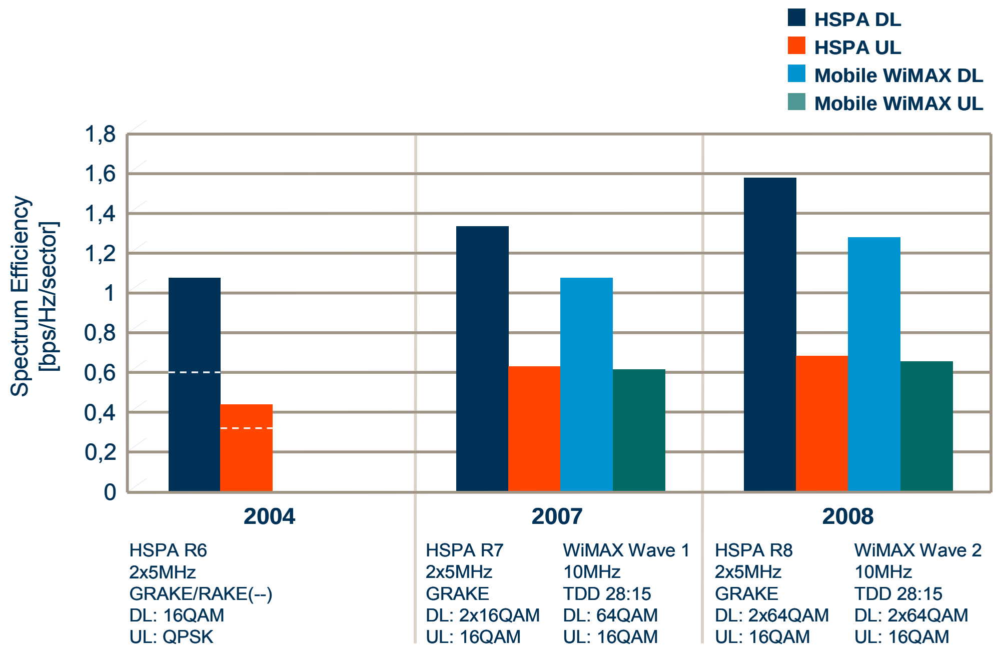

Figure 8 Spectrum efficiency comparisons (note that absolute spectrum efficiency values vary with models and assumptions. The above values should be used for relative comparisons. The HSPA Release 8 results are based on preliminary features.)

4.3 Coverage

Coverage is a crucial performance metric, as it determines the number of sites needed to deploy a complete network, and the data rate available at a given distance in a given deployment. A common way to measure coverage is to use link budgets, which provide an estimate of the maximum path loss between the base station and the terminal that the system can sustain.

Accurate absolute link budgets depend on several factors, and are best simulated for each specific case. However, relative comparisons of link budgets for different system concepts are straightforward to perform, and still informative.

HSPA and Mobile WiMAX have distinctive characteristics that affect the link budget, including output power, duplex method and frequency band – especially on the uplink, as this is typically the limiting link. Their impact is summarized in Figure 9.

Using typical terminal power classes, the maximum output power is 1dB lower for Mobile WiMAX terminals (23dBm) than for HSPA (24dBm). This leads to a 1dB difference in link budget. One reason for this difference is the difference in uplink modulation and multiple access methods. Although it is possible to build higher-power terminals for both technologies, this difference is expected to continue for devices of comparable complexity.

With TDD, if the link is only used half the time, for a given average data rate, the data rate when transmitting must be twice as high. If the link is used one-quarter of the time, the data rate when transmitting must be four times higher. Radio links to terminals at the cell border are typically ‘power-limited’, so that the bit-rate achieved is proportional to the transmitted power, but quite insensitive to the channel bandwidth. Therefore, to compensate for this loss, the terminal must have a factor 2 (3dB) or 4 (6dB) better path loss for activity factors of 50 per cent and 25 per cent, respectively.

If Mobile WiMAX is deployed in higher frequency bands than typically used for HSPA, this will lead to an additional loss in link budget. The path loss is proportional to the square of the frequency. With Mobile WiMAX operating in the 2.6GHz band and HSPA operating in the 2.1GHz band, and the uplink operating at about 2.0GHz, the path loss increases by a factor of $(2.6/2.0)^2$ = 1.7, or 2.3dB. At 3.5GHz the corresponding figure is 4.9dB.

In addition to these differences, HSPA enables improved coverage through soft handover, as well as improved sensitivity through lower overhead.

In summary, despite being based on similar techniques, the Mobile WiMAX link budget can be some 6dB worse than HSPA’s. In a coverage-limited network, this in turn leads to a need for 2.2 times more sites. This site increase is derived on the basis of $d^{3.5}$ propagation (which is typical in urban and suburban areas). In this case, a path loss increase of 6dB, or a factor of four, corresponds to a distance coverage loss of a factor of $4^{1/3.5}$ = 1.5, or an area coverage loss of a factor 1.5^2 = 2.2. In rural areas with lower path loss exponents, there are larger differences.

For a coverage-driven deployment, Mobile WiMAX at 2.6GHz would need approximately 2.3 to 3.4 times more sites than HSPA at 2.1GHz. Even compared with HSPA on 2.6 GHz, Mobile WiMAX increases the site count by approximately 1.7 to 2.5 times.

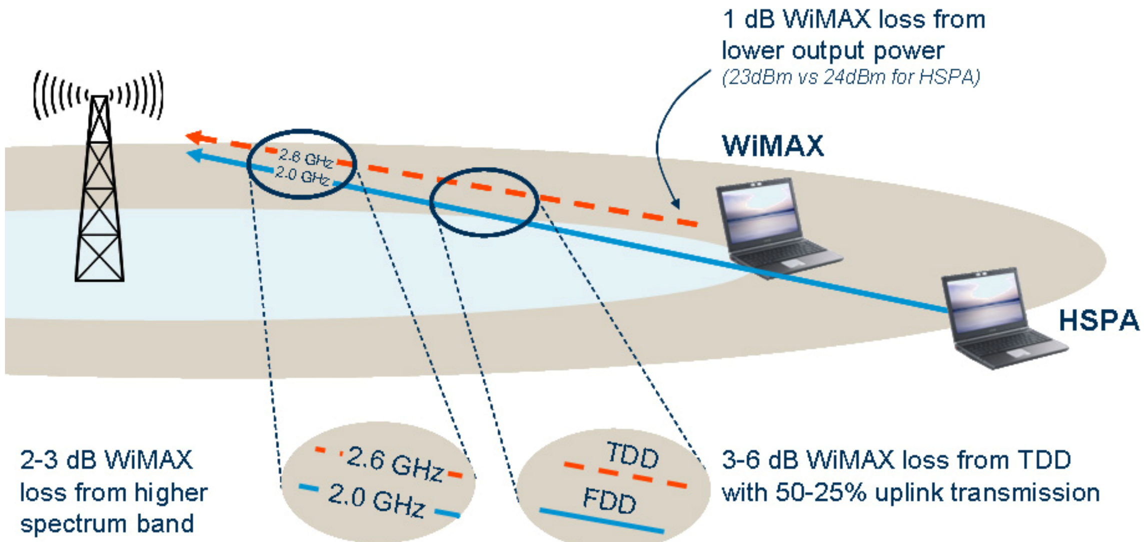

Figure 9 In a typical deployment, HSPA has a 6-10dB coverage advantage over Mobile WiMAX.

4.4 Real-life experience

HSDPA has been commercially available since 2005, and has been rolled out for commercial operation in networks around the world. Initially, user terminals were limited to five codes and 16-QAM modulation, which have a theoretical maximum data rate of 3.6Mbit/s. Even so, feedback from live networks is close to the theoretical simulations (as shown in Figure 10).

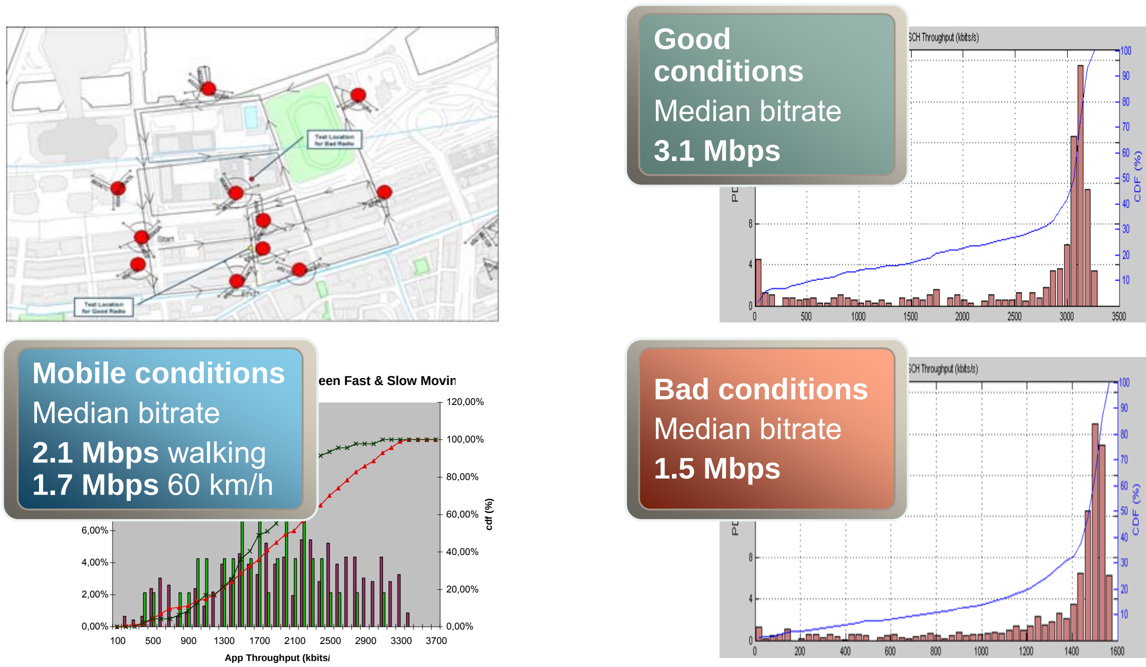

Figure 10 HSPA performance measured in a live commercial network

User terminals that support ten codes, with a theoretical maximum data rate of 7.2Mbit/s are now available and tests run on commercial systems have proved the simulation results (as shown in Figure 11).

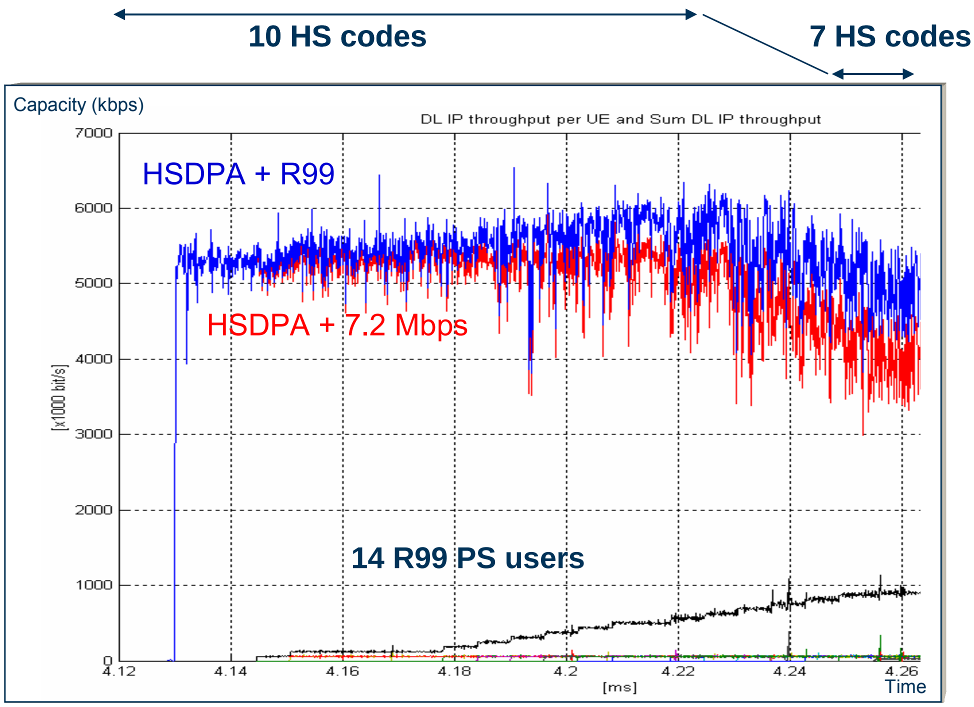

Figure 11 HSPA performance measured on a commercial system using a terminal supporting up to 7.2 Mbps

HSPA is a mature technology that offers mobile broadband services to rival the performance of fixed broadband networks (such as ADSL and cable). Load calculations in an HSPA network show that it gives operators a way to deliver a commercially viable flat rate mobile broadband service, with a 10GB monthly 'bit bucket', to every subscriber in the network

5 HSPA and Mobile WiMAX network architecture

The 3rd Generation Partnership Project is a collaboration agreement that brings together a number of telecommunications standards bodies. 3GPP handles GSM and WCDMA standardization for the complete mobile system, including terminal aspects, radio access networks, core networks and parts of the service network.

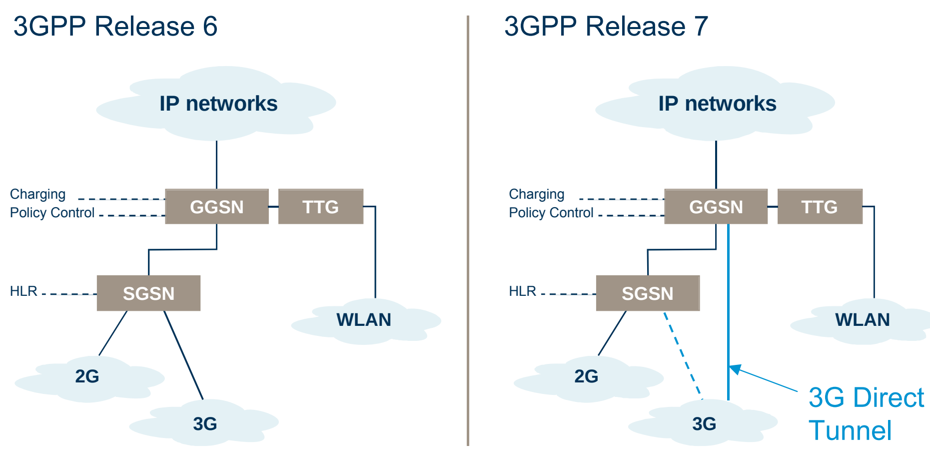

Figure 12 Overview of the 3GPP reference architecture

Just as the radio interface is progressively being improved with every advance in the 3GPP specification, so too is the network enhanced and optimized. In step with HSPA, the 3GPP Release 7 reference architecture has been enhanced with a 3G Direct Tunnel that optimizes the delivery of mobile and wireless broadband services. The Direct Tunnel architecture provides a direct data-path from the RNC to the GGSN, and offers increased topological flexibility and improved latency compared with 3GPP Release 6 and earlier architectures.

5.1 WiMAX Forum and IEEE

The IEEE 802.16 standard covers the air interface (IEEE 802.16e) and basic connectivity up to Media Access (MAC) level. The network architecture specifications for WiMAX networks are defined by the WiMAX Forum. The first network architecture specification (Release 1.0) focuses on delivering Internet services with mobility as the first step.

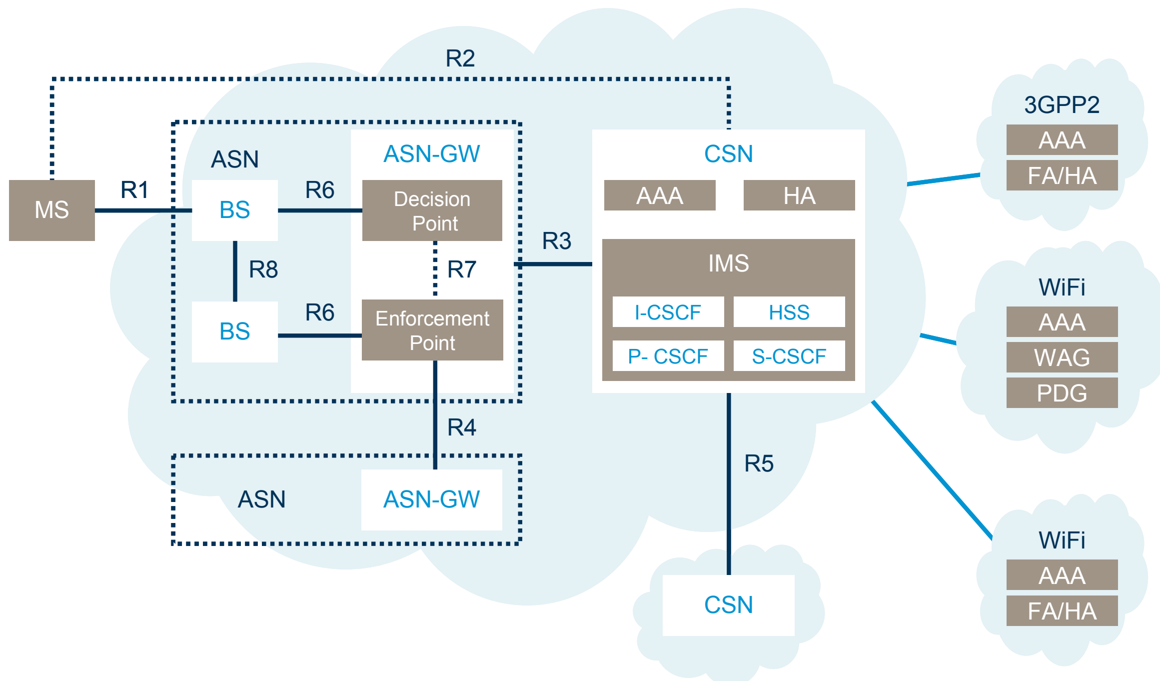

Figure 13 Mobile WiMAX network architecture

The WiMAX Forum network architecture currently defines three different RAN profiles, each with a different functional allocation.

- Profile A:
  - centralized ASN model with base station and ASN gateway (ASN-GW) implemented on separate platforms, interacting through the R6 interface
  - split radio resource management, with the radio resource agent in the base station and the radio resource controller in the ASN-GW
  - open interfaces for Profile A: R1, R6, R4, and R3
- Profile B:
  - ASN solution where the base station and ASN-GW functions are implemented on a single platform
  - open interfaces Profile B: R4 and R3
- Profile C:

- o Similar to Profile A, except that radio resource management is not split and is located entirely in the base station.

5.2 Architecture comparison

Figure 14 shows a comparison of an expected Mobile WiMAX architecture and the 3GPP Release 7 architecture for mobile broadband services.

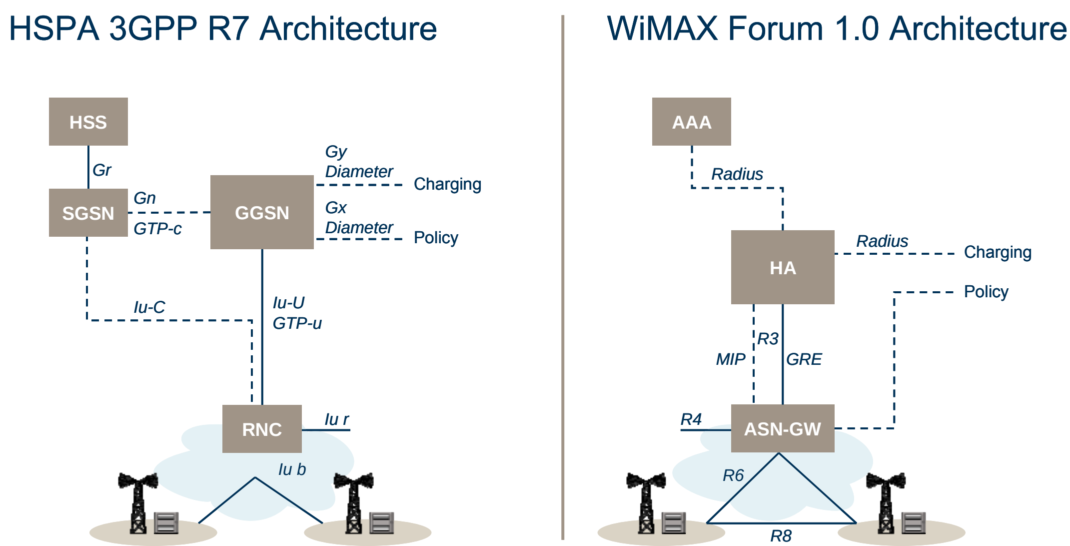

Figure 14 HSPA and Mobile WiMAX network architecture

The target requirements are broadly similar and have similar functional allocations and architecture. However, the selection of protocols in each standards organization has been influenced by the background of the technology. 3GPP builds on GTP and Diameter, which provides optimized interworking with legacy GSM terminals and common anchoring in the GGSN for dual-mode GSM/WCDMA/HSPA terminals. GTP also provides an efficient way to handle QoS and to create the binding to the radio bearers. The WiMAX Forum has instead made protocol decisions in favor for Mobile IP and Radius; both PMIP and CMIP for both IPV4 and IPV6 is supported.

A comparison of Mobile IP and GTP reveals several similarities in terms of the functionality supported. The protocols solve the same type of problems in areas such as session management, user plane tunnel set-up for both IPv4 and IPv6 payload, multiple packet sessions, and other functions.

However, meeting the need for wireless mobility using IP tunneling protocols requires a lot of functionality in areas such as bearer management, QoS, charging, radio access type information and others. GTP has been tailor-made as an IP protocol to support this functionality from day one. This is different from the approach of standardization forums such as the WiMAX Forum, which have instead extended the baseline IETF protocols to include wireless-specific functionality and to deploy multiple protocols in parallel over the same interface.

Radius and Diameter also look very similar on a high level. Both protocols have been developed within IETF, where Diameter was developed as an evolved version of Radius. Diameter is widely used within IMS specifications and provides functionality beyond Radius, mainly in the area of carrier-grade performance. This translates into functionality such as standardized application packages, rather than vendor-specific attributes, reliable transport layer, bi-directional communication and heartbeat mechanisms.

5.3 System architecture evolution

The next step in the 3GPP architecture evolution, specified together with LTE, is the System Architecture Evolution (SAE), which will deliver a flattened network architecture with simplified QoS, for the delivery of IP services (as illustrated in Figure 15).

SAE is scheduled for completion during 2007 and is an evolution of 3GPP Release 7, with support for 3GPP LTE and non-3GPP access technologies, as well as existing 2G and 3G access technologies.

This architecture splits packet core control and user plane functionality into separate nodes. The HSPA architecture is further optimized for mobile broadband services, and contains two nodes in the user plane for the main use cases – the eNodeB and the SAE Gateway (SAE-GW).

The Mobility Management Entity (MME) is an evolution of the SGSN server, as specified for 3G Direct Tunnel in 3GPP Release 7. It is expected that in many implementations, the MME will be co-located with the SGSN.

The SAE-GW node will include evolved GGSN functionalities including IP networking interfaces and end-user IP Point-of-Presence, shallow and deep packet inspection, as well as real-time charging, policy control capabilities and mobility to non-3GPP accesses using mobile IP. Further, for operators evolving to LTE/SAE from GSM/WCDMA/HSPA, it will maintain full backward compatibility with legacy networks.

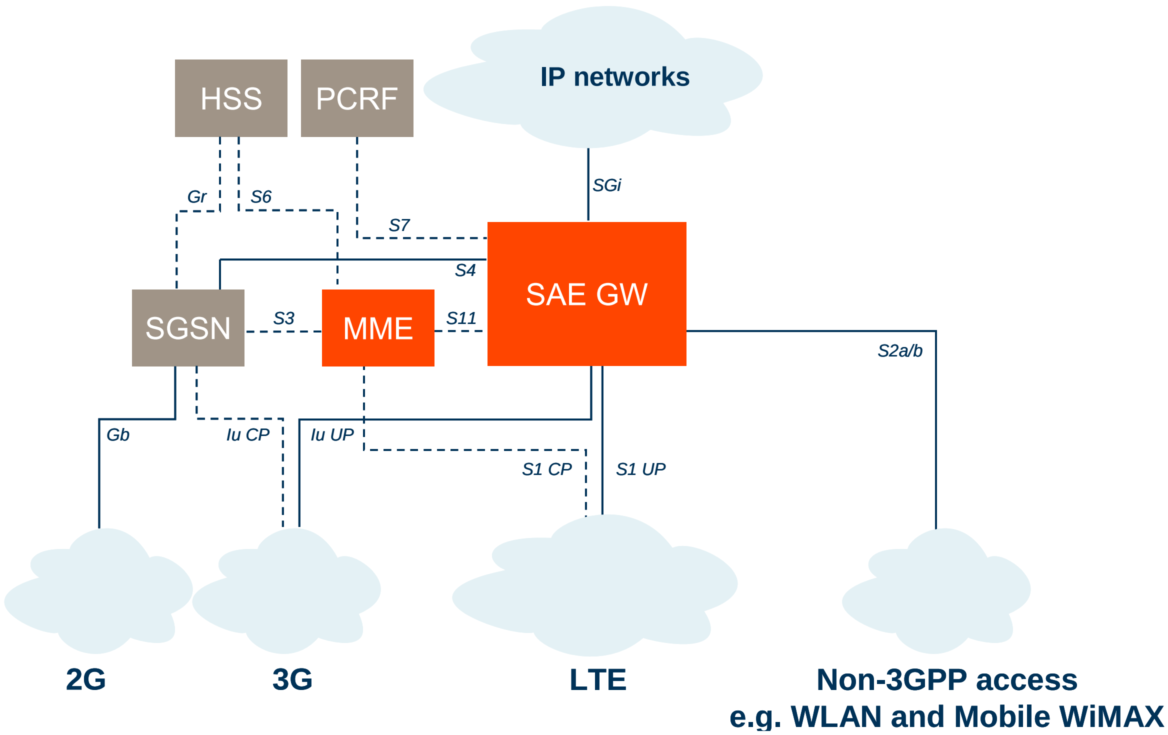

Figure 15 SAE architecture overview

5.4 Mobile WiMAX

The details of the network architecture evolution for Mobile WiMAX beyond the Release 1.0, which was approved in March 2007, are yet to be determined. However, it is expected to include and enhance functionality such as policy management and IMS support, prepaid support, emergency services and roaming.

6 Conclusion

HSPA and Mobile WiMAX employ many of the same techniques and so their performance is comparable in many areas. However, there are key differences in areas such as duplex mode (FDD versus TDD), frequency bands, multiple access technology and control channel design – leading to differences mainly in uplink bit-rates and coverage.

While the peak data rates, spectral efficiency and network architecture of HSPA Evolution and Mobile WiMAX are similar, HSPA offers better coverage than Mobile WiMAX. In short, Mobile WiMAX does not offer any technology advantage over HSPA.

What is more, HSPA is a proven mobile broadband technology that is already deployed in over 100 commercial networks. It is built on the firm foundations of the 3GPP family, and offers users the broadband speeds they desire and the carrier-grade voice services they expect.

HSPA can be built out using existing GSM radio network sites and is a software upgrade of installed WCDMA networks. Together with dual-mode terminals, these factors help ensure nationwide coverage both for voice (GSM/WCDMA) and data (HSPA/EDGE).

Thanks to its heritage, HSPA offers operators a single network for multiple services, with a sound business case built on revenues from voice, SMS, MMS, roaming and mobile broadband.

HSPA offers an ecosystem of unrivalled breadth and depth, as well as unmatched economies of scale that benefit all players in the ecosystem – which are uniquely available to a technology that is part of the 3GPP family of standards, currently serving over two billion subscribers.

For operators, technology choices made today will influence operations for many years to come. 3GSM technologies are the future-proof choice – from the standpoint of initial investment, economies of scale and the ability to extend and continuously enhance the solution.

HSPA is the clear and undisputed choice for mobile broadband services.

7 Glossary

AAA: Authentication, Authorization and Accounting.

3G (third generation): Radio technology for mobile networks, telephones and other devices. Narrowband digital radio is the second generation of technology.

3GPP: 3rd Generation Partnership Project, a collaboration agreement that brings together a number of telecommunications standards bodies

3G LTE / SAE: 3G Long-Term Evolution /System Architecture Evolution

DSL: Digital Subscriber Line

EDGE: Enhanced Data rates for Global Evolution

FDD: Frequency Division Duplexing

GSM: Global System for Mobile communications

GPRS: General Packet Radio Service

HSPA: High Speed Packet Access, an extension of WCDMA to provide high bandwidth and enhanced support for interactive, background and streaming services

IEEE: Institute of Electrical and Electronics Engineers

IMS: IP Multimedia Subsystem

IPR: Intellectual Property Rights

ITU: International Telecommunication Union

MAC: Media Access Control

MIMO: Multiple Input Multiple Output

OFDM: Orthogonal Frequency Division Multiplexing, a digital encoding and modulation technology used by 802.16-based systems (including WiMAX) as the air interface.

PC: Personal Computer

TDD: Time Division Duplexing.

WCDMA: Wideband Code Division Multiple Access, a wideband spread-spectrum 3G mobile telecommunication air interface.

WiMAX: World wide interoperability for Microwave Access, a standards-based technology that enables the delivery of last mile wireless broadband access as an alternative to cable and DSL.

VoIP: Voice over Internet Protocol technology enables users to transmit voice calls via the Internet using packet-linked routes; also known as IP telephony.

8 References

[1] 3GPP, TR 25.814, 'Physical Layer Aspects for Evolved UTRA'.

[2] 3G Americas, 'Mobile Broadband: EDGE, HSPA and LTE', September 2006, www.3gamericas.org/English/Technology_Center/WhitePapers/

[3] 3rd Generation Partnership Project (3GPP), http://www.3gpp.org/

[4] WiMAX Forum, http://www.wimaxforum.org/

[5] IEEE 802.16-2004 Air Interface for Fixed Broadband Wireless Access Systems

[6] IEEE 802.16e-2005 Air Interface for Fixed and Mobile Broadband Wireless Access Systems