# MOBILE BROADBAND WIRELESS ACCESS

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## Abstract

Mobile broadband wireless access is needed to provide advanced telecommunications services effectively and affordably to consumers around the world. This paper evaluates the current commercial alternatives to satisfy that need: WiMAX variants, MBWA (IEEE 802.20), Flash-OFDM and 3G technologies. Regulation aspects affect technology adoption and those are discussed along with the current market situation in all major market areas. Finland provides an interesting example and is handled separately and with more depth. Finally, vendor strategies and future developments are also evaluated to provide conclusions about which technology or technologies are most likely to gain market acceptance. Based on the material, both 3G (HSDPA) and Mobile WiMAX (IEEE 802.16e) have widespread support and credible evolution and stand out as the main contenders for mobile broadband deployment within the immediate future.

## Key Words

3G, HSDPA, LTE, WiMAX, Flash-OFDM, MBWA

## 1. Introduction

Emerging telecommunications applications such as multimedia streaming, music download, on-line gaming and content browsing are popular examples of the digital revolution we have been facing as the world gets connected. Fixed broadband access has already become an urban commodity in the developed countries, but so far there have been few means of delivering these bandwidth-consuming services effectively and affordably to the significant number of rural and mobile users. However, recent advances in e.g. signal processing, radio protocols, and mobile network infrastructure are now enabling the concept of mobile broadband for consumers around the world.

Mobile broadband is defined here as the potential to transfer low-latency user data with speeds exceeding 256 kbit/s while roaming the network with seamless handovers between adjacent cells. This paper presents the different mobile broadband technologies with commercial availability already or within a few years. Related regulation aspects are important factors affecting the regional markets. Analysis of the current market situation, significant vendors' strategies and foreseen future developments are also used to draw the conclusions about the respective potential of these technologies.

## 2. Mobile Broadband Technologies

Currently there are a number of different technologies for broadband wireless access for both fixed and mobile applications. Some of them are completely proprietary, based on vendor-specific solutions that are non-interoperable, while others are based on open standards developed by industry working groups. In the following subsections, we briefly describe the fundamental characteristics of the currently most significant wireless broadband technologies, focusing on key metrics such as operating frequencies, channel bandwidth, cell sizes, user data rates and latency, handover capabilities, and timeframe of availability.

### 2.1 WiMAX (IEEE 802.16-2004)

WiMAX is short for Worldwide Interoperability for Microwave Access and it is defined by the IEEE 802.16 Working Group. Although first intended for fixed applications, the initial WiMAX standards have evolved to form the basis for mobile WiMAX as well.

The current version of the fixed WiMAX standard is 802.16-2004, sometimes also referred to as 802.16d. It is essentially frequency independent, allowing also non-line-of-sight (NLoS) operation in the lower end of the frequency range (frequencies below 3 GHz, according to Richardson (2006)). The radio access interface is based on orthogonal frequency division multiplexing (OFDM) with 256 subcarriers, although OFDMA2048 and single carrier access modes are included in the 802.16-2004 standard as alternatives. OFDM allows good resistance to interference and multipath fading. Channel bandwidth ranges from 1.25 to 20 MHz, and either FDD or TDD may be used for duplexing.

WiMAX cell size is dependent on the used frequency band, but coverage radiuses of 1 to 2 km for NLoS and 10 to 16 km for LoS are typical with standard base station equipment. With some optional enhancements, however, the figures are 4 to 9 km (NLoS) and 30 to 50 km (LoS) (Baines 2005). Actual data rates are also highly variable and depend on a number of factors. Although rates as high as 75 Mbit/s have been advertised, according to results of trials conducted by AT&T in late 2005, 2 Mbit/s over a range of roughly 5 to 10 km is closer to reality. For a comprehensive performance analysis, one may refer to, e.g., Ball et al. (2005). Fixed WiMAX, as defined in 802.16-2004, does not support handovers or any other basic mobility mechanisms. As such, it lends itself only to fixed or, at most, nomadic applications.

