HSPA and mobile WiMax for Mobile Broadband Wireless Access

Written in association with:

Praxis High Integrity Systems

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Executive summary

The advent of mobile broadband access is accompanied by significant uncertainties over the likely future successes of the new technology choices that are becoming available. In particular, the relative commercial and technical advantages and disadvantages of operating HSPA vs. mobile WiMax remain unresolved. Operators, regulators and vendors are developing their plans for the future in a cloud of hype, biased comparisons, and easily misinterpreted statistics.

In this report, Arthur D. Little attempts to take an unbiased view of both technologies, assessing their limitations and achievements on a like-for-like basis, in a framework that is relevant to investors and operators making strategic decisions about technology investments.

For this purpose, we have interviewed 31 HSPA and WiMax equipment vendors, operators running the networks, government regulators and financial investors around the globe. We have not only gathered and analyzed the qualitative assessments made by our interviewees but together with our colleagues from Altran Telecoms & Media and Praxis have also collected some 300 parameters required for a quantitative assessment of the differences and have modelled these in realistic deployment scenarios.

Main findings

Our findings can be summarized as follows:

- HSPA will account for the majority of mobile broadband networks worldwide over the next five years
- Mobile WiMax is a competitive technology for selection by operators over this period in only a limited number of circumstances where conditions are favourable
- There are 93 commercial HSDPA networks in operation today, while the first commercial mobile WiMax networks are expected to enter service during 2007[1]
- In the long term mobile broadband wireless systems will be characterized by technologies such as OFDMA and MIMO whose development is being actively pursued throughout the industry and are part of the evolution path for both WiMax and 3GPP

[1] Sources: GSA and WiMax forum - the first mobile WiMax Forum Certified™ products are expected in early 2007

- While first generation mobile WiMax systems are expected to achieve significantly greater data transfer rates than today's HSPA networks (theoretical peak data rates of e.g. 16.8 Mbps in urban areas vs. around 10 Mbps for HSPA in the same 5MHz channel bandwidth), mobile WiMax cells supporting these higher data rates will tend to be notably smaller, at only one half to a quarter the cell radius of the equivalent HSPA cell[2]
- Reasonable trade-offs between range and throughput which effectively eliminate WiMax's speed advantage are likely to involve a relative CAPEX disadvantage for WiMax of around 20-50%. Indications from our quantitative commercial model are that CAPEX for current WiMax technology would be increased by up to 5-10 times (with the increase being greater for rural than for urban and suburban deployments) to achieve maximum theoretical WiMax throughput
- Compared to 3G/HSPA networks early generation mobile WiMax systems are less capable in terms of voice traffic capacity, limiting the size of the markets and scope of user needs they can address and hence the revenues and returns they will be able to generate; also they cannot support the same level of mobility, and their core OFDMA technology is more prone to inter-channel interference from Doppler shifts caused by the rapid movement of user terminals

The results of our quantitative commercial model illustrate the relative benefits and limitations of HSPA and WiMax. WiMax is capable of achieving higher peak bandwidths to the user than HSPA through higher modulation techniques of 64QAM in up- and downlink, compared to 16QAM (downlink) and QPSK (uplink) for HSDPA. Higher modulation means a higher data rate is available, but the signal is less robust and so does not travel as far as lower modulation signals. Such high bandwidth is, however, only available very close to a base station, and falls away rapidly as the user moves away from the cell centre.

In contrast, the bandwidth available in an HSPA system falls off much more slowly with distance from the base station, allowing for larger cells. For example, the peak data rate per sector expected to be available through WiMax can be up to 16.8 Mbps in urban areas vs. the already commercially available 10 Mbps or so for HSPA (which will increase substantially in its next generation) under identical conditions, but this higher bandwidth is only available within a significantly smaller cell area. Typically, the radius of HSPA cells can range up 2-4 times larger than that of mobile WiMax cells, leading to cells that are 4-16 times larger in area.

[2] Sources: GSA and WiMax forum - the first mobile WiMax Forum Certified™ products are expected in early 2007

In practice, mobile WiMax operators will use means that will extend the range of each base station but to the detriment of data rates. To increase the cell range and hence reduce CAPEX and OPEX, WiMax technology enables operators to deploy networks using PUSC modes (Partially Used Sub Carriers) that can achieve cell ranges closer to or in some cases beyond those of HSPA. In many such cases **WiMax will have a CAPEX disadvantage of 20-50%, without any speed advantage for users compared to HSDPA.** The bandwidth available to the WiMax user will be substantially reduced below its theoretical maximum values, particularly in the uplink where it can drop by up to ~95%.

If WiMax is to realize its theoretical speed advantage in terms of peak data rates, it will require a much larger number of base stations and sites, and its CAPEX could be increased by up to 5 to 10 times, with the lower multiple applying to urban deployments. Even assuming that theoretical maximum WiMax data rates are achieved in large scale real world deployments and can be made available to users, this finding raises the question for operators of whether there is sufficient additional revenue to be won to justify the investment to offer these higher data rates, compared to much less expensive networks which offer the speeds of which HSPA is proven to be capable.

The economic balance between the two technologies will shift more in favour of WiMax when capacity-limited rather than coverage-limited situations are encountered, so that cell radii and numbers of cell sites required are determined by capacity and not by range, as they are in the cases covered in this model.

The range of WiMax like all wireless technologies is sensitive to the overall link budget (the maximum allowable path loss) which involves in particular two parameters where for the moment WiMax equipment is at a relative disadvantage (receiver sensitivity and transmit power, particularly on the uplink) compared to HSPA. If the available WiMax link budget improves to a value closer to that achieved in HSPA networks, then in some deployment scenarios its CAPEX premium may disappear or even be reversed into a modest advantage. In making choices between technology alternatives operators should pay careful attention to the tradeoffs between coverage and throughput that must be made in the deployment of any wireless technology. Simplistic technology comparisons that focus only on one figure of merit, typically theoretical peak data rate, often largely neglect these tradeoffs, or fail to connect them to their critical commercial and financial implications. All the parameters in a radio system have an impact on the others. This can be thought of as a “water bed” effect, in that “squeezing” performance in one area makes the “bed bulge” somewhere else. For example maximizing the data rate of a radio network limits the range of the network, and, correspondingly, increasing the range reduces the data rate. The value of one parameter can only be maximized at the expense of another.

Both technologies are expected to improve significantly in terms of price/performance in coming years. Operators facing deployment decisions in future should develop indicative comparisons of the technologies they are considering in light of the actual performance parameters which they are confident vendors will be able to deliver at the time the equipment is to be acquired and deployed.

In selecting wireless technologies to deploy operators also have to take into account a wide variety of business/market, regulatory (notably spectrum allocation), market, and competitive considerations, as well as the CAPEX and performance aspects of the technologies themselves already alluded to, and the costs, performance, and availability of user terminals. They also consider the influence of their existing investments, if any, and how much of this installed base can be reused or applied to reduce the costs of deploying a new or upgraded technology. The assessments we have undertaken of these other factors indicate that their combined effect will more often favour the choice of HSPA over mobile WiMax rather than the opposite during the next few years.

The momentum behind HSPA

Over the next five years HSDPA networks and upgrades, including HSUPA and HSPA+, will be deployed much more widely than mobile WiMax thanks to the combination of:

- The substantial **momentum in HSDPA deployments** and plans that have been built up since late 2005, and its time-to-market advantage over mobile WiMax
- The large number of GSM and UMTS operators **already operating commercial networks in 3G spectrum** for whom HSDPA (and upgrades) constitute a natural migration path
- This large HSDPA base gives rise to significant **economies of scale**, particularly on handsets and user devices
- This is supported by a very **large ecosystem** of global suppliers of components, subsystems, equipment and network design and implementation services
- Demands for higher speed data services in nomadic and mobile environments which earlier (pre-HSDPA) 3G systems cannot satisfy, and are being generated by competitive pressures and **demands from significant customer segments**

Clearly, the momentum in HSDPA deployments has been stimulated among other factors by competition from other broadband wireless technologies and the prospect of competition from mobile WiMax.

In contrast to preceding versions of 3G technologies, HSDPA achieves a quantum leap over dial-up speeds, reaching levels comparable to that of the first generations of DSL access in fixed networks, which was sufficient to help trigger the takeoff of broadband internet services. HSPA offers for most operators the least risky and best understood route to offering broadband mobile services with speeds comparable to early DSL access services. Furthermore, in contrast to the environment at the beginning of this century, today powerful internet-based interests (e.g. Google, Yahoo! and MSN) are devoting considerable resources and ingenuity to deliver innovative and valuable services and capabilities aimed at mobile users. This will stimulate demand for mobile broadband wireless access. Hence, there are strong incentives from both consumer demand and competitive pressure for operators to deploy available wireless infrastructure and handsets capable of achieving user speeds comparable to first generation DSL access. Less risk in business terms translates into a lower cost of capital, which makes it easier to achieve a desirable level of profitability[3].

The limitations of WiMax

Over the past year WiMax has made significant progress in building a comprehensive "ecosystem" of supply, albeit one which has not yet established the depth and breadth of the HSPA equivalent. This progress is making mobile WiMax a credible alternative to consider for deployment by operators where appropriate circumstances exist. The number of operators which fall into these circumstances is much smaller than the number for whom HSPA represents a natural upgrade.

Unlike HSPA which can address large numbers of established networks as a natural upgrade, the deployments of mobile WiMax will be constrained by the:

- Timing of proof of performance of mobile WiMax in large scale deployments with significant numbers of users before 2008
- Timing of availability of suitable WiMax-embedded user devices at attractive prices and with acceptable power consumption and other characteristics; the first such devices in notebook PC and PDA-like formats are expected to be available in quantity in 2008 and handsets only in 2009 or later
- As a consequence of the above, WiMax user devices will not enjoy the same benefits of economies of scale as HSPA

[3] Furthermore, the riskier the venture the greater the return expected to justify it.

There are situations where an operator may choose mobile WiMax in preference to other mobile technologies. These are where the operator:

- Does not currently have access to harmonized 3G spectrum but does have spectrum at frequencies such as 3.5, or 2.3 GHz[4]
- Is a fixed operator wishing to deploy broadband to areas where wired alternatives, notably DSL, are neither available nor economic to deploy
- Is looking to develop or enlarge and enhance "hot spot" or "hot zone" broadband, primarily nomadic services

In this last case it is unlikely that the operator will offer national or wide area coverage or mobility capabilities comparable to those which existing mobile networks and their HSPA upgrades will provide. At least in its early implementations, WiMax will not handle voice traffic as efficiently as 3G/HSPA networks, nor will it offer the same degree of mobility (let alone national or global roaming capability) as the latter. Hence operators, whose business cases depend on generating a significant amount of revenues from voice services, or from users in mobile rather than nomadic environments, will find it hard to justify investment in a mobile WiMax network, except perhaps if it can be operated in a complementary mode to a 3G/HSPA or other mobile network.

An operator in this last situation that possesses both 3G and WiMax spectrum assets (Sprint Nextel is one example in the U.S.) may deploy two broadband wireless networks, with the idea of concentrating the delivery of new data services over WiMax and voice over 3G. Operators who consider this path will need to factor into their business plans the added operational cost of running two networks, to show that this cost will be more than compensated for by the generation of new revenues from mobile WiMax.

The mobile WiMax network will involve a variety of WiMax-enabled user terminals in different formats from the typical handset, most likely acquired by the customer at full retail cost. Given the limitations of WiMax, these terminals may need to be dual mode in some instances so they can rely on the 3G or 3G+ network for connectivity where there is no WiMax coverage, to provide wide area coverage and to enable mobile WiMax operators to gain scale. However the development and use of dual mode handsets does not come without its own development and integration costs, as well as increased terminal size and complexity.

[4] Spectrum in the 2.5 GHz band is allocated as an IMT-2000 (i.e. 3G) extension band by the ITU, thereby excluding in many countries the deployment in this band of mobile WiMax that is not yet recognized as an IMT-2000 technology. If a current initiative to include mobile WiMax as an IMT-2000 technology is successful, then the number of operators able to consider mobile WiMax deployments will increase over what would otherwise be the case

A major factor that operators considering mobile WiMax will have to take into account is the cost of WiMax user terminals in markets, notably price-sensitive emerging or developing economies, where business cases without significant voice revenues are not viable. Because of low WiMax volumes, the prices of WiMax handsets will remain significantly higher than those of other, much higher volume, mobile terminals, which are being developed and offered in increasingly lower cost versions.

The upper hand on performance

There are conflicting claims about the presumed superiority (or inferiority) of mobile WiMax compared to HSDPA technologies in terms of technical performance and costs. To date, there is no convincing real-world evidence of the actual relative performances of these technologies across the wide variety of network environments and designs that operational networks will encounter in diverse conditions of terrain, climate, density of users, and traffic patterns. However, in the context of the systems that are expected to be available in the near future, it is likely that these technologies will achieve comparable levels of performance in specific situations. This means that mobile WiMax should not be regarded as a "killer" or "disruptive" technology. So it is unlikely that operators will abandon the upgrade paths of WCDMA/HSPA networks. Operators with a need to deploy networks offering high speed services to their customers can do so with HSPA without the risk of a possible loss in competitiveness by delaying deployment until another technology becomes available.

In the fullness of time

In the longer term, during the second decade of this century, new OFDMA technologies will form the foundation of the next step change in access speeds in broadband wireless networks. Development of these technologies is being pursued by the 3G/HSPA "ecosystem", within the framework of 3G LTE[5] as well as by WiMax. Once economic demand for faster speeds exceeds the capabilities of HSPA and the first versions of mobile WiMax, then competitive and demand forces will lead many operators to plan the deployment of networks based on this new generation of technologies. At this point numerous existing HSPA networks will face "upgrades" or "makeovers" that are likely to be more extensive and expensive than earlier upgrades from UMTS to HSDPA.

[5] [5] Long Term Evolution – the next major revision of the 3G WCDMA air interface

Hence a longer term competitive question for equipment vendors and markets is whether in this longer term either the mobile WiMax or the 3G LTE streams will achieve a significant time-to-market advantage over the other. It is possible that mobile WiMax might enjoy a time-to-market advantage over 3G LTE, if the latter were delayed substantially beyond its current roadmap for standards completion and commercial implementation. This opportunity for mobile WiMax would only arise if it succeeded itself in building a solid niche installed base with proven performance and a credible upgrade path in coming years. The prospects for this outcome would be enhanced if during the intervening period one or more of the following developments were to unfold:

- Very evident economic demand, which consumers were willing and able to pay for but HSPA could not satisfy, grew rapidly for the capabilities associated with higher speed throughput
- The implementation of new business and use models for wireless networks driven by the mobile internet rather than by traditional voice-centric mobile models
- Establishment of roaming capability between mobile WiMax and other mobile networks as well as between WiMax networks themselves

However, it is also possible that the mobile WiMax stream may be delayed or frustrated in its drive to develop a credible alternative to 3G LTE for the long term if its own progress is slowed by the time it takes to overcome inevitable teething problems in achieving creditable network performance. At this stage, the availability of WiMax-enabled user devices remains low, and while their prices are higher than alternative broadband wireless-enabled terminals, this is likely to change provided demand does develop in line with the commercial launch of significant mobile WiMax networks.

The risk faced by today’s mobile WiMax community is that its products may be both too late and too early to capture a significant proportion of billion dollar contracts. Mobile WiMax may be too late to address a market segment for speeds between a few hundred kbps to one Mbps or so which HSPA is now filling rapidly. Yet it may also be too early in terms of the readiness of components technology and network capabilities (e.g. rapid cell handover) needed for the full flowering of OFDMA/MIMO-based networks, the large scale deployment of which may not take place until the year 2015 or thereabouts.

The long term outcome for the roles of WiMax and 3G LTE broadband wireless systems will be influenced by the initiatives of both equipment vendors themselves and operators. Closer collaboration between these groups, although rejected in the past, may arise if the perceived interests of their members change as result of developments in the market and pressure from major operators. The outcome may range from convergence of the separate technology streams, with possible changes in vendors' relative competitive positions depending on whether one stream is perceived as more profitable in this convergence than the others, to a continued separation into distinct technology "camps."

Current debates over HSPA vs. mobile WiMax tend to be dominated by vendors. However, the influence of vendors will be affected by possible changes in their priorities and alignments comparable to the impact of well publicized recent consolidations within the telecommunications equipment industry. These realignments may result from business initiatives such as divestment and acquisition, corporate M&A, or the formation (and abandonment) of partnerships, driven by the realities of the broadband wireless market, which, in our judgment, cannot profitably support all the current vendors. Vendors' decisions will be determined by their respective competitive positions and perceptions of their prospects in various market segments, as well as by their overall corporate goals. These decisions may lead to reallocations of their finite resources across various R&D initiatives which are competing for financial, staff and other investments (i.e. there is an opportunity cost involved in resource allocation). The WiMax movement itself has been spearheaded by vendors who did not achieve leadership in the 3G network equipment market, and are striving to grow their market share in the overall broadband wireless equipment market thanks to the hope for success of mobile WiMax.

Operators will also influence the long term shape of wireless equipment markets, as they pursue their interests as buyers rather than sellers of equipment, for example by enhancing their influence on standards and specification procedures. This motivation lies behind the multi-operator NGMN (Next Generation Mobile Network) consortium formed during 2006 (which includes the mobile WiMax operator Sprint Nextel as well as several of the largest GSM operators) to foster interoperable multi-vendor equipment markets in which no one vendor can exploit a privileged position with respect to IPR, or unreasonably limit operators' individual choices of supplier(s) by proprietary approaches.

Towards a common agenda

Growing attention is now being paid to the complementary rather than the competitive aspects of mobile WiMax with respect to mobile networks and their upgrades, as evidenced by interest in the value of multi-mode user devices and roaming capabilities across these different technologies. This development reflects the widespread anticipation of the central role of OFDMA and other technologies involved in WiMax and 3G LTE in all eventual future broadband wireless networks. The design and implementation of any wireless network involves inevitable tradeoffs between figures of merit such as data rate, coverage, power, CAPEX etc. which operators have to evaluate in the context of the specific business model and business case which they are targeting. Recognition of the implications of these tradeoffs within widely varying operator environments and goals, as well as of the respective capabilities of alternative wireless technologies will be a welcome change from the provocative and misleading headlines that have appeared over the past two years. In our view many figures of merit in radio systems are intimately inter-related, and changing one will have an impact on the others, for example data rates and cell ranges. Headlines that often emphasize only one figure of merit to the neglect of other equally important ones and imply that mobile WiMax threatens the viability of today’s HSPA and related technologies, are doing a disservice to operators, regulators and others who are trying to decide which technologies are capable of delivering the greatest value for themselves and their core constituencies.

1. Introduction

1.1 Purpose of this report

The purpose of this report is to compare the likely implementation issues as well as cost and performance differences in deploying and running wide-area mobile data networks through HSPA vs. mobile WiMax. We have assessed the likely roles of HSPA and mobile WiMax technologies from the perspective of investors, both:

- Operators themselves who are and will be considering which wireless network technology or technologies to deploy in the context of the business models which they believe can generate sufficient revenues to obtain a satisfactory return on investment (ROI)
- Financial investors and regulators trying to understand what the prospects may be for various wireless technologies in the global marketplace over the next few years.

We have carried out this assessment as objectively as possible, with no bias or interest in favour of or against any one technology, to determine which would be **commercially** better in a wide range of deployment scenarios. We have developed a wireless network model for the purpose of generating indicative comparisons of the two technologies in terms of capital expenditures (CAPEX) and operating expenses (OPEX) in these scenarios. However the model is not designed to be used as a detailed planning tool for a country, with topography, wealth, and population distributions for example, that can be applied to value a specific spectrum opportunity.

We have attempted, as far as is possible, to compare the technologies on a like-for-like basis, taking account not only of questions of relative and absolute performance and costs of various technologies, but also of all the other factors that enter the selection of a network technology by operators, whose circumstances vary widely.

Unfortunately, many misleading statements have been publicized in recent years that tend to present one technology or another as decisively superior and threatening to achieve or take over market dominance. We have noticed that many of these statements do not reflect all the real world considerations that go into the actual decisions which operators make. These considerations include for example the timing of the availability of proven commercial equipment (including user terminals as well as network equipment), and the availability and allocation of suitable and adequate spectrum, as well as the implications of the business models different operators are pursuing, the current and anticipated importance of voice revenues for them, and the offer of attractive financing terms from vendors and others.

In comparing technologies it is essential to compare what they can actually do at the same points in time, taking account of how they are likely to improve in future, rather than to compare one contemporary technology with what another technology may be able to achieve several years from now. It is also essential, as far as is possible, to carry out comparisons between technologies that do not unfairly handicap one in comparison with the other, for example by including a technique in one implementation of a technology but not in the implementation of another, even though the technique may also be applied in the latter to improve its performance.

At the same time we recognize that a 100% like-for-like comparison is unattainable in practice, since any scenario chosen for comparison may tend to favour one technology over another. It is often the case that no one technology is the best choice for all situations, although it may be used even in situations where it is sub-optimal because of other factors such as ease of interoperability if the same technology is used everywhere, and minimization of inventory and training costs etc.

Furthermore a focus on only one parameter or figure of merit, such as peak data rate which is frequently the theme of comparisons between alternative wireless technologies, does not give an adequate picture of the tradeoffs that inevitably have to be made , for example between costs, coverage, and throughput, when designing and deploying a wireless network. All wireless technologies are subject to the same laws of physics which govern these tradeoffs, and all operators are seeking to achieve a reasonable return on their investments (ROI). The commercial value of a network ultimately depends on whether it can attract enough revenues (i.e. enough customers or users or other sources of revenue willing and able to pay enough money) to meet an ROI goal.

