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Operator options beyond 3G

A Northstream analysis of the viability of new access technologies and their impact on the mobile telecom industry

From a mobile-industry perspective, alternative access technologies such as WiMAX, Flarion's FLASH-OFDM and IPWireless's TDD-WCDMA, have sometimes been mentioned as potential candidates for delivering the next generation of mobile networks. At the same time, mobile operators are presented with "natural" technology evolution paths by the vendors who sold them their current 3G networks.

In this white paper, Northstream takes a look at some of the most talked-about alternative access technologies and compares them with the evolution paths of the currently dominant cellular standards.

The alternative access technologies we have examined are all credible technologies, which for some uses outperform established standards. Having said this, we do not expect to see 3G operators abandon their current technology paths. Both operators and their customers benefit greatly from using standardised technologies, supported by multiple vendors and deployed by many operators worldwide. However, some alternative access technologies could complement cellular 3G networks.

Executive summary

Alternative access technologies such as WiMAX, Flarion's FLASH-OFDM, and IPWireless's TDD-WCDMA, have been frequently mentioned in reports and trade press as potential candidates for delivering the next generation of mobile networks. At the same time, mobile operators are presented with ”natural” technology evolution paths by the vendors who sold them their current 3G networks.

The move towards all-IP core networks and more data-rich applications has made it interesting for mobile operators to consider data-oriented radio networks. Other players in the market may also see an opportunity to challenge the current mobile operators by deploying new access networks using some newer, and potentially more cost-efficient, technology.

In this report, Northstream takes a look at some of the most talked-about alternative access technologies and compares them with the evolution paths of the cellular standards that dominate the market today. All of the alternative access technologies we have looked into are good technologies, which for some uses outperform the established standards.

The technologies covered are WCDMA, CDMA2000, TD-SCDMA, EDGE, WiMAX (802.16), TDD-WCDMA, FLASH-OFDM, and WiFi (802.11). Some of the technologies, such as WCDMA and CDMA2000, are established mobile technologies that have been widely deployed and offer multitudes of different handsets. Others, such as TDD-WCDMA and FLASH-OFDM, are in very early stages of deployment and the end-user devices available are limited to PC cards and desktop modems. Some are entirely proprietary technologies, such as FLASH-OFDM, while others, such as WiMAX, are based on standards with broad industry support.

Technical performance like data rates, spectral efficiency and latency are important. However, there are several other factors that we believe play a larger role for the success or failure of a particular technology. To assess what roles the various access technologies might play for a 3G operator, we have investigated three key parameters: The first parameter, coordinated availability, addresses the availability of end-user devices, infrastructure and spectrum. The second parameter, cost efficiency, deals with how well the investment would fit with existing infrastructure and operations, economies of scale and whether it is possible to make the investment gradually or not. The third parameter, service attractiveness, is about what kind of services the technology would enable for end users.

We do not expect to see 3G operators abandon their current technology paths. For both operators and their customers, the benefits which come from using standardised technologies, supported by multiple vendors and deployed by multiple operators worldwide, are hard to compete with. We do not believe that operators will achieve substantial gains by differentiating in terms of radio technology. For a 3G operator, if a service can be delivered using the currently deployed technology, using this is likely the operator's best choice. If more capacity is required, the obvious remedy is to look for more spectrum for the deployed network technology. However, since licensed spectrum is a scarce and often expensive resource, this might not always be possible or economically sound.

In some cases, alternative access technologies could complement and co-exist with current 3G networks. This becomes especially likely if users turn out to be more data-hungry than expected. The fixed-broadband wireless access (FBWA) market grows increasingly interesting, for both currently fixed and mobile operators. Several alternative access technologies could even be combined: for instance, a mobile operator could use WiMAX to feed WiFi hotspots and cellular base stations.

The uptake of alternative access technologies will vary across regions. Fixed broadband wireless access deployment is likely to occur initially in regions with poor copper infrastructure but significant demand, for example, Eastern Europe and rural UK. TDD technologies are most interesting for Europe and Asia, where many operators have already obtained unpaired spectrum through their 3G licences. Deployment of data networks for nomadic usage is likely to occur initially in the US and Asia due to the technology-agnostic spectrum allocations there.

Using several different radio technologies for offering the same end-user service, increases industry fragmentation. This risks making it harder to reap the benefits of economies of scale (both for network equipment and handsets). It also makes it harder to enable broad international roaming between networks. In our view, a true mobile service should offer end users not only cell handovers and good coverage but also the ability to use the same subscription and device anywhere in the world. Multimode and multi-frequency devices are ways to deal with differences in spectrum allocation and technology deployment. However, these are costly and require large volumes to reach attractive pricing. Regulators around the world have an important role to play in assuring that spectrum is allocated to allow for deploying standardised network equipment in globally harmonised frequency bands.

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Introduction

Background

Just as mobile operators sorted out their network evolution paths for migration from 2G to 3G (e.g. EDGE, WCDMA or CDMA2000), the path complexity is increasing again. For a 3G operator, the natural network-evolution alternatives offered by their existing vendors include HSDPA (High Speed Downlink Packet Access), and EV-DO (Evolution – Data Optimised), depending on the operator's selected 3G technology. However, access technologies driven by the IT industry, fixed-line and broadband operators are also emerging as potential alternatives for mobile operators. These include e.g. WiMAX, TDD-WCDMA and FLASH-OFDM.

A few mobile operators, starting in the US, have initiated trials of solutions combining, for example, VoIP/WiFi and mobile access, while most are monitoring each other's moves, wondering how to relate to the new access alternatives. Geographical differences in operators' approaches to alternative access technologies risk resulting in industry fragmentation, impacting both individual operators and the industry as a whole. Depending on the approaches taken by the mobile and IT industries, these new, alternative-access technologies may either complement current 3G technologies or disrupt their evolution.

Evolution of the industry environment

To understand the impact of these various access technologies, it is useful to make a few observations of the markets where they will be sold and used. We believe the relevant environment to study is that of broadband wireless access (BWA), coming into existence as the result of a gradual convergence between the mobile-telephony industry, the IT industry, and the fixed-broadband industry. Taken together, users of BWA services wish to satisfy a range of use cases, which can broadly be generalised into any of three levels of mobility: fixed, nomadic, and mobile. The fixed case will include, for example, a desktop-computer user accessing his/her employer's intranet via ADSL or a person watching TV/video over the Internet. The nomadic case is semi-mobile: It includes a user who regularly moves from the office to a coffee shop, to an airport or to his/her home, etc., and requires a wireless service with similar performance in all of these locations, but does not require it when actually travelling between the locations. Today, this is often a laptop user. The mobile case includes a mobile-phone subscriber who calls while inside a moving car or in a high-speed train. Any of the technologies studied in this paper will typically handle some of these use cases especially well, others acceptably well and some possibly not at all.

Most users prefer not to think in terms of access technologies, but in terms of applications. Some of the applications that were previously used solely in a fixed (i.e. non-mobile) setting will increasingly be used while on the move. The reasons for this vary – one important, especially unpredictable, and often overlooked reason being that it has simply become possible to do it. Other reasons include more classic considerations of user benefits, efficiency, and changed life styles. Regardless of reason, for the same application, users tend to tolerate only a limited discrepancy between the performance in one environment and that in another environment. This indicates that as fixed-access data rates (typically delivered through some sort of broadband cable) increase, mobile services will have an increasingly difficult task in satisfying the user. As long as mobile and nomadic use cases are centred on continuous access to a network, the wireless technologies used to support these use cases must not lag too far behind.

Technology-social evolution of telecommunications

A few relevant, broader technological-social changes in telecommunications deserve to be mentioned before delving into the various access technologies.

The first change is the application-level phenomenon of Internet telephony, where users choose to communicate using a non-traditional voice technology, mainly to save money but also to achieve a richer user experience (integration with video calls, instant messaging, presence, and file transfer). This allows new IP-telephony operators of various shapes and forms to enter the telephony market.

The second change is the increasing usage and decreasing prices of wireless local area network (WLAN) equipment and the integration of such equipment onto the motherboards of laptop computers. WLAN could possibly come to play a role in extending Internet telephony calls wirelessly inside the home. This is also compatible with a trend in several countries of choosing laptops instead of stationary computers for use in small apartments, at universities, and at work.

A third change is taking place in terms of mobile network architectures. This is, in fact, a set of directions in which technology evolution moves:

- Firstly, there is a slow but steady move towards packet-switched architectures, particularly based on IP. The use of IP gradually extends throughout the network all the way to the base station. For current mobile operators, the benefit with VoIP in the air interface is not obvious today since current circuit switched voice implementations are very efficient. Eventually, this is likely to happen anyway but we expect it to take some time.
- Secondly, mobile core networks have slowly embarked on a road to becoming access-network agnostic. This means that they will gradually integrate several access technologies more or less seamlessly and learn how to handle users and applications when the former move from one access network to another.
- Thirdly, mobile networks are equally extending their architectures (and mobile operators their business models) to accommodate the wide set of applications-level services that are available to fixed-Internet users, but also new services, e.g. TV to mobiles. Offering various types of content (e.g. video, music) in a way that is perceived by the users as broadcasting may require new technical solutions for ensuring efficient use of the mobile network resources.

The combined effects of these changes could open up for new vendors and operators. It also pushes existing mobile operators to carefully consider which technology or mix of technologies that will put them in the best position to deliver value to present and potential new customer segments.

Purpose

The purpose of this paper is to objectively evaluate the viability of a selection of relevant access technologies and discuss their impact on the mobile industry in the context of the above-mentioned convergence process. In particular, the viability of each of the different access technologies is evaluated from the perspectives of WCDMA and CDMA2000 operators. In this paper we use the term ”alternative access technologies” to denote technologies that are not in the traditional WCDMA or CDMA2000 roadmaps going forward.

Methodology

This paper has been developed in close dialogue with leading industry players, such as mobile operators with an interest in new access technologies, vendors of infrastructure and terminals, and the industry forums for various access technologies.

Access technologies identified as alternatives for 3G operators are analysed in-depth using Northstream's model for determining the viability of network evolution paths, see Figure 1. The model takes into account the three main aspects of service availability, service attractiveness and operator cost-efficiency.

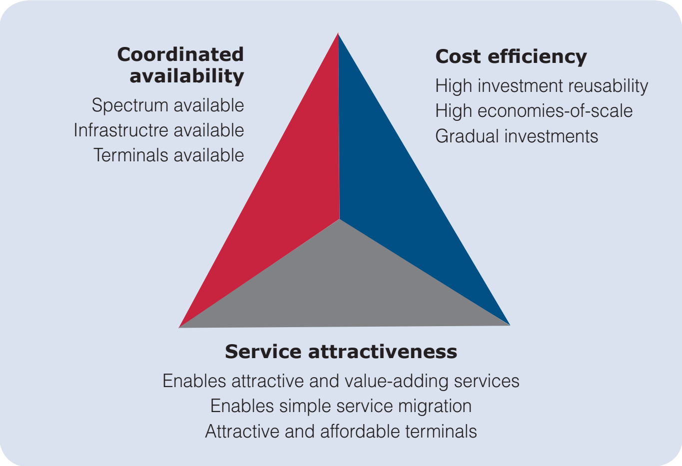


Figure 1. Model for determining technology viability

Coordinated availability. Basic prerequisites for choosing a specific evolution path are the availability of appropriate spectrum, a supply of infrastructure from a sufficient number of vendors and expectation of a broad range of end-user devices (including mobile handsets and PC cards) supporting the bearer. The availability of these different items needs to be well coordinated in time.

Cost efficiency. A preferred technology should ideally allow a high degree of reuse of investments already made, it should have high future economies of scale to minimise cost, and the evolution scenario available should allow gradual investments (avoiding high up-front costs such as network CAPEX and new handset subsidies).

Service attractiveness. Intimately related to revenue potential, a preferred technology should enable an attractive service offering to the end-user. Finally, to maximise service attractiveness, the end-user device portfolio should be rich and attractive and available at non-prohibitive prices.

Based on this analysis, conclusions are drawn on viability and risks of different access technologies and their impact on industry development. One important discussion is whether these access technologies can complement current 3G technologies or if they could potentially disrupt the 3G evolution.

Current status of the mobile market

The current status of the mobile market is an important starting point in understanding the industry impact of alternative access technologies. This section gives a brief overview of current mobile-technology usage and spectrum allocation in the global mobile market.

Global usage of mobile technologies

By the end of September 2004, there were almost 1.6 billion users of digital mobile networks worldwide. GSM is the dominant mobile technology, with 74% of the mobile users, see Figure 2[1]. At the same time, CDMA represented 14% of the users, including both CdmaOne and CDMA2000. WCDMA still comprises a small share of the total number of subscribers, but the technology is experiencing strong growth, mainly in relation to GSM and PDC. Both GSM and CDMA have benefited from the decreasing usage of TDMA technology. Motorola's iDEN has 1.1% of the digital subscribers. In addition, there is also a decreasing group of users of mobile analogue systems (less than 15 million worldwide).

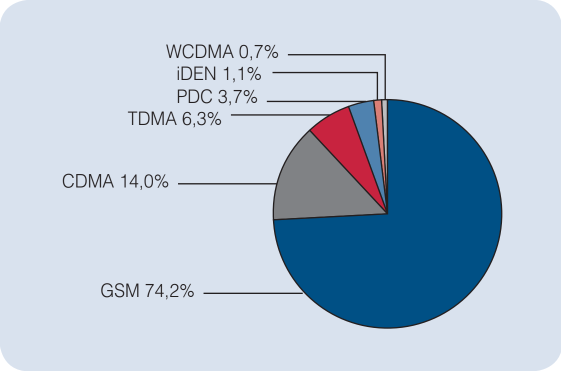


Figure 2. Global distribution of subscribers per technology. Sept 2004

[1] Source: EMC

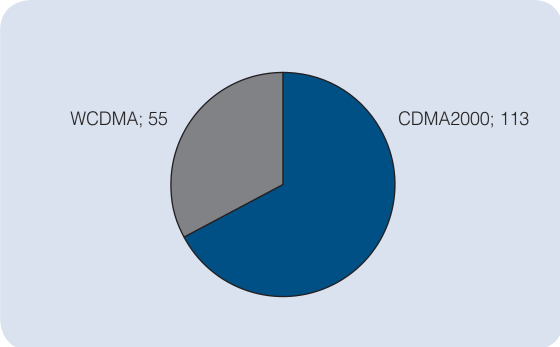


Figure 3. Number of commercially launched WCDMA and CDMA2000 networks. October 2004

Third-generation mobile telephony, defined by the International Telecommunication Union (ITU) as International Mobile Telecommunications – 2000 (IMT-2000) networks, incorporates five standards: WCDMA, CDMA2000, CDMA-TDD (including TDD-WCDMA and TD-SCDMA), EDGE and EP-DECT. This analysis includes the cellular standards WCDMA, CDMA2000, TDD-WCDMA, TD-SCDMA and EDGE, as are also a set of non-3G wireless technologies that we deem useful to examine because of the benefits they could offer a mobile operator.

WCDMA and CDMA2000[2] are the third-generation mobile telephony systems that have been commercially deployed to a larger extent. Figure 3 shows the number of WCDMA and CDMA2000 networks that were in commercial use worldwide in October 2004. The number of CDMA2000 networks is more than double the number of WCDMA networks, but it should be noted that the majority of the CDMA2000 networks are of the CDMA2000 1X version. The number of the more evolved CDMA2000 1xEV-DO networks commercially launched to date is 16[3]. In total, 125 WCDMA licenses have been awarded.

Spectrum allocation in the global mobile market

The spectrum allocation situation is closely related to available network evolution strategies at hand. In many countries, spectrum bands are also explicitly associated with specific technologies. Spectrum regulation, combined with various market-related factors have led to a regional distribution of mobile subscribers.

Europe's primary wireless technology is GSM, see Figure 4, which in this region uses the 900 and 1800 MHz bands.[4] In most European countries, the IMT-2000 2 GHz band has been allocated to operators for WCDMA (most commonly together with some specific spectrum for TDD-WCDMA). Europe was estimated to have around five million WCDMA subscribers by the end of November 2004[5], constituting approximately 1.4% of the total mobile-subscriber base.

Historically, the usage of CDMA in Europe has been low, with networks in use mainly in Eastern Europe and Russia. Lately, CDMA450 has emerged as an option for the various 450 MHz bands that have become available with the phase-out of, for example, NMT450. CDMA450 is a term used for CDMA2000 technologies deployed in the 450 MHz band. This is applicable not only in Eastern Europe and Russia, where operators have already launched CDMA450 services, but also to operators in the Nordic countries.

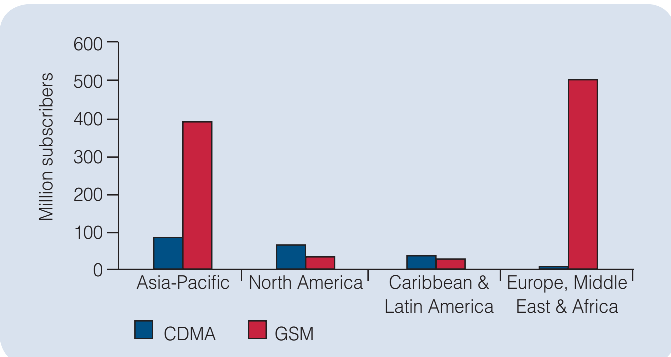


Figure 4. Distribution of GSM and CDMA subscribers per region, end of 2003. Sources: EMC, CDG

[2] In this report the term "CDMA2000" is used as a collective reference to CDMA2000 1X, CDMA2000 1xEV-DO and CDMA2000 1xEV-DV. CDMA2000 1X is an ITU-approved 3G standard, but in practice provides only approximately twice the throughput of GPRS, which is a 2.5G system.

[3] Source: CDG, November 16 2004

[4] Source: EMC; CDG

[5] Source: Northstream

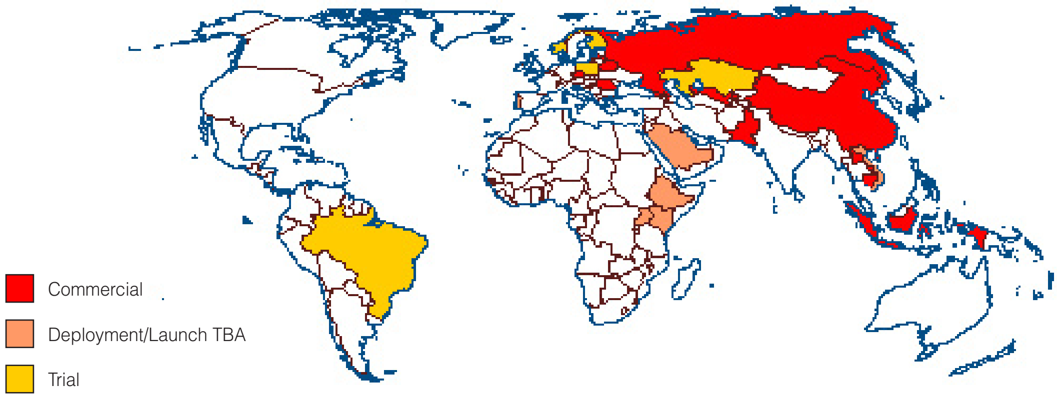


Figure 5. CDMA450 networks. February 2005

Figure 5 shows the status of CDMA450 worldwide by February 2005. The number of commercial CDMA450 networks today is 17, with networks launched in for example Eastern Europe, Russia, Pakistan, Cambodia, Laos and Indonesia[6].

In North America the current CDMA, TDMA and GSM technologies use the 800 MHz cellular band and the 1900 MHz PCS band, the latter blocking the IMT-2000 2 GHz band and causing a shortage of spectrum. In November 2002, the US telecom regulator, the FCC, published a document discussing rules to allocate 90 MHz in the 1700 MHz and 2.1 GHz bands for the provision of Advanced Wireless Services, plus another 30 MHz in parts of the 2.1 GHz band. However, the actual licensing process will not occur until 2006. Until then, US operators are using their PCS band to provide WCDMA services.

In Central and South America, wireless technologies are dominated by analogue and 2G operations in the 800 MHz band using AMPS/TDMA, with some GSM and CDMA coverage. In most countries, such as Chile, Mexico and Argentina, the 1900 MHz band has been allocated, as in the US. The biggest market, Brazil, has allocated the 1800 MHz rather than the 1900 MHz, leaving IMT-2000 2 GHz band available for the future.

The major technology shift when migrating from 2G to 3G took place in the American market, where the TDMA operators had to select either the GSM/WCDMA or the CDMA2000 network evolution path. Figure 6 shows that GSM experienced a yearly subscriber growth of 124% in the Americas while CDMA grew by 26% (measured from September 2003 to September 2004)[7].

The most common technology in Asia-Pacific is currently GSM, used in the 900 and 1800 MHz bands. Many countries in the region have selected WCDMA as their main 3G technology, but there are exceptions. South Korea strongly favours CDMA and continues to do so also for 3G. Japanese operator KDDI has gained momentum due to the higher data speeds being provided by its CDMA2000 network compared with other available standards. In addition, there are commercially operational CDMA2000 networks in such countries as Australia, China, Indonesia, Mongolia, New Zealand, Pakistan, Taiwan and Thailand.[8]

The Asian spectrum situation for 3G is complex, since it is influenced by both European and American interests. The Europeans are pushing for the Core/IMT-2000 band, while the Americans favour the PCS band. The telecom spectrum allocation in Europe, the Americas and Asia is summarised in Table 1.

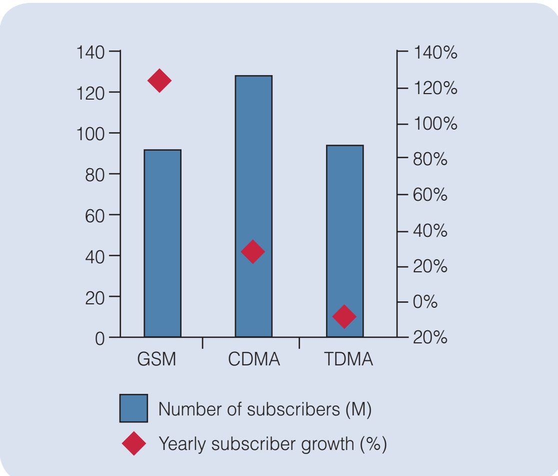


Figure 6. Number of subscribers and growth per technology in Americas. September 2004

[6] Source: CDG
[7] 3G Americas ; EMC
[8] Source: CDG

Frequency band	Europe	USA	Americas excl. the US	Asia	Comment
700 MHz	Used for other purposes	698-746 MHz (lower) 746-794 MHz (upper)	Used for other purposes	Used for other purposes	Refarming under licensing rules to mobile services. The broadcasting industry is in transition from analogue to digital systems.
850 MHz	Used for other purposes	824-894 MHz	824-894 MHz	824-894 MHz	”Cellular band” used for TDMA, CDMA, GSM and WCDMA, including IMT-2000 in Americas, partly used in Asia, such as Australia, China, India, Indonesia and New Zealand
900 MHz	890-960 MHz (GSM) 880-960 MHz (Extended GSM)	Used for other purposes	890-960 MHz used in some Latin American countries e.g. in Brazil and Chile	890-960 MHz (GSM) 880-960 MHz (Extended GSM)	”GSM 900 band”
1800 MHz	1710-1880 MHz	1710-1755 MHz paired with 2110-2155 MHz	1710-1770 MHz paired with 2110-2170 MHz 1710-1880 MHz e.g. Brazil	1710-1880 MHz in most Asian countries. Other arrangements exist in some few Asian countries.	”GSM 1800 band” ”the Clinton bands” in the US
1900 MHz	Other spectrum arrangements	1850-1990 MHz (+ 5 MHz in the G-block, discussions about allocation of 5 MHz in H-block)	1850-1990 MHz	Other spectrum arrangements	”PCS band” used for TDMA, CDMA, GSM and WCDMA, including IMT-2000 in Americas.
2 GHz	1920-1980 MHz paired with 2110-2170 MHz; 1900-1920 MHz, 2010-2025 MHz unpaired	Other spectrum arrangements	Other spectrum arrangements 1920-1980 MHz paired with 2110-2170 MHz in Brazil	1920-1980 MHz paired with 2110-2170 MHz; 2010-2025 MHz unpaired	”Core band”/ IMT-2000 Partly possible ”WiMax band” (TDD-version)
2.3 GHz	Used for Aeronautical and Military services	2300-2400 MHz DARS and WCS	2300-2400 MHz Used for other purposes	2300-2400 MHz WiBro in Korea, China TD-SCDMA	WiBro, similar to WiMAX Possible future ”WiMAX band” (TDD-version)
2.45 GHz	2400-2483.5 MHz	2400-2483.5 MHz	2400-2483.5 MHz	2400-2483.5 MHz	ISM band: Bluetooth and WLAN etc.
2.5 GHz	2500-2690 MHz IMT-2000/UMTS extension	2500-2690 MHz AWS, including IMT-2000 Potential usage for BWA	2500-2690 MHz IMT-2000 used mainly for MMDS	2500-2690 MHz IMT-2000 extension	”IMT-2000 expansion band” 2500-2690 ”AWS, including IMT-2000” in the US Possible WiMAX band (USA)
3.5 GHz	3410-3600 MHz Partly allocated for FWA. Regional licenses in some countries but most often National licences	3400-3650 MHz Partly allocated for FWA. Partly used for military purposes (Radar)	3400-3650 MHz allocated for FWA.	Unclear, no homogenous usage in region	FWA and BWA band Possible future ”WiMAX band” (FDD version)
5 GHz	5150-5350 MHz 5470-5725 MHz	5150-5350 MHz 5470-5725 MHz	5150-5350 MHz 5470-5725 MHz	5150-5350 MHz 5470-5725 MHz	WAS and WLAN etc. coexisting with Radar Possible future ”WiMAX band”
5.8 GHz	Used for other purposes, used for military purposes (Radar)	5725-5825 MHz	5725-5825 MHz	Used for other purposes	”ISM band”; WLAN etc. Possible future ”WiMAX band” (TDD-version)

Table 1. Spectrum allocations to public communication services (as of January 2005). Sources: Northstream, Ericsson

Viability of selected access technologies

Introduction

Many competing radio-access technologies have been standardised, proposed or are under development. In this paper, a thorough look is taken at some of the more prominent technologies regarded as potential options for 3G operators.

When analysing the service attractiveness of different access technologies, it must be remembered that there is a theoretical limit to how much data can be transmitted down a given channel bandwidth and no technology (or modulation) has or will have a clear advantage over any other. Marketing material often mentions unqualified peak throughput and maximum range figures, but this should not necessarily be interpreted as if they can be achieved at the same time. Any radio signal can go a long way if you build the base station high enough, which in practice can be difficult to realise.

The key factors that effect throughput are occupied signal bandwidth (more bandwidth allows higher throughput) and transmit power level (more power allows a wider range).

Capacity and throughput calculations for mobile data networks

It is necessary to scrutinise the performance claims of various vendors and normalise their performance and identify whether the technology really does provide something better than competing solutions. The physical limitations of radio are applicable independently of radio access technology.

Peak Bit Rate

This "headline" figure is quoted by most vendors – even where it does not represent the user-achievable rate. For example, 802.11b claims 11 Mbit/s although under exceptionally good radio conditions it is quite impossible to get above 8 Mbit/s user data throughput due to the protocol overhead consisting of guard band, packet headers and packet acknowledgements.

Spectral Efficiency

The bandwidth (Hz) used for a given bit rate (bit/s) gives a good indication of the spectral efficiency of a technology.

Frequency Reuse

Additionally, different modulation techniques require different signal-to-noise ratios (or Eb/No) which will impact capacity in a system. A system that requires a high signal-to-noise ratio will require that co-channel interference is minimised by using a loose frequency reuse. This in turn reduces the amount of spectrum available at each site. Even the reuse factor depends on what propagation model the vendor used for their simulation - if any.

Cell centre vs. cell edge performance

All of the systems mentioned feature some sort of adaptive data-throughput characteristic. If the user is near the base station, better performance or less resources are used than if they are at the cell-coverage edge. This has a subtle but important effect on the cell capacity and depends on the user data usage characteristics, which are difficult to predict.

If we take speech in WCDMA as an example, each voice call requires approximately 20 kbit/s. If all users are at the cell edge then cell capacity drops so that around 40 simultaneous users can be supported. If all the users are near the cell centre, the cell capacity can exceed 100 users. The average could be claimed to be (100+40)/2 = 70 users. The user distribution has a huge effect on the actual cell capacity: Since more of the area in a cell is closer to the edge than to the centre, even such a mean value might be misleading.

Similarly, in data-network dimensioning, if all users have the same long-term average usage (a conventional assumption in ADSL planning), then that means that users download the same amount of data over a given period. If the cell- edge data rate is, say, one-tenth of the cell-centre rate (as is approximately the case for 802.11b) then this means that the edge users occupy the base station resource for 10 times longer than the cell-centre users – remember, they have the same long-term number of bits to send. Cell-edge users dominate the base station usage and thus reduce the average cell performance.

This is a potential fallacy of all the systems that claim high peak rates near the cell centre. By increasing the throughput for the cell-centre users, their capacity requirements are fulfilled more rapidly and they leave the channel, but the cell-edge users continue to dominate the bulk of the data sent – the throughput average does not necessarily increase.

This applies to the HSDPA, WiMAX and higher order modulation capacity claims – if the high order modulation only applies to the cell centre, where the signal to noise is sufficiently good enough to support it, then only the users in the cell centre will benefit. Unfortunately, the edge of a coverage area is always bigger than the cell centre. In Non Line-of-Sight (NLOS) systems, the cell edge includes indoor or poor-signal locations near the cell centre – so the cell edge is even larger.

The whole system performance depends a great deal on how the users are distributed throughout the cell-coverage area and how the adaptive throughput mechanism manages them.

On another note, the seemingly endless need for additional spectrum is largely driven by economics. If cost was not a problem, spectrum that is already in use could be used more efficiently than is the case today, since the radio network could be more densely built and technology improved. However, additional sites for base station equipment and antennas are difficult to acquire and backhaul is often expensive. At a certain level, it becomes cheaper to acquire additional spectrum than to make the existing network denser.

Shared capacity – statistical multiplexing

Almost every element in the Internet is a shared capacity resource. The bigger the pipe, the more efficiently data services can take advantage of statistical multiplexing.

For example, a 1 Mbit/s ADSL service is typically shared at a higher level. A single 1 Mbit/s ADSL user may actually be one of 200 users sharing 4 Mbit/s capacity – at a 50:1 contention ratio, with each user capped to 1 Mbit/s. The long-term average rate per user is assumed to be about 10 kbit/s. The statistical distribution of traffic means that network congestion is minimised.

If the shared capacity is, say, only 1 Mbit/s, then far fewer users can be supported – even if they have the same long-term average-rate requirement. This is analogous to trunking efficiency in tele-traffic dimensioning.

Comparing wireless networks with DSL

Each DSL (e.g. ADSL) user will have their full capacity available to them on the access network. Contention will be at the Digital Subscriber Line Access Multiplexer (DSLAM) in the local exchange – not in the copper line to the individual household. The operator can add more trunk capacity (or DSLAMs) without technical limit.

In a broadband wireless access arrangement, the contention occurs for access: the radio channel capacity is shared. Limited spectrum constrains the operator access capacity to certain bounds. This is the key difference between wireless and wired broadband access – a landline operator can always add more capacity.

It should be noted, however, that the reach of DSL technologies shows characteristics similar to those of wireless technologies. In fact, DSL technologies can only be provided within a certain distance from the local exchange. And the further away the customer is, the lower the maximum data rate.

Flow control in wired vs. wireless systems

A general difference between wired and wireless concerns transport-level protocols. TCP/IP contains a flow-control mechanism based on two characteristic features: Slow start and Congestion avoidance. The former means that as long as transmission goes well, the transmission rate gradually increases towards the maximum value. The second means that when packet acknowledgements are lost or errors encountered, the algorithm assumes that the reason is network congestion: Therefore the congestion-avoidance feature makes TCP slow down its transmission rate of packets, and then invoke slow start to get things going again. Essentially, all errors are treated as congestion. This mechanism permits fair sharing of the Internet bandwidth. If many users try to send data, the resulting congestion triggers TCP Congestion avoidance and thereafter slow start. This way, the data rates from all users will increase until they all get an equal share of capacity.

In wireless access networks the error rate due to radio interference and fading is naturally much higher than in a wired system. This causes raw TCP/IP to be continually 'slow-starting' and the effective data rate would always be very low. Thus TCP/IP is not an efficient air-interface protocol. This problem is avoided to some extent by using a forward-error correction (FEC) mechanism on the radio link. FEC adds additional protection bits to the data stream so that some minor errors can be detected and corrected without the receiver asking for a retransmission, thus avoiding TCP/IP slow starts and thereby maintaining throughput.

Quality of Service mechanisms are being introduced in IP networks to allow guaranteed bandwidth for, or prioritisation of, services that need it. Examples of such services include voice over IP (VoIP) and streaming services.

Non-Line of Sight (NLOS)

A key characteristic claim of many Broadband Wireless Access (BWA) systems is the Non Line-of-Sight (NLOS) ability of these technologies. This sets them apart from regular microwave services, or Local Microwave Distribution Services (LMDS), which operate in the higher microwave frequency bands and require an obstruction-free, clear Line-of-Sight (LOS) path to operate correctly. The performance of LOS systems is much higher, but they require fixed antennas and CPE-installations that tend to be quite expensive.

At frequencies above approximately 2.5 GHz, NLOS could be thought of as "Near Line-of-Sight" rather than "Non Line-of-Sight", as radio waves in higher frequency bands do not diffract or scatter as usefully as they do in lower frequency bands. This means it becomes more expensive to achieve good area coverage in urban areas, where there are many obstructions.

WiMAX forum claims that NLOS communication is achieved by using a combination of power control, adaptive equalisation, modulation and coding techniques, and advanced antenna systems to overcome some of the problems of channel dispersion and fading. These techniques add a few extra dB onto link budgets allowing paths that are slightly obstructed to be useful[9]. However, this comes at the cost of reduced throughput or capacity. Thus, in mobile systems where fading and dispersion is part of the network's normal propagation conditions, this reduction in coverage and throughput should be reduced from the static headline throughput figures. Propagation characteristics are mainly a function of the frequency band in use and not the modulation scheme. NLOS techniques do not provide coverage to areas where the signal is totally blocked by terrain or buildings.

Mobile technologies and a true mobile end-user experience

When talking about mobility and access technologies, analysts often refer to whether the technology supports handovers when users cross cell boundaries and how fast you can travel without losing your connection. This is relevant, but is only part of what is required for an operator to be able to offer the end user true mobile services. Mobility for the end-user also includes the possibility to use the service at as many different locations as possible. This means that coverage is important. Coverage could be obtained by deploying a large network, but it could also be obtained by making sure that the customer can use networks deployed by other operators using the same technology in the same frequency band. To do so, a commercial framework for roaming is needed. Even greater coverage could be obtained by roaming agreements, with operators deploying different access technologies or the same technology but in other frequency bands. In addition to regular roaming agreements, this latter option also places requirements on multimode and multi-frequency devices and interoperability.

WCDMA

Description

FDD-WCDMA (WCDMA) is the most widely deployed version of the UMTS standard (others being TDD-WCDMA and TD-SCDMA).

For WCDMA operators, High-Speed Downlink Packet Access (HSDPA) is the next logical step along the 3G evolution path. Most importantly HSDPA introduces a new higher-order modulation format (16QAM) and some minor feature improvements to fully exploit it, resulting in higher downlink data speeds. The new modulation allows double the number of bits per symbol and thus a higher raw data rate.

To take advantage of this higher-order modulation format, good radio link quality is required. Cleverly, the user equipment transmits the link quality parameter to the base station more often. The speedy channel quality assessment allows for the higher modulation format and lighter coding overhead to be used under the momentarily good conditions normally experienced in a fading environment, thus dramatically improving the user throughput. Additional latency improvements are achieved by scheduling and retransmissions at the Node B rather than further back in the RNC (Radio Network Controller). This avoids extra framing delays through the backhaul. To do this, the Node B must retain packets for possible retransmission. The spreading factor and power control remains constant and the coding level adjusted according to link quality. All of these features combine to enhance the data throughput and reduce the latency of WCDMA.

HSDPA only applies to the downlink. Enhanced Uplink or High-Speed Uplink Packet Access (HSUPA) will bring corresponding improvements to the uplink throughput. The HSUPA standard is expected to be finalised in 2005.

Further improvements of WCDMA include HSDPA phase 2 and what is referred to as ”Super 3G”. Super 3G is not yet a defined standard, but will build on reusing the current WCDMA spectrum with improvements of current standards to allow for data rates in the range of 20-100 Mbit/s. Potential improvements could be to use higher-bandwidth carriers or different modulation techniques on uplink and downlink. Super 3G will not only be developed for the WCDMA spectrum, but also for use in the current GSM bands.

Coordinated availability

There are 104 3G/WCDMA device models in the market and 20 suppliers of WCDMA devices globally[10]. Even if this number includes data cards and models no longer for sale, the supply of WCDMA terminals is rich and the form factors have improved substantially since when the first dual-mode 3G phones appeared early 2003. Network equipment is available

[9] Source: WiMAX Forum “WiMAXNLOSgeneral_versionaug04.pdf”
[10] Source: GSA, 1 December 2004

immediately from many vendors, e.g. Nokia, Ericsson, Nortel, Alcatel, Huawei and Siemens.

Licensed spectrum for WCDMA is available in most major markets, mainly in the 2 GHz band but also in the 2.6 GHz band from 2006.

The HSDPA standard is ready and most major vendors plan to offer network upgrades from mid-year 2005. We estimate that PC cards supporting HSDPA are likely to be available early in 2006 and that handsets with integrated HSDPA support will be introduced 9-12 months later.

Upgrades for Enhanced Uplink / HSUPA and further improved downlink capacity will probably not be available before 2007.

Cost efficiency

HSDPA is a step in the ongoing development of WCDMA, i.e. with the 3GPP standardisation support and related vendor and operator involvement. Most WCDMA base stations will support the upgrade through either hardware or software modification. Network core equipment will likely need a software upgrade. Since the upgrade is relatively easy and the data capacity gain is 2-3 times it is a very cost-efficient upgrade. To fully support the potentially higher throughputs of HSDPA, backhaul transmission capacity expansion may be necessary.

Work is ongoing to develop WCDMA for use in the 900 MHz band. This technology, when available, will be cheaper per voice carrier compared to GSM.

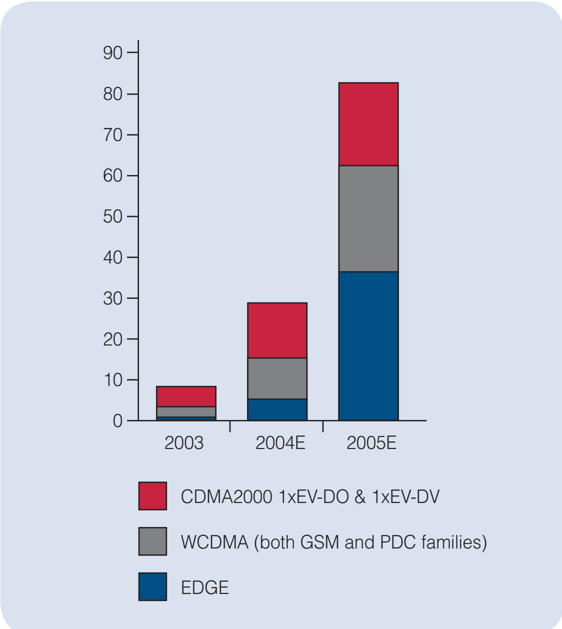


Figure 7. 3G handset sales volumes. Source: ARC Group

Service attractiveness

Currently, practical implementations of the WCDMA standard support circuit-switched voice and video calls, and packet-data rates of up to 384 kbit/s for several users per sector.

HSDPA will improve this further. Since higher-order modulation schemes rely on good signal quality it is likely that the high data rates will not be available in all parts of a cell. As mentioned, systems with adaptive modulation will always have lower average throughput than quoted peak rates. However, HSDPA fast link-quality signalling on the uplink allows the Node B to immediately react to momentary channel quality improvements and push a faster data rate – even where average link quality may be poor, for example, at the cell edge. Such responsiveness is not possible in TDD systems due to the longer transmit-receive cycle introducing delays to the link quality feedback mechanism.

All together, the family of feature enhancements in HSDPA will allow single carrier data throughput to rise from the maximum of 384 Mbit/s for current WCDMA systems to around 14 Mbit/s downlink (over the air). Since not all users will have access to the maximum performance at all times, the end-user experienced data rate will be lower, but still much better than with current WCDMA. This improvement will be especially noticeable for services like download of video and music. The user-experienced data rate is estimated at max 8 Mbit/s under favourable conditions indoors and maybe 2-5 Mbit/s in a normal urban radio environment. The improved data rate combined with a 2-3 times increased capacity per cell will also make it possible for the mobile operators to use HSDPA to offer DSL-like services. Evolutions of the 3GPP standard will allow for an even more attractive data offering further on.

The availability of dual-mode handsets (GSM/WCDMA) and the vast amount of roaming agreements already in place makes it possible for users to access voice services from most countries. The footprint for high-speed data services is rapidly growing as new WCDMA networks are deployed and as roaming agreements are updated to incorporate 3G services in addition to GSM/GPRS.

Conclusions

WCDMA is a well established standard with wide industry support and millions of users world wide. It is also a natural choice when current GSM operators need to upgrade their mobile networks. We believe that nearly all operators that have deployed WCDMA networks will sooner or later upgrade to new versions, such as HSDPA and enhanced uplink / HSUPA etc.

CDMA2000

Description

CDMA2000 1X and CDMA2000 1xEV-DO (Evolution – Data Optimised) are well-proven technologies originally proposed by Qualcomm and widely deployed in the US, Latin America, Asia, Africa and Eastern Europe. The technology delivers 3G services while occupying a small amount of spectrum (1.25 MHz per carrier).

CDMA2000 1X is a voice-capacity enhancement to the original IS-95B, bringing the number of voice channels supported to around 34 (~26E) per 1.25 MHz carrier. The theoretical peak data rate under CDMA2000 1X is at 153 kbit/s. Typical user-experienced data rates are in the range 60-70 kbit/s.

1xEV-DO is an evolution optimised for data traffic and provides a peak data rate of 2.4 Mbit/s. EV-DO Rev. 0 is currently available, but the CDMA roadmap contains an improved Rev. A expected to be available for deployment in 2006.

Further enhancements include 1xEV-DV (EVolution – Data and Voice). The main purpose of 1xEV-DV is to allow operators to share data and voice on the same carrier. In data-only mode, 1xEV-DV has similar performance to 1xEV-DO (Rev. A). In voice-only mode, it will have similar capacity performance to CDMA2000 1X. With the QoS enhancements coming to 1xEV-DO (Rev. A), there seems to be little incentive for operators to change to 1xEV-DV. At this time it is unclear if any CDMA equipment manufacturers plan to introduce 1xEV-DV products.

Coordinated availability

CDMA networks are available in several frequency bands, including the 450, 700, 800, 900, 1700, 1800, 1900 and 2100 MHz bands. The latest addition is the 450 MHz band, where operators have limited spectrum and can take advantage of CDMA's high capacity in a narrow bandwidth.

Qualcomm has been pushing the use of CDMA450 for the various 450 MHz licenses that are currently being allocated around Europe. This is an interesting option for operators with a small allocation of 450 MHz spectrum as it will have superior coverage suitable for sparsely populated areas.

Generally, CDMA2000 1X and CDMA2000 1x EV-DO Rev. 0 infrastructure and terminals are available now, with 16 1xEV-DO Rev. 0 networks commercially launched by November 2004. There are over 578 CDMA2000 1X and 68 CDMA2000 1xEV-DO Rev. 0 terminals available from vendors like Audiovox, Axesstel, SonyEricsson, CURITEL, Handspring, Huawei, Kyocera, LG, Motorola, Nokia, Research in Motion, Samsung, Sanyo, Telular and ZTE. CDMA/GSM dual-mode handsets have been commercially launched by both China Unicom and Verizon Wireless. In addition to phones, wireless modem products from AnyDATA, Sierra Wireless and others have also been released.[11]

1xEV-DO Rev. 0 terminal devices will not be able to take full advantage of the improved data rates available from Rev. A infrastructure – however, Rev. A terminals will be backward compatible on Rev. 0 infrastructure with reduced performance.

1xEV-DO Rev. A infrastructure will not be available until 2006. South Korea is likely to lead infrastructure deployment. Rev. A devices will likely be available in quantity shortly after the South Korean roll-out.

Cost efficiency

The CDMA family of technologies has broad industry support in the US, Korea, China and other Asian countries, and most notably in India – where the number of CDMA phones exceeds the number of GSM phones.

With the Chinese and Korean manufacturers involved, it can be expected that costs will be kept low.

CDMA2000 1xEV-DO offers an opportunity for CDMA2000 1X operators to add a strong data offering to their portfolio of services for an incremental investment. 1xEV-DO Rev. 0 requires channel cards and upgraded software in base stations and the switching parts of the network.

Service attractiveness

CDMA2000 1X is best-suited to voice and moderate speed packet-switched data services. Reasonably good speech capacity is available now with up to 35 voice channels on a single carrier.

The data dedicated 1xEV-DO carrier enhancement offers peak downlink data rates of up to 2.4 Mbit/s (average 1 Mbit/s depending on level of mobility, range, signal level, noise and interference, cell loading, radio propagation environment etc.) and up to 153 kbit/s uplink in the Rev. 0 versions. Rev. A offers up to 3.1 Mbit/s downlink and a greatly improved 1.8 Mbit/s uplink.

Field reports indicate that CDMA2000 1xEV-DO performance is quite acceptable, with the peak rates achievable under good conditions.

CDMA2000 1X and 1xEV-DO are continually being enhanced to eventually allow handoff to UMTS. For operators with the US-aligned cellular bands, CDMA2000 represents an attractive way forward with a roadmap of improvements and enhancements.

[11] Source: CDG, August 2004

CDMA vendors have been working to produce multimode chipsets supporting GSM/CDMA/WCDMA. However, these chipsets may offer simple network reselection rather than true in-call handoff. Some Korean suppliers are working on true CDMA/UMTS handoff, which will be of specific interest to US operators, since all these three network technologies are being used in US. These devices will allow US operators to catch up with the roaming advantage of the GSM/WCDMA world.

Qualcomm continues to support the CDMA2000 1X standard with Internet services, Qualcomm's Java-like BREW technology, streaming, location-based services and other technologies, including plans for enabling broadcast of TV to the mobile.

Conclusions

CDMA2000 1X and CDMA2000 1xEV-DO are proven technologies with wide industry support. We do believe that the next step for the CDMA2000 1xEV-DO operators will be 1xEV-DO rev A. We do not expect to see 1xEV-DV gaining any traction. We do not see any strong reasons for operators with legacy CDMA networks to look for alternative access technologies as long as similar services can be delivered using upgrades of existing technology.

TD-SCDMA

Description

Time Division - Synchronous Code Division Multiple Access (in short, TD-SCDMA) is a 3G standard using 1.6 MHz wide channels to support voice, symmetric and asymmetric data services. It is primarily being developed for the Chinese market.

Key to the technology is a set of advanced radio features, such as smart antennas and joint-detector receivers, aiming at increasing capacity and spectrum efficiency.

With TDD, it is possible to adjust the uplink/downlink ratio[12], which would be useful for Internet-type traffic where the downlink traffic stream is usually larger than the uplink one. However, the flexibility to adapt to traffic asymmetry has some limitations. An entire network will likely need to have the same asymmetry to avoid interference between adjacent sites. Although the asymmetry is not applicable on user level (but rather on network level) it is still a very useful feature, since the optimal level of asymmetry depends on what applications will be used in the future.

Smart antenna techniques are used to direct the radio signal to where the mobile device is located. This decreases interference both in the cell and between cells. A key requirement for smart antennas is TDD, which allows fast and accurate direction estimation to be applied on the downlink (beam-forming) once the direction of the mobile device has been established. This is more difficult to do in an FDD system because the difference in uplink and downlink frequencies introduces direction estimation errors that are not easily offset. Smart antennas are not without problems, though. If some antennas do not receive a signal due to fading, this can result in inaccurate direction estimations.

Coordinated availability

TD-SCDMA production volumes depend very much on China, which has not issued 3G licences yet. As the Chinese consider TD-SCDMA to be 'the Chinese' 3G standard, as opposed to WCDMA ('the European') and CDMA2000 1X ('the American'), it is widely expected that pressure will be exerted to ensure that at least one – possibly two – out of the three or four 3G licences will go to operators deploying TD-SCDMA networks. The Chinese Ministry of Information Industry (MII) announced as early as 2002 that a 155 MHz block of spectrum around the 2 GHz band would be used for TDD service, with part of that being earmarked for TD-SCDMA. Another 60 MHz of spectrum would be allocated for WCDMA and CDMA2000 1X together.[13] This development would ensure rapid take-up of TD-SCDMA production volumes and, as a result, several vendors have expressed interest in the manufacture of TD-SCDMA equipment. Until recently, it was widely expected that Chinese 3G licences were to be distributed in mid-2005. However, such expectations have been proven wrong on several earlier occasions, as the MII has repeatedly delayed licence distribution.

The key unknown regarding the availability of TD-SCDMA networks, is how long the MII will accept to wait for the TD-SCDMA technology development, which is lagging behind the other two 3G technologies considerably. Field tests during the second half of 2004 are reported to have shown disappointing technical results for TD-SCDMA handsets, in particular, which were perceived as "bulky and hot." This has led telecom analyst Signals Research to predict commercial availability of TD-SCDMA

[12] TD-SCDMA uses 7 timeslots in a 5 ms frame. Typically the frame is divided into a 4:3 downlink-to-uplink ratio.

[13] In December 2004, Chinese media reported that, contrary to earlier information (according to which the 2000, 2300, and 2400 MHz bands would be used for TD-SCDMA in China), the 800 MHz band was now also being considered by authorities in order to improve TD-SCDMA performance. Northstream notes that the last word has apparently not been said on this issue.

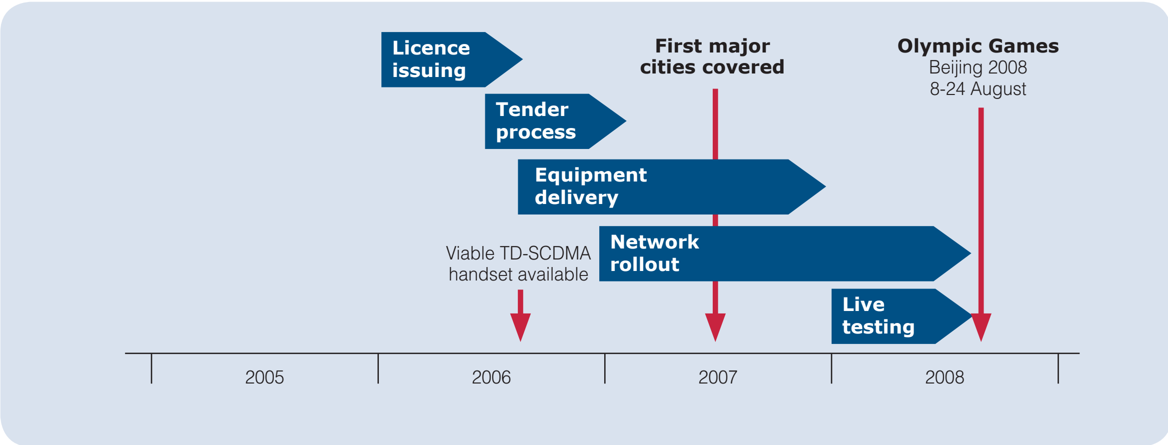


Figure 8. Squeezed, but viable, Chinese schedule if MII/NDRC chooses to wait even longer than currently expected (2H-2005) to issue licences, allowing TD-SCDMA technology time to show acceptable performance. We believe that Chinese operators could cover substantial parts of the urban and suburban areas with 3G networks in a year's time. After that, another 6 months' real-world testing and tuning of the commercial networks would be desirable to assure they are running smoothly by the 2008 Olympic Games.

handsets by mid-2006 at the earliest[14]. On the other hand, if Chinese 3G licences were to be handed out during the second half of 2005, we assess that the initial commercial networks would arrive in major cities towards the end of 2006, leaving some time to engineer smaller handsets.

In short, TD-SCDMA can be seen as a 'Chinese' radio air interface, developed to secure Chinese vendors part of the 3G market – an important step in China's build-up of its own telecommunications industry.

A range of vendors have announced TD-SCDMA network equipment. These include ZTE, Huawei & Siemens, Datang Mobile, and Putian. Once licences have been distributed, we would expect more companies, such as UTStarcom, to join this range. Note that several major vendors, such as Ericsson and Nokia, have not announced any plans to deliver TD-SCDMA equipment.

Siemens Communications and Huawei Technologies have formed an alliance under the name TD Tech to jointly develop TD-SCDMA equipment. The alliance aims to have network-infrastructure equipment commercially available by the end of 2005[15]. Chinese state-owned Datang Mobile, which cooperated earlier with Siemens on TD-SCDMA technology development, is also a key player in this field. Along with ZTE, Datang Mobile has constructed two trial networks in Shanghai, which are being run by China Unicom and China Satcom. Another two trial networks have been put in place in Beijing jointly by Datang Mobile, Nortel, and Putian. These are being operated by China Netcom and China Railcom, respectively.

Several vendors have announced TD-SCDMA handsets, including Samsung, Datang Mobile & Alcatel, Bird, DBTel, and more[16]. However, during the 2004 trials, only one TD-SCDMA handset was available (provided by Datang), compared with a rich supply of WCDMA and CDMA2000 handsets. The MII has however complained about the lack of WCDMA and CDMA2000 1xEV-DO handsets from domestic vendors.

Cost efficiency

Siemens and Datang are the main vendor proponents of TD-SCDMA. Other Chinese vendors, such as those mentioned in the previous section, will also contribute to volume and competition in the TD-SCDMA equipment and handset market. The economies of scale originate from the potentially large Chinese market and the huge production capacity Chinese vendors can mobilise.

From an operator perspective, a technical-commercial advantage of TD-SCDMA is that the

[14] Global Mobile, 17 November 2004.
[15] Source: Interview with Mr. Martin Sanne, VP Portfolio Management at Siemens Communications Mobile Networks, 13 January 2005.
[16] Samsung, Datang Mobile, and Philips have launched a joint-venture under the name T3G Technology, which will produce TD-SCDMA handset chipsets. Other TD-SCDMA chipset vendors include Analog Devices and CYIT.

minimum block of capacity is small, eliminating the need to install large-capacity base stations early on in the network lifecycle. However, when the need arises to add new carriers for capacity expansion, the operator may be presented with some interesting challenges. While the smart antenna may be able to support more carriers, it will likely only be able to do it with lower transmission power, due to amplifier-linearity limitations, leading to reduced reach. Initial-coverage networks may be readily built, but capacity expansion of existing sites may be more difficult in the future, since the amplifiers are built into the smart antennas themselves. Since the spectrum available in China is large, it seems reasonable to assume that large site configurations will be used to offer high capacity where needed. Multi-carrier smart antennas will need to be developed to make the expansion easy.

Service attractiveness

Analysts have varying opinions, and vendors are reluctant to specify, in what Chinese regions they expect TD-SCDMA to play the key role. However, consensus is that the technology will be very suitable for voice applications, and the Chinese market is very voice-oriented today.

The formal data transfer capacity per user of TD-SCDMA is on a par with that of WCDMA, according to the standard. However, the use of advanced antenna technologies may make it possible to provide more subscribers simultaneously with positive user experiences, by using the total spectrum more efficiently.[17] These advanced technologies still have to prove that they bring the promised technical capacity increases in real-world deployments and that they are commercially viable.

Conclusions

To summarise this discussion of TD-SCDMA, the commercial future of this technology depends on several things: how soon stable terminals with an acceptable form factor and performance will be commercially available, how strongly this technology gets pushed by the Chinese authorities in the final licence distribution, how well the technology's advanced antenna features perform technically compared with their life-cycle cost, and, once available in volumes, how TD-SCDMA compares to other technologies for unpaired spectrum being considered in the rest of the world.

The future of TD-SCDMA is far from certain, although the potential volumes of 3G network equipment to be used in China points at some economy of scale and certainly spurs interest from major manufacturers. We do not expect to see TD-SCDMA in other countries until it has been successfully rolled out on a wide scale in China. In fact, even after that, the competition from the more widely deployed WCDMA and CDMA2000 technologies will be fierce, since the experiences gained from the first commercial deployments are already being fed back into WCDMA and CDMA2000 network development. This may contribute to further widening the gap between the established 3G standards and TD-SCDMA. Most likely TD-SCDMA will remain a Chinese technology.

EDGE / GERAN

Description

EDGE is a 3G technology, which is essentially an extension to GSM/GPRS and IS-136. EDGE is used in the same frequency bands as GSM. The current EDGE technology (EDGE phase 1)[18] uses eight-phase shift keying (8PSK) modulation in the GSM frequency bands (850, 900, 1800, or 1900 MHz) to increase data throughput when the radio channel conditions allow for it. Under poor radio conditions, EDGE phase 1 uses part of the increased bandwidth to add increasing error-correction coding to compensate. First under very poor radio conditions, it steps down to Gaussian minimum shift keying (GMSK), as used in GSM and GPRS. EDGE phase 1 is capable of retransmitting a packet which has not been received correctly with a more robust coding scheme, to ensure that packets will be delivered as far as possible. EDGE phase 1 also introduces other enhancements over GPRS, including a more apt retransmission mechanism and faster adaptation to changes in radio conditions. Overall, EDGE phase 1 networks typically provide user-experienced data rates that are three times those of GPRS, or in the range 100-130 kbit/s for a four-timeslot device.[19] (The theoretical maximum (shared) capacity in a sector is 473.6 kbit/s.)

The EDGE evolution track has not necessarily reached way's end yet. Work on improving EDGE is being performed in standardisation bodies, under the GERAN (GPRS/EDGE Radio Access Network) label. This evolution is concerned with aligning EDGE with UMTS, especially by adding support for the non-real

[17] In addition, considerably more spectrum is expected to be available for 3G networks in China than elsewhere in the world.
[18] The EDGE standard as well as vendors' products still evolve. Different terms are being used to describe this process: while some say GERAN, others use the terms EDGE phase 1 and phase 2, and others refer to UMTS-style release numbers or release years. On top of this, vendors' releases do not map perfectly onto the standardisation releases, since vendors choose to implement individual features based on customer demand.
[19] Rysavy Research, "Data capabilities: GPRS to HSDPA", September 2004

time UMTS QoS streaming and conversational classes, so that similar applications may be supported. It also improves the radio network latency over EDGE phase 1. If the maximum data rate achievable using EDGE will increase further is unclear today, as standardisation is still ongoing.

Coordinated availability

A fair amount of operators in Asia, Europe and Latin America has already launched or is planning to roll-out EDGE phase one[20]. Worldwide, 38 operators had EDGE phase 1 networks in commercial operation in December 2004.[21] Most mid- to high-end GSM handsets support EDGE phase 1.As the standardisation of EDGE phase 2 is ongoing, availability dates are highly dependent on the progress of that work. Worldwide operator interest in EDGE phase 1 means that we could see an evolution to EDGE phase 2. Standardisation of UMTS for the current GSM bands is also underway, but looking worldwide, UMTS and EDGE are likely to be complementary technologies in this band. Even in countries where the GSM bands can be expected to eventually be re-farmed for using UMTS900, the end of life of GSM may be postponed if EDGE is deployed in the meantime and particularly if the EDGE technology evolves.[22] If successful, EDGE phase 2 could be expected in commercial deployment around 2007/2008 at the earliest.

3.5.3 Cost efficiency

Introduction of EDGE phase 1 into a GPRS network typically only affects the base stations, whereas the core network remains untouched. However, one conceivable effect of beefing up the capacity of the radio link is that backhaul, and potential core network and backbone capacity may require re-dimensioning to handle potentially increased amounts of data sent.

Several vendors state that many of their GPRS base stations are ”EDGE ready.” What this means tends to differ, however. Sometimes only software upgrades are required to support EDGE phase 1. Other times ”EDGE ready” base stations require software plus a transceiver unit to be installed, which can be costly.[23] This is potentially an important aspect, since software normally constitutes 10-20% of the price of a radio access network, with hardware constituting the rest. On the other hand, upgrading existing GPRS base stations to EDGE is done under a strong lock-in effect, so depending on contracts, vendors could use the occasion to regain some lost revenue from the original sales of the radio access network equipment.

When moving further to EDGE phase 2, an important change to the radio access network is the alignment with the UMTS QoS classes, possibly requiring an upgrade of the GPRS part of the core network.

Service attractiveness

EDGE phase 1 is a substantial improvement over for instance GPRS, when it comes to data speeds. This enables 3G services, including music download, e-mails, and a good user experience for content services. EDGE however provides a lower throughput than WCDMA. The GERAN evolution, EDGE phase 2, will offer UMTS-style quality of services classes, improving support for e.g. streaming music. If EDGE phase 2 will also bring further increased data throughput remains to be seen.

Conclusions

EDGE will play an important role in certain regions, with a number of networks already commercially operational. The standard and products evolve and can be expected to be partly aligned with UMTS when it comes to such areas as quality of service (QoS). As such, the EDGE technology track allows operators to use GSM frequency bands and existing infrastructure more efficiently, possibly extending the life of GSM. An unknown factor is also standardisation of UMTS for the GSM bands, and its related time-frame.

IPWireless's TDD-WCDMA

Description

Time Division Duplex (TDD) WCDMA is a 3GPP standard using the unpaired spectrum blocks in UMTS. In TDD the base station transmits and receives alternately on the same frequency channel to communicate in both directions – duplex. With TDD it is possible to adjust the uplink/downlink asymmetry to give more throughput in one direction than the other. Since all base stations use the same frequency, it is necessary to have tight synchronisation (and asymmetry) between base stations to avoid interference. This is easily resolved by having GPS synchronisation or some other global timing reference for outdoor sites.

[20] Magazine Latincom (7 January 2005) states that 10 Latin American operators had launched EDGE services in December 2004, with another 13 operators in the region planning launches.
[21] Latincom quoting figures from the Global Mobile Suppliers Association, dated 6 December 2004.
[22] This scenario was discussed in the slightly older Northstream whitepaper “Whitepaper on the role of EDGE technology” from February 2002. The document can be accessed on Northstream’s website www.northstream.se.
[23] TNomura states that the cost of a transceiver unit in some cases can be as much as half the price of a base station. Source: Nomura, “On the EDGE of 3G”

3GPP TDD-WCDMA has the same bandwidth (and 3.84 Mcps chip rate), modulation, 15 slots in 10 ms framing and same development path as FDD-WCDMA. Typically, out of the 15 slots available, two are used for downlink signalling (one broadcast and one signalling), one for uplink random access leaving 12 for data traffic either uplink or downlink. This flexibility allows TDD to operate an asymmetric downlink/uplink ratio to match the services provided. However, this flexibility to adapt to traffic profile is somewhat overstated as interference between adjacent sectors or sites with different asymmetry would result unless all sectors are changed together.

The TDD standards closely match the features available in FDD, data voice etc. However, it has been regarded as a low-power or indoor-only capacity solution for FDD operators. Part of the TDD spectrum allocation is adjacent to the lower FDD uplink which could cause serious interference to the lower FDD channel without taking special interference suppression measures. Additionally, if adjacent TDD channels are used on co-located sites or in the same geographical area, they would likely need to be TX/RX frame synchronised and have the same asymmetry to avoid adjacent channel interference. It is not clear if the TDD standard has addressed the need for universal synchronisation under these circumstances.

The TDD standard does differ from the FDD-WCDMA specification in some critical areas. Firstly, the number of spreading codes is limited to 16 per timeslot. This allows advanced interference-cancelling joint-detector receivers resulting in performance that does not decrease under increased cell loading (no 'cell breathing') and avoids the need for stringent power control on the uplink. Secondly, different calls can be allocated to different timeslots and then interference is again reduced. Joint detectors are not practical in FDD-WCDMA due to the complexity of handling large numbers of spreading codes.

IPWireless has been one of the main proponents of this standard and has developed a range of data-only base stations, core infrastructure and customer modem devices. IPWireless targeted the data market and implemented only the parts the 3GPP TDD specification required for data. The company did not implement the voice elements. This allowed for simplifying the system a great deal – for example, there is no need to call a data modem. This removes the need for a paging channel and corresponding database of mobile status.

IPWireless is compliant with the parts of the 3GPP TDD specification with which it chooses to be compliant. This has allowed IPWireless to drive the TDD standard within the 3GPP and enabled it to introduce new innovation earlier than has been possible within the normal WCDMA FDD standard development process. Examples of this are use of a 10 MHz bandwidth option (using a 7.68 Mcps chip rate) to double capacity and an early implementation of some of the key features of HSDPA, such as 16QAM higher order modulation and operation in other frequency bands.

Coordinated availability

Data-only TDD solutions from IPWireless are commercially available now in the UMTS unpaired band and in the 3.5 GHz band. End-user devices in the form of PC cards and desktop modems are available. Since TDD solutions operate in single blocks of spectrum, they are easily adapted to any available frequency block.

UK Broadband (www.ukbroadband.com) operates an IPWireless TDD fixed network in the 3.5 GHz band and offers fixed 512 kbit/s and 1 Mbit/s ADSL replacement. Mobile service is not available due to UK Broadband's license limitations.

Several operators in various parts of the world are currently testing IPWireless technology. According to IPWireless the number of users in the largest operational network is "in the low ten-thousands."

IPWireless is likely to license its technology to vendors who can take advantage of manufacturing scale and ability to tackle bigger system integration tasks. UTStarcom, a major Chinese telecoms manufacturer has already licensed the technology and base stations combining WCDMA and IPWireless technology will be available this year.

IPWireless also points out that a benefit of TDD-WCDMA is that its shares a lot of elements in the standard with FDD-WCDMA, making it much easier to develop combined FDD/TDD chip sets than it was to develop GSM/WCDMA chipsets.

Cost efficiency

TDD-WCDMA is interesting for operators who already have the TDD spectrum available. However it requires new base-station equipment and antennas (unless some antenna combiner is used). Since the base station capacity can peak to high throughputs, large capacity backhaul is needed to prevent congestion. IPWireless implemented an all-IP transmission system that may be suitable for integration into an operator's existing 3G core network. However, since the data capacity of the base stations can be more than a normal FDD base station the dimensioning of the packet core may need adjusting.

Using IPWireless technology to build a data network using already allocated TDD spectrum may be a cost-effective way to address a new market segment.

Service attractiveness

The IPWireless solution is a truly mobile wideband data service. In a 5 MHz spectrum block maximum downlink throughput rates up to 3 Mbit/s can be achieved, with HSDPA in a 10 MHz channel this can rise to around 12-14 Mbit/s.

The user-perceived performance will be some fraction of the base station peak rates depending on their location within the cell and number of other users they are sharing with. Characterising user usage, behaviour and identifying the applications used will be important to correctly dimension and plan both the network and the business case.

Whoosh, an operator in New Zealand, operates an IPWireless network and plans to implement VoIP on their system. A reliable QoS mechanism is necessary to implement VoIP over an essentially best-effort system.

Conclusions

For operators who already have TDD-spectrum available, IPWireless technology could prove to be an interesting option. This is especially true if IPWireless is successful in licensing the technology to one or several of the major vendors of WCDMA equipment and if they could develop integrated base stations. However, none of the operators we have interviewed are in a hurry to evaluate this option since they have plenty of capacity in their regular WCDMA networks. Some are also waiting for the TDD roadmap from their current vendor. It must also be remembered that the amount of allocated TDD-spectrum per operator is typically only 5 MHz compared with 2x15 MHz FDD-spectrum, and TDD-WCDMA is not the only option for use of the TDD spectrum. Another use for that spectrum could be an enhanced downlink for the WCDMA network.

Flarion's FLASH-OFDM

Description

FLASH-OFDM (Fast Low Latency Access with Seamless Handoff-OFDM) is an OFDM-based proprietary technology from Flarion. The main use case for FLASH-OFDM is for desktop modem and PC-cards for wireless access, regarded as a complement to existing mobile services.

Flarion has tried to standardise the FLASH-OFDM via the IEEE 802.20 working group for Mobile Broadband Wireless Access (MBWA). However, progress towards an 802.20 standard has been difficult due to conflicts of interest in the working group, which has led to the 802.20 standard lagging behind the 802.16 development. In case the progress of the 802.20 work group picks up, Flarion still sees this as an interesting opportunity, but current focus is to work with 3GPP and ITU standardisation groups.

OFDM is the modulation of choice for new standards as it avoids some patent issues with CDMA and has similar performance. Flarion's implementation of OFDM brings a few innovations that improve performance of OFDM in a mobile environment.

Coordinated availability

The Flarion technology is available in many standard US & European cellular-frequency bands from 400 MHz up to 3.5 GHz. Due to technology restrictions in the 3G licenses issued, particularly in Europe, the 1.9-2.1 MHz spectrum is not likely to be available for the FLASH-OFDM technology. The system needs two blocks of 1.25 MHz spectrum for FDD.

FLASH-OFDM infrastructure and PC card modems are available from Flarion today. Chipsets supporting data and VoIP are also offered, although Flarion expects third-party vendors to develop the final end-user devices. Devices are likely to be frequency-band specific. Depending on the frequency bands used, market adaptations may be needed.

Although Flarion's technology can be licensed by independent vendors, interest from such has not yet materialised as the technology is still regarded as proprietary. In October 2004, Siemens signed a Memorandum of understanding with Flarion and announced plans to offer equipment for the 450 MHz band using FLASH-OFDM. According to Siemens, an end-to-end solution will be available in Q2 2005.

Flarion has several trials underway, most notably with Nextel in the US and T-mobile in the Netherlands. The Nextel network is launched on a small scale for commercial usage, containing approximately 3,000 users. (See www.nextelbroadband.com for more information).

As this white paper was finalised, Flarion announced its improved Flexband technology, for 1.25 MHz and 5 MHz multi carrier systems. Flarion states that mobile operators have performed field trials with Flexband, and that it will offer some capacity advantages over FLASH-OFDM.

Cost efficiency

With an average rate quoted at 1 Mbit/s shared, the Flarion solution could be reasonably efficient for delivering low-medium bandwidth mobile internet services. This is particularly useful for operators without a 3G license or operators that would like to build Greenfield networks for the 450 MHz band. However, for an existing CDMA operator it would be more challenging to justify the business case since performance is similar.

The Flarion technology demonstrates again that innovation by smaller companies can outperform current standard technology offerings. Yet, the performance advantage might be short-lived as it will take time to rollout a Flarion network and, by the time that happens, the standard technology performance is likely to have caught up and, more importantly, will be simple hardware upgrade to existing base stations. The economies of scale and terminal availability would be another concern.

Service attractiveness

FLASH-OFDM offers peak downlink rates of up to 3.2 Mbit/s per user (shared experience), while average rates are quoted at 1-1.5 Mbit/s. The uplink offers up to 900 kbit/s peak data rates, with average rates of 300-500 kbit/s. In the end, the end-user experienced data rates will depend on the specific radio environment and conditions. As for all mobile systems, data rates will be lower towards the cell edges compared with the centre of the cell. The low latency (sub 50 ms) and the short time it takes to set-up a connection will lead to a user experience superior to the one currently offered in a traditional WCDMA or in CDMA2000 1xEV-DO networks for such applications as web browsing. The low latency will also lead to capacity advantages for VoIP applications. The Flarion network performance seems to be better than what is currently available from CDMA2000 1xEV-DO Rev. 0, but the performance will be matched by Rev. A equipment when it comes to peak data transfer rates. However Flarion's technology is working today and 1xEV-DO Rev. A is at least a year away.

Traditional telecom roaming will be a challenge to achieve for the operators choosing to implement FLASH-OFDM, as the number of systems will be limited for the foreseeable future. It will be possible to offer IP roaming from a technical perspective, but it will be some time before the commercial aspects of IP roaming are addressed (if ever).

Conclusions

So why would an operator consider a proprietary network such as FLASH-OFDM in locations where a WCDMA or a CDMA2000 1xEV-DO network is available? Flarion offers some technology advantages over existing CDMA2000 and WCDMA networks in terms of user experience for a data service than could also be attractive to current 3G operators and Flarion claims that it would be possible to co-exist with a 3G network: in this case, using FLASH-OFDM on some channels dedicated for data services. This would require one or several major infrastructure providers to license the technology from Flarion and incorporate it in their product lines, and also that regulators in many countries open up the spectrum currently reserved for UMTS for alternative technologies.

It is considered that the recently announced merger between Sprint and Nextel is will reduce Flarion's chances. Nextel evaluated Flarion as a replacement for its Motorola iDEN network, but we do not expect the merged company to go for a proprietary technology, especially since Sprint already has a CDMA network.

We believe that Flarion is more likely to succeed in the 450 MHz band where a lot of new licenses will become available in the near future, but will face fierce competition from CDMA450 that is already deployed by many operators in this frequency band. Another area in which Flarion's technology could be useful is for smaller private network operators or niche applications, e.g. local government or police data network. Here global roaming or compatibility is less of an issue, although they would not enjoy the economies of scale or range of choice from competitive vendor offerings. The ability to adopt the technology for non-standard spectrum is valuable here and the price of handsets is less of an issue.

WiMAX (802.16)

Description

The IEEE 802.16 wireless WAN/MAN standards aim to provide wide-area, high-throughput coverage, potentially offering wide-area DSL, T1/E1[24], and backhaul-level service to multiple homes and businesses. Initially, the standard was designed to support a combination of best effort and guaranteed bandwidth point-to-multipoint backhaul service over a wide coverage area using any available spectrum in the 11-60 GHz band. A revision added the 2-11 GHz range for fixed broadband wireless access. Ongoing enhancements to the standard will allow for a degree of mobility with a reduced range and throughput.

The 802.16 standards use Orthogonal Frequency Division Multiplexing (OFDM) which uses many discrete tones (e.g. 256, 512 or 1024) each carrying a separate data stream on the radio frequency carrier. Since the bit rate is low on each tone, the dispersion is less of a problem. However, frequency stability and multi-tone RF power amplifier linearity are technically challenging. OFDM is becoming more widespread due to recent technical and cost-level improvements in digital signal processing. Similar technologies are used in Digital Video Broadcast (DVB) and Digital Audio Broadcast (DAB).

[24] A T1 connection equals 1.544 Mbit/s. An E1 connection equals 2.048 Mbit/s.

Wireless Interoperability for Microwave Access (WiMAX) backed by the WiMAX Forum is an attempt to ensure interoperability of the IEEE 802.16 broadband wireless WAN/MAN family standards. The WiMAX Forum is specifying a testing and certification program to ensure compatibility by introducing option profiles limiting the range of possible service combinations.

With the introduction of point-to-multipoint systems used for fixed-broadband wireless access (FBWA) in the 2-11 GHz bands and the resulting growth in the number of expanding applications, it became clear that a standards-based approach would bring benefits to operators, equipment manufactures and customers.

The standards process under the IEEE 802 group includes different technology versions for targeting fixed-broadband access (802.16d) and mobility (802.16e). Since the full scope of 802.16 tries to serve many different applications and services, some mutually exclusive, the WiMAX Forum is defining a set of profiles to ensure a high degree of interoperability between network elements and end-user equipment.

Additionally, the IEEE supports the 802.20 standard which is specifically designed to address mobile broadband. However, the 802.20 standard is further behind the 802.16e in development and does not seem to carry the same political support.

Many applications of 802.16 will require guaranteed quality of service (QoS) performance – particularly backhaul applications, so QoS profiles are an embedded feature of 802.16.

What WiMAX potentially offers is a set of standards-based technologies offering high bandwidth, carrier grade, point-to-multipoint services for backhaul, broadband access and mobile access.

Coordinated availability

WiMAX standardises frequency-band allocation, channel bandwidth configurations and application profiles, allowing interoperability and economies of scale for operators and vendors. Several channel bandwidth configurations shall be supported to allow best use of the spectrum band allocation while optimised for each application.

The profiles that WiMAX will initially support are FDD and TDD in the 3.5 GHz and 5.8 GHz bands with 3.5 MHz, 7 MHz and 10 MHz allocations, respectively. This means there is no initial WiMAX support for 3G band allocations.

WiMAX-compliant products are not currently available. The WiMAX Forum plans to have its lab open for interoperability testing and certification by mid 2005 and the first WiMAX-certified products are expected to appear at year-end 2005.[25]

Currently, several vendors are offering ”pre-WiMAX,” ”WiMAX-class” and ”WiMAX-platform” equipment which is said to be upgradeable to WiMAX compliance. It is unclear how difficult or expensive such upgrades will be or when they will be available. It would be reasonable to estimate that upgrades could be available after the profile compliance testing has been completed around end-2005.

There are several market trials ongoing in such countries as France, Spain, the UK and Russia. The largest of them incorporate a few thousand users.[26]

The mobile version of WiMAX (802.16e) has not yet been ratified as a standard. Intel states that PC cards supporting 802.16e will be available mid-year 2006 and that integrated WiMAX support on laptop motherboards (compare with the Centrino concept for WiFi) will be available at the end of 2007. The mobile version of WiMAX (802.16e) will not be

802.16a	Options
Spectrum allocation	
Licensed (GHz)	2.1 (Int'l), 2.6 (US), 3.5 (Int'l), 4.8 (Japan)
Unlicensed (GHz)	2.4, 5.2, 5.8
Channel bandwidth (MHz)	1.75, 3.5, 7, 14,- (ETSI), 10, 20 -(Int'l), 3, 6 -(US)
Access method	TDD, FDD
Throughput (gross)	5 bits/Hz
Services supported	Constant bit rate, variable bit rate, best effort

Table 2. Source: WiMAX Forum 'righttechrightplace.ppt'

25 Source: WiMAX Forum
26 Source: Interview with Intel

compatible with the fixed version (802.16d). When 802.16e is available we believe that it, if successful, will be the WiMAX version used not only for mobile applications, but also fixed broadband wireless access. This will mainly be driven by economies of scale in the chipset manufacturing and a potentially greater industry support for 802.16e.

Currently there is no global spectrum availability set aside for WiMAX. The 3.5 GHz and 5.8 GHz bands are the first ones for which WiMAX-compliant equipment will become available. The 3.5 GHz band has not yet been standardised in terms of applications, bandwidth or duplex split. It has previously typically been used for fixed-links or radar. The other possibility is that WiMAX is deployed in an existing nearly-global spectrum allocation such as cellular, GSM or UMTS.

In countries where the 2.5 GHz band is allocated to UMTS, WiMAX supporters are hoping to be successful in lobbying attempts to free up that part of the spectrum (UMTS expansion band) for other technologies as well. In the US, deployment of WiMAX in this frequency band is already permitted.

Cost efficiency

802.16 and WiMAX will offer reasonably high throughputs for best-effort IP connections. If applied to VoIP codec rates, this translates into quite large numbers of simultaneous calls.

WiMAX base stations will initially not enjoy the economies of scale of cellular due to, in part, the non-standard frequency spectrum allocations. Building a WiMAX network will involve similar numbers of base stations to cellular due to the same or similar operating frequency having the same or similar signal propagation characteristics. Site and tower rental and backhaul will continue to dominate the OPEX.

WiMAX will offer a standardised, low-cost chipset with baseband processing for microwave link and point-to-multipoint options. With the addition of a frequency-band specific radio module, the technology can be deployed in whatever spectrum allocation is available. This represents an interesting cost-reduction proposition for operators who can now purchase backhaul equipment from multiple vendors with economies of scale.

Service attractiveness

WiMAX, and more generally 802.16, are able to support best-effort, fixed bit-rate and variable bit-rate services with QoS in a fixed-wireless environment. WiMAX Forum mentions supporting T1/E1 and ADSL services for many residences and small businesses. The actual throughput will depend a great deal on the coverage level and interference of the subscriber equipment within the coverage area. Guaranteed QoS for larger bandwidth applications would be most feasible in a fixed environment.

It is unlikely that high-capacity constant bit-rate services, like full or fractional T1/E1, will be fully supported to a customer in a mobile environment due to the difficulties in providing sufficient and reliable coverage, quite apart from managing the other mobile users competing for capacity and service from the same base station.

Low-capacity guaranteed rate could be used for VoIP applications, which require an approximately 40 kbit/s (8 kbit/s speech + 32 kbit/s headers for 10 ms packets) minimum for speech unless header compression is applied or a proprietary algorithm used.

WiMAX has sometimes been associated with exceptionally high 'headline' throughput and range figures, implying these throughputs are available to end-users rather than massively shared and that the user equipment is the size of a WiFi card. Throughput numbers of up to 70 Mbit/s at 50 km range have been mentioned without qualification of occupied bandwidth, antenna size, height, equipment configuration and so on.

Looking in more detail at the claims, we see 75 Mbit/s gross in 20 MHz bandwidth and 5 bit/Hz. So with a more reasonable 3.5 MHz per sector the throughput will drop to around 14 Mbit/s (gross).

The 802.16 standards were originally designed for fixed-link microwave communications with a large Mbit/s capacity, characteristic line of sight and with protection from interference by licensing, regulator-planning and highly directional dish antennas on high towers on mountain tops.

When used in a dense cellular-like environment, capacity and range will certainly decrease due to the much higher levels of interference and need for frequency reuse, further reducing the usable spectrum in each cell. Mobile systems also require a significant link budget margin to account for temporary fading and shadowing that users experience as they move around.

Conclusions

In the short term, the fixed version of WiMAX (802.16d) will most likely be used to offer DSL-like services in areas with poor copper infrastructure. The use of WiMAX for backhaul of traffic from base stations could be potentially interesting if licensed spectrum is used. In this case, it could also be used to feed WiFi hotspots and to offer enhanced data services to selected customers, such as small businesses. However the prices for the microwave links used for backhaul today has dropped and they are now readily available at fairly low cost. A possible development is that deployment of 802.16d will be slow due to people waiting for the 802.16e standard to become available, thereby tapping into the potentially larger economies of scale offered.

The mobile version (802.16e) is the version of the standard that Intel hopes for when it comes to volumes. But since it will take at least 2 years before equipment is ready it remains to be seen how successful it will be. Also one has to remember that there are critical differences between the WiFi and the WiMAX-hotspot business models. WiFi is an equipment business and anyone can buy an access point from the closest IT retailer and thus make use of the built-in WiFi capabilities of the laptop. WiMAX (especially deployed in licensed spectrum) will imply an operator business model, and will require users to have a subscription, pass a credit check, etc. In that aspect, WiMAX support in the computer is more similar to integration of a cellular modem. We believe that use of WiMAX to feed a WiFi hotspot is more likely, making the built-in WiFi support you already find in many laptops today useful. The added value of also integrating WiMAX onto laptop motherboards is harder to see.

We do not believe that WiMAX will be a threat to any of the established 3G standards when it comes to delivering wide-area coverage voice and data services. It is more likely to be a complementary service if users are data-hungry and if capacity in the current network is not enough.

WiFi (802.11)

Description

IEEE 802.11 represents a family of low-power wireless LAN standards 802.11a (in the 5.8 GHz band) and b & g (in the 2.4 GHz band). WiFi refers to 802.11 family products that have been "WiFi-certified" for interoperability with other WiFi devices in either the 2.4 GHz or 5.8 GHz band, or both.

The key point of wireless LAN is that it uses unlicensed frequency spectrum. The 2.4 GHz band is more or less available worldwide for Industrial, Scientific, Medical (ISM) use. For example, microwave ovens, industrial heating processes and some cordless speakers use the 2.4 GHz band – so, it is not exactly free from interference. The transmit power is typically low - about 100 mW for consumer devices.

IEEE 802.11b and 802.11g operate in the 2.4 GHz band. 'b' gives a peak over-the-air bit-rate of 11Mbit/s and 'g', using OFDM modulation, offers an improved 54 Mbit/s.

IEEE 802.11a operates in the 5.8 GHz band using COFDM (Coded OFDM) giving a peak over-the-air bit-rate of 54 Mbit/s.

WiFi was initially envisaged as a physical LAN cable replacement - it operates on physical-MAC layer, (Media Access Layer), and not IP layer. This makes routing somewhat difficult. Handoff between access points on the same LAN subnet is possible with appropriate (and proprietary) protocols. The requirement to have all the access points on the same LAN subnet is what has effectively prevented wireless LAN becoming a serious mobility networked solution.

Security is another concern. The well publicised weakness of the WiFi encryption Wired Equivalent Privacy (WEP) algorithm is one of many that prevent IT departments embracing the technology. Nor is there any QoS mechanism, which would be necessary for serious streaming or VoIP applications.

WiFi user-perceived performance under multi-user/multi-access point conditions has not been fully explored – considering the enthusiastic WiFi hotspot press coverage. Indeed, few users stop to ask why they never seem to get 11 Mbit/s or why they seem to get only a few kbit/s on moderately busy systems.

There are several reasons why performance degrades, firstly, in 802.11b there are only three non-overlapping channels. Secondly, interference from unsynchronised radios and 802.11b contention control only allows one transmitter to 'speak' when the channel is clear. So a constant interference source (e.g. a wireless camera) can permanently silence several nearby access points. Thirdly, there is a little known performance anomaly with the 802.11 access protocol. This causes the throughput of all users to fall to that of the slowest user on the access point[27].The overall effect appears as many users sharing a 1 Mbit/s link.

Various efforts to turn WiFi into wide-area, mobile coverage are ongoing. Notably RoamAD (www.roamad.com) in New Zealand operates a WiFi network using a proprietary access point radio-router network – the user terminals are standard 801.11a/b/g devices. Vivato (www.vivato.net) has a large smart-antenna array for long-range WiFi. The performance of these systems, with external interference from other WiFi devices, would probably degrade considerably.

The feasibility of wide-area coverage using WiFi is very questionable because of the limited power (100 mW) available from standard WiFi devices and the lack of network scalability.

[27] Source: Performance anomaly of 802.11b, Heusse et al

Coordinated availability
All types of WiFi equipment are available at low cost. WiFi cordless phones are now becoming available. Several dual-mode GSM/WiFi smart phones (PDAs or phones with browser/email clients) are available.

WiFi hotspot operators generally only disclose the number of hotspots deployed, not revenues – suggesting that these businesses have not been particularly profitable so far. WiFi technology has also not proven successful for wide-area network deployments, like metropolitan area networks, where high quality and reliability is required.

However, WiFi technology may have a future in operator networks under other conditions. Initiated by the demand of American mobile operators for better indoor coverage, standardisation is being implemented to introduce WiFi technology as an alternative access method for GSM networks. Under the name Unlicensed Mobile Access (UMA), vendors and operators have specified how a GSM/WiFi phone could access exactly the same services (including voice and data) when on a GSM network as when on a WiFi network. The handset chooses the currently available network and switches seamlessly between the technologies. British Telecom's Bluephone initiative is one example of such a deployment. Figure 9 describes the UMA architecture, introducing a new node, UNC, in GSM networks.

The UMA development is backed by vendors like Alcatel, Ericsson, Motorola, Nokia, Nortel Networks, Siemens, and Sony Ericsson. Participating operators include Cingular, British Telecom, O2, AT&T Wireless, T-Mobile US, and others.[28] This industry support indicates that WiFi may come to play an increasingly important role as an integrated complement to mobile networks.

Cost efficiency
To complement an already existing network with WiFi access points is a small investment. To deploy a wide-area WiFi network could be very costly. A large part of the investment is for transmission from the access points.

Service attractiveness
WiFi is a convenient way to offer wireless data services in selected locations. It works fine as cable replacement in home and office environments. In those environments it could also be used with a cordless WiFi phone to deliver voice services.

It is also a good way to offer data connectivity in certain public locations. Today WiFi hot spots are often deployed by mobile operators as a complement to the wireless data offering. We also see more and more examples of roaming agreements between mobile operators letting each others' users access the Internet on both networks' WiFi hot spots and pay on their regular cellular bills. This makes the service even more attractive.

Although the air interface allows for bit rates of 11 Mbit/s or 54 Mbit/s depending on version, the user-experienced bit rate is often much lower depending on cell loading and, in practice, is often limited by the capacity of the backhaul connection.

Conclusions
We believe that WiFi will be used in parallel and in combination with many of the other access technologies described in this white paper, with the most widespread use in home and office environments. A WiFi access point could very well be connected to a WiMAX, TDD-WCDMA or Flash-OFDM network. This could be used to extend the indoor coverage of the other network.

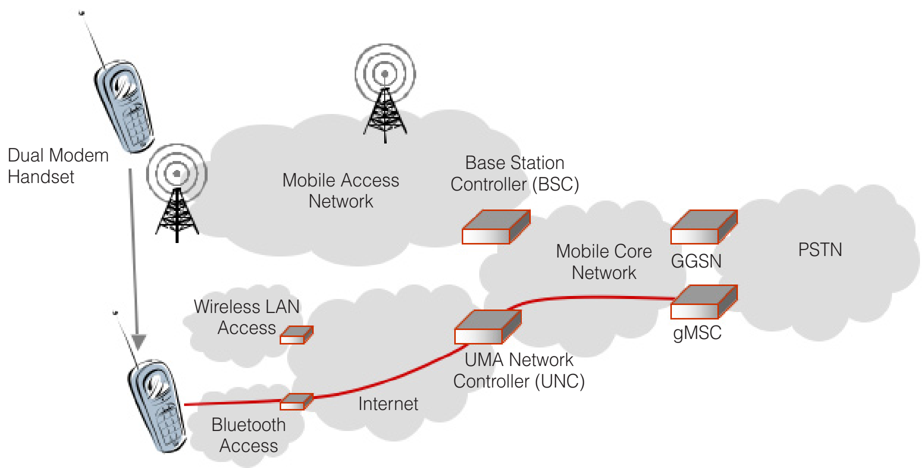
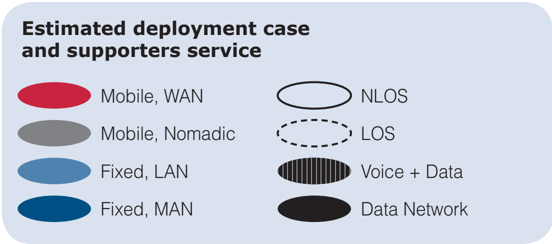


Figure 9. UMA network architecture

[28] More information on UMA is available at www.umatechnology.org.

Comparison tables

Now when we have completed the walk-through of the chosen access technologies, let's spend some time trying to put them in relation to each other. Figure 10 is an attempt to show how they relate to each other in a number of selected dimensions and selected use cases.



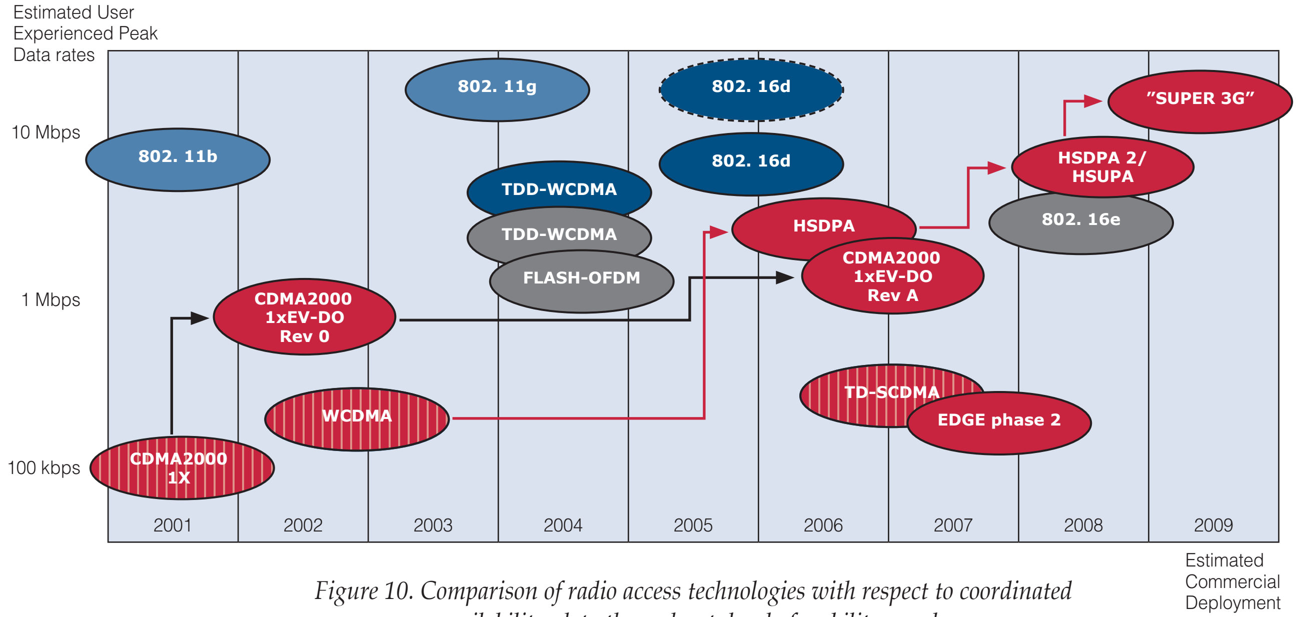


Figure 10. Comparison of radio access technologies with respect to coordinated availability, data throughput, level of mobility, reach, line-of-sight characteristics and application. Source: Northstream

Technology	Availability	Mobility	Standards	Data rate*[29]	Comment
WCDMA (FDD) 2x5 MHz	Now	Yes	3GPP	2 Mbit/s DL	Voice + Data
WCDMA (FDD) (HSDPA) 2x5 MHz	End 2005	Yes	3GPP	14 Mbit/s DL	Voice + Data
TDD-WCDMA (IPWireless) 10 MHz	Now	Yes	3GPP	12 Mbit/s DL	Data + VoIP
TD-SCDMA 1.6 MHz	2005	Yes	3GPP	2 Mbit/s DL	Voice + Data
CDMA2000 1xEV-DO (Rev. 0) 1.25 MHz	Now	Yes	TIA IS-856 3GPP2	2.4 Mbit/s DL 153 kbit/s UL	Voice + Data
CDMA2000 1xEV-DO (Rev. A) 1.25 MHz	End 2005	Yes	TIA IS-856-A 3GPP2	3.1 Mbit/s DL 1.8 Mbit/s UL	Voice + Data
WiMAX 802.16d	Q3 2005	No	IEEE 802.16d		Data (+ VoIP)
WiMAX 802.16e	Mid 2006	Yes	IEEE 802.16e		Data (+ VoIP)
WiFi 802.11a/(b)/g 20 MHz	Now	Limited	802.11a/(b)/g	54 Mbit/s (11 Mbit/s), DL + UL	Data + VoIP[30]
FLASH-OFDM (Flarion) 1.25 MHz	Now	Yes	Proprietary	3.2 Mbit/s	Data + VoIP

Table 3. Basic comparison parameters for the studied radio access technologies.

[29] Peak rates/over-air bit rate – shared between users – and optimistic.
[30] No QoS, but VoIP possible and WiFi cordless phones

Alternative access technologies from an operator perspective

WCDMA and CDMA2000 operator options in terms of alternative access technologies

The natural evolution path for a WCDMA operator is to upgrade the network to HSDPA and later Enhanced Uplink/HSUPA. The corresponding natural evolution path for a CDMA2000 operator is to implement 1xEV-DO Rev. 0 and later 1xEV-DO Rev. A. Both these technology paths allow for mobile voice and mobile data, and their respective upgrades lead to improved data capabilities.

In addition to this, there are a few scenarios under which a mobile operator may consider deployment of one or more of the alternative access technologies discussed in this paper:

One potential scenario is to deploy an overlay network to the current WCDMA or CDMA2000 1xEV-DO network. Since the current network will provide wide area coverage, the rationale for the overlay network could be to provide higher capacity and a better data service in parts of the coverage area. This extra capacity for pure data services may be needed if the service consumption patterns of regular consumers change and they start to download large amounts of music and video on the regular 3G network. We believe that the most obvious way for an operator to mitigate capacity constraints is by seeking access to new spectrum into which the already deployed technology can be extended. However, since licensed spectrum is a scarce and possibly costly resource, in some cases the solution involving an overlay network based on an alternative access technology might be more cost-efficient. A second reason for building an overlay network is that it would allow the mobile operator to offer a fixed BWA (DSL replacement) service to residents and small businesses. Fixed Broadband Wireless Access is especially attractive in countries with poor copper infrastructure (E.g. India) or where many people live too far from a switch to get DSL (E.g. USA). In this case there would be no need to support the alternative access technology in regular phones. Initially, PC cards or desktop modems would be sufficient. Later, support for the technology could potentially be incorporated in smartphones and connected PDAs. Such fixed BWA could also be used to feed WiFi networks.

In Europe, many WCDMA operators have TDD spectrum available. In this case a technology like that of IPWireless could be deployed using licensed spectrum already allocated. The technology already exists and has been proven in commercial networks. However, we believe that as long as the capacity in current WCDMA networks is enough there will only be limited demand for starting to use the TDD spectrum. 3G operators tend to be fully occupied with their current network rollouts and operations. Some WCDMA manufacturers see other possible uses of this spectrum, including improvement of the WCDMA downlink or to use for broadcasting.

FLASH-OFDM from Flarion is another potential candidate for an overlay data network. The technology is available today and proven commercially on a small scale. In our eyes, the performance benefits do not seem big enough to motivate major infrastructure vendors to develop products that would allow a 3G operator to use FLASH-OFDM on certain channels for data traffic and regular WCDMA on the remaining channels. The operators we have interviewed wish a single vendor to assume responsibility for the base stations' proper function. By mixing equipment from various vendors in the same base station, operators give up this safety. We believe that a product like Flarion's would need to be included in one or several of the major equipment vendors' equipment portfolios to be commercially feasible. We have not yet seen this happen for the 3G frequency bands.

Regarding WiMAX 802.16d (i.e. the fixed version of the technology), the standard is ready, but fully WiMAX-compliant commercial products have yet to appear. A potential use case is to deploy fixed WiMAX for backhaul of traffic from cellular base stations, and maybe also use the technology to feed WiFi hotspots. If fixed WiMAX develops into a widely used standard, low price levels and the point-to-multipoint characteristic could make this an interesting and cost-efficient technology compared with the point-to-point microwave links used today. This would require WiMAX to be run in licensed spectrum to secure carrier-grade services, at least in urban and suburban areas. In several European countries there are national licenses for the 3.5 GHz band available which could be used for this. In certain other countries, such as Sweden, regional licenses have been distributed, thus making this application harder to implement.

WiMAX 802.16e (i.e. the mobile version of the technology) is another option for complementary data networks, especially in the USA and Asia. In Europe, with the attractive 2.1 GHz band allocated for WCDMA, the technology will face tougher competition. According to Intel, it is the mobile version of WiMAX (802.16e) that will be most important from an equipment-volume standpoint.[31] This is the part of the standard that they plan to integrate on PC motherboards in a way similar to the Centrino concept for WiFi today. We expect this to be several years away, at best. The standard has significant backing from major industrial players and it remains to be seen how successful it proves to be, and when it will be available in volumes.

Options for non-mobile operators

For non-mobile operators we see three different scenarios for using alternative access technologies. The first one is to use a broadband wireless access technology to offer DSL-like services in unlicensed spectrum. The second (which can be combined with the first) is to offer nomadic data services in a way very similar to WiFi-hot spots but using another access technology. The third option is to apply for a license in the 450 MHz band and build a wide-area coverage network for data and/or voice services.

DSL replacement

One opportunity could be to take a share of the current DSL business. This would not require mobility, handovers, roaming or handset integration. A PC card or a desktop box connected to WiFi equipment would be sufficient. However, where a copper or cable infrastructure is already in place, wireless DSL replacements would have difficulties competing. In countries or regions with poor infrastructure, fixed BWA is much more interesting provided that the price point for the equipment drops enough to make the business economically sound. We believe that this is already the case in, for example, Eastern Europe and rural UK. This area could also be of interest to fixed operators that are looking to extend their data service to regions with poor infrastructure.

Nomadic data service

Several companies have already tried to offer data services in the form of WiFi hotspots as a stand-alone business, but more or less failed. More common now is the offer of hotspot WiFi coverage as an extension to the data offering by a regular mobile network. Would the stand-alone business model be viable if, instead of WiFi hotspots, one used a network based on one of the alternative access technologies discussed in this report? Although the service offered would look much more attractive using, say, 802.16e WiMAX instead of WiFi, since these enable larger coverage zones, we still believe that such a service would require several elements to be in place before becoming really attractive. One challenge would be to offer a network with sufficient coverage. Indoors, in particular, this can prove difficult if the 3.5 GHz band is used. Networks for this type of services could be built in presently not allocated spectrum using FLASH-OFDM or IPWireless TDD-WCDMA already today and WiMAX when available. When no regular 3G network is available as fall-back, users may suffer from spotty coverage. The option would be to cooperate with a mobile operator and offer a combined service with roaming and single billing etc. However we believe it to be unlikely that a mobile operator would allow a competitor to gain a foothold in this area.

450 MHz licences

Another option for players currently without licensed spectrum and networks is to apply for one of the upcoming licences in the 450 MHz band. The technology of choice for this frequency band has so far been CDMA450, but with Siemens planning to manufacture equipment based on Flarion's FLASH-OFDM technology, this could be an interesting option for operators who currently have no infrastructure for this frequency band. This is especially true if the purpose is to offer data services, since Flarion's technology today has some performance advantages over CDMA450. However, we expect that multi-national operators that currently have CDMA450 networks in some countries are likely to continue using that technology in any new countries where they acquire 450 MHz spectrum. Handset availability also favours CDMA.

Industry impact of alternative access technologies

What is required for an access technology to succeed?

What is required for a new technology to succeed? Clearly the technology must be capable of delivering something that there is a demand for in the market. However, being the best technology to fill a certain need is not nearly enough. There are countless examples of superior products that failed against products that performed more poorly but had wider industry support. We believe that for a technology to be truly successful and become widely deployed, it is vital to have strong industry support from network equipment manufacturers, handset or device manufacturers, and from operators. Technologies that are widely deployed and supported are the ones that are most likely to deliver services to end-users at acceptable prices.

The success of GSM was built on wide acceptance of the technology as a standard. This and the fact that spectrum was allocated specifically for this technology

[31] Interview with Intel, 10 January 2005.

led to wide-area deployment in many countries and consequently large volumes. This, combined with roaming agreements between individual operators facilitated by cooperation in industry forums, has been the foundation for an attractive service offering in terms of both price and mobility.

Is there a risk of industry fragmentation?

Will the wide choice of access technologies fragment the current industry? What consequences would that have for operators and end-users? To answer these questions we need to look at both the network and device markets.

Industry impact on network development

An operator selecting the access technology in which to invest is not only looking at price and performance. Another criterion that is important for the selection process is if the technology is available from several vendors. Multiple vendors enable a wider range of choices and the benefits of competitive pricing. Choosing a technology that is proven and likely to be widely deployed also reduces the risk of ending up in a dead end with a network no longer supported and without an attractive roadmap forward or without sufficient end-user devices.

Currently most 3G operators use GSM/WCDMA or CDMA2000 equipment for their mobile networks and products based on these standards are available for several frequency bands. If operators start to deploy other technologies to deliver similar services, this may have undesired effects on the industry. Price levels for equipment may increase due to a smaller market share for each technology. End-users would suffer from decreased interoperability and higher device and service prices.

Industry fragmentation's impact on handsets

One way to solve interoperability issues between networks using different technologies is to integrate support for multiple access technologies in end-user devices. Multimode terminals are technically possible and are common today. Many devices use the same standard but for different frequency bands, e.g. GSM 900/1800/1900, whereas others combine different access technologies, e.g. GSM/WCDMA.

However, multimode handsets are not trivial to develop and handset vendors are not likely to put any effort into this unless the market is sufficiently large. Early multimode devices also suffer from less appealing form factors, high power consumption and technical challenges when it comes to operating in environments with several networks available simultaneously. The form factor issue could be resolved by integrated chipsets that support several technologies, but this is also costly to develop and will not solve all technical issues. To reach competitive prices for handsets, volumes in the order of tens of millions devices over the lifetime of the chipset are likely to be required.

We believe that multimode handsets will primarily support several of the established mobile network standards. This could be WCDMA/CDMA 2000, TD-SCDMA/CDMA2000 1xEV-DO or GSM/EDGE/WCDMA handsets. It is unlikely that there will be a significant market for integrating alternative access technologies into regular handsets. Maybe an exception could be devices combining WCDMA and TDD-WCDMA since they are part of the same standard and similar in many aspects. If alternative access technologies are deployed on a large scale, we would expect the end-user devices to be laptops with PC cards, outdoor wireless access points for use with indoor WLAN, and possibly connected PDAs/smartphones.

The impact of VoIP

VoIP is regarded by some as the wildcard that could make or break the business case for a mobile-data network. Integration of support for VoIP both in the network and in handsets could be the disruptive technology that would generate sufficient data traffic for a healthy return on the investment. Is this likely to happen? We believe that there are several benefits in VoIP and all-IP networks and we see a clear development in these areas.

Today, many operators believe in VoIP in the core network and some use it all the way out to the base station. Introduction of VoIP in the air interface of mobile networks seems less attractive in the short to medium term. A circuit-switched voice call in a 3G network is very efficient in terms of used capacity: In WCDMA it requires about 13 kbit/s. It is very hard to deliver a good-quality VoIP call at that low bit-rate, including packet overhead. Operators who believe in eventually having IP all the way to the end-user device (i.e. over the air) say that this will not be attractive before it can be done considerably more efficiently than today.

This situation applies to most operators, with the possible exception of CDMA2000 1xEV-DO operators with spare data capacity and limited voice spectrum. For these, it could be attractive to migrate some of the voice traffic to the data network.

Players interested in building new networks to compete with mobile operators have other incentives. For them it would be vital not only to compete with data but also benefit from the significant voice revenues. To do this it is necessary to offer voice among mobile devices as a managed service. The user would perceive this as a regular voice service, and should not have to be aware that it is implemented by extensive use of VoIP. In this case, billing and interconnect etc. could be managed in the same manner as in a traditional telecom network. It remains to be seen if this will drive development of devices capable of both circuit-switched voice and VoIP calls – and drive the price points of these devices down to competitive levels.

Apart from VoIP as a managed service, there is no question that voice data transport over IP networks generated by application-level Internet telephony will increase. This is mainly driven by increased residential broadband penetration and the use of telephony applications like Skype from homes and offices but also potentially over mobile networks from laptops and smartphones. Still we believe that this will long remain a small part of the total voice volume.

The role of the regulators

Obviously telecom regulators have a very important part to play in shaping tomorrow's wireless access environment. The time when it was easy to distinguish between data, radio broadcasting, TV and telecom traffic is rapidly coming to an end. Today almost everything could be transported as data traffic, often carried in the same cables or over the same air interface. This puts new requirements on the regulators.

In some areas however, these requirements remain the same. One such area is whether to dedicate certain spectrum to a specific technology or to open up for operators to deploy the access technology they select. There are good arguments for both approaches. A technology-agnostic spectrum allocation would make it easier for new, innovative solutions to get a foothold on the market, while a more restrictive approach would secure a larger footprint and economies of scale for the dictated technology. For both operators and end-users, we believe that the benefits of securing a large footprint for a certain technology is worth more than the possible local performance benefits that could be realised by deployment of proprietary technologies. We therefore believe that it is an important mission for regulators to create an environment where a global footprint is achievable for at least some standards.

To make spectrum allocation technology-agnostic may be tempting. However, in our opinion, regulators who do this to a large extent in essence abdicate an element of their responsibility: the objective of assuring the best possible use of the spectrum. This does not mean that all spectrum allocation should be reserved for a certain technology. There could also be spectrum that could be used at will – but an overly fragmented market is bad for both operators and consumers.

Conclusions

In a five-year perspective, we believe that existing 3G mobile standards and their evolution paths will be the best choice for delivering mobile voice telephony and basic wide-area data coverage to fully mobile users. WCDMA and CDMA2000 have wide industry backing and those standards will evolve further. Major vendors are committed to bringing network equipment and a diversity of handsets to market; the volumes will lead to price points that are likely to allow for continued mass-market adoption.

We think it would be unwise of operators to use technology as a differentiating factor. Competition and development within established standards is to be preferred compared to competition among various standards. This applies to both operators and end-users, also in the long term. This said, it could make sense to use different technologies for different purposes, but when similar services can be delivered using a proven standardised technology this is likely to be the best choice.

The most likely use cases for alternative access technologies are those where the new technology is positioned as a complement to existing mobile networks. These use cases will be especially likely if users turn out to be more data-hungry than expected. The fixed broadband wireless access market is increasingly interesting, both for current fixed and current mobile operators. Several alternative access technologies could even be combined, for instance a mobile operator could use WiMAX to feed WiFi hotspots and cellular base stations.

The use and uptake of alternative access technologies will vary by region. Fixed broadband wireless access deployment is likely to occur in regions with poor copper infrastructure but significant demand, e.g. in Eastern Europe and rural UK, at first. TDD is most interesting for Europe and Asia, where many operators already have TDD spectrum in their licences. Deployment of data networks for nomadic usage is likely to occur in the US and Asia due to the technology-agnostic spectrum allocation there.

Contact

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List of Abbreviations

ADSL	Asymmetric Digital Subscriber Line
AMPS	Advanced Mobile Phone System
AWS	Advanced Wireless Services
BTS	Base Transceiver Station (”base station”)
BWA	Broadband Wireless Access
CDMA	Code Division Multiple Access
COFDM	Coded OFDM
CPE	Customer Premises Equipment
DAB	Digital Audio Broadcast
D-AMPS	Digital Advanced Mobile Phone System
DL	Downlink
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DVB	Digital Video Broadcast
E1	Wired digital transmission format supporting 2.048 Mbit/s
EDGE	Enhanced Data rates for Global Evolution
EV-DO	EVolution - Data Optimised
EV-DV	EVolution - Data and Voice
FBWA	Fixed Broadband Wireless Access
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FLASH-OFDM	Fast Low Latency Access with Seamless Handoff - OFDM
GMSK	Gaussian Minimum Shift Keying (modulation)
GPRS	General Packet Radio Service
GSM	Global System for Mobile communication
HSDPA	High-Speed Downlink Packet Access
HSUPA	High-Speed Uplink Packet Access
iDEN	Integrated Digital Enhanced Network
LOS	Line of Sight
MAC	Media Access Control
MAN	Metropolitan Area Network
MBWA	Mobile Broadband Wireless Access
Mcps	Megachips per second (chip rate)
NLOS	Non Line of Sight
NMT	Nordic Mobile Telephony
OFDM	Orthogonal Frequency Division Multiplexing
PCS	Personal Communications Service
PMP	Point to Multipoint
PSK	Phase Shift Keying (modulation)
PTP	Point to Point
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RNC	Radio Network Controller
T1	Wired digital transmission format supporting 1.544 Mbit/s
TD-SCDMA	Time Division - Synchronous Code Division Multiple Access
TCP/IP	Transfer Control Protocol / Internet Protocol
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
UL	Uplink
UMA	Unlicensed Mobile Access
UMTS	Universal Mobile Telecommunications System
VoIP	Voice over Internet Protocol
WAN	Wide Area Network
WCDMA	Wide Band Code Division Multiple Access