## 2.2 Mobile WiMAX (IEEE 802.16e-2005)

Perhaps the biggest shortcoming of 802.16-2004 is the lack of support for mobility. IEEE addressed this issue by developing specifications for a separate version of the standard, the 802.16e, which was approved on December 7, 2005 (IEEE 2005). Also known as mobile WiMAX, the standard is seen to be in competition with 3G cellular technologies. Its radio access method is even more sophisticated than that of fixed WiMAX, utilizing scalable OFDMA and thus achieving an even better link budget. The tradeoff is increased complexity in physical layer processing. Fast handover signaling is supported, e.g., to allow users in moving vehicles to seamlessly switch between base stations. (Baines 2005)

Mobile WiMAX operates in the 2 to 6 GHz range that mainly consists of licensed bands. Mobile applications are likely to operate in frequencies below 3 GHz, while even some fixed applications are expected to use 802.16e due to its better characteristics. However, it should be noted that there is no backward compatibility with fixed WiMAX. Cell radiuses are expected to be typically 2 to 5 km, and user data rates up to 30 Mbit/s are achievable in theory with full 10 MHz channels. The first certified 802.16e products are expected to be available by late 2006, though wide scale commercial deployments are expected not earlier than 2008.

On a further note, South Korea has its own variant of mobile WiMAX called WiBro which is standardized by TTA. It uses 10 MHz channels in the 2.3 GHz band in Korea, and aims for interoperability with official 802.16e equipment. According to a recent performance analysis, WiBro performs favorably in comparison with 3G High-Speed Downlink Packet Access (HSDPA) in multipath fading channels (Shin et al. 2005).

## 2.3 MBWA (IEEE 802.20)

The IEEE 802.20 (or Mobile Broadband Wireless Access) Working Group was established on December 11, 2002 with the aim to develop a specification for an efficient packet based air interface that is optimized for the transport of IP based services. The goal is to enable worldwide deployment of affordable, always-on, and interoperable BWA networks for both business and residential end user markets. The group will specify the lower layers of the air interface, operating in licensed bands below 3.5 GHz and enabling peak user data rates exceeding 1 Mbit/s at speeds of up to 250 km/h.

The goals of 802.20 and 802.16e are similar. However, 802.16e is much more mature, whereas even the standardization process of 802.20 is far from complete. A draft version of the specification was, however, approved on January 18, 2006.

## 2.4 Flash-OFDM

Flash-OFDM, short for Fast Low-latency Access with Seamless Handoff OFDM, is a proprietary wireless broadband technology originally developed by Flarion Technologies which was recently acquired by Qualcomm, a major developer and patent holder of CDMA and other advanced wireless technologies.

As the name implies, Flash-OFDM's radio access method utilizes OFDM in relatively narrow 1.25 MHz FDD channels. Frequency hopping is employed in the subcarriers, which provides frequency diversity. Operation is supported in several licensed frequency bands, such as 450 MHz, 700 MHz, 800 MHz, 1.9 GHz, and 2.1 GHz. The network is all-IP based, and inherently supports applications such as VoIP due to its low latency and enhanced QoS support. Flash-OFDM is claimed to reach user data rates of 1 to 1.5 Mbit/s in downlink and around 300 to 500 kbit/s in uplink, with a typical latency of 50 ms. (Rysavy 2005, Flarion 2006)

Compared to mobile WiMAX, Flash-OFDM has a time-to-market advantage in that its equipment is readily available on the market, but a major disadvantage in having only limited vendor support and not being an open technology. Interestingly, Flash-OFDM is also a candidate for the IEEE 802.20 standardization effort. (Rysavy 2005)

## 2.5 3G

3G cellular systems, most notably UMTS, are currently the most widely deployed mobile broadband technology with a huge established presence in terms of operators, customer base, brand, deployed base station sites, and backhaul capacity. Standardized by 3GPP in its Release 5, HSDPA is a tremendous performance upgrade for UMTS packet data, enabling peak data rates up to 14.4 Mbit/s, although the initial limit is 1.8 Mbit/s. Latency is also reduced, and spectral efficiency is improved as well. These improvements are achieved through improved modulation and coding, and implementing fast scheduling and retransmissions at base station level.

Although most WCDMA/HSDPA deployments are based on FDD where different radio bands are used to separate downlink and uplink transmission, 3GPP specifications also include a TDD version of UMTS where both transmit and receive functions alternate in time on the same radio channel. This can be beneficial for the many asymmetric data applications that consume more bandwidth in the downlink than in the uplink. A TDD radio interface can dynamically adjust the downlink to uplink ratio accordingly, and thus can balance both forward link and reverse link capacity. Spectral allocation is also more straightforward, as TDD requires only one band instead of two bands and a further guard band in FDD. UMTS TDD is also known as TD-CDMA and has been commercialized by the vendor IP Wireless. (Rysavy 2005)

## 2.6 Comparison of Key Metrics

To summarize, the key metrics of the different technologies described above are listed in Table 1. It should be noted that especially the cell radius and RTT

figures are only approximations in typical conditions and as such are not necessarily accurate. Furthermore, for FDD based technologies, the channel bandwidth is given for one link direction only.

**Table 1: Mobile Broadband Metrics**

| Technology | Channel band-width | Cell radius | Data rates (DL) | RTT |
|---|---|---|---|---|
| Fixed WiMAX | 1.25–20 MHz | 1–9 km, 10–50 km | < 75 Mbit/s | < 50 ms |
| Mobile WiMAX | 1.25–10 MHz | 2–5 km (typical) | < 30 Mbit/s | < 50 ms |
| 802.20 | 1.25–??? MHz | MAN scale | > 1 Mbit/s | N/A |
| Flash-OFDM | 1.25 MHz | 5–20 km (typical) | 1–1.5 Mbit/s | 50 ms |
| WCDMA/ HSDPA | 5 MHz | < 0.1 km, < 1 km, < 20 km | 1.8–14.4 Mbit/s | < 100 ms |
| TD-CDMA | 5 or 10 MHz | 2.5–30 km (typical) | 1.5–3 Mbit/s | < 50 ms |

## 3. Regulation Aspects

Almost all current BWA technologies are designed to operate in licensed frequency bands, although the available bands for them may differ across countries and regions. This is especially true for 3G, Flash-OFDM, and 802.20. For WiMAX, operation is possible also in unlicensed bands. However, most current deployments seem to use licensed bands such as 3.5 GHz and 5 GHz in Europe. Wi-Fi-like mass deployment in unlicensed bands seems attractive also for WiMAX, but it is much more complex due to the higher transmission power levels and the fragmented radio spectrum. Figure 1 shows the global distribution of WiMAX frequency bands, excluding unlicensed bands and some licensed bands below 2 GHz (e.g., 700 MHz) for which there are planned WiMAX deployments at least in the United States.

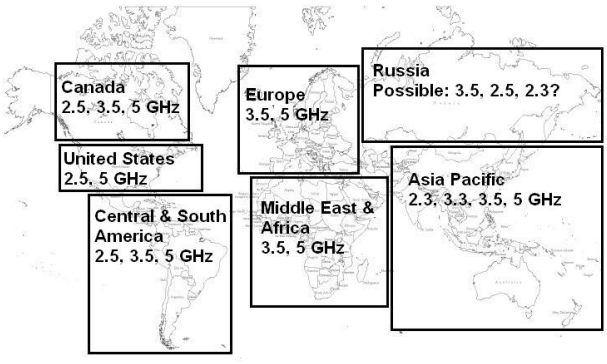


**Figure 1: WiMAX frequency bands (Baines 2005)**

Licensed bands allow operators to manage frequency planning. As this cannot be done for unlicensed bands, different techniques are needed. Although carrier-sense multiple access (CSMA) is sufficient for Wi-Fi, a considerably more stringent radio access control mechanism is necessary for WiMAX. This, in turn, leads to increased complexity. Taking into account the effects of terminal mobility, fast fading channels and long ranges in which WiMAX is designed to operate, this complexity is even more evident. (Baines 2005)

The selection of operating frequency affects not only cell radius but consequently also cost of coverage. This is why lower frequency bands such as 450 and 700 MHz are attractive for nationwide BWA deployments. The relationship between frequency, radius, and weighted average cost per km$^2$ is depicted in Figure 2.

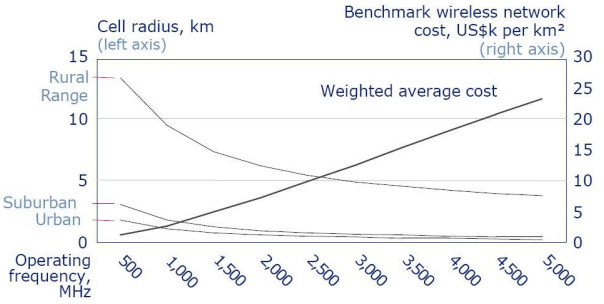


**Figure 2: Frequency vs. radius vs. cost (Lee 2005)**

## 4. Current Market Situation

Although most BWA technologies are still in a state of infancy, with at best first generation products on the market, there are already a number of fixed and even some mobile BWA networks operational around the world. The fixed deployments are mostly based on pre-certified or certified WiMAX (802.16-2004), whereas the mobile deployments use either HSDPA or proprietary technologies.

### 4.1 Finland

Finland's first WiMAX networks were deployed in the rural areas of North Ostrobothnia and Pirkanmaa during the first half of 2005. Similar deployments followed later in South Savo. Their operators are mainly local players. Finland's first true city WiMAX network was deployed in Turku in October 2005. The networks operate in the 3.5 GHz band which is currently the only available licensed band for WiMAX use in Finland.

3G FDD licenses in Finland have been divided between the main GSM network operators: TeliaSonera, Elisa, and DNA. Geographically these networks are still quite small, but major cities already have coverage. As the first operator globally, Elisa has upgraded its whole 3G network into HSDPA and opened it for commercial use already in April 2006. At least TeliaSonera is expected to follow that move during the near future. One 3G TDD license has also been awarded to a small company called SkyWeb, which is planning to build regional networks around Finland as needed.

Another interesting development is the decision to grant an operating license for a Flash-OFDM based mobile broadband network in the 450 MHz band to Digita Oy on June 22, 2005 (LVM 2005). Digita has already conducted trials in the Helsinki metropolitan area in late 2005. In its first phase, the network is expected to cover 204 cities and municipalities by September 2006, including the coastal areas of Finland and parts of Eastern and Northern Finland.

## 4.2 Europe, Middle East, and Africa

In the United Kingdom, the local company Telabria launched the country's first WiMAX network in the Kent area in September 2005. The start-up Urban Wimax launched the country's first certified WiMAX network in Westminster in March 2006. In Sweden, the first pre-WiMAX network in the Nordic countries was deployed already in December 2004.

Most European countries have distributed their 3G licenses, and there are now numerous 3G networks in active use. The major operator groups like Vodafone and Orange are running commercial HSDPA trials, but the aspiration towards HSDPA is at least equally great with the greenfield 3G operators like '3' and mass deployments are expected within this year. New growth areas for 3G include individual African countries and the Middle East, where e.g. Kuwait's Wataniya Telecom is actually already running HSDPA.

In South Africa, Wireless Business Systems provides a mobile broadband network based on ArrayComm's proprietary iBurst technology, a.k.a. High Capacity Spatial Division Multiple Access (ArrayComm 2004). The current coverage includes five major cities.

## 4.4 Americas

In the United States, there are operational WiMAX networks in major cities such as Boston, Chicago, Los Angeles, New York, San Francisco, provided by Towerstream, and in Seattle, provided by Sprint Nextel and Speakeasy. Several other trials and deployments are also underway. In Canada, a national pre-WiMAX network covering over 100 urban and rural areas was announced in March 2006. In Colombia, the local company Telecom launched WiMAX in the city of Bucaramanga in January 2006, with other cities such as Bogotá, Medellín and Cali to follow during the year.

Latin America is still building up their basic GSM networks, so the interest for HSDPA has been mostly dormant for now. However, individual countries with high subscriber penetration have already started their evolution towards 3G. North America is different to the rest of the world in the sense that GSM/UMTS serves only a minority of the cellular subscribers. As the rivalry between technologies is fierce, Cingular Wireless is using HSDPA to attract customers. T-Mobile USA is expected to follow Cingular and launch a 3G network some time next year.

## 4.5 Asia Pacific

In South Korea, WiBro roll-outs in the 2.3 GHz band are scheduled to start in April 2006. In the first stage, only simple mobility is supported. Taiwan has similar plans, with trials expected in the second half of 2006.

Apart from Korea, Asia Pacific is heavily involved with 3G. Japanese operators had the first commercial UMTS networks and are accelerating them now with HSDPA. New entrants with e.g. UMTS TDD are also expected. 3G deployment is on-going in Australia and the Philippines, while China is expected to grant licenses for UMTS within the near future.

In Australia there are currently also two large proprietary mobile broadband deployments. Personal Broadband Australia has nearly nationwide coverage with iBurst and Unwired Australia uses Navini Networks' proprietary Ripwave solution in its sites in Sydney and Melbourne. A major difference between the two is that iBurst offers true vehicular mobility, whereas Ripwave is limited to fixed or nomadic use. Both currently support speeds up to 1 Mbit/s.

## 4.6 Current and Future Prospects

3G and fixed WiMAX are off to a good start in the developed markets, but many operators are faced with the difficult decision whether to wait for mobile WiMAX certified products. The role of proprietary mobile broadband technologies such as Flash-OFDM also remains to be seen. In spite of the technological uncertainty, studies forecast exponential 3G and other BWA subscriber growth for the next few years. For WiMAX, one such estimate is depicted in Figure 3.

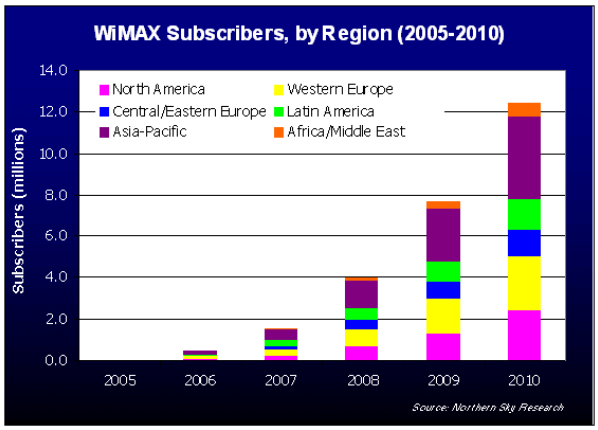


**Figure 3: WiMAX subscribers by region (Northern Sky Research 2005)**

## 5. Vendor Strategies

The major telecommunications vendors providing mobile broadband can be roughly divided into three categories: chipset, infrastructure and handset suppliers. Chipset providers operate in a horizontal industry and are easy to distinguish: Intel, Qualcomm, and Texas

Instruments are the largest and most important silicon vendors for telecom equipment manufacturers.

It is harder to draw a line between infrastructure and handset vendors, as some companies like Nokia have significant business in both areas leading to true end-to-end capability, and some vendors like Samsung are striving hard to eventually build a similar situation. By looking at where the majority of their sales come from, one can however categorize Nokia, Motorola, and Samsung as being nowadays mostly handset vendors.

Ericsson and Cisco are clearly the two iconic vendors for network equipment. After selling its handset business to BenQ, Siemens clearly also belongs to this category. The recently announced merger between Alcatel and Lucent will create a formidable player to challenge these three and Nokia. Nortel keeps on suffering from its bookkeeping discrepancies, but is still a notable vendor in some regions. As for Asian companies, NEC is involved with Siemens in 3G network development and Fujitsu has been working with Alcatel in another 3G joint venture. Chinese Huawei and ZTE are trying hard to establish their position and capability to serve developed markets outside of their natural home domain.

Ever since Qualcomm announced to buy the Lucent spin-off company Flarion in November 2005, the future of Flash-OFDM technology has been somewhat uncertain. Amidst other takeover rumors, Siemens is partnering and playing around with all technologies and had even some activities with Flarion (Siemens 2005), but those may have been hurt by the technology acquisition. As Qualcomm is a renowned IPR powerhouse and major chipset vendor for all 3G technologies, Flash-OFDM is now mostly seen as a proprietary step towards IEEE 802.20. Hence the main battlefront of mobile broadband has formed between 3G and IEEE 802.16e. Figure 4 is a rough illustration of where different vendors are strategically aiming, not necessarily where they are today.

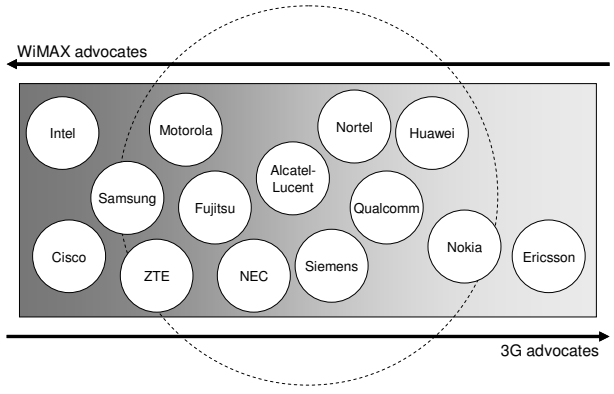


**Figure 4: Strategic inclination of telecom vendors**

However despite the strategic inclinations, pretty much all vendors seem to be playing both sides of the game. For example even Intel, one of the strongest proponents of WiMAX technology with related partnerships to several other vendors, believes that both 3G and WiMAX will coexist and work in tandem to meet the global needs (Intel 2004). This is naturally due to the fact that Intel has also major business in current 2G and 3G technologies and does not wish to disrupt them too much. As laptop users are undeniably the first potential mass-market adopters of mobile broadband, Intel is anyway in a key position to integrate the required radio technologies to its various chipsets.

Samsung is another interesting player. It has a good market position with basic 3G and first HSDPA handsets and continues strongly on that path, but at the same time it wants to expand its position in the value chain and sees WiMAX as the opportunity to do that. Samsung has extensive pre-WiMAX experience due to the early WiBro deployment in South Korea (Cherry 2005). Nortel also has some experience from WiBro as it has worked in co-operation with LG in the Korean market. Curiously, despite or exactly because of that experience Nortel appears to be more focused on 3G long-term development (Nortel 2006).

Motorola is in a similar position as Samsung, It has good business with 3G handsets, but has not managed to gain foothold as a 3G infrastructure vendor. Motorola also sees WiMAX as the opportunity to get back in the end-to-end game and challenge the market leader Nokia. Cisco is another natural supporter of WiMAX as it is a major player in Wi-Fi and has not established 3G business. However, Cisco's strategy is to partnership with other vendors and to provide the broadband IP technology needed in base stations (Cisco 2004).

Although Huawei does not yet have a solid HSDPA commercial offering, it has gained some basic 3G network deals in the new growth markets. Its local rival ZTE has not been as successful, so it appears to be aiming its resources more towards WiMAX. ZTE is even one of the board members in the industry body WiMAX Forum along with Intel, Motorola, Fujitsu and Samsung (WiMAX Forum). It remains to be seen how the merger eventually affects Alcatel and Lucent, but at least the former has previously also been a clear WiMAX advocate (Alcatel 2005).

Being the market leader in 2G/3G network infrastructure, Ericsson is obviously pushing for HSDPA. It sees WiMAX more as a semi-fixed access technique, but is keeping on eye on the developments anyway. Nokia, the leading mobile handset vendor and #2 in networks is somewhat more interested in WiMAX, but also promotes it mainly as an alternative to operators without a 3G license (Nokia 2005). Some advanced Nokia handsets already support both Wi-Fi and 3G, and adding WiMAX should be a logical step. Figure 5 presents Nokia's vision of radio technologies and their evolution. It is also worth to note that Texas Instruments is a key supplier to Nokia and closely supports their visions with the needed silicon.

HSDPA data cards with Qualcomm chipsets are already commercially available from several OEMs, and handsets are expected in the second half of 2006 from

all the major 3G handset vendors including Nokia, Samsung and Motorola. By then Samsung will also have its WiBro handset on the Korean market, and the first mobile WiMAX-capable data cards using Intel chipsets should become available as well. Unlike 3G, it is probable that the Taiwanese OEM vendors will play a significant role with early WiMAX equipment. Nokia, Motorola et al. are however prepared to follow them soon if or when the volumes take up.

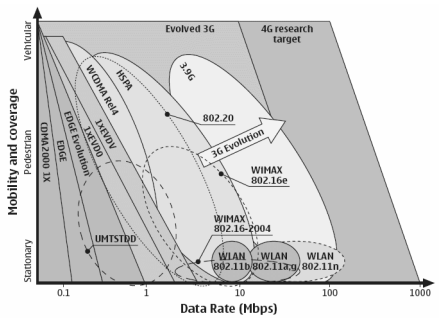


**Figure 5: Nokia's vision of radio access (Nokia 2005)**

## 6. Future Development

It is becoming clear that the current year 2006 will mark the true beginning of widespread deployment for mobile broadband. 3G/HSDPA and mobile WiMAX are seen as the main contenders, although they can also be used as complementary techniques in a number of markets. In the meanwhile, user experience continues to improve with upcoming enhancements on several levels.

High-Speed Uplink Packet Access (HSUPA) is included in 3GPP Release 6. The combination of HSDPA and HSUPA is often called simply HSPA. It will deliver uplink data rates of up to 5.76 Mbit/s and further decrease the network RTT to a level of 50 ms. HSUPA trials are expected to begin gradually and the technology is bound to hit the market in 2007.

More fundamental 3G developments proceed under the umbrella name of UMTS Long Term Evolution (LTE). Key elements are currently being standardized for 3GPP Release 8 and LTE aims for peak data rates of 200 Mbit/s for downlink and 100 Mbit/s for uplink. Such improvements are sought with the help of new radio techniques as well as architectural evolution, cf. Nortel's HSOPA concept (Nortel 2006).

While the current 3G network architecture is well suited to handle voice applications and mobility, it is quite heavy for most data services. WiMAX-like flat network architecture would be more cost effective in many cases, and LTE is studying such alternatives as well. There are already a number of 3G pre-LTE solutions including Nokia's Internet-HSPA (I-HSPA), Lucent's Base Station Router (BSR) and Motorola's AXPT.

As a common step for WiMAX, 3GPP Release 7 and other radio techniques, Multiple Input Multiple Output (MIMO) antennae systems are expected to materialize within a couple of years. They provide increased capacity by using multi-stream transmissions, but require a lot of processing power to handle that. Increased power consumption will probably also delay MIMO's initial adoption to mobile environments.

The TDD world is evolving as well. As licensed frequencies are becoming a scarce resource, TDD's single band operation may prove to be just what is needed. China is perhaps the single biggest driver behind TDD as it tries to cumulate knowledge and relevant IPR for business and political reasons. E.g., the TDD Special Work Group has contributed an interesting vision of the future (Ping et al. 2005).

Finally, if different access techniques are used to complement each other, inter-system handovers need to be solved in an elegant way. One possible solution for data is to use Mobile IP and Home Agents either within the networks or directly in terminals. The related signaling could be based on Session Initiation Protocol (SIP) with an IP Multimedia Subsystem (IMS) machinery to take care of network core functions.

## 7. Conclusions

Mobile broadband wireless access is strongly entering the consumer markets. There are several alternative techniques for it, the most notable of which are 3G HSDPA and mobile WiMAX. Both of those standards enjoy widespread support among leading vendors and operators, while proprietary solutions such as Flash-OFDM are more likely to end up as niche solutions.

While licensed frequency bands are generally sought for BWA deployment, regulators have much power to influence over the technology selection. Finland will provide an interesting example with all the major technologies represented: 3G/HSDPA, WiMAX, Flash-OFDM, and even 3G TDD. Globally thinking HSDPA will build upon existing 3G/GSM networks with vast subscriber bases, while WiMAX seems more popular with operators that have Wi-Fi or fixed background.

Vendors can be strategically divided between 3G and WiMAX, but most of them seem to play both sides of the game at least for now. The end of this year should witness terminals for both techniques, and perhaps even multimode devices. The vision of complementary techniques is quite user-centric: consumers need not know what network they are using as long as their services work. Such functionality may require e.g. some protocol changes, but those should be feasible. There are also several upcoming enhancements, which promise to make the user experience even better and to provide the services more cost efficiently.

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