Customers' needs and priorities as well as their ability to pay vary widely across the overall market that the network may try to address to achieve commercial viability. This observation confirms the idea that a focus on only one aspect of the performance of a network technology while ignoring others is a misleading and inadequate basis for assessing its likely commercial value. Our work emphasizes the tradeoffs between parameters such as costs, data rates, coverage, CAPEX etc. which must be explicitly considered in assessing the commercial value of wireless networks to ensure that they can meet the diverse requirements of a sufficiently large number of addressable or target customers.

It should be stressed that our report is concerned with mobile and not fixed WiMax and while 802.16d (fixed) shares the same WiMax name as 802.16e (mobile), there are incompatibilities in their underlying technologies, leading to different cost and performance parameters.

We fully acknowledge that recent and ongoing initiatives with respect to mobile WiMax have had the beneficial effect for the entire wireless sector of stimulating progress in and deployment of other wireless technologies more rapidly and effectively than would probably have occurred in the absence of WiMax as a competitive wireless system. These initiatives involve a growing group of powerful commercial and technical interests which is increasing the level of confidence among operators that WiMax could become a technology with staying power.

We also recognize that in the longer term mobile networks are expected to incorporate several of the technologies which WiMax is emphasizing. However, these technologies are being actively pursued by all significant wireless technology developers, including those identified most closely with the larger 3GPP group. They will eventually be deployed (but not in the next 5 years and probably even longer) on a widespread basis as progress in components and other capabilities enable them to meet demands for continued increases in bandwidth. But as investors know full well, market timing is critical if a good return on investment in a technology is to be achieved, and being too early can be as damaging as being too late.

1.2 Work program

Our work comprised three components:

- Establish a qualitative overview
- Gather all base parameters which impact performance comparisons
- Model network performance and cost

To establish the qualitative overview of the position of HSPA vs. mobile WiMax, we compared vendor and operator roadmaps as well as forecasts by industry players and independent observers. This was arrived at by a mixture of desk research as well as a thorough interview program. Please also see Appendix 6.2 "Qualitative Interview Questionnaire" for the questionnaire used to understand the views of senior industry figures and Appendix 6.4 for a list of selected main sources. Our desk research was extensive and exhaustive. We have covered some 100 references – white papers, presentations, studies, etc. With the vast amount of information available, the challenge is to distinguish relevant and in-depth information from biased "hype" or papers that only repeat the standards.

In all, were we able to conduct 31 interviews divided between:

- 18 vendor interviews
- 10 operator interviews
- Interviews with regulators and others

Out of these 31 interviews, 14 interviews were predominantly qualitative in nature. The list of model parameters was at least partially discussed in 23 interviews and the values and likely ranges of at least some of the parameters were discussed in 16 interviews. In terms of geography, 17 of our interviewees were based in Europe, 12 in North America and 2 in Asia, and many of these interviewees had or had held responsibilities for activities in regions outside their current base.

Many of our interview partners hold senior positions in some of the world's best known vendors and operators. Other companies we approached for comment declined to cooperate or withdrew their cooperation during the interview process. Overall, however, we are satisfied that we have sampled a sufficiently large and high quality pool of opinion and understanding for the findings to be representative.

Our interviews have led us to an understanding of some of the key parameters involved in operator decisions on technology and have assembled an overall assessment of these influencing factors:

- Business model
- Performance
- Spectrum
- Timing
- Momentum, scale and unit costs

The interviews have also allowed us to assemble a detailed list of the base performance parameters that can be used to compare the two technologies. We have populated this parameter list and iterated it with selected vendors and operators, sometimes several times.

The next step involved defining the modelling scenarios (urban, suburban, rural) and establishing the network performance and cost model. This model is an approximate but full network cost model (OPEX and CAPEX) based on the collected performance parameters. It allows a view of relative performance as well as a fully costed comparison of access technologies under the three scenarios.

1.3 Structure of this report

The structure of this report mirrors the work steps outlined above. We first cover a qualitative overview, based on the input from senior executives in the industry. This overview addresses the operator decision criteria, gives an overview of the current situation and some scenarios for future development.

We then describe the model and its findings in terms of cost and network performance. This last section contains detailed model comparisons between HSPA and mobile WiMax. As far as we are aware, this is the most comprehensive and like-for-like comparison of the two technologies.

Finally, we summarize our conclusions and provide supporting material to the report.

2. Qualitative overview

The decisions by operators on whether, when and if so which new wireless network technology or technologies to deploy depend on a wide variety of external and internal factors and forces, such as:

- The business model operators are implementing (the customers they wish to serve, the services they will offer, the basis on which they choose to compete and how they intend to achieve a return on their investment)
- The spectrum available to them, and the conditions of use associated with this spectrum (including regulatory conditions such as rules regarding resale and interconnection)
- The costs and performance of the technologies available to them – including user devices as well as the actual network equipment itself
- The state of maturity of the various technologies (timing of commercial availability, roadmap for future improvements etc.) and the strengths of the “ecosystems” of suppliers which provide and support them, and
- Other factors including the need for and value of interoperability with operators’ existing investments (if any), their ability to negotiate attractive supply contracts with different technology vendors, the state of competition and/or cooperative relationships between operators (in the same or different geographic markets), as well as - in some countries -government support for specific technologies

The circumstances of operators vary widely within as well as between countries, so it is not surprising that operators should reach different decisions regarding which technology to deploy at any given point in time. Exceptions to this expectation would only occur if one technology were so overwhelmingly superior to all alternatives that its selection would be practically a “no brainer” under almost any circumstances.

When a new technology arrives on the scene, only if it is truly a “killer” technology, i.e. it offers a decisive (say 10x) advantage over existing alternatives in terms of cost and/or performance, can it be expected that it may sweep all before it and, in winning adoption by all or the great majority of potential buyers, destroy the market for competing solutions.

There is no evidence that the new mobile WiMax (mWiMax) broadband wireless technology fits this definition of a "killer" technology as compared to HSPA (or EV-DO). Mobile WiMax may be competitive with, or even somewhat (but not decisively) superior to these technologies in certain specific deployment scenarios (as defined by the characteristics of the traffic the network will have to carry), and inferior in others, although so far there is no convincing evidence from large scale deployments either way. But it is clear that mWiMax is far from matching the impact of fibre optics which, once it became viable as a long distance transmission technology, ruined or severely limited the future for all other long distance transmission systems by virtue of its unmatchable capacity and economics.

Solid evidence of the actual (as distinct from simulated and small scale) performance of mobile WiMax in large scale deployments will only become available in the years 2007/2008 based on the Sprint Nextel mobile WiMax (in the U.S., which is expected to enter initial commercial service in some areas by the end of 2007) and Korean WiBro networks (which were launched on a small scale in mid-2006). However it is reasonable to anticipate that mobile WiMax technology will be competing for operators' investments over the next few years within the context of the full set of criteria outlined above, to the extent that it is proven to be competitive in price/performance with other broadband wireless technologies with mobile capability, and is available from a credible "ecosystem" of suppliers who can demonstrate its performance in large scale real world deployments. It is also reasonable to assess the potential for WiMax to complement other network technologies in enabling operators to maximize their coverage of the total set of customers' potential demands and expectations by exploiting specific areas of superiority of WiMax, provided these advantages can be demonstrated as compared to alternatives for certain combinations of services and coverage, including machine-to-machine communication in addition to services involving humans.

Nevertheless, the question of the likely total size of the market for WiMax equipment is still very open, yet in the absence of a sufficient total market volume it will be hard for WiMax to achieve the costs and revenue thresholds necessary to ensure a sustainable ecosystem of suppliers. However, in assessing the scale implications of the demand for WiMax, it should be noted that this technology (or set of technologies) is not an isolated or independent development, but benefits (in a reciprocal process) from progress in and demands for components and subsystems which it shares in common with other broadband wireless technologies.

The following discussions assess the issues and uncertainties which operators will have to take into account in their choices of broadband wireless technologies to deploy over the next 5 to 6 years. Beyond this period (say post-2011/12), as will also be discussed, additional factors come into play, such as the experience that is developed over the next few years with the mobile Internet and possible, indeed likely reconfigurations of vendors, which further complicate the long term forecasting picture.

It is generally agreed that the future of broadband wireless technologies will be characterized by core technologies such as OFDMA, and MIMO that are part of the WiMax standard, but are by no means exclusive to WiMax. Indeed vendors who are not among the leading proponents of WiMax also have significant experience and expertise in these technologies. Just as the landscape of telecommunications vendors has changed substantially since 2000/2001, so this landscape may well look very different in 2011/2012 from today's configuration, with inevitable consequences for the priorities, technology strategies, and foci of suppliers[6].

Among the large infrastructure vendors the two (Motorola and Samsung) which have been the most prominent advocates of mobile WiMax until now have not been the leaders in established GSM/WCDMA and CDMA infrastructure markets (which are respectively Ericsson and Nokia for GSM/WCDMA and Lucent and Nortel for CDMA), and have therefore been motivated to push a technology alternative in which they could aspire to achieve a higher market share. Realignments of vendors or parts of vendors that may take place for strategic and financial reasons may lead to corresponding realignments of technology foci and hence perhaps to a consolidation of, or closer cooperation between currently distinct streams of technology development (e.g. WiMax Forum and 3G LTE) and/or to their restructuring, as individual vendors jockey for advantage, or in some cases survival in the wireless infrastructure market.

Before tackling the issues of the relative attractiveness of mobile WiMax to operators it should be noted and acknowledged that regardless of its ultimate success in the marketplace, mobile WiMax has already had a noteworthy impact in stimulating the more rapid development and commercialization of other broadband wireless technologies than would probably have occurred in its absence. In this sense the WiMax initiative has already benefited the overall development of broadband wireless technology, and its ability to support new and enhanced services of value to users.

[6] As an illustration of the kinds of changes that can occur, in mid-2006 Nokia announced it was ramping down its CDMA 2000 R&D and manufacturing efforts, and a few months later revealed its intention to supply WiMax base stations and handsets

2.1 Assessment of operators' criteria for network deployment

2.1.1 Business model

Wireless operators face a fundamental challenge in the broadband era, which is how to achieve reasonable returns on their investment, in light of the reality that the revenues per bit of installed capacity which they can expect to receive in traditional operator business models are much lower in a broadband environment than they are for their heretofore "bread and butter" narrowband services of voice communication and SMS.

The history to date of broadband wireless operators over the past ten years is littered with failures as result of the high costs of equipment and service provisioning, and inadequate revenues due to various combinations of low subscriber densities in some of the served areas, and competition from other broadband access technologies (notably DSL and cable modem). Today global interest in broadband wireless is sparking another wave of attention after the many disappointments of the late 1990s and early 2000s. This revived attention is helped both by considerable progress in the technology's performance and economics, and by the growing interest – and related initiatives from players outside the traditional telecommunications industry from Google to Yahoo to Microsoft as well as many others – in offering information and rich media services to customers while they are nomadic and mobile, environments for which wireless solutions are required. In principle, these new services offer substantial opportunities for wireless operators to generate new sources of revenues, such as those derived from their participation in transactions, advertising, and content delivery in ways that go beyond "bit pipe" delivery alone.

However, as noted, this transition to broadband creates at least as many challenges as it does opportunities for mobile broadband operators. These challenges are fundamental to the future business models of these operators. They involve choices and issues that are far broader than the question of which broadband wireless technology (or technologies) to implement. They go to the heart of the operators' business models which, if they are to capture these new sources of revenues, will require very different attitudes and approaches to their customers and to third parties (e.g. owners of content, Web services players) than most cellular operators have traditionally followed, in which they largely control the user device (handset) and follow a "walled garden" approach to the services their customers can access. New business models are much more likely to involve significant roles for user devices which are not controlled (in terms of design or linkage to a specific customer) by the operator, and allow users to access any services which they desire and not only those which are pre-selected by the operator.

The basic observation with which operators have to contend is that the revenue which they can expect to receive per bit carried in a “bit pipe” context is much lower for broadband services than it is for voice or other narrow band services, most notably messaging such as SMS[7] . Revenues per bit transmitted today accruing to a network operator are typically on the order of $\$10^{-4}$ for SMS, $\$10^{-7}$ for voice, and $\$10^{-9}$ for a downloaded movie. Yet in broadband networks (this phenomenon has already become apparent in fixed broadband and will eventually come to pass in the nomadic and mobile environments as well) competing service providers can offer voice with today’s technologies as an incremental add-on, and either take advantage of, i.e. undercut, continuing price umbrellas associated with traditional telephony, or offer voice as a “bundled” or “free” component linked to other services. Either way the outcome can be severe erosion of the revenues of established telephone companies, resulting in a substantial loss in value of traditional voice markets on which almost all telephone companies – and mobile operators even more than their fixed counterparts – still depend. This result occurs whether the newcomers deliberately take aim at the network operators’ business, or indirectly as “collateral damage” from these newcomers’ (to the telecommunications services market) main business thrusts, which may be entertainment- (as for cable MSOs) or Web services-focused (as for the large internet-based players).

Other major strategic challenges for mobile operators include how to successfully navigate convergence and/or competition with fixed broadband providers. This challenge applies for both theoretically “integrated” (i.e. fixed and mobile) operators and for a stand-alone mobile operator. It involves in addition key operational challenges such as when and how to launch mobile broadband services. Furthermore the mobile broadband operator has to choose which end-user segments to target, with what devices and at what prices, as well as how to differentiate services in an increasingly competitive market featuring incumbent fixed and mobile operators. Established cellular operators also have to contend with entrants using new technologies operating in new spectrum (e.g. WiMax). The entrants themselves confront the same challenges in principle as their established rivals, all within a very wide range of circumstances across the world as a function of differences in the current states of penetration of fixed and mobile communications, as well as regulatory climates, and the overall economic wealth of the geographic market in question.

[7] This comment and the revenues/bit quoted refer equally to fixed as to mobile operators

The suppliers of wireless infrastructure and components face as many difficult challenges as mobile operators themselves, and will have to pursue effective strategies to establish strong positions in the emerging mobile broadband and convergence markets. The technology choices of operators are of course influenced by the decisions of vendors, since among their selection criteria are the strengths, sustainability and product road maps of the vendors from whom they buy equipment. The WiMax technology stream or "ecosystem" has made significant progress over the last 12-18 months in creating a credible "ecosystem" of suppliers (led most notably by Motorola, Intel, and Samsung, and including Alcatel-Lucent and Nortel and more recently Nokia as well as several entrepreneurial chipset suppliers) to inspire confidence in operators that it is an alternative technology with staying power that should be considered along with the longer lived ecosystems of 3GPP and 3GPP2.

The business models being pursued by operators who are deploying or thinking of deploying WiMax vary widely. Some operators see WiMax as a basis of broadband internet access services, similar to and, where there is overlapping coverage, competitive to established DSL-based services. This approach is found for example among entrants trying to serve regions of a country with no or inadequate existing broadband coverage. Other operators view WiMax as an opportunity to build new mobile internet services models which are very different from traditional cellular models in that they envisage much more open and diverse approaches to the devices which their customers may use and the services to which they have access than do the handsets offered (and often subsidized) by the former. Sprint Nextel's WiMax plans are perhaps the best known example of this perspective. Still other operators envisage WiMax as an opportunity for them to compete with incumbent telecommunications operators with a range of voice and non-voice services, for example Wateen Telecom's nationwide rollout in Pakistan.

Beyond the year 2011 the picture for mobile broadband becomes murkier, as the alignment of vendors and various standards efforts, including notably 3G LTE, EV-DO Rev. C[8] ,or 3GPP and 3GPP2 respectively, WiMax, and possibly even IEEE 802.20, is very likely to change. There is considerable commonality, despite differences such as the choice for now of single carrier FDMA for the uplink in 3G LTE, across these various streams of mobile broadband wireless development in areas such as the value of the OFDMA air interface, the need for intelligent antenna technologies and other aspects.

[8] Now renamed Ultra Mobile Broadband by Qualcomm

The competitive interests and priorities of vendors are bound to change over time – as they have in recent years and months following various mergers and acquisitions and the formation (and in some cases dissolution) of various alliances – which will influence the pace of progress of the different technology streams towards commercial implementation and decisions about their convergence and/or continuing competition. So whether for example WiMax and 3G LTE will remain distinctive technology streams in the longer term is today very much of an open question.

2.1.2 Performance

The respective performances (technical and economic) of various mobile broadband wireless technologies including mobile WiMax, HSDPA and others are the subject of much controversy and conflicting claims of superiority. Perhaps this is not surprising, since making true "apples-to-apples" comparisons is very difficult, given the range of circumstances and factors under which mobile broadband wireless technologies may be deployed , the uncertainties in these factors which they will encounter, and the intrinsic variability of wireless performance of wireless channels as a function of factors outside the operator's control, such as weather, changes in building configurations and other aspects of the terrain, and time-varying external sources of interference. Among the most prominent variables to consider are:

- **Spectrum** (frequency and bandwidths available)
- **Coverage requirements** and nature of terrain to be covered, as well as availability and characteristics (e.g. height) of sites for base stations
- **Capacity requirements** (and hence whether the numbers of base stations needed will be determined by coverage or capacity requirements) – capacity is itself a multidimensional variable, involving considerations such as latency and delay requirements of the services offered, traffic patterns of users (number of simultaneous users for example) respective importance of uplink and downlink capacity, role of uni-cast versus multi-cast services, quality-of-service requirements and expectations, mobility speeds supported (from stationary nomadic, to pedestrian, to moderate and high speed vehicular), and capabilities of the user terminals (power, antenna performance etc.)
- **Business models** of the network operators, which are related to the capacity requirements but also involve factors such as whether they involve significant operator subsidies of user terminals (as in the traditional cellular operator model for handsets) or not (as in the broadband wireless-enabled portable computer model propagated by Intel among others)

- **Assumptions** regarding not only the air interfaces but also the use of techniques beyond the air interface such as MIMO and beam forming, and in the longer term inter-base coordinated networks, dynamic network optimization, cognitive radio techniques and others

It should be noted that the link capacity or spectral efficiencies of several air interfaces are rapidly approaching the Shannon limit in terms of bps/Hz independently of technology. Hence differences in performance of deployed systems will largely depend on techniques beyond the air interface. These techniques are generally not unique to any one technology, any more than are optimization techniques applied to speed up the delivery of data (improve the user experience) over wireless IP networks through such means as content-aware compression and overcoming the inefficiencies of the TCP (transport control protocol) under the much more variable conditions of wireless as compared to fixed network channels.

The claims made by the proponents of various technology "camps" are often designed for marketing purposes and cover a very wide and conflicting range. They should not be taken at face value as applying across the board. Rather each operator has to assess its specific situation and how the alternatives will perform over time, based on the technologies or equipment actually available when it decides deployment will be necessary. Typical examples of claims include on the WiMax side: "Its cost per bit is one-tenth of what 3G can provide"[9] ; to in contrast "WiMax data capacity is 1/2 to 1/3 that of 3G"[10] . These claims and counterclaims based upon different assumptions are helpful in that they confirm the idea that WiMax should not be regarded as a "killer" technology, but they do not by themselves provide any clear indicator for the market shares that will be captured by the various technologies over the next few years. As emphasized throughout this report, these market shares will be a function of many other factors in addition to this kind of direct technology comparison. They will be primarily sensitive to the circumstances of individual operators and the environments they are seeking to address.

[9] John Roese, CTO Nortel, quoted in Oct. 13, 2006 issue of Computerworld

[10] Qualcomm paper "3G Offers Mobile Broadband Today", Nov. 2006

Table 1: Most promising opportunities/motivations for deployment of Mobile WiMax[11]

Network Environment	Fixed Operators	Mobile Operators (existing cellular)	Entrants
Developed markets *urban areas*	To enter nomadic and mobile markets	To provide data-centric services and address mobile internet	To provide data-centric services and address mobile internet
Developed markets *rural areas*	To offer broadband access in underserved areas	To offer broadband access in underserved areas	To meet demands in underserved areas
Emerging markets *densely populated areas*	Fixed operators for areas with poor fixed networks	To compete with fixed broadband services	To compete with existing operators while minimizing dependence on their facilities
Emerging markets *rural areas*	Fixed operators for areas with no or poor fixed networks	To meet demands in areas with no or poor fixed networks	To meet demands in areas with poor or no networks

(where attractive spectrum assets are available, and licensing conditions permit)
Source: Arthur D. Little analysis

As a general rule it can be stated that subject to the availability of spectrum, which works today as a major constraint for the deployment of WiMax, the best short term (next 5 years) opportunities for WiMax will lie in the arenas shown in Table 1. This table does not imply that WiMax will necessarily be the dominant solution in these deployment scenarios, rather that it will have the best chances of finding customers among operators who fit these profiles, who are also likely to consider alternatives such as HSPA in many of the cases. There are many other operators with existing 2G and 3G networks and no attractive available spectrum for WiMax (or spectrum which could be used for WiMax or alternative technologies) who will find that adopting HSDPA and then HSUPA technologies is the most natural and economical way for them to increase their capacity for voice services and offer higher capability data services over the next 5 years.

It should be emphasized however that the huge global base of GSM and UMTS operators for which HSPA is a natural upgrade path in many markets, ensures that this technology, as evidenced by the pace of its adoption over the past year, will find many more buyers than WiMax over the same period.

[11] Mobile Wimax equipment be installed for fixed and nomadic use only, at least initially, and also (or subsequently) applied for mobile use as well

The current picture of mobile connections is shown in Table 2, which demonstrates that the GSM "family" accounts for over 80% of today's mobile subscribers. Against the power of such an installed base, the prospects for technologies to succeed in moving beyond a niche role depend upon gross failures or an inability of the "incumbent" vendors of entrenched technologies to build a reasonable migration path for their customers, and/or the success of the new technology in enabling the creation of entirely new business models that in effect bypass the power of the installed base by finding and exploiting new user demands which the installed base cannot meet.

Table 2: Global mobile connections by network technology

Number of connections (million)	Q2 2005	Q4 2006
GSM	1,463	2,158
WCDMA	29.9	99.2
TDMA	65.1	20.6
PDC	53.1	31.4
IDEN	19.1	25.6
CDMAOne	67.0	20.4
CDMA2000 1x	184.9	280.1
CDMA2000 1xEV-DO	18.8	49.9
Analog	7.8	3.1
Total	*1,910*	*2,693*

Source: Wireless Intelligence

2.1.3 Spectrum

The question of spectrum assignment and subsequent allocations to operators for WiMax deployments – whether reserved for WiMax or where WiMax is a permitted and reasonable technology among alternatives in a relatively technology-neutral approach to spectrum management – is critical to the development of the market for WiMax equipment and WiMax-based services. Since spectrum is already available in many countries to other wireless technologies – including UMTS/HSPA and EV-DO – delays in assigning spectrum which is suited to and may be used by WiMax networks inevitably inhibits or handicaps the eventual scope of its deployments. Operators faced with demands driven by customers and strong competitive pressures to offer broadband wireless services will choose alternatives to WiMax over the next few years if they cannot acquire spectrum for WiMax even in the subset of circumstances where on paper WiMax might be a better choice.

Figure 1 Spectrum allocations and costs[12]

Spectrum – WiMax costs are lower but HSPA allocations are greatly superior	
mWiMax spectrum	**HSPA spectrum**
■ Status of 2.5-2.7 GHz spectrum – Allocated in US, Brazil, Mexico, trials in Singapore – many other countries targeting auctions in 2007/2008 – US, Canada, Brazil, Mexico, UK, Australia allow/will allow 802.16e in this band – 802.16e access uncertain in much of Europe; unclear in India, China ■ Goals for mWiMax over next few years – Build sufficient globally or regionally harmonised spectrum access for operators – Two licensed band ranges: – 3.3-3.8+ GHz – initial focus on 3.4-3.6 GHz – 2.3-2.4 GHz (Asia); 2.5-2.69 GHz (global) – Single RF chip for these bands – Spectrum costs have been relatively low (but mainly for non-mobile services) from $0.04 in Asia to $0.006 in Europe per Hz/million POP	■ Operators have access to harmonised spectrum allocated to 3G (e.g. 2.1GHz and extension bands) and in some countries, e.g. US, to existing 2G spectrum ■ Over 160 3G licenses have been awarded in more than 55 countries, and recently 58 HSDPA networks have been launched commercially in 37 countries ■ Costs of 3G spectrum have varied from $0.21 in Asia to $0.87 in Europe per Hz/million POP with very wide intra-regional differences (from zero to up to over $4 per Hz/million POP within Europe) – but most 3G licenses are national, whereas the majority of WiMax licenses are regional

Source: Maravedis, Arthur D. Little analysis

The forecasting of when and how WiMax spectrum may be available – especially in the more attractive frequency bands such as 2.3 and 2.5/2.6 GHz and 700 MHz – is among the most problematic of forecasts which affect market developments. It depends on the outcomes of the pressures from politically-motivated, commercial, and special interest lobbies as well as the workings of government bureaucracies. The relative strengths of these influences vary enormously from one country to another, and their impact often dominates arguments based on unbiased engineering analyses or the best available broadly based economic assessments of the value of alternative implementations of spectrum management.

[12] The timing of the availability for WiMax is one of the most critical factors for the growth of WiMax equipment markets – continuing delays such as those in Brazil (postponement of WiMax spectrum auctions from mid-2006 to 2007) and continuing lack of clarity about spectrum allocation in Chian (for 3G as well as for WiMax) complicate the ability of WiMax to build momentum as a possible core driver for wireless networks beyond 2011/2012

HSPA (and EV-DO) have the advantage compared to WiMax of implementation in frequency bands already allocated to their "mother" technologies in many countries, with other countries expected to follow suit in accordance with frequency assignments established within the framework of the ITU. These frequencies fall in attractive ranges (from the perspective of propagation and hence network costs) around 2GHz or even below 1GHz (e.g. the implementation of HSDPA by Cingular in the U.S. in the 850 MHz band). In the most attractive scenario for WiMax, it would be using frequencies such as 2.3/2.5/2.6 GHz and (as expected eventually in the U.S.) 700 MHz. However, in many countries the band most likely to be used for WiMax in the short term is 3.5GHz, with somewhat less attractive propagation characteristics.

The issue of spectrum cost is of course not an issue for existing UMTS operators who already have spectrum. Spectrum auction fees paid in the past are "sunk costs" (in economic terms), and have no impact on economically efficient future investment decisions. However, in countries which have not yet awarded 3G spectrum the relative and absolute cost of spectrum for 3G and WiMax is one of the economic factors which operators take into account in their choice of network technology.

An overview of the spectrum landscape (allocation and costs) with respect to HSPA and mobile WiMax is summarized in Figure 1.

2.1.4 TIMING

In terms of the timing of commercial availability and proven performance in real world large scale deployments, both HSDPA and EV-DO are today well ahead of mobile WiMax deployments (Figure 2).

Experience with wireless services has been that often a lack of compelling devices and content has been the gating factor which has led to delayed launches and slow take-up. This situation arose with the earlier 2G mobile services and more recently with WCDMA and EV-DO services. Many early HSDPA services were launched with only PC cards and notebooks as user terminals (they are less sensitive to battery power limitations than are handsets), and although HSDPA handsets have now started arriving they are not likely to be mature for several years. Other broadband wireless network-based services, most notably mobile WiMax, will face the same challenges.

We expect that the extent of availability of attractive handsets with acceptable performance (e.g. with respect to bulk, weight, battery life, design etc.) will constrain mass-market adoption of new and improved mobile broadband services through 2007. Handsets should start to mature in the year 2008, enabling a significant increase in mobile broadband device sales and subscribers in the years 2008-09. Wireless broadband-capable user devices in other formats, such as notebook PCs and emerging handheld ultra mobile PCs (as are being developed by Intel with a screen size intermediate between that of a notebook and a handset) are also becoming available at various times over the 2007-2009 time frame.

Terminals other than handsets are generally envisaged as relevant to different business models than the traditional voice-centric handset, namely they will be paid for by the user and not subsidized by the operator, and they will be focused on the mobile internet or Web services. Intel in particular is arguing for a “two device” mobile or nomadic user environment, in which for example a user will carry both a handset optimized for voice communication and a second device optimized for the mobile internet. This approach is aligned with the notion that some operators should consider deploying a WiMax network (most likely with less extensive geographic coverage than existing cellular networks) to deliver rich data-centric services as a complement to the voice-centric cellular networks, in contrast to trying to accommodate all services within a single cellular network. Operators faced with the alternatives (assuming spectrum assets are available) of either (a) deploying a new WiMax network to carry new services and launch a new internet-focused business model (allowing its customers to use its cellular facilities where the WiMax network has no coverage) or (b) continuing to follow a capacity-expanding migration path as defined by HSPA (or EV-DO) will have to weigh their respective advantages and disadvantages taking account not only of the factors identified earlier but also the OPEX implications or added costs they may incur as a consequence of introducing a new network technology (e.g. additional staff training, new spare parts and inventory requirements etc.).

Figure 2: Timing of broadband wireless developments

Timing – HSDPA has a time to market advantage over WiMax (as does EV-DO)

	2005	2006	2007	2008	2009	2010
Mobile WiMax	Dec 2005 – 802.16e amendment ratified	Jan – US agrees to open spectrum at 700, 1710 and 2110 by 2008	Certified product available in volume	Handsets/laptops and other wireless devices with embedded WiMax	Handsets in commercial volumes, multi-mode in laptops	Integrated WiMax/WIFI/ cellular handsets
	Increasing support from several major global firms + entrepreneurs	June – Intel ships Rosedale2, dual (fixed/mobile) WiMax chipset	First PCMCIA cards			
	First deployments of pre-802/16e equipment	July/Aug – WiBro service launched in Korea; Sprint chooses mWiMax				
	EC consultation on opening use of 2.5 GHz spectrum to non-IMT-2000 technologies	3.5GHz spectrum awarded in several markets – but mobile use not allowed	2.5GHz spectrum to be awarded in some markets	2.5GHz spectrum to be awarded in some markets; 700MHz spectrum auction in US		
GSM/3G	3G spectrum already awarded in multiple markets	163 3G licenses awarded in 57 countries	3G license awards in China and India	First launch of HSUPA service		First long-term evolution (LTE) product
		Sept – 71 HSDPA devices from 26 suppliers available (incl. embedded HSDPA laptops)	85 HSDPA networks expected in service early 2007 in about 40 countries			

Source: Gartner, GSM Association, Global Mobile Suppliers Association, OECD, IDC, WiMax Forum, Intel, Arthur D. Little analysis

It is likely that mobile WiMax will only play a relatively minor role in the mobile broadband market through to the year 2011, not only because of continuing limitations in spectrum availability and the timing of when proven performance in large scale network deployments will be demonstrated, but also largely because mobile WiMax-enabled notebooks and handheld devices will not arrive in volume until the years 2008-09 at the earliest. In addition the early versions of mobile WiMax will not achieve the full mobility capabilities of HSPA and EV-DO. Over the next five years until about 2011 WiMax has better prospects for gaining significant momentum in the fixed, nomadic and portable wireless broadband segments. These opportunities are being found both in the poorer developing markets, where fixed broadband is often hardly developed at all, and in wealthy markets in areas where fixed broadband alternatives are not viable.

2.1.5 Momentum, scale and cost

As of October 2006 there were 40 live HSDPA services worldwide, less than one year after Cingular Wireless (now AT&T) launched the first such service in December 2005 in the U.S. In addition, SK Telecom introduced the first HSDPA handset in May 2006 in Korea, and more than ten HSDPA services worldwide offer handsets as of end-2006. The launch of handsets is a strong indication that operators are optimistic about the future of HSDPA, and its ability to help increase customer ARPU.

HSDPA has until now lagged behind EV-DO networks, the first one of which was launched as long ago as January, 2002 (by SK Telecom in Korea). By October, 2006 there were a reported 42 EV-DO (Rev. 0) networks in operation worldwide, a much higher percentage of the CDMA 2000 1x networks in operation than HSDPA represents today of the more numerous WCDMA networks. The rise of HSDPA has led major EV-DO operators to look to a new version of EV-DO, namely EV-DO Revision A, which boosts both downlink and uplink speeds, compared to HSDPA which only increases download speeds over WCDMA. The first commercial availability of HSUPA in WCDMA networks, which boosts uplink speeds, is scheduled for the year 2007, e.g. in Austria. Sprint Nextel launched EV-DO Rev. A services with a data card in October 2006 in San Diego, California and KDDI is launching EV-DO Rev. A services in Japan with a handset as well as data cards in December, 2006. Verizon Wireless is trialling EV-DO Rev. A in the U.S. and is expected to launch service in the near future.

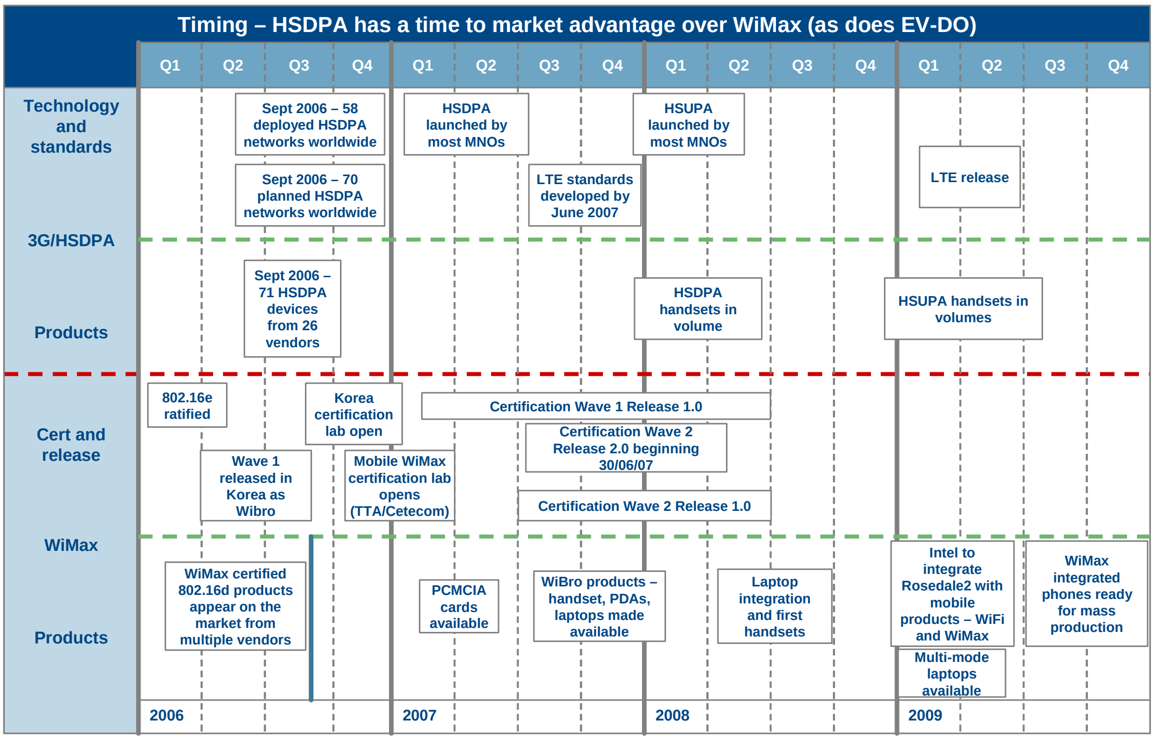
Many more HSDPA launches have been announced in addition to the networks already in service, and by end-2006 it is anticipated that there may be a total of about 80 HSDPA networks implemented worldwide. As of late 2006 a total of 108 HSDPA networks in 51 countries were planned, being deployed, or already launched according to a survey by the GSM Association. As another indicator of the prospects for HSDPA at the same time there are over 140 UMTS networks worldwide (with over 80 million UMTS users) and all of these are natural candidates for deploying HSPA. Hence the evidence at end-2006/early 2007 is that among broadband wireless technologies the greatest volume and momentum are associated with HSDPA.

As momentum behind a technology is translated into scale, the scale of the equipment based upon it increases, and the costs are reduced along typical learning and volume curves, with the fall in prices to buyers being further stimulated by competition between vendors attracted to the market by virtue of its size (which may be partially offset if there are effects from powerful individual IPR or proprietary positions which enable some suppliers to command premium prices). WiMax is counting on the lower intrinsic costs of TDD (the first mobile WiMax profiles are all TDD), in which the transmitter and receiver use the same filters, mixers etc. to enable WiMax-capable user devices (and chipsets) to match the costs of other higher volume broadband wireless technologies even at the much lower volumes that will be supplied over the next few years. In addition, WiMax equipment at similar frequencies shares many components and subsystems in common with other wireless technologies, which means that its economies of scale are not dependent solely upon the volume of WiMax equipment that is sold.

2.2 Current status and roadmaps for HSPA and WiMax

Product and deployment roadmaps are intrinsically fraught with uncertainty or liable to change over time as function of the experiences, problems encountered, and business results gained with the respective network technologies. Figure 3 presents the end-2006 “best estimates” of some key events and developments with respect to deployments and product roadmaps in the unfolding of HSPA and WiMax.

Figure 3: Roadmap of broadband wireless products[13]



Sources: Gartner, GSMA, WiMax Forum, HSBC, IDC, Intel, Arthur D. Little analysis

Critical developments to watch for in order to keep up to date and anticipate the future include:

- Spectrum allocations
- Frequency and bandwidths
- Cost of future spectrum acquisition
- Performance results (both technical and business, i.e. user uptake and revenues) from initial large scale deployments of the various technologies
- Availability, price, and performance of user devices
- Progress in standards, from their publication and agreement to product certification, availability, and trials by operators.

[13] If 3G LTE suffers significant delays, and mobile WiMax fulfils its performance goals in 2008-2010, then WiMax may benefit in the longer term from a time to market advantage over 3G LTE

In addition, but not covered in these figures, the outcome of IPR-related disputes and concerns can have a significant impact upon the costs of equipment and hence the attractiveness of a particular technology to operators. Concerns have been expressed that royalty-related costs could account for up to 20-25% of the costs of WCDMA-based handsets, which would be in stark contrast to the IPR burdens of under 5% which would likely be acceptable. However, many powerful technology suppliers, including leading HSPA, EV-DO and WiMax vendors all claim that they own so-called “essential” patents for both WCDMA- and OFDMA- based technology and systems. The champions of WiMax argue that WiMax enjoys a very buyer-friendly and vendor-neutral IPR regime as a significant point in its favour as compared to other broadband wireless technologies. However, it is not obvious that any one technology stream (e.g. HSPA compared to WiMax) will eventually suffer from a relative disadvantage in terms of its economic IPR “burden.”

Whatever technology is deployed the costs of user devices – especially if subsidized by operators – are a key consideration in operators’ perspectives. So it is important for vendors – among whom as noted different players lay claim to various portions of a complete IPR portfolio - to ensure that IPR issues do not adversely affect the development of markets for products on which their business depends.

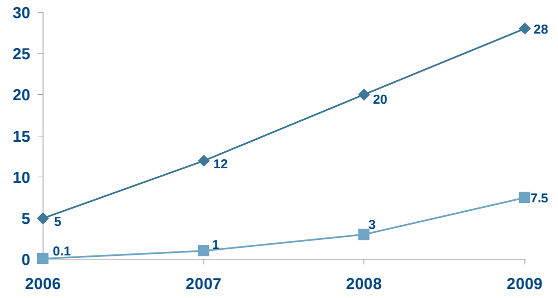
2.3 Scenarios of broadband wireless development

Under any conceivable circumstances, the mobile WiMax access network equipment market will capture at best a niche within the overall market for radio access network equipment over the next few years, reaching according to various forecasts anywhere between $2-6 billion per year by 2011/12. This estimate, based upon the expectations shown in Figure 4 can be contrasted with the global combined market for GSM/GPRS/EDGE, WCDMA and CDMA/EV-DO radio access equipment for cellular operators which totals over $40 billion per year (and whose composition is shifting towards the WCDMA segment, which will account for the major share by 2009). The largest part of this combined market is accounted for by the Asia Pacific region (over 40%), a proportion which is expected to increase further in future.

Hence during this period vendors who capture or continue to capture the leading shares of contracts for non-WiMax equipment will benefit from revenue flows which can support substantial R&D programs in further developments of broadband wireless technologies, including WiMax and WiMax-comparable technologies as they see fit, and from establishing and/or maintaining or enhancing business relationships with, and insights into their mobile network operator customers which are valuable assets for the longer term. In contrast, vendors – especially larger vendors - whose positions in the largest wireless equipment markets shrink will find it difficult to sustain their revenues over a 5 year time frame even if they are successful in capturing a respectable share of WiMax markets.

Figure 4: Forecasts of WiMax growth

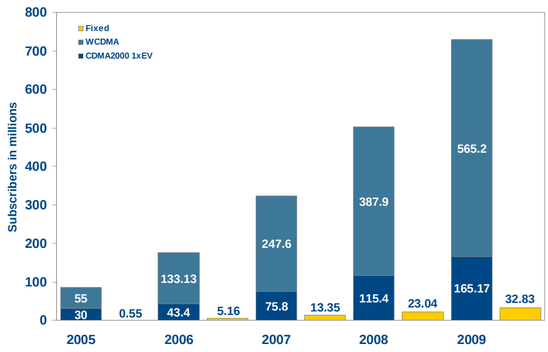
WiMax shipment numbers



- **WiMax** best and worst case scenarios for shipments of subscriber equipment, 2005-2009
- Includes both 902.16-2004 and 802.16e (fixed and portable/mobile) shipments

Total subscribers worldwide (2005-2009)

- Forecasts for 2012 WiMax subscribers are very divergent, ranging from about 20 to 100 million, depending on spectrum assignment/allocation



- Other forecasts (millions) include: **HSPA**: 40 (end 2009, W. Europe) and almost 170 (world, 2011); **EV-0DO Rev.A/B**: 32 (world, 2011)

Sources: Gartner, IDC, Informa Telecoms & Media, Juniper Research, ABI Research, Forward Concepts, Strategy Analytics, Maravedis, Arthur D. Little analysis

In the longer term, as discussed below in 2.3.1, 2.3.2, and 2.3.3, the potential for significant changes in the positions of vendors and hence of the "flavours" of technology which they support becomes wider. Even vendors which may encounter a marked downturn in revenues from their mobile equipment business over the 5 year perspective, but have sufficient resources to survive this downturn, may be able to build a solid position for the longer term. Vendor initiatives such as partnerships, divestments, and M&A can also change the competitive landscape and lead to shifts in emphasis in R&D and commercialization strategies, as has been witnessed in recent years and months (e.g. in 2006 alone: Nokia's ramp down with respect to CDMA 2000, as already mentioned; Nortel's sale of its UMTS access business to Alcatel; and Motorola's collaboration with Huawei in the same UMTS space). The role of Chinese vendors (Huawei and ZTE), which have only recently emerged onto the global telecommunications stage, is also expected to increase, including their participation in WiMax as well as other broadband wireless developments.

Hence during the second decade of the 21st century there may be room for significant shifts in market share among the suppliers of mobile wireless network equipment. The potential for such shifts would be increased in favour of vendors currently emphasizing WiMax by two developments:

- In the standards process and subsequent product development and availability for 3G LTE
- Success (technical and business) of initial mobile WiMax networks between now and 2010

Today's distinctions between WiMax and other mobile broadband wireless technologies may become increasingly blurred and perhaps even meaningless during the second decade of this century. This development may be welcomed by operators if it helps to create an environment in which vendors compete vigorously to supply equipment based on standards which allow a high degree of interoperability between their solutions – and minimize the potential for further provocative eye catching headlines such as "WiMax battles 3G" and "WiMax Revolution threatens 3G", which can mislead the investment community. It should be noted that in broadband wireless as in other equipment markets there is a constant balance or tension between the interests of operators (as buyers) to maximize their negotiating power vis a vis their suppliers (which can be helped if they have the choice between multiple vendors competing to offer standards-based and in the limit interchangeable products) and on the other hand the interests of vendors. Vendors would like to offer products with proprietary aspects which will allegedly be superior to, and benefit from more innovation than, their competitors' products, allowing them to charge a premium and/or to ensure that they have a lock on future expansion and upgrade contracts.

Both the original 2G GSM standard and other successful standards such as DOCSIS in the arena of cable modems have enabled buyers of these products to benefit both from economies of scale and from reducing their dependence on any one vendor. The stated intent of the WiMax community is to offer solutions that will be both less vendor-dependent (i.e. more "open") and less burdened with respect to IPR-related costs than alternatives.

The following sections outline the "best case" and "worst case" scenarios for WiMax in terms of its global prospects for capturing contracts for deployment over the next few years. Subsequently the different circumstances and conditions in developed and emerging markets are assessed in light of their impact upon the prospects for WiMax, and finally the question of the longer term outlook for WiMax is addressed in more detail.

We have chosen to develop these assessments from the starting point of WiMax because, while there is some overlap between the choices of HSPA and WiMax, we have concluded that for the next few years the key question is not whether WiMax will replace or stifle the deployment of HSPA, which is certain to be a mainstream choice by many 2G and 3G operators. This finding is reinforced by the recent tone of the positions of Intel and some other proponents of WiMax as well as some operators who position WiMax as for the moment at least as much, if not more, as a complement than as a competitor to so-called 3.xG technologies in many circumstances. The key question is rather whether WiMax as a newcomer will succeed in building a sufficiently large niche market for itself with proven performance in large scale deployments that it (and the suppliers who are its champions today) will be positioned, if other factors are favourable, to become a major or even mainstream force in the broadband wireless sphere in the longer term beyond the next 5 years.

We note that although there is no evidence that WiMax in its expected deployments in the 2008/2009 time frame will deliver significant performance advantages over HSPA in the same time frame, nevertheless this is not a goal it has to achieve in order to win contracts in some circumstances. Of course, if mobile WiMax did demonstrate such superiority its likely market would become larger. Under certain conditions of spectrum (e.g. no 3G spectrum) and competitive imperatives some operators will find WiMax an attractive solution, as long as it reaches a threshold level of performance and is offered by credible vendors with a solid roadmap for future generations of equipment.

2.3.1 Best WiMax case

The best case outcome for mobile WiMax will be defined by both short term and longer term outcomes, the latter of course being influenced by the former, which will affect the decisions vendors will make in the next few years about what proportion of their R&D and other resources to devote specifically to WiMax. There are significant variations in the possible scenarios for WiMax (including its "worst" and "best" cases) by country, as a function in the first instance of the state of a country's current networks and its wealth. As a first order simplification, we assess this level of detail after some general findings by distinguishing between so-called "developed" and "emerging" economies, recognizing that these two broad categories themselves contain very wide variations in their regulatory, competitive, cultural, and other factors which will affect the prospects for the adoption of WiMax equipment.

For the shorter term (until the year 2011 or thereabouts)

- Proven reasonable performance data in the 2008 timeframe from the first large scale deployments of mobile WiMax networks in the U.S. (Sprint Nextel) and Korea in terms of the speeds experienced by users under real world conditions of usage
- Availability of user devices with costs (including an IPR "burden" that is demonstrably lower than other technologies), battery lives, and other characteristics which are acceptable and, even better, attractive to users (and operators)
- Steady progress in making spectrum available for WiMax deployments in countries with significant actual and potential markets
- Further reinforcement of the WiMax ecosystem with continuing investments by the most prominent players to date (Intel, Motorola, Samsung) and by other influential suppliers, such as Alcatel-Lucent, Nokia-Siemens, and Nortel, as well as entrepreneurial chipset vendors

For the longer term

- Progress in implementing roaming that is seamless from users' perspective not only between WiMax networks but also between WiMax and other wireless networks
- Movements towards convergence of different broadband wireless technology roadmaps and vendor alignments around a common set of technology standards

In addition, the market attractiveness of WiMax to operators will be helped if products based on other technologies such as HSDPA, EV-DO etc. are burdened with evidently significantly higher IPR-related costs than is the case with WiMax-based products.

2.3.2 Worst WiMax case

The worst case outcome for mobile WiMax will also be defined by both short term and longer term outcomes:

For the shorter term (until 2011 or thereabouts)

- Significant delays in overcoming the "teething" problems of the initial large scale deployments of mobile WiMax identified above, so that their performance is seen to be manifestly inferior to that of contemporary HSPA and EV-DO networks in 2008-2009
- Very limited availability of WiMax-capable user devices, and device costs (including an IPR "burden" that is no better or higher than that of other technologies), battery lives, and other characteristics which are unattractive to users (and operators)
- Little or no progress in making spectrum available for WiMax deployments
- Decisions by some major vendors to decrease the proportion of their resources devoted to WiMax-specific developments

For the longer term

- Little or no progress in implementing roaming that is seamless from users' perspective between WiMax and other wireless networks
- Rapid progress in reaching agreement and developing products for the 3G LTE standard which incorporates many of the WiMax technologies, but remains separate from the WiMax camp, and is dominated by vendors who have not been among the WiMax champions so far

In addition, the market attractiveness of other broadband wireless technologies to operators will be enhanced if IPR issues associated with products based on these other technologies such as HSDPA, EV-DO etc. are resolved in a manner which is largely vendor-neutral and ensures that IPR-related product costs are kept to a reasonable level.

2.3.3 Most developed markets

The motivation and incentive behind the rollout of mobile and nomadic broadband wireless networks lie in the prospects for revenues associated with the mobile Internet and the distribution of multimedia content to (and from) users wherever they are.

The most significant differences between developed markets (e.g. Western Europe, North America, Japan) lie in their regulatory climates and the influence of incumbents. For example, in the U.S. the FCC has adopted a largely technology-neutral approach – although of course the details of spectrum allocations (e.g. whether paired or unpaired) affect the relative attractiveness and practicality of alternative wireless technologies. Mobile WiMax networks are being deployed, with the greatest publicity given to the WiMax contract awarded in mid-2006 by Sprint as well as the properties of the other major holder of 2.5 GHz spectrum, Clearwire. The Republic of Korea has allocated spectrum (2.3GHz) for WiMax and both Korea Telecom (KT) and SK Telecom have deployed WiMax equipment in this frequency range. For the very short term SK Telecom, the leading mobile operator, seems to placing more emphasis on its HSDPA network than on WiBro, with announced investments of 810 billion won (about $ 870 million) already in 2006 to build towards nationwide HSDPA coverage (out of its total 2006 CAPEX of 1.6 trillion won), in contrast to its WiBro roll out plans which have a more limited coverage objective and an additional investment of 117 billion won (about $126 million) expected in 2007. Reportedly there were over 100,000 HSDPA subscribers in Korea as of November, 2006 (6 months after launch of service), while the growth of WiBro customers was still being inhibited by issues of availability of user devices and teething problems with their power consumption.

In contrast opportunities for mobile WiMax in much of continental Europe are for the moment severely limited by a lack of availability and ability to use the so-called 3G (or IMT-2000) extension bands (2.5-2.69 GHz) for WiMax. The question of whether mobile WiMax should be considered an approved technology at these frequencies is the subject of intense lobbying at both national and European Union levels. In the U.K. British Telecom (BT) is interested in WiMax as a means of extending broadband to areas which are underserved by fixed networks and to re-enter mobile and nomadic communications markets (it divested its mobile operations for financial reasons, which are now owned by Telefonica). The U.K. regulator Ofcom has a more technology-neutral stance towards spectrum use than some of its Continental counterparts, and the future acquisition of spectrum and then deployment of WiMax by BT would be an important milestone for WiMax in the European environment.

In Japan the second largest mobile operator KDDI has been the most active so far in testing mobile WiMax. KDDI's approach includes an emphasis on the ability to roam between WiMax and other broadband wireless technologies such as EV-DO. The same approach will be important for Sprint Nextel's WiMax deployment in the U.S., since even with the coverage that is projected for WiMax (100 million POPs) after the estimated investment of between $2.5-3 billion this coverage will be significantly lower than that of Sprint's EV-DO network in the same time frame (around 230 million POPs).

2.3.4 Emerging markets

In many emerging markets wireless access (this is already the case for voice communication) plays a much larger (and even dominant compared to wired access) role in the overall telecommunications landscape than it does in developed markets where an efficient wired network infrastructure was already in place when mobile communications became a mass market offering. Broadband wireless technologies can be seen as a major, even perhaps the primary, means of providing broadband access services to users, rather than as a complement or extension of wired broadband. Governments and other bodies which perceive that making broadband internet access available as rapidly and widely as possible will help boost economic growth favour the introduction of broadband wireless where its deployment may greatly accelerate this process beyond what can be achieved by building out and/or modernizing fixed network infrastructure. As the costs of wireless equipment have come down, in absolute terms as well as relative to the costs of deploying fixed access lines in areas with no existing copper coverage, the scope of applicability of broadband wireless in the environments of many emerging economies has grown.

A challenge for WiMax in this context is that voice services are an important part of any viable business case (a non-voice only play may simply not be a viable business from the revenue perspective)[14][15] . Furthermore GSM- and CDMA-based cellular services in these emerging markets are expected to expand considerably over the next 3 to 4 years, enabled by the advent of low cost (<$30 or even <$20 handsets). One estimate of growth in mobile connections between 2005 and 2010 is shown in Table 3. As much as 50% of this growth worldwide is likely to come from 5 countries alone, namely India, China, Brazil, Russia, and Indonesia.

[14] See for example the Invitation for Comments issued by the European Commission on the impact of a decision on the 2.5-2.69 GHz band as discussed in the Working Document of the Radio Spectrum Committee of May 18, 2005 (RSCOM05-18)

[15] In telecommunications to date (both fixed and mobile) there has been no instance of a successful operator who depended only on a data-only network. This experience (or "conventional wisdom") poses a challenge to the argument that WiMax networks can be data-centric complements to voice-centric cellular networks, with the operator concerned capturing the same customers for voice and non-voice services, and providing them with as seamless as possible a user experience, while maximising the potential cost synergies across the two networks

Table 3: **Emerging markets will dominate future mobile network growth (mobile connections in emerging and developed markets (billion, end-year))**

	2005	2010
Emerging Markets	1.36	2.68
Developed Markets	0.81	1.00
Total	2.18	3.68

Source: Gartner

If this rapid expansion of cellular services takes place – and all the signs of growth in 2006 point in this direction – then WiMax networks launched in these countries when very wide cellular coverage has already been achieved will find it very difficult to find enough customers to justify the investments involved on a nationwide basis. A more promising business scenario for WiMax would involve a focus on selected urban and other areas with reasonable numbers of data users, namely the professional and middle and upper income levels whose absolute numbers in some of these countries may be sufficient to support a business case (with roaming and fall back to relatively narrowband cellular networks outside the areas of WiMax coverage) even if they represent a relatively small percentage of the population.

2.3.5 Long term (the years 2012+) landscape

During the second decade of the 21st century there may be room for significant shifts in market share among the suppliers of mobile wireless network equipment as networks will require new technologies that involve much larger investments than upgrades from first generation 3G networks to HSPA. The potential for such shifts would be increased in favour of vendors currently emphasizing WiMax by developments such as:

- Early proof of existence of successful “open gate” (in contrast to “walled garden”) mobile operator business models oriented towards the mobile Internet, thereby stimulating interest in and the need for increased mobile capacity which only the effective combination of the technologies foreseen in (but not exclusively by) the ongoing evolution of WiMax can provide
- Proof of successful first generation mobile WiMax networks with performance at least comparable to HSPA
- Widespread availability of affordable low power effective handheld WiMax-enabled user terminals with the power of 2006/7 generation notebook PCs
- Convergence of the WiMax and 3G LTE (and even 3GPP2) technology streams, encouraged by delays in the availability of 3G LTE and resulting pressures from operators on vendors

In an alternative outcome, in which WiMax developed according to the “worst case” scenario, the vendors who have placed a strong emphasis on mobile WiMax would find it very difficult to challenge the leading vendors in the WCDMA/HSPA radio access market, who will introduce 3G LTE equipment. This equipment is itself likely to resemble in many respects the forecast evolution of WiMax equipment, but will have emerged from a distinctly separate working forum than WiMax.

3. Network performance and modelling

As emphasized earlier, many factors and analyses enter into an operator's choice of which network technology to deploy. Modelling of network performance and costs is one tool that can provide useful input to this decision process, provided that very careful attention is paid to ensuring that its inputs are realistic, its limitations are recognized, and the results obtained are interpreted carefully in light of the operator's specific circumstances. In this chapter we describe the goals and requirements which modelling of this type should meet if it is to yield results that are relevant (albeit with some caveats) to operators. Then we define and describe the scope and structure of the model we have developed and the range of deployment and usage scenarios to which it has been applied.

3.1 Goals and requirements of modelling

The main goal of the model is to provide an idea of the likely and comparative levels of performance of two wireless technologies in a significant number of anticipated real world environments. These comparisons are based on equipment parameters and techniques that are expected to be commercially available. To ensure that the results of this modelling are legitimate and relevant in the context of decisions on the network technology investment choice they should reflect:

- Deployment environments that represent as far as is possible (because no model can reproduce all the elements which affect wireless propagation) the realistic conditions and constraints which the network operator expects to encounter and the business goals it is pursuing
- Comparisons that are as close as possible to "apples to apples" situations, so that for example they do not include the impact of an application of techniques beyond the air interface to one wireless technology that improves its performance, but not to another where they could also be beneficial

Even if the conditions outlined are met, interpretations of the results obtained from the modelling have to be reviewed carefully keeping in mind certain limitations, including:

- The ideal of "apples to apples" comparisons is not fully realizable, since any environment will tend to favour or handicap (i.e. be more suited to the characteristics of) one technology more than another. For example OFDMA performs relatively better compared to alternative air interfaces with wide channel bandwidths (i.e. 10MHz and above compared to 5MHz let alone 1.25MHz)

- Inevitably the relative rankings in terms of cost/performance of various wireless technologies will not necessarily be the same under all conditions, but will most likely vary depending on the parameters of the environment in which they are modelled ("one size does not fit all"), as a result for example of the differential impact of traffic characteristics and mobility requirements on the performance of different wireless technologies
- For all wireless technologies modelling provides at best an approximation to the performance that will actually be experienced in large scale operational deployments, because there are many influences that cannot be comprehensively and accurately simulated in all their details, e.g. propagation effects caused by buildings and changes in buildings due to construction, customer habits and behaviour, effects of other time-varying factors such as vehicles, weather, interference from other wireless sources etc. Hence any new technology is bound to go through a period of tuning or "tweaking" to optimize its performance under the conditions it encounters, which are not fully reproducible in the results of the modelling work

Although the model provides absolute outputs, the main functionality of the model is to enable a relative comparison of the costs and performance of the two technologies (HSPA and mobile WiMax) from a perspective of network CAPEX and OPEX in conditions which approximate as closely as possible those which many operators will encounter in the deployments they will be making over the next few years. The results of the model presented and analyzed in this report are not universally applicable, since the model does not cover all the circumstances of all operators in all countries, and makes use of data about the two technologies which refer to systems that can be selected for deployment over the next few years. However, the model has been designed for flexibility and ease of use. The inputs the model relies on have been used in a way such that in many cases the model can be applied in a wider range of potential deployment scenarios than those which are specifically assessed in this report. The model can accommodate changes in data pertaining to the respective technologies as these technologies are improved over time. Further details of the limitations and areas of applicability and relevance of the model are described in sections 3.2, 3.3, and 3.4 below. It should be noted that in practice terrestrial network coverage of a country will rarely if ever amount to a true 100%, since for example highly mountainous areas are most unlikely to be included. Hence absolute CAPEX calculated to cover an entire country or region will tend to be overstated compared to what an operator would actually invest in, nevertheless the relative CAPEX incurred by the two technologies will be correct.

3.2 Model outline and scope

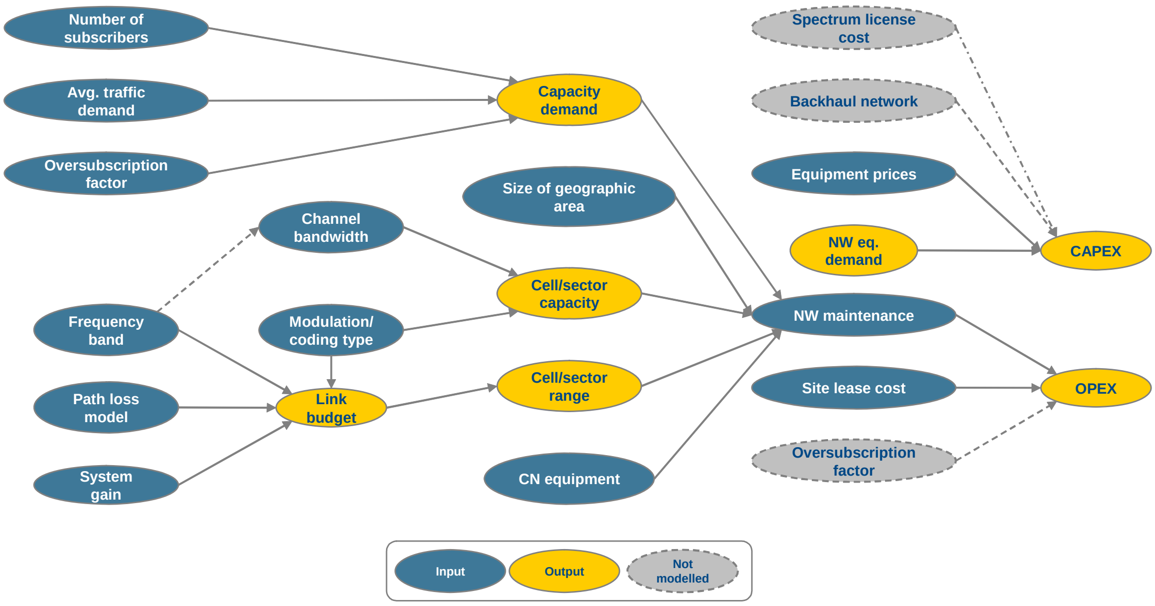
The purpose of the modelling work is to compare two mobile technologies – 3GPP HSPA versus mobile WiMax 802.16e – in two domains:

- System Spectrum Efficiency
- Relative Cost Economics (CAPEX, OPEX)

It should be emphasized that the modelling work undertaken in this report covers a first order network cost and performance model with specific scope as described below. It does not address other very important questions which operators must also consider such as the costs and availability of user terminals, the extent to which its existing assets (other than cell sites) can be re-used or easily upgraded, or the characteristics of the business model which the operator decides to pursue. For example, operators vary in terms of the extent to which they subsidize mobile terminals, and regarding the types and characteristics of services e.g. voice and other latency-sensitive services, high speed data downloads, interactive services, etc.), and levels of mobility which they support.

The model has been designed using a top-down approach, with commonly agreed input and output parameters of the model as illustrated in Figure 5 below. These high-level parameters have been refined and modelled using first principles and fully dynamic calculations providing the ability to compare a large variety of scenarios. Input parameters are a reflection of the feedback we received from industry experts during our interviews, or based on standards where appropriate. They can, however, be adapted to operator specific settings.

Figure 5: Model outline



Source: Arthur D. Little Analysis

CAPEX is determined by the demand for and prices of network equipment and by the number of cell sites required. The amount of equipment required depends on factors such as sector capacity to satisfy capacity demands of the subscriber base and their assumed traffic demand, and on cell range to cover a given geographic area. This is also a key factor for the network maintenance and site lease cost considered for OPEX.

Initial network deployments are expected to be coverage limited and only reach capacity limits after some period of operation. Therefore, emphasis has been put on modelling system capacity driven by factors such as channel bandwidth and modulation and coding schemes to determine throughput performance, and link budget calculations to determine cell range and therefore site coverage areas. However it is possible to alter inputs to the model manually to give an indication of the impact of greater interference as cells become heavily loaded with traffic, i.e. when the network becomes capacity constrained.

The key aspects of the model that has been built and the range of scenarios that have been exercised are the following:

- Use of "standard" urban, suburban and rural environments for wireless propagation and population densities as commonly applied in mobile wireless network planning

- Calculations using a 10MHz channel for WiMax (TDD, with symmetric DL:UL ratio of 1:1), and a paired 5+5MHz FDD channel for HSPA in the 2.5 GHz band, to achieve as close a "like for like" comparison as possible while considering technologies used in current deployments[16]
- A range of modulation schemes as supported for each technology respectively
- Assessment of both "greenfield" situations (no existing wireless assets) as well as upgrades from (a) existing GSM; (b) existing GSM/UMTS; and (c) UMTS-only networks; including comparisons of "greenfield" WiMax versus HSPA upgrades from existing networks, as well as comparisons between: (i) greenfield WiMax and greenfield HSPA, and (ii) adding WiMax and adding HSPA to existing GSM or UMTS infrastructure

It should be noted that the scope of the model does not cover (the following Section 3.3 discusses the limitations of the model in more detail):

- Backhaul and core network transmission or interconnection costs
- Costs of network elements that are not carrying traffic, e.g. billing centre or network management/O&M equipment
- Assessment of the differential capabilities of the two wireless technologies in terms of how efficiently they handle types and mixes of traffic with different characteristics
- Assessment of the different capabilities of the two wireless technologies with respect to mobility management
- Cost of spectrum licenses, as this is assumed to be equal for the same frequency band (e.g. the default assumption of 2.5GHz band in the model)

3.3 Limitations and uses of modelling results

As indicated in the preceding section 3.2 the model does not claim to cover all the economic and operational issues which an operator has to address in the context of providing end-to-end services over a network. It is focused on the radio access network (RAN) and specific equipment in the core network (Figure 5 above).

[16] Since useable capacity and hence peak UL/DL (uplink/downlink) rates increase with channel bandwidth, a wider channel provides greater data rates in a capacity limited (e.g. dense urban) scenario. At higher channel bandwidths, any gap in peak data rate capacity between HSPA and WiMax, such as the results of the modelling indicate, increases proportionally (see following Chapter 4)

For the core network side, only equipment related to user traffic, such as gateways, mobility servers, HLR/AAA functionality has been considered, as well as the cost of an MSC without the need to support voice traffic. Other elements such as billing centre and operation and maintenance centre, amongst others are omitted. Furthermore, based on the assumed traffic model of data traffic only, no additional equipment related to voice traffic has been included.

It should be noted that with the standard area sizes and population density, some of the core network elements may not be fully utilized and therefore add to CAPEX and OPEX disproportionately. Also, the cost of an MSC without voice traffic may be lower than currently assumed. However, due to the fact that typically the cost of the core network is significantly lower than the cost of the access network, these discrepancies will not usually affect the overall result or cost to a significant degree. A recent development for GSM/UMTS concerns the installation of pico or femto cells to enhance coverage in buildings and specific areas of concentration of users. For example, some manufacturers such as ip access and Zynetix are developing core network MSCs/HLRs for much smaller scale networks. These BSC/MSC/HLR core network elements are designed to offer much lower costs than traditional equipment costing a few million dollars, but with reduced capacity. The commercial success of this development would tend to reduce the core network cost overhead for smaller networks.

Furthermore, the cost of site installation and maintenance may vary across different countries, e.g. due to variations in cost for land or labour. As this cost can be assumed as equal for any technology in a country, the impact on relative comparisons will be limited.

We recognize that backhaul and core network transmission or interconnection costs can be significant and are included by operators in determining and planning their overall CAPEX and OPEX expectations. Operators pay careful attention to optimizing these transmission costs from among the range of alternatives that may be available in their market, which may include leasing capacity from other carriers and/or installing their own wired and/or wireless facilities. Backhaul costs to link base stations and aggregation nodes (RNC, AGW) will be higher the greater the number of cell sites that are needed, a factor that should be kept in mind when assessing the results of the model calculations (Chapter 4 below) which indicate significant differences in the numbers of these sites required for HSPA and WiMax networks respectively in many environments. However, the prices of backhaul facilities and leased lines vary widely between countries, and if included in detail would tie the model to market-specific circumstances and complicate the ability to draw conclusions that are relevant across many markets.

Furthermore, various traffic types generate different requirements for overall end-to-end network performance to meet user demands and expectations, e.g. low latency real-time traffic such as voice and streaming video versus delay-tolerant traffic such as file transfers. Hence operators assessing their technology alternatives will apply their business and market models and expectations to these assessments, for example whether they expect to operate as a “full service” provider including voice, data and other services, or will depend primarily or exclusively on revenues from services other than voice.

The model itself only addresses the question of the data throughput that can be achieved per sector. It makes no predictions for latency and does not take into account, for example, whether (or when) mobile WiMax will be able to handle VoIP traffic from multiple users in a cell as efficiently as a UMTS/HSPA network, should an operator wish to offer voice communication as a significant component of its service portfolio.

The impact of users moving at different speeds upon the effective performance of the network for users, i.e. the effectiveness of mobility management, is also not analyzed. In assessing the comparative merits of HSPA and mobile WiMax operators have to take into account the extent to which they expect (and/or target) customers whose demands are primarily nomadic, as contrasted to mobile usage at up to vehicular speeds, or even in high speed trains, where quality is critically dependent upon the efficiency and effectiveness of the handoff procedures associated with the respective wireless technologies. There are concerns that current mobile WiMax technology suffers more severely from Doppler shift at vehicular speeds than HSPA in a comparable situation.

The results of modelling should be interpreted and assessed by each operator with the following considerations in mind:

- Are the conditions built into the model (e.g. frequency, channel bandwidth, expected traffic patterns and user density, deployment topology etc.) and hence the results obtained reasonably representative of my circumstances (recognizing that the best choice for me may not necessarily be the best choice for another operator under different conditions)?
- Has the technology that seems to offer the best price/performance for my situation been commercially and operationally proven on a large scale, so I can be reasonably sure that the inevitable tuning or tweaking that may be necessary is well understood - or will I be a pioneer with the technology and if so am I prepared and strong enough to take that risk?

In the modelling undertaken for this project, we have tried to achieve a reasonable balance between a high degree of specificity in the details of a network deployment - which would limit the range of applicability of its results and the insights gained to a very small fraction of the hundreds of wireless operators found worldwide - in contrast to building a model which would attempt to include all or almost all the possible permutations of parameters that operators might encounter, which would be impractically complex.

We have also endeavoured to construct a model which is easy to use and adaptable along several key dimensions – such as the frequency band of deployment - so that it can be applied to a significant proportion of the circumstances which operators encounter around the world.

The results of the type of model described in this report are indications of the likely performance of wireless technologies. But they do not obviate the need for and value of field trials, up to and including the measurement of actual user-related performance in deployed and commercially launched networks where possible, to determine and/or confirm or revise expectations of what users will experience in the real as distinct from the simulated world.

In summary, the model is designed to provide insights for operators at a high level in the context of the commercial and business decisions they face regarding the choice of which network technology to deploy. The model is not intended, nor is it designed to be used, as an operational planning tool for actual network deployments. Furthermore, while the model has been designed to cover a very large proportion of market and competitor environments, neither should it be interpreted as aiming to account for all the circumstances of all operators everywhere.

In reaching decisions about the selection of network technology operators and other stakeholders including investors should not apply in isolation the insights gained from the model about the relative performance and costs of HSPA and mobile WiMax networks and the sensitivities of these performances and costs to variations in the conditions and goals of the network deployment. The value of these insights depends on their careful interpretation in combination with the many other considerations relevant to operators' business models and decisions, as discussed and evaluated in the preceding chapters of this report.

3.4 Definition and description of modelling scenarios

Some 300 technical and cost parameters have been defined to specify the characteristics of both network technologies, to enable modelling at an adequate and meaningful level of detail.

3.4.1 Topology and environment

The model is based on a theoretical deployment area. Three area types are available for the user to choose from (with default size as indicated):

- Urban: size of 30km², population density of 5000/km²
- Suburban: size of 300km², population density of 500/km²
- Rural: size of 6000km², population density of 25/km²

The total size and distribution of area types can be specified directly, or by using predefined settings. Furthermore, four operator profiles are available:

- Greenfield: a new entrant to the market with no existing infrastructure
- Existing GSM network: an operator with existing GSM/GPRS network infrastructure
- Existing UMTS network: an operator with existing UMTS (but no GSM/GPRS) network infrastructure
- Existing GSM/UMTS network: an operator with existing GSM/GPRS and UMTS network infrastructure

To estimate the number of existing cell sites and RAN equipment, average cell ranges for existing GSM and UMTS networks have been specified. These can be adapted to operator-specific settings. Note that these settings do not reflect maximum cell ranges of the respective technology, but average ranges of real-world networks that are typically a mix of coverage and capacity limited areas. The purpose of these cell ranges is to determine the average number of existing sites and not e.g. the minimum number required for full coverage.

3.4.2 User traffic

A traffic model, FTP with full buffer has been assumed. Voice traffic (and other latency-sensitive traffic) has not been considered. One of the reasons for this decision is that there seems to be limited momentum behind a VoIP roll-out for WiMax. This may partially be due to concerns over rapidly deteriorating network performance in terms of throughput and latency if large numbers of users were to use VoIP on mobile WiMax. Operators who hope to generate significant revenues from voice traffic may find it hard to justify investment in a mobile WiMax network, at least until it is shown to be capable of handling voice traffic with an efficiency and capacity comparable to that of 3G/HSPA networks.

This modelling decision also impacts the cost modelling, in particular in the core network where for HSPA, there is no need for Media Gateways to carry voice traffic, and the demand on and therefore cost of MSCs can be reduced.

3.4.3 Radio system parameters

The values of many of the parameters used in the model which resulted from our research have been reviewed and validated in an iterative process with vendors and operators willing to participate in the study. These values are meant to be reasonable for equipment and networks that can be offered for deployment over the next year to 18 months. The values of the WiMax parameters have been validated with WiMax vendors. They are not as favourable compared to HSPA equipment or to the values quoted in the WiMax Forum's references (Mobile WiMAX - Part I: A Technical Overview and Performance Evaluation and Mobile WiMAX – Part II: A Comparative Analysis) in terms of receiver sensitivity and transmit power, although the use of PUSC modes makes up much of the range disadvantage compared to HSPA (however, at the cost of data capacity).

The radio system parameters are designed to help meet the goal of achieving as close an "apples to apples" comparison as possible, avoiding confusion that may be introduced by comparing the capabilities of different technologies at different points in time, rather than using values applicable concurrently when an operator is facing a decision about an investment. Although as noted earlier the ability of a vendor to present a convincing road map of future developments and improvements is another significant factor or criterion in the decision making process that operators follow. Both HSPA and WiMax have announced such roadmaps with significant advances in their capabilities expected to become available over the next 3 to 4 years. Individual vendors may of course show variations in the values of some of these parameters for the systems and equipment they offer. The model is sufficiently flexible to allow interested parties to adjust such parameters accordingly, to take account of variations between vendors as well as of improvements which progress in technology will enable.

Both HSPA and mobile WiMax technologies will improve over time with respect to price and their performance in terms of individual link budget parameters. The overall link budget (or maximum allowable path loss) depends on and can be increased by improvements in a number of parameters (not only receiver sensitivity and transmit power but also through narrower margins, the application of "smart antenna" technologies etc.). The results of the model which are presented in this report are based on the best available price and performance information together with some indication of sensitivity to variations in overall link budget. They should be updated as progress in the respective technologies (cost reductions and performance improvements) is shown to be real in actual deployments.

The importance of paying careful attention to the link budget is shown in the same WiMax Forum white papers that have already been referenced. In these papers there is a significant discrepancy between the coverage (and hence the CAPEX that would be calculated in the model used in this report) assumed with a cell site-to-site distance for mobile WiMax of 2.8 km. at 2.5 GHz, in contrast to the much smaller distance that reflects the claimed link budget. The necessary tradeoffs between range or coverage and data rates which is one of the keys to an assessment of the commercial value of wireless systems, and is one of the core messages resulting from this work, is not addressed adequately in these papers.

It should also be noted that the values of some parameters are derived directly from applicable standards, while others are the same or very similar for both HSPA and WiMax systems, which embody many components and subsystems that are common to both.

Figure 6: Common radio parameters

Common Parameters				
Scenario				
Area Type			rural	area [km²]: 6000 population density [1/km²]: 25
Radio System				
operating frequency	F	=	2.5	[GHz]
Link Budget				
BS antenna height	h_{BS}	=	30	[m]
SS antenna height	h_{SS}	=	1.5	[m]
building height	h_B	=	25	[m]
distance between buildings	dB	=	30	[m]
width of streets	w	=	15	[m]
angle of incident wave	Φ	=	90	[°]
h_{SS} correction factor	C_H	=	0.000	[dB]
area correction factor	C	=	0.0	[dB]
Hata correction factor	C_{Hata}	=	33.8	[dB]
inbuilding penetration loss	L_{IP}	=	10.00	[dB]
	0		15.00	[dB]
	0		12.00	[dB]
	0		10.00	[dB]
avg. PUSC gain DL (Rx sensitivity, PUSC: 1/3)	$G_{PUSC,DL}$	=	-4.90	[dB]
avg. PUSC gain UL (Rx sensitivity, PUSC: 1 SC)	$G_{PUSC,UL}$	=	-12.30	[dB]
average MIMO gain	G_{MIMO}	=	0.00	[dB]
average AAS gain	$G_{AAS,DL}$	=	7.80	[dB]

Source: Vendor Interviews, Arthur D. Little / Altran Telecoms and Media analysis

Some of the key parameters of the model assumptions are discussed below in several sections, in particular parameters that are a result of our research across the industry. The values used are typical ones derived from standards documents as well as from discussions with vendors and reviews of documents prepared by them.

Common Radio Parameters (Figure 6)

- **Area Type**: This allows the user to choose between urban, suburban and rural areas per drop-down menu. Next to this field, area size and population density are displayed according to the selected area type
- **Operating Frequency**: This has been set to 2.5GHz for both technologies but can be modified to other licensed or unlicensed frequencies (covered by the propagation model) as required
- **BS/SS antenna height**: These are standard input parameters for COST231-Hata model and reflect generally used assumptions
- **In-building penetration loss**: For link budget calculations, these values are typical assumptions that apply to both technologies
- **Average PUSC gain**: For WiMax, these are gains in receiver sensitivity for downlink and uplink when using PUSC mode. For downlink, PUSC 1/3 is assumed, and for uplink PUSC with 1 sub-carrier
- **Average AAS gain**: This parameter reflects the average DL gain that can be achieved by using smart antennas supporting AAS. This can vary significantly depending on area type and vendor

The results of Table 4, which refer to an urban area and may be directly compared with the model results presented later (Figure 13, Chapter 4), show that for asymmetric TDD rates (e.g. DL/UL = n:1), the higher DL data rates are accompanied not only by lower UL rates, but also by a significant decrease in range, which will lead to a need for more cell sites, i.e. higher CAPEX, to cover an area in a coverage-limited situation.

Table 4: Comparison of nominal data rates for WiMax TDD 1:1, 2:1, 3:1

Downlink	WiMax TDD - DL/UL = 1:1		WiMax TDD - DL/UL = 2:1		WiMax TDD - DL/UL = 3:1	
Modulation and coding	**Range [km]**	**Peak DL rate per sector [Mbit/s]**	**Range [km]**	**Peak DL rate per sector [Mbit/s]**	**Range [km]**	**Peak DL rate per sector [Mbit/s]**
QPSK - ¼	0.213	1.75	0.190	2.33	0.175	2.63
QPSK - 1/3						
QPSK - ½	0.213	3.50	0.156	4.67	0.144	5.25
QPSK - ¾	0.213	5.25	0.138	7.00	0.127	7.88
16-QAM - ¼						
16-QAM - 1/3						
16-QAM - ½	0.213	7.00	0.101	9.33	0.093	10.50
16-QAM - ¾	0.209	10.50	0.094	14.00	0.087	15.75
64-QAM - 2/3	0.146	14.00	0.066	18.67	0.061	21.00
64-QAM - ¾	0.141	15.75	0.063	21.00	0.058	23.63

Uplink	WiMax TDD - DL/UL = 1:1		WiMax TDD - DL/UL= 2:1		WiMax TDD - DL/UL = 3:1	
Modulation and coding	**Range [km]**	**Peak DL rate per sector [Mbit/s]**	**Range [km]**	**Peak DL rate per sector [Mbit/s]**	**Range [km]**	**Peak DL rate per sector [Mbit/s]**
QPSK - ¼	0.213	1.36	0.190	0.91	0.175	0.68
QPSK - 1/3						
QPSK - ½	0.175	2.72	0.156	1.81	0.144	1.36
QPSK - ¾	0.154	4.08	0.138	2.72	0.127	2.04
16-QAM - ¼						
16-QAM - 1/3						
16-QAM - ½	0.114	5.44	0.101	3.63	0.093	2.72
16-QAM - ¾	0.106	8.17	0.094	5.44	0.087	4.08
64-QAM - 2/3	0.074	10.89	0.066	7.26	0.061	5.44
64-QAM - ¾	0.071	12.25	0.063	8.17	0.058	6.13

Source: Vendor Interviews, Arthur D. Little / Altran Telecoms and Media analysis

Figure 7: System specific radio parameters

System Specific Parameters

Radio Parameters	HSPA			WiMax			[unit]
multiplexing technique			WCDMA			SOFDMA	
duplexing mode			FDD			TDD	
channel bandwidth	b	=	5	b	=	10	[MHz]
DL/UL ratio	r	=	1	r	=	1	
DL bandwidth	bDL	=	5	bDL	=	5	[MHz]
UL bandwidth	bUL	=	5	bUL	=	5	[MHz]
system bandwidth	(paired: b+b)		10			10	[MHz]
number of total sub carriers				NSC	=	1024	
number of DL data sub carriers				NDSC,DL	=	720	
number of UL data sub carriers				NDSC,UL	=	560	
number of data sub carriers - FUSC				NDSC,FUSC	=	768	
number of data sub carriers - DL PUSC All				NDSC,PUSC,DL	=	720	
number of data sub carriers - DL PUSC 1/3				NDSC,PUSC,DL	=	240	
number of data sub carriers - UL PUSC All				NDSC,PUSC,UL	=	560	
number of data sub carriers - UL PUSC 1 SC				NDSC,PUSC,UL	=	16	
modulation scheme & coding rate			QPSK - 1/4			QPSK - 1/4	
symbol size	s	=	2	s	=	2	[bit/symbol]
overall coding rate	ocr	=	0.25	ocr	=	0.25	
cyclic prefix				G	=	0.125	
sampling factor				n	=	1.12	
spreading factor DL	SFDL	=	16				
max number of user codes DL	Ncode,DL	=	15				
spreading factor UL	SFUL	=	8				
number of user codes UL	Ncode,UL	=	7				
TTI / frame size	TTI	=	2	Tf	=	5	[ms]
Inter-TTI	iTTI	=	1				
max transport block size	LTB	=	28776				[bit]
number of slots	Nslot	=	3				
symbol rate DL	srDL	=	3.84				[symbol/µs]
symbols per frame	Ns/f	=	520	Ns/f	=	48	[symbol/frame]
PUSC supported						yes	
AAS supported			no			no	

Source: Vendor Interviews, Arthur D. Little / Altran Telecoms and Media analysis

System Specific Radio Parameters (Figure 7)

- **Duplexing mode**: HSPA is being deployed in FDD mode, while WiMax is currently only defined for TDD, although both technologies could in principle be supported in the other mode. TDD and FDD systems differ along several dimensions that operators will take account of in deciding which technology to implement, most notably of course whether the spectrum to which they have access is unpaired so TDD is required. Since TDD does not require paired spectrum it is more flexible in the context of unlicensed bands and fragmented spectrum. TDD systems are also more suited to asymmetric traffic (such as much download-dominated Internet traffic) and can offer flexibility through dynamic bandwidth allocation. This flexibility is useful for handling “bursty” traffic patterns, whereas spectrum allocation and the DL/UL ratio in FDD cannot be modified, and may lead to underused spectrum in these traffic conditions. TDD hardware should in principle be less expensive than FDD, leaving aside volume effects, since the transmitter and receiver operate at the same frequency so the costs associated with separating the transmit and receive antenna are avoided. As TDD uses the same frequencies for uplink and downlink, the smart antenna technologies (beam forming/adaptive antenna systems (AAS)) that are suited to improving performance for fixed and nomadic users are more effective in the TDD environment, since UL channel estimation by the base station can be used to achieve DL beam forming. In contrast in FDD the user terminal has to provide the channel response for the DL direction, which increases the latency and reduces the performance of the beam former. However, FDD offers lower average and best case latency than TDD and does not require a guard time at the end of DL transmission. The TDD guard time required is greater the longer the round trip delay, i.e. the greater the distance between the base station and the customer’s terminal. FDD is also better suited to handling symmetric traffic (such as voice or interactive applications in which the user is transmitting content as much as receiving it). Furthermore FDD can be implemented with less complex hardware and lower power consumption than TDD, the radio planning is easier, and the interference protection better. There is no need as there is in TDD to introduce guard bands between base stations with a loss in overall spectral efficiency, nor is synchronization of base stations necessary to avoid overlapping transmission and reception. Base station synchronization increases network complexity and costs, especially in large scale and/or multi-operator scenarios, and requires the DL/UL ratio to be the same across all base stations and sectors. Overall - apart from the question of spectrum - the relative merits of FDD and TDD depend on the traffic scenarios and user environments that are being considered.

- **Channel bandwidth** and **DL/UL ratio**: To compare both technologies "like for like" as close as possible, the channel bandwidth for WiMax has been set to 10 MHz TDD, with a symmetric DL/UL ratio of 1:1. HSPA is set to operate in a paired 5+5 MHz channel. This results in a comparable setup with 5 MHz bandwidth available for both downlink and uplink, for both technologies. For other WiMax DL/UL ratios such as 2:1 or 3:1 gains in DL capacity will have to be traded against lower UL capacity, but more significantly against less available UL link budget and hence shorter cell ranges and a resulting increase in the number of required cell sites and CAPEX (see Chapter 4 below for an expanded discussion). The WiMax Forum references (e.g. Table 6, Part I in this reference) indicate the increase in DL speeds that can be achieved with higher DL/UL ratios, but do not point out the resulting decrease in range. Furthermore our research indicates that DL/UL ratios of 3:1 or more may result in a reverse link signal quality that is too low for reliable network performance
- **Modulation scheme & coding rate**: These parameters can be set to values supported by the respective standards, and will have a key impact on the results in both Radio and Cost domains. Hence, the choice for these parameters needs to be taken into consideration before interpreting any results and outputs of the model
- **Cyclic prefix**: Although standards support shorter cyclic prefix settings of up to 1/32, our research has shown that in a real-world deployment 1/8 is a typical setting to reduce interference, e.g. to support adequate mobility. This increases the overhead and therefore decreases capacity and spectral efficiency
- **PUSC supported**: This choice is currently only available for WiMax, and typical network rollouts would use PUSC mode to extend the cell range. This comes at the cost of available data rates, however operators do have the flexibility to combine FUSC and PUSC modes, with FUSC available closer to the base station, and PUSC towards the cell edge in each sector
- **AAS supported**: This is set to "not supported" by default, as it is not part of a typical deployment, and the use of MIMO and other factors such as antenna size have to be taken into account

Figure 8: Link budget (Downlink)

Link Budget								
Downlink								
Base Station (Tx)								
Transmitted power	PTx,DL	=	43	PTx,DL	=	41	[dBm]
Tx antenna gain	GA,Tx,DL	=	17	GA,Tx,DL	=	17	[dBi]
Tx AAS gain	GAAS,Tx,DL	=	0	GAAS,Tx,DL	=	0	[dB]
Tx loss	LTx,DL	=	0	LTx,DL	=	0	[dB]
Mobile Subscriber Station (Rx)							
Receiver sensitivity (WiMAX: FUSC)	SRx,DL	=	-108.9	SRx,DL	=	-99.4	[dBm]
	QPSK - 1/4		-108.9	QPSK - 1/4		-99.4	
	QPSK - 1/3		-107.9	QPSK - 1/2		-96.4	
	QPSK - 1/2		-106.9	QPSK - 3/4		-94.5	
	16-QAM - 1/4		-104.9	16-QAM - 1/2		-89.8	
	16-QAM - 1/3		-103.9	16-QAM - 3/4		-88.7	
	16-QAM - 1/2		-102.9	64-QAM - 2/3		-83.2	
	16-QAM - 3/4		-98.9	64-QAM - 3/4		-82.7	
Rx sensitivity gain (WiMAX: PUSC)			0			-4.9	[dB]
Rx antenna gain	GA,Rx,DL	=	0	GA,Rx,DL	=	0	[dBi]
Rx diversity gain	GRx,Div,DL	=	3	GRx,Div,DL	=	3	[dB]
Rx loss	LRx,DL	=	0	LRx,DL	=	0	[dB]
Margins & Losses							
fade margins	LFF,DL	=	9.6	LFF,DL	=	9.6	[dB]
	urban		9.6	urban		9.6	
	suburban		9.6	suburban		9.6	
	rural		9.6	rural		9.6	
interference margin	LIF,DL	=	3	LIF,DL	=	3	[dB]
	urban		3	urban		3	
	suburban		3	suburban		3	
	rural		3	rural		3	
shadowing margin	LSM,DL	=	5.9	LSM,DL	=	6.9	[dB]
	urban		5.9	urban		6.9	
	suburban		5.9	suburban		6.9	
	rural		5.9	rural		6.9	
other margins	Mmisc,DL	=	0	Mmisc,DL	=	0	[dB]
inbuilding penetration loss	LIP,DL	=	10	LIP,DL	=	10	[dB]
	urban		15	urban		15	
	suburban		12	suburban		12	
	rural		10	rural		10	
other losses	Lmisc,DL	=	0	Lmisc,DL	=	0	[dB]

Source: Vendor Interviews, Arthur D. Little / Altran Telecoms and Media analysis

Figure 9 Link budget (Uplink)

Link Budget								
Uplink								
Mobile Subscriber Station (Tx)								
Transmitted power	PTx,UL	=	21	PTx,UL	=	17	[dBm]
Tx antenna gain	GA,Tx,UL	=	0	GA,Tx,UL	=	0	[dBi]
Tx loss	LTx,UL	=	0	LTx,UL	=	0	[dB]
Base Station (Rx)							
Receiver sensitivity (WiMAX: FUSC)	SRx,UL	=	-112.9	SRx,UL	=	-102.6	[dBm]
	QPSK - 1/4		-112.9	QPSK - 1/4		-102.6	
	QPSK - 1/3		-111.9	QPSK - 1/2		-99.6	
	QPSK - 1/2		-110.9	QPSK - 3/4		-97.7	
	16-QAM - 1/4		-110.9	16-QAM - 1/2		-93	
	16-QAM - 1/3		-110.9	16-QAM - 3/4		-91.9	
	16-QAM - 1/2		-110.9	64-QAM - 2/3		-86.4	
	16-QAM - 3/4		-110.9	64-QAM - 3/4		-85.8	
Rx sensitivity gain (WiMAX: PUSC)			0			-12.3	[dB]
Rx antenna gain	GA,Rx,UL	=	17	GA,Rx,UL	=	17	[dBi]
Rx diversity gain	GRx,Div,UL	=	6	GRx,Div,UL	=	6	[dBi]
Rx loss	LRx,UL	=	0	LRx,UL	=	0	[dB]
Margins & Losses							
fade margins	LFF,UL	=	9.6	LFF,UL	=	9.6	[dB]
	urban		9.6	urban		9.6	
	suburban		9.6	suburban		9.6	
	rural		9.6	rural		9.6	
interference margin	LIF,UL	=	3	LIF,UL	=	3	[dB]
	urban		3	urban		3	
	suburban		3	suburban		3	
	rural		3	rural		3	
shadowing margin	LSM,UL	=	5.9	LSM,UL	=	6.9	[dB]
	urban		5.9	urban		6.9	
	suburban		5.9	suburban		6.9	
	rural		5.9	rural		6.9	
other margins	Mmisc,UL	=	0	Mmisc,UL	=	0	[dB]
inbuilding penetration loss	LIP,UL	=	10	LIP,UL	=	10	[dB]
	urban		15	urban		15	
	suburban		12	suburban		12	
	rural		10	rural		10	
other losses	Lmisc,UL	=	0	Lmisc,UL	=	0	[dB]

Source: Vendor Interviews, Arthur D. Little / Altran Telecoms and Media analysis

Link Budget Parameters (Figure 8 and Figure 9)

For the link budget, both downlink and uplink are modelled. Although for maximum path loss and cell range calculations, the reverse link is typically the restricting factor, the forward link is used e.g. for capacity calculations.

- **Transmitted power**: For both base station and mobile station, our research found on average a lower transmit power used for WiMax. Although in principle only small differences, if any, between the two technologies were expected for these parameters, and in fact are ultimately expected to be restricted by regulatory limits, there appears to be room for performance optimization for WiMax e.g. in the field of amplifier technology
- **Receiver sensitivity, Rx sensitivity gain**: From our research, current WiMax technology shows significantly worse receiver sensitivity when using FUSC mode. The lower receiver sensitivity of WiMax will in practice be compensated for by using PUSC modes that allow for significantly better Rx sensitivities in both the forward and particularly in the reverse link which is critical for achieving higher cell coverage. This increase in coverage will, however, result in a significant reduction in downlink and uplink data rates available to the user
- **Fade margin**: This is assumed to be the same for both technologies. The use of e.g. smart antennas supporting MIMO with STC can mitigate fade margins, and can enhance mobility, but will increase required interference margins and hence reduce the benefits for the overall link budget
- **Interference margin**: Margins quoted for both technologies are typically around the standard 2-3dB, and hence assumed to be equal. However, there are concerns about the scheduler implementation in current WiMax technology that can significantly increase the required margins, up to values of 12-14dB, with corresponding detrimental impact on link budget, cell range and consequently CAPEX and OPEX estimates. Smart antenna technologies like AAS can improve interference in some scenarios, but effects like angle spread, predominantly in cluttered environments found in urban areas, would reduce the benefits. Also, the WiMax standard supports MIMO to automatically switch between Spatial Multiplexing (increasing capacity, but reducing mobility) or Spatial Diversity (Alamouti-STC, increasing range), but this leads to an increased complexity of antenna implementations particularly at the mobile station side, and has not been modelled. Whether mobile WiMax will in practice require a higher interference margin than HSPA will become clearer once there is evidence from large scale real-world deployments

4. Model findings and interpretation

The principal findings from the model results included in this chapter indicate clearly that:

- In coverage-limited situations, HSPA will frequently enjoy a CAPEX and OPEX advantage over mobile WiMax, which is most marked in rural areas; this advantage is based primarily on the smaller number of cell sites that HSPA deployment requires;
- The number of cell sites, and hence CAPEX, required in coverage-limited situations is sensitive to the claimed link budget, which depends on multiple parameters, in some of which WiMax is currently at a disadvantage compared to HSPA. The CAPEX difference between HSPA and WiMax can be significantly reduced (and possibly turn to the slight advantage of WiMax in urban areas and for Greenfield operators) if the relative performance of WiMax equipment is improved to allow for a link budget that is closer to that of HSPA. This difference is much less sensitive to the costs of the base station equipment;
- In capacity-limited situations, mobile WiMax becomes relatively more competitive in terms of deployment costs, suggesting that it is most likely to be worth consideration by operators seeking to offer extended wireless "hot spot" or limited coverage high capacity data service to meet the demands of significant numbers of high-end data users concentrated in urban areas;
- The peak data rates that mobile WiMax can achieve are higher than those which HSPA offers, however, the latter is better suited to achieving more uniform coverage of users over a wider area at speeds that are comparable to first generation DSL services; and
- Trade-offs between capacity (data rate) and coverage should be carefully reviewed by operators in making comparative assessments of wireless technologies best suited to their business models, especially since the nature and impact of these trade-offs are often neglected or presented very inadequately in technology comparisons that focus on only one parameter or figure of merit (typically peak data rate).

The following chapter of this report (Chapter 5: Conclusions) combines and coordinates the findings from the model with those of the more qualitative research and analysis into a more comprehensive set of messages for operators and other investors in mobile wireless networks.

4.1 Spectral efficiencies

The model compares spectral efficiencies based on nominal useful capacity for the given channel bandwidth. The respective maximum capacity (modulation and coding: HSPA: 16-QAM / ¾, WiMax: 64QAM / ¾) compares as follows:

Spectral Efficiency: HSPA: WiMAX = 2.16bit/s/Hz: 3.36bit/s/Hz

However, average spectral efficiency of a real world network deployment will be significantly below such theoretical maximum numbers. This is due to factors such as the impact of interference between cells, the distribution of users and corresponding modulation and coding schemes, use of smart antenna technologies, and the efficiency of the scheduler. The spectral efficiency of WiMax is unlikely to be significantly greater than HSPA unless a significant proportion of its users can in practice be served with 64QAM. However the use of higher modulation schemes increases the cost and complexity of terminals, and affects power amplifier performance (which in turn affects battery life). Furthermore, the use of sub-channels in PUSC mode further reduces WiMax spectral efficiency. Figure 10 illustrates the variability and range of spectral efficiency for HSPA and WiMax FUSC.

Figure 10: Nominal spectral efficiency per modulation and coding scheme

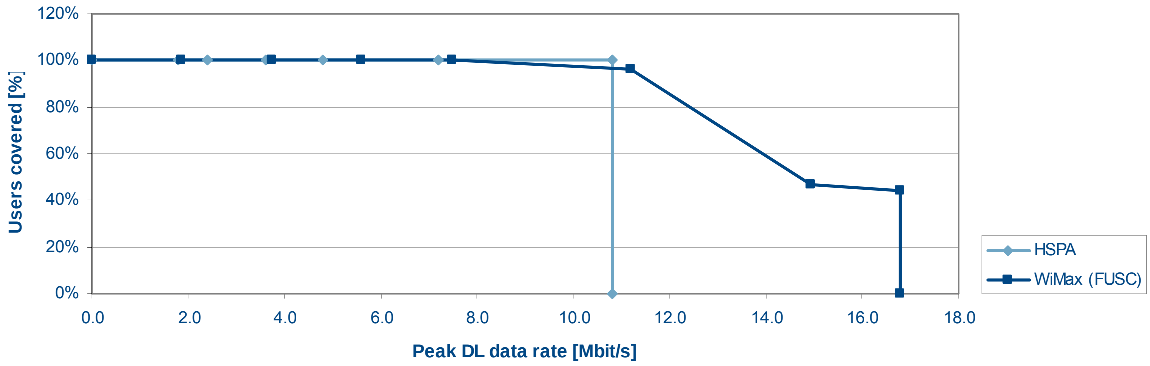
Modulation and coding	Spectral efficiency [(bit/s)/Hz]	Spectral efficiency [(bit/s)/Hz]
QPSK - 1/4	0.360	0.373
QPSK - 1/3	0.480	
QPSK - 1/2	0.720	0.747
QPSK - 3/4		1.120
16-QAM - 1/4	0.720	
16-QAM - 1/3	0.960	
16-QAM - 1/2	1.440	1.493
16-QAM - 3/4	2.160	2.240
64-QAM - 2/3		2.987
64-QAM - 3/4		3.360

Source: Arthur D. Little / Altran Telecoms and Media analysis

Figures 11 and 12 show how users in a cell may be distributed by modulation scheme (i.e. data rate) in a sector as a function of the quality of their connection for downlink and uplink, respectively. These graphs assume that users are physically distributed evenly throughout the cell, with the population densities as outlined in section 3.4.1 above.

Figure 11 reflects the higher theoretical downlink peak data rate available to a large proportion (~47%) of WiMax subscribers using 64QAM modulation in FUSC mode. It also shows that with significantly higher downlink budgets compared to uplink budgets, both technologies are capable of providing high peak downlink speeds to their users even at the cell edge. It does not, however, show that at the same time cell areas for WiMax are significantly smaller and hence fewer users are covered per cell, and more cell sites and equipment are required than for HSPA – this aspect, and the resulting impact on cost economics, is discussed in more detail in following sections. Furthermore, by deploying WiMax in PUSC mode, as is expected for many operators, the available downlink peak data rate of WiMax is reduced to 5.25 Mbit/s, only half of the peak data rates HSPA will be able to offer to its users.

Figure 11: User Distribution per sector - assumption: even user distribution across coverage area, DOWNLINK, WiMax FUSC

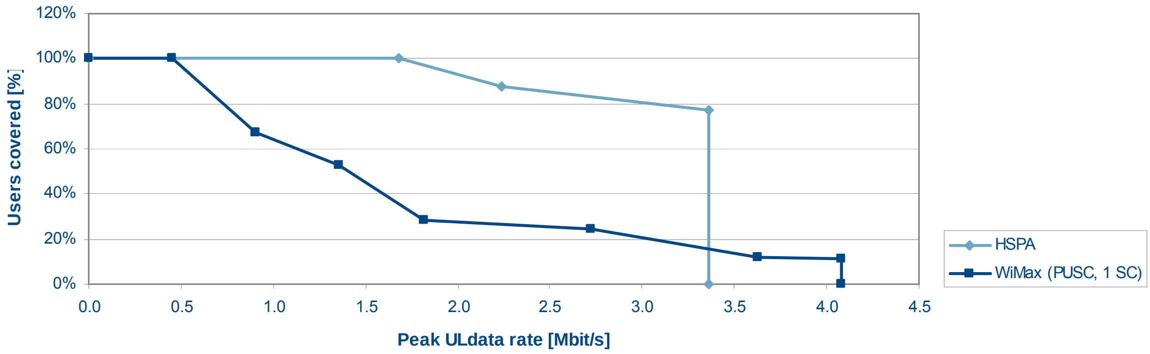


Source: Arthur D. Little / Altran Telecoms and Media analysis

Figure 12 shows that HSPA can cover a higher proportion of users at relatively high uplink peak data rates, but cannot match the highest peak rate of WiMax, which is however only available to a small minority of all users.
While HSPA uplink data rates today are limited by the availability only of QPSK modulation schemes (which at the same time provide a more reliable signal), mobile WiMax offers higher modulation schemes of up to 64QAM, but data rates are limited by the use of PUSC mode which will be deployed to extend the cell range. HSUPA that will first be launched in 2007 will employ link adaptation methods similar to those

employed by HSDPA to achieve significantly higher uplink data rates. As in Figure 11 above, Figure 12 does not reflect the smaller cell areas, resulting smaller number of users covered, and higher number of cell sites required for WiMax networks.

Figure 12: User Distribution per sector - assumption: even user distribution across coverage area, UPLINK, WiMax PUSC



Source: Arthur D. Little / Altran Telecoms and Media analysis

4.2: Link budget

A key part of the model is the comparison of link budgets. Based on the respective transmitter and receiver gains and losses, margins and other losses of the radio path for each technology, the maximum allowable path loss (MAPL) is shown for the selected modulation and coding. This translates into maximum cell range and therefore site coverage area using the COST231-Hata propagation model for the three different area types (urban/suburban/rural)[17].

The site coverage area links directly into the cost modelling aspects, as the key driver for both CAPEX and OPEX is the number of cell sites required for network deployment. A more detailed discussion of the key parameters of the forward and the reverse link budgets, their impact and comparison between the two technologies was provided in Section 3.4.3.

4.3 Network costs and performance by scenario

The model assumes that operators deploying HSPA or WiMax networks will initially need to provide sufficient network coverage, and will not be capacity limited. Only

[17] Results are for the chosen modulation scheme and coding rate, the selected area type and other assumptions. Hence, resulting figures are for the chosen scenario only, e.g. "maximum cell radius" for 16QAM -¾ - urban area is **not** the maximum cell radius achievable by the system (which will typically be achieved with QPSK in a rural area)

when the number of subscribers increases over time will network capacity need to be considered, i.e. additional cell sites and equipment will be necessary.

In a coverage-limited situation as assumed for the model, the key driver for network deployment and maintenance is the number of cell sites. This translates into CAPEX for site preparation, installation and commissioning, base station equipment and controller and aggregation elements (RNC, AGW), as well as into OPEX for site lease and maintenance.

The model allows comparison of CAPEX and OPEX for various scenarios, primarily distinguished by operator profile (Greenfield existing GSM and/or UMTS operators) and by area type (i.e. urban, suburban and rural).

Operators with existing network infrastructure will typically require a significantly smaller number of additional sites, reflected in significantly lower capital expenditures and lower additional operational expenditures. The extent of such relative savings depends not only on the number of HSPA or WiMax sites required, but also on site density in the currently deployed network which may vary between operators. This density is based on assumptions on typical cell radii for GSM and UMTS that will need to be adjusted to operator specific data.

In case of deployment of HSPA, operators with an existing UMTS network will face significantly lower CAPEX, as HSPA then requires in many cases only a software upgrade at minimal cost. However, some of the early UMTS network equipment does require additional hardware upgrades that will impose higher costs on the operator. For such cases, the cost of upgrade for RAN equipment needs to be adjusted accordingly.

We have also found that there is a wide range of pricing for some of the network equipment. This is usually linked to differences in performance aspects such as lower receiver sensitivity of base station equipment, which in turn will impact link budget and therefore the number of cell sites and quantities of equipment required. Operators are advised to carefully consider the total cost implications of opting for low-cost and low-end equipment – which may require more cell sites for example - as compared to high-cost and high-end equipment, or combinations of these alternatives. Results shown later (Figure 19 and Figure 21-Figure 23) later indicate the sensitivity of CAPEX (number of cell sites needed) to overall link budget which depends among other factors on the parameters of equipment performance such as transmit power and receiver sensitivity.

Figure 13-Figure 18 present the peak DL and UL data rates that can be achieved by HSPA and WiMax in the three area types per sector and per user for specified numbers of users. The major message from these figures is the much more rapid variation of range with theoretical peak data rate for WiMax than for HSPA. Indeed in conditions

which do not allow the highest peak data rate (or highest modulation level) which WiMax can offer and HSPA cannot it is often the case that the range of HSPA at essentially equal peak data rates is greater than that of WiMax.

Figure 13 Peak data rates – urban area

Downlink	HSPA		WiMax (PUSC, all SC)	
Modulation and coding	Range [km]	Peak DL rate per sector [Mbit/s]	Range [km]	Peak DL rate per sector [Mbit/s]
QPSK - 1/4	0.259	1.80	0.213	1.75
`QPSK - 1/3	0.259	2.40		
QPSK - 1/2	0.259	3.60	0.213	3.50
QPSK - 3/4			0.213	5.25
16-QAM - 1/4	0.259	3.60		
16-QAM - 1/3	0.259	4.80		
16-QAM - 1/2	0.259	7.20	0.213	7.00
16-QAM - 3/4	0.259	10.80	0.209	10.50
64-QAM - 2/3			0.146	14.00
64-QAM - 3/4			0.141	15.75

Uplink	HSPA		WiMax (PUSC, all SC	
Modulation and coding	Range [km]	Peak UL rate per sector [Mbit/s]	Range [km]	Peak UL rate per sector [Mbit/s]
QPSK - 1/4	0.259	1.68	0.213	1.36
QPSK - 1/3	0.242	2.24		
QPSK - 1/2	0.227	3.36	0.175	2.72
QPSK - 3/4			0.154	4.08
16-QAM - 1/4				
16-QAM - 1/3				
16-QAM - 1/2			0.114	5.44
16-QAM - 3/4			0.106	8.17
64-QAM - 2/3			0.074	10.89
64-QAM - 3/4			0.071	12.25

Source: Arthur D. Little / Altran Telecoms and Media analysis

Figure 14 Peak data rates – suburban area

Downlink	HSPA		WiMax (PUSC, all SC)	
Modulation and coding	Range [km]	Peak DL rate per sector [Mbit/s]	Range [km]	Peak DL rate per sector [Mbit/s]
QPSK - 1/4	0.899	1.80	0.739	1.75
QPSK - 1/3	0.899	2.4		
QPSK - 1/2	0.899	3.6	0.739	3.50
QPSK - 3/4			0.739	5.25
16-QAM - 1/4	0.899	3.60		
16-QAM - 1/3	0.899	4.80		
16-QAM - 1/2	0.899	7.20	0.739	7.00
16-QAM - 3/4	0.899	10.80	0.724	10.50
64-QAM - 2/3			0.506	14.00
64-QAM - 3/4			0.489	15.75

Uplink	HSPA		WiMax (PUSC, all SC)	
Modulation and coding	Range [km]	Peak UL rate per sector [Mbit/s]	Range [km]	Peak UL rate per sector [Mbit/s]
QPSK - 1/4	0.899	1.68	0.739	1.36
QPSK - 1/3	0.842	2.24		
QPSK - 1/2	0.789	3.36	0.607	2.72
QPSK - 3/4			0.536	4.08
16-QAM - 1/4				
16-QAM - 1/3				
16-QAM - 1/2			0.394	5.44
16-QAM - 3/4			0.367	8.17
64-QAM - 2/3			0.256	10.89
64-QAM - 3/4			0.246	12.25

Source: Arthur D. Little / Altran Telecoms and Media analysis

Figure 15: Peak data rates – rural area

Downlink	HSPA		WiMax (PUSC, all SC)	
Modulation and coding	Range [km]	Peak DL rate per sector [Mbit/s]	Range [km]	Peak DL rate per sector [Mbit/s]
QPSK - 1/4	3.990	0.30	3.280	1.75
QPSK - 1/3	3.990	0.40		
QPSK - 1/2	3.990	0.60	3.280	3.50
QPSK - 3/4			3.280	5.25
16-QAM - 1/4	3.990	0.60		
16-QAM - 1/3	3.990	0.80		
16-QAM - 1/2	3.990	1.20	3.280	7.00
16-QAM - 3/4	3.990	1.80	3.216	10.50
64-QAM - 2/3			2.245	14.00
64-QAM - 3/4			2.172	15.75

Uplink	HSPA		WiMax (PUSC, all SC)	
Modulation and coding	Range [km]	Peak UL rate per sector [Mbit/s]	Range [km]	Peak UL rate per sector [Mbit/s]
QPSK - 1/4	3.990	1.68	3.280	1.36
QPSK - 1/3	3.738	2.24		
QPSK - 1/2	3.501	3.36	2.696	2.72
QPSK - 3/4			2.381	4.08
16-QAM - 1/4				
16-QAM - 1/3				
16-QAM - 1/2			1.751	5.44
16-QAM - 3/4			1.629	8.17
64-QAM - 2/3			1.137	10.89
64-QAM - 3/4			1.094	12.25

Source: Arthur D. Little / Altran Telecoms and Media analysis

Figure 16: Peak data rates per user – urban area

Downlink	HSPA (5 users/cell)		WiMax (3 users/cell, PUSC 1/3)	
Modulation and coding	Range [km]	Peak DL rate per sector [Mbit/s]	Range [km]	Peak DL rate per sector [Mbit/s]
QPSK - 1/4	0.259	0.36	0.213	0.19
QPSK - 1/3	0.259	0.48		
QPSK - 1/2	0.259	0.72	0.213	0.39
QPSK - 3/4			0.213	0.58
16-QAM - 1/4	0.259	0.72		
16-QAM - 1/3	0.259	0.96		
16-QAM - 1/2	0.259	1.44	0.213	0.78
16-QAM - 3/4	0.259	2.16	0.209	1.17
64-QAM - 2/3			0.146	1.56
64-QAM - 3/4			0.141	1.75

Uplink	HSPA (5 users/cell)		WiMax (3 users/cell, PUSC: 1 SC)	
Modulation and coding	Range [km]	Peak UL rate per sector [Mbit/s]	Range [km]	Peak UL rate per sector [Mbit/s]
QPSK - 1/4	0.259	0.34	0.213	0.01
QPSK - 1/3	0.242	0.45		
QPSK - 1/2	0.227	0.67	0.175	0.03
QPSK - 3/4			0.154	0.04
16-QAM - 1/4				
16-QAM - 1/3				
16-QAM - 1/2			0.114	0.05
16-QAM - 3/4			0.106	0.08
64-QAM - 2/3			0.074	0.10
64-QAM - 3/4			0.071	0.12

Source: Arthur D. Little / Altran Telecoms and Media analysis

Figure 17: Peak data rates per user – suburban area

Downlink	HSPA (6 users/cell)		WiMax (4 users/cell, PUSC 1/3)	
Modulation and coding	Range [km]	Peak DL rate per sector [Mbit/s]	Range [km]	Peak DL rate per sector [Mbit/s]
QPSK – 1/4	0.899	0.30	0.739	0.15
QPSK – 1/3	0.899	0.40		
QPSK – 1/2	0.899	0.60	0.739	0.29
QPSK – 3/4			0.739	0.44
16-QAM - 1/4	0.899	0.60		
16-QAM - 1/3	0.899	0.80		
16-QAM - 1/2	0.899	1.20	0.739	0.58
16-QAM - 3/4	0.899	1.80	0.724	0.88
64-QAM - 2/3			0.506	1.17
64-QAM - 3/4			0.489	1.31

Uplink	HSPA (6 users/cell)		WiMax (4 users/cell, PUSC: 1 SC)	
Modulation and coding	Range [km]	Peak UL rate per sector [Mbit/s]	range [km]	Peak UL rate per sector [Mbit/s]
QPSK – 1/4	0.899	0.28	0.739	0.01
QPSK – 1/3	0.842	0.37		
QPSK – 1/2	0.789	0.56	0.607	0.02
QPSK – 3/4			0.536	0.03
16-QAM - 1/4				
16-QAM - 1/3				
16-QAM - 1/2			0.394	0.04
16-QAM - ¾			0.367	0.06
64-QAM - 2/3			0.256	0.08
64-QAM - ¾			0.246	0.09

Source: Arthur D. Little / Altran Telecoms and Media analysis

Figure 18: Peak data rates per user – rural area

Downlink	HSPA (6 users/cell)		WiMax (4 users/cell, PUSC 1/3)	
Modulation and coding	Range [km]	Peak DL rate per sector [Mbit/s]	Range [km]	Peak DL rate per sector [Mbit/s]
QPSK - ¼	3.990	0.30	3.280	0.15
QPSK - 1/3	3.990	0.40		
QPSK - ½	3.990	0.60	3.280	0.29
QPSK - ¾			3.280	0.44
16-QAM - ¼	3.990	0.60		
16-QAM - 1/3	3.990	0.80		
16-QAM - ½	3.990	1.20	3.280	0.58
16-QAM - ¾	3.990	1.80	3.216	0.88
64-QAM - 2/3			2.245	1.17
64-QAM - ¾			2.172	1.31

Uplink	HSPA (6 users/cell)		WiMax (4 users/cell, PUSC: 1 SC)	
Modulation and coding	Range [km]	Peak UL rate per sector [Mbit/s]	Range [km]	Peak UL rate per sector [Mbit/s]
QPSK - 1/4	3.990	0.28	3.280	0.01
QPSK - 1/3	3.738	0.37		
QPSK - 1/2	3.501	0.56	2.696	0.02
QPSK - 3/4			2.381	0.03
16-QAM - 1/4				
16-QAM - 1/3				
16-QAM - 1/2			1.751	0.04
16-QAM - 3/4			1.629	0.06
64-QAM - 2/3			1.137	0.08
64-QAM - 3/4			1.094	0.09

Source: Arthur D. Little / Altran Telecoms and Media analysis

While Figures 13-15 show peak data rates *per sector* for the different area types, Figures 16-18 reflect peak data rates that *users* may experience. Based on a constant user distribution and density described in section 3.4.1, larger cell areas of HSPA will serve more users, and therefore the available data rates *per user* will be lower on average as the total sector data rate is shared among more users.

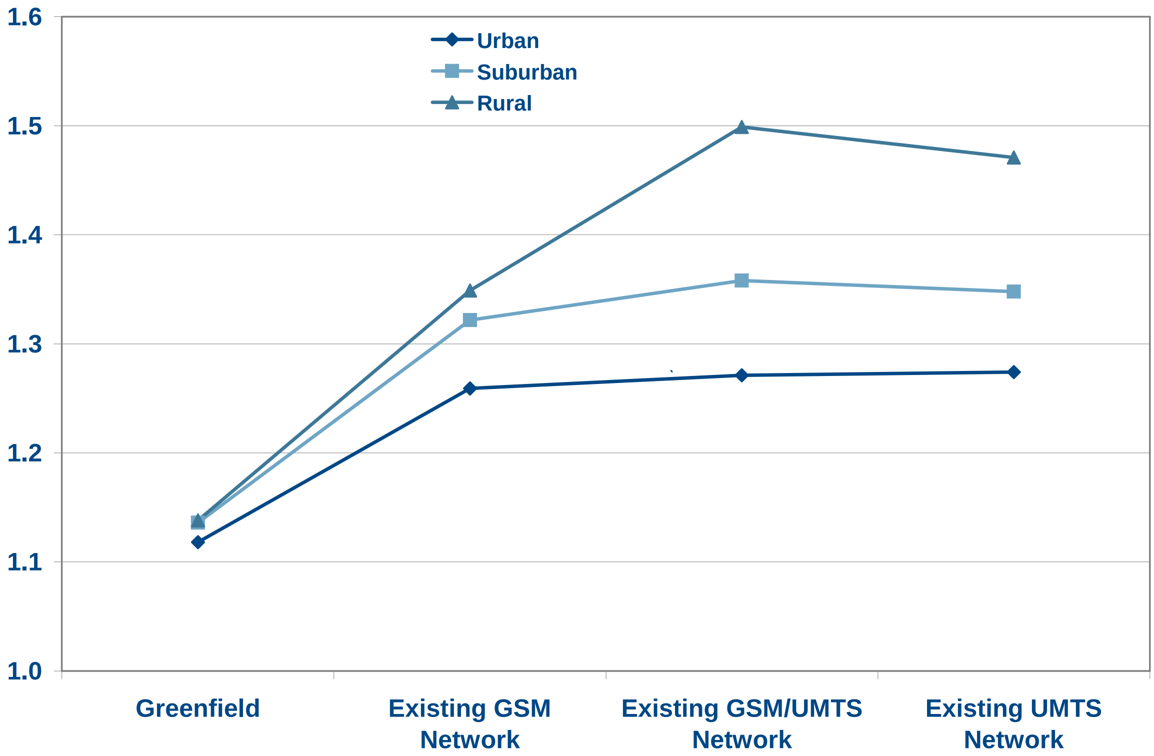
Much has been made of the theoretical ability of mobile WiMax to achieve higher peak data rates than other available broadband wireless technologies, including HSPA. This claim is substantiated by the results of the model, as a consequence of the higher order modulation (64-QAM) which WiMax supports and HSPA does not. However, every wireless system is subject to the same laws of physics, which means that in real-world system deployments there are inevitable trade-offs to be made between performance parameters such as throughput, coverage (or range), power, and of course cost. Indeed one major message from the results of the model is that HSPA, while not capable of attaining the highest data rates which WiMax may offer under favourable conditions to a few users in privileged circumstances, can serve a larger number of users than WiMax with fewer cell sites, and hence lower CAPEX (and OPEX), at first generation DSL-like speeds. As shown in Figures 13 - 18, the peak data rate of WiMax is only available close to a base station. When the range of WiMax is extended by using PUSC then the data rate users can expect is considerably reduced.

The relative results of CAPEX calculations for HSPA and WiMax are shown in Figure 19 and Figure 20 for the three area types and four operator profiles, assuming that in each situation the same operator has the choice of deploying either WiMax or HSPA. The results are presented for both PUSC (Figure 19) and FUSC (Figure 20) implementations of WiMax. In all of these cases CAPEX and OPEX were lower for HSPA than for WiMax, and for FUSC WiMax dramatically so. The OPEX included in the model is between 30-35% higher for WiMax PUSC and more than 6.5 times larger for WiMax FUSC than for HSPA. Not surprisingly, the CAPEX advantage of HSPA is found to be least significant for a greenfield operator where the HSPA deployment enjoys no benefit from earlier investments in a cellular network.

Figure 21 shows the CAPEX ratios for the three area types in circumstances in which WiMax is deployed as a greenfield network (with no reuse of existing cell sites), while HSPA is installed in existing GSM, GSM/UMTS, and UMTS networks as well as on a greenfield basis. Not surprisingly, the CAPEX disadvantage of WiMax increases when the latter is able to reuse existing cell sites while the former is not.

Figures 22 - 24 illustrate the sensitivity of CAPEX to specific equipment performance parameters. The only difference between the results shown in Figures 21 and 22, and Figures 18 and Figure 20 respectively is that the link budget of the WiMax base station has been improved by 2dB in the calculations for Figures 21 and 22, while all other parameters for both WiMax and HSPA remain the same as in Figures 18 and 20 respectively. The result is that the CAPEX for mobile WiMax becomes slightly lower than HSPA in all area types for head-to-head Greenfield comparisons and for all urban operator profiles, and close to but higher than the HSPA CAPEX in most suburban and rural circumstances. The most marked remaining CAPEX disadvantage for WiMax is found in the comparison between a Greenfield WiMax operator and an HSPA operator with an existing GSM/UMTS or UMTS-only network in a rural area. Figure 23 shows the effect of adding 2dB to the uplink interference margin of WiMax, leaving all other parameters the same as in Figure 18. As a result the relative CAPEX disadvantage of WiMax is increased, by about 30% in most cases.

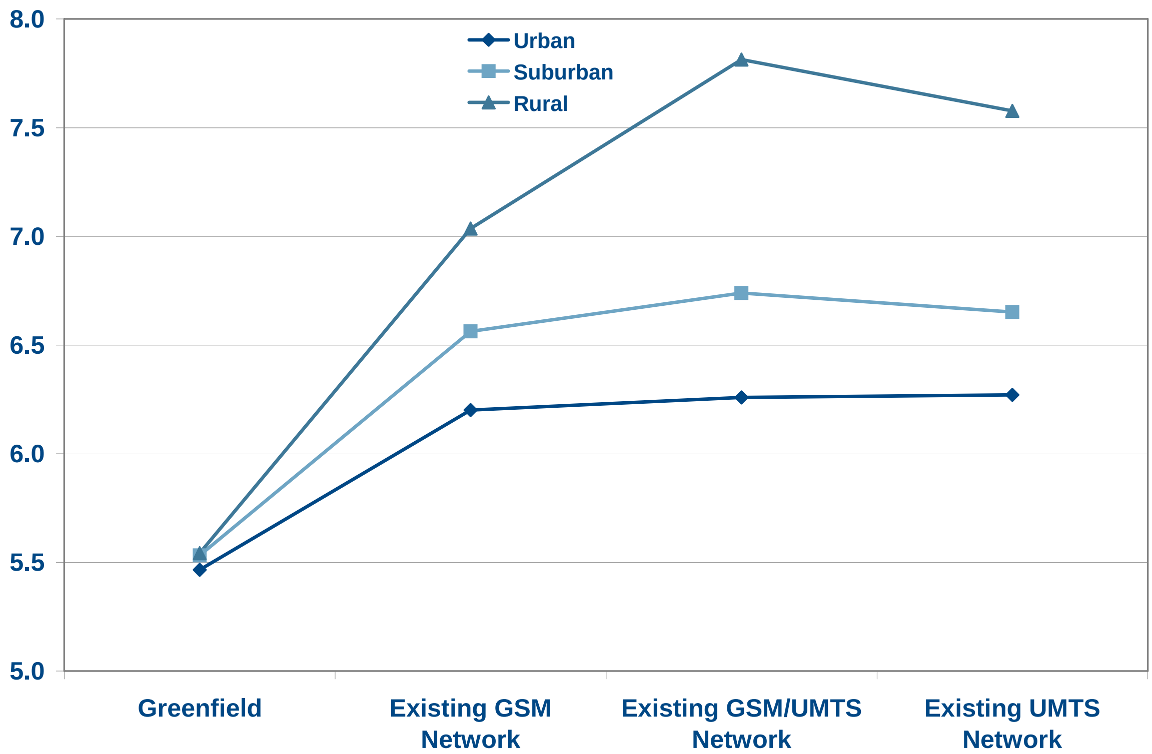
Figure 19: CAPEX Ratio – WiMax with PUSC compared to HSPA (same operator profiles)



Source: Arthur D. Little / Altran Telecoms and Media analysis

The HSPA CAPEX is always lower than the WiMax CAPEX. It is assumed that both the WiMax and the HSPA networks are able to reuse existing cell sites (GSM and/or UMTS). The smallest difference is found for a Greenfield operator who for both HSPA and WiMax has to build the entire network (all cell sites are new), although the HSPA operator has the advantage of requiring fewer cell sites to achieve coverage. For the other operator profiles for which the relative CAPEX disadvantage of mobile WiMax is greater the HSPA operator also benefits from savings on equipment that has already been installed, which is not the case for the WiMax network.

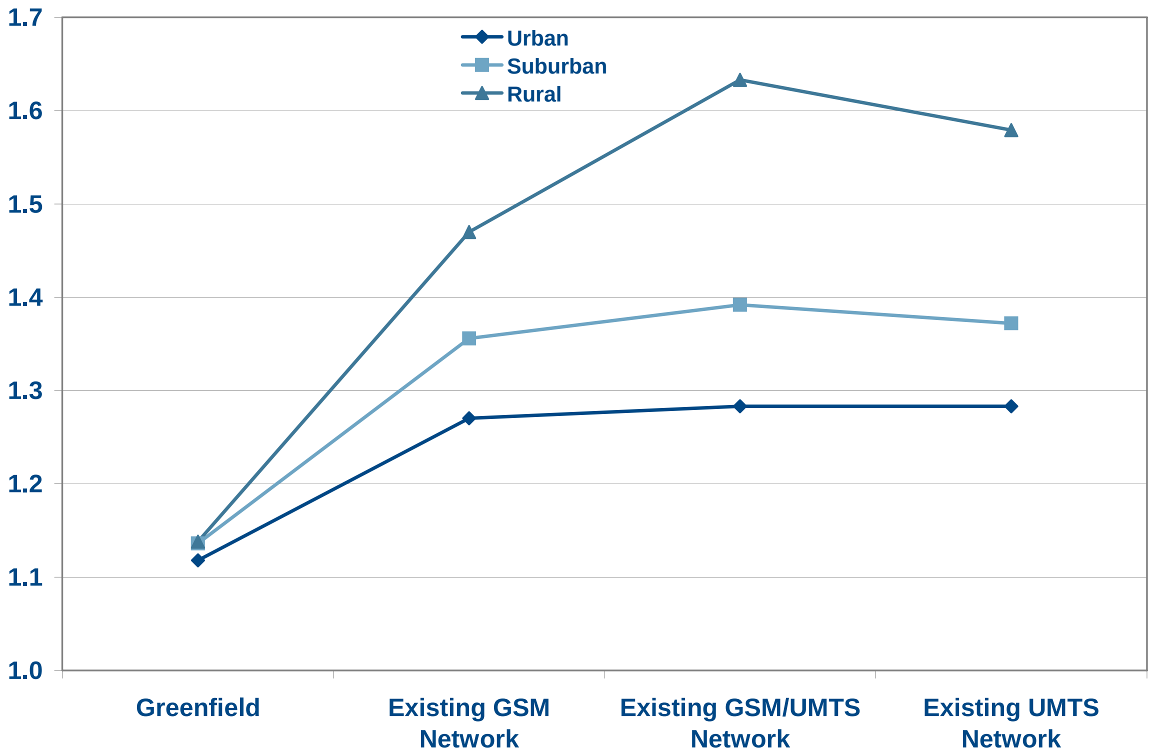
Figure 20: CAPEX ratio - WiMax with FUSC compared to HSPA (same operator profiles)



Source: Arthur D. Little / Altran Telecoms and Media analysis

The WiMax network requires much higher CAPEX in its FUSC than its PUSC implementation because of the much smaller range – and hence much larger number of cell sites – of PUSC. Again the relative CAPEX disadvantage of WiMax is least if Greenfield networks are involved.

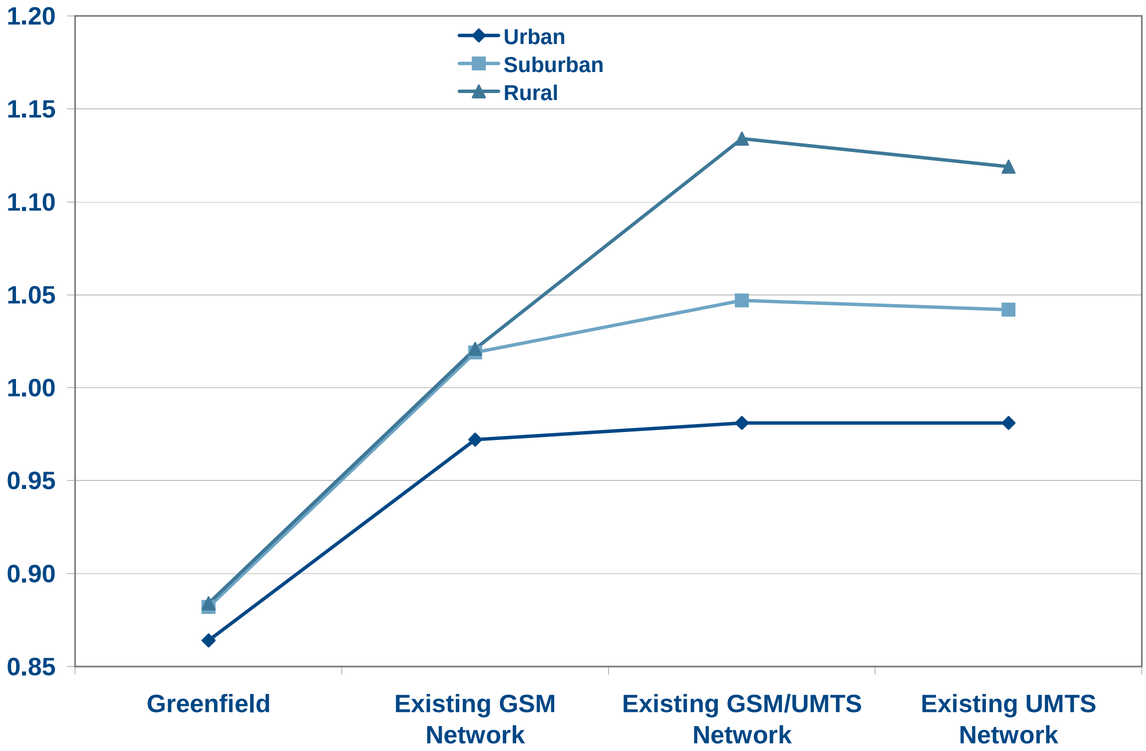
Figure 21 CAPEX ratio – Greenfield WiMax with PUSC compared to HSPA operator profiles)



Source: Arthur D. Little / Altran Telecoms and Media analysis

The CAPEX disadvantage of WiMax is greater in this scenario than in Figure 19, except for the greenfield comparison, because it assumes a Greenfield WiMax network in all cases which cannot share any GSM and/or UMTS infrastructure. So in every situation all its cell sites have to be acquired.

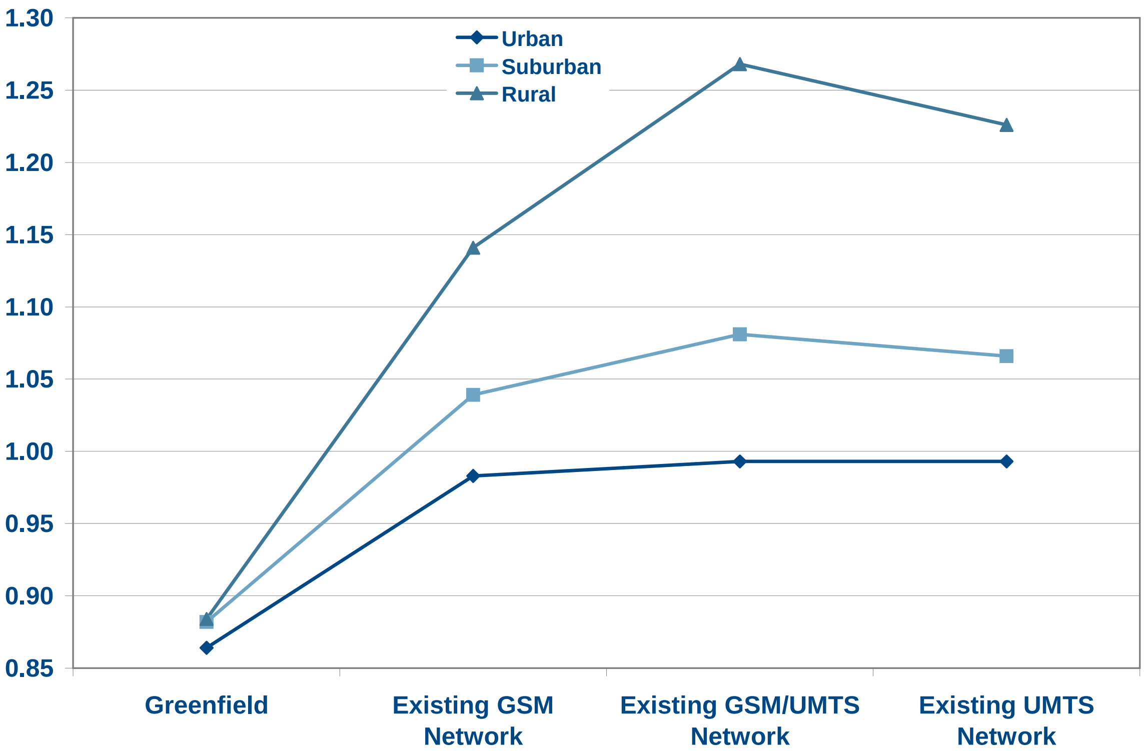
Figure 22: Sensitivity analysis: CAPEX impact of improvement of 2 dB in WiMax link budget (all other parameters remain the same as in Figure 18)



Source: Arthur D. Little / Altran Telecoms and Media analysis

In this figure, the WiMax link budget is improved by 2dB, while the HSPA link budget stays the same. As a consequence the CAPEX disadvantage of WiMax is reduced and even reversed in urban areas and for Greenfield operators in all areas.

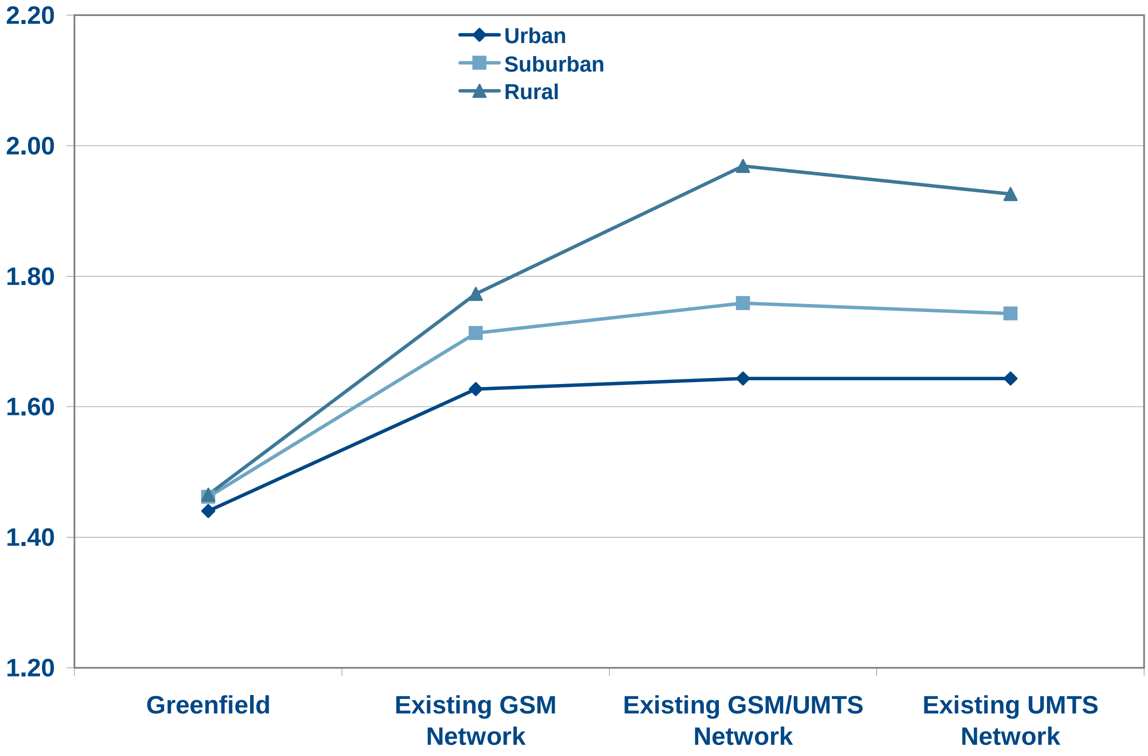
Figure 23: Sensitivity analysis: CAPEX impact of improvement of 2 dB in WiMax link budget (all other parameters remain the same as in Figure 20)



Source: Arthur D. Little / Altran Telecoms and Media analysis

In this comparison of a greenfield WiMax operator which cannot share any existing GSM and/or UMTS infrastructure, the effect of a 2dB improvement in the WiMax link budget is similar to that shown in the preceding figure.

Figure 24: Sensitivity analysis: CAPEX impact of a 2dB increase in the uplink interference margin for mobile WiMax (all other parameters remain the same as in Figure 18)



Source: Arthur D. Little / Altran Telecoms and Media analysis

The comparison with Figure 19 shows a significant increase in the CAPEX disadvantage of mobile WiMax of around 30% if a greater interference margin is required than is the case for HSPA.

The principal reason for CAPEX and OPEX advantages of HSPA is simply the lower number of cell sites required to cover a specific area. If, for example, the costs of the WiMax base station were reduced to zero, then in the example of the urban area, existing GSM/UMTS network the CAPEX for the two technologies would be almost identical ($53.1 million for HSPA and $51.2 million for WiMax (PUSC). Thus the CAPEX results of the model are much less sensitive to the costs of base station equipment than they are to improvements in its performance.

The use of all sub-carriers in WiMax (FUSC) leads to a significantly lower cell range and hence many more sites and substantially higher costs. Of course as mentioned earlier operators can deploy their WiMax networks so that a cell supports a mix (e.g. 50:50) of FUSC and PUSC, with an FUSC “zone” close to the base station and three PUSC sectors towards the cell edge. It should be noted that in WiMax PUSC there is a difference between DL and UL. The model assumes PUSC 1/3 on the DL, i.e. transmitting a third of the sub-carriers channels per sector, which reduces DL capacity. On the UL the model assumes PUSC with one sub-carrier channel (SC). This choice is the worst case in terms of UL data rate, which will likely be lower than HSPA’s UL data rates (see Figure 16, 17 and 18) but the best case in terms of cell range and hence costs. Of course such low UL rates make a VoIP service impractical. Another option would be to use more sub-carriers on the UL, which would have a reduced range in exchange for a higher data rate.

The characteristics of the model results for comparing HSPA and mobile WiMax have an interesting implication for the business and revenue models which an operator may be considering. At its simplest, mobile WiMax offers an operator the potential to offer customers perhaps the highest data rates attainable over the next few years, but at the cost of high CAPEX and OPEX. In contrast, HSPA offers an operator the potential to offer lower, but still respectable – this definition will be discussed further in the next paragraph – data rates at significantly lower CAPEX and OPEX. An operator who intends to offer a “premium” service to the highest end customers, and believes that prices can be set accordingly, may conclude that deployment of WiMax within limited areas in which there is a high concentration of such customers can be a winning proposition. Extension of WiMax nationwide or even region-wide is unlikely to meet this criterion. This will limit the mobility of users of such high-end service as they will lack coverage outside the vicinity of their usual coverage area. This limitation could be mitigated with the help of dual-mode (e.g. WiMax/HSPA) terminals and roaming arrangements that will however add to costs and require the establishment of appropriate technical and commercial arrangements between networks and in many cases between operators.

The economic balance between the two technologies will shift more in favour of WiMax when capacity-limited rather than coverage-limited situations are encountered, so that cell radii and numbers of cell sites required are determined by capacity and not by range, as they are in the cases covered in this model. However, operators will also recognize that the characteristics of HSPA are such that it will be easier for them to match their rollout and investment with revenue as customers and traffic increase over time than it will be with WiMax. Larger numbers of WiMax cell sites have to be deployed at the coverage- and not capacity- limited outset of network rollout to provide minimum acceptable coverage that is of any interest even to the first customers.

It is not entirely clear and very operator-dependent when networks will become capacity limited, and to what extent, (as opposed to range limited) in urban areas. The timing of this shift will depend on the amount of spectrum available to an operator, and the volume of market demand and market share which the operator succeeds in capturing.

A possible argument against HSPA could be made on the grounds that its peak data rates are simply inadequate (i.e. not respectable) in the face of the theoretically higher peak data rates which WiMax can achieve, and will not support the delivery of new services from which operators hope and need to generate revenue. The disappointed expectations associated with “first generation” 3G systems (in terms of real-world speeds as well as revenues) give reason for caution. Data rates themselves are not the issue; rather it is how consumer demand responds to the capabilities of these data rates and the services that can be offered. The business and economic issue for an operator is whether the higher peak data rates that a substantially more expensive (because of small cell size) mobile WiMax network could theoretically offer will stimulate enough otherwise untapped demand at a higher enough price from a large enough number of users to make the investment in WiMax worthwhile. Evidence from fixed networks indicates that with user DL speeds of around 0.5 Mbps and somewhat slower UL speeds (i.e. equivalent to the practical performance of early DSL systems) the qualitative capabilities of, and consumer demand for, the communications channel do take a quantum leap forward and broadband services can develop. Although the question of which services will find wide acceptance and how operators can make money from them is beyond the scope of this project, nevertheless the conclusion is that HSPA represents a significant enough improvement over earlier 3G technologies that it can form a platform for the growth of new mobile and nomadic services that demand speeds substantially beyond those of typical voice services.

It should be re-emphasized that the modelling results reported here are based upon equipment that is available now or for deployment in the near term, with corresponding costs and capabilities. Different results would be obtained were parameter values to be used that are derived from forecasts of the costs and performance of HSPA and mobile WiMax systems that might be offered in, say, 2010-11. Both these wireless technologies and the networks based on them have substantial room for improvement over the next few years in terms of performance and economics. Furthermore there are many other technologies and techniques in which improvements can be anticipated and applied to either of them (i.e. are largely independent of the air interface), such as content-specific compression and optimization of the data delivery capability of the IP protocol over wireless channels, to support services that will fulfil and provide expanded and enriched experiences to customers. So there is little reason to anticipate that one technology will improve dramatically relative to the other in terms of deliverable capabilities over the next few years.

5. Conclusions

The two preceding chapters have focused on the cost economics of HSPA and mobile WiMax in terms of data throughput and coverage with no specific reference to the types and characteristics of the services that might be offered over these networks. This project was not designed to provide quantitative analyses of the revenue opportunities for the networks. Nevertheless a few observations can be made to take account of the respective capabilities of HSPA and WiMax in particular with respect to mobility and latency-sensitive voice traffic and their impact upon the NPV (Net Present Value) calculations which are typically used to assess and justify major investments.

Situations in which WiMax requires greater earlier investments than HSPA to provide coverage in coverage-limited situations, such as have been identified in the results of the model, work to its disadvantage in an NPV calculation. Less clear are the consequences of mobile WiMax's limitations – at least in the first generation – as compared to 3G/HSPA networks with respect to handling voice traffic and meeting demands for vehicular-level mobility. In addition, but not considered further, there may be concerns about how many potential customers for WiMax will not be prepared to sign up until the technology has established the kinds of roaming agreements which the traditional cellular world enjoys on a national and global basis.

A simple revenue model would allocate potential or addressable revenue streams for mobile WiMax into 3 broad categories:

- Traditional voice and other narrowband services (the "bread and butter" of today's mobile networks)
- Broadband services (and business models) which both HSPA and WiMax are perfectly capable of supporting
- Broadband services (and business models) which – at least hypothetically – only WiMax networks but not HSPA can support, a proposition being publicly promulgated by Sprint Nextel that remains to be proven

A further refinement would need to consider the respective merits and viability of national, regional, or zonal/hot spot coverage. 2G experience shows that consumers place a premium on a service if ubiquitous coverage is offered nationally, as well as abroad through international roaming partners. So for example, the decision to offer zonal coverage might reduce some or all of the above revenue streams, compared to what a national operator could charge. Also zonal/hotspot operators would experience fewer economies of scale in terms of core networks, billing, brand presence, etc. These fixed costs could not be shared over as many customers as a national operator. A decision to focus WiMax on zonal coverage would also mean that an operator would most likely be competing in the same market as WiFi hotspot networks. An extension of this approach would involve establishing roaming and interoperability between the zonal networks and wider area cellular technology, such as Sprint Nextel intends, which in their case mitigates some of the problems of economies of scale just mentioned. However, this approach does nevertheless involve significant implications in terms of both overall network and terminal costs, which have to be weighed against the amount of incremental revenues that it can attract.

The number of places where there are no cellular networks in place which are expanding coverage nationwide – and/or enhancing their capabilities substantially through deployment of HSPA – is diminishing rapidly as shown in the discussion and evidence presented in Chapter 2. Hence unless there is good reason to believe that the third category of services outlined above (WiMax-only) will soon become large and comparable in size to the first two, it is likely that mobile WiMax networks will face severe competition from established mobile networks and in its early generations a realistically addressable market that is substantially smaller than that being served by these existing competitors. Even if it is reasonable to forecast that the margins in and the size of the mobile voice business will respectively shrink and stagnate (or decline) in future, it appears highly unlikely that voice (and other traditional) revenues will contribute less than , say 50% of mobile revenues for several years to come, at least five to seven. In the arena of fixed telecommunications, the rapid rise of broadband – linked to the internet – has not proved sufficient to support viable data-only operators such as mobile WiMax networks with limited voice traffic capacity might become.

Hence the current or first generation limitations of mobile WiMax with respect to mobility and especially mobile voice traffic make a WiMax investment from both the revenue and cost side of an NPV perspective intrinsically more risky than one by an established cellular operator in HSPA. This risk will make a WiMax investment subject to a higher discount rate in an NPV calculation which further weakens the business case for WiMax. This risk can be somewhat mitigated if the WiMax investment can be successfully applied in a manner that maximizes its complementary rather than competitive aspects to an existing cellular network, and it can benefit from significant cost sharing with the latter's infrastructure and other upfront costs (billing etc.). Another way of mitigating the WiMax risk lies in applying the WiMax network to emphasize the delivery of competitive fixed and nomadic (in contrast to truly) mobile services to customers where alternative networks (e.g. wired, combined with Wi-Fi) are inadequate. This latter scenario is more likely to be found in emerging markets.

The key conclusions of this study, combining the findings of the qualitative research and analysis and the output of the high-level network cost and performance model can therefore be summarized as:

Over the next 5 years

- HSPA will account for the majority of deployments of broadband, mobile-capable wireless networks over the next five years or so, building on the very large number of 2GSM and 3GSM networks already offering service over allocated spectrum around the world;
- Mobile WiMax systems have the opportunity to capture niche markets over this period, whose extent will be dependent upon (a) suitable spectrum assignments and allocations reserved for or open to WiMax; and (b) proof of performance (technical, economic and commercial) of the first large scale mobile WiMax networks being rolled out over 2007-2008 in the Korea and the U.S. (with the first small scale installations in 2006 in Korea);
- In coverage-limited situations, HSPA will frequently enjoy a CAPEX and OPEX advantage over mobile WiMax, which is most marked in rural areas; this advantage is based primarily on the smaller number of cell sites that HSPA deployment requires. This characteristic (fewer cell sites to launch a service) will also allow an HSPA operator entering a market or offering a new service to match its network investment over time more closely to the growth of its customers and traffic than is the case with WiMax;
- The number of cell sites, and hence CAPEX, required in coverage-limited situations is notably sensitive to the overall link budget, so the CAPEX difference between HSPA and WiMax will be significantly reduced (and possibly turn to the slight advantage of WiMax in urban areas and for Greenfield operators) if the performance of WiMax equipment improves to the point where the WiMax link budget is closer to that of HSPA. In contrast the CAPEX required is relatively insensitive to the costs of the base station equipment;
- In capacity-limited situations, mobile WiMax becomes relatively more competitive in terms of deployment costs, suggesting that it is most likely to be worth consideration by operators seeking to offer extended wireless "hot spot" or limited coverage high capacity data service to meet the demands of significant numbers of high-end data users concentrated in urban areas. However, urban WiMax networks, many of whose target users will be in fixed and nomadic environments, face a broader set of alternatives – at least in developed markets – than HSPA, namely wired or wired plus Wi-Fi networks, which (in many cases already installed) can offer higher data capacities and therefore pose an additional competitive factor to consider in making the business case for WiMax;

- The peak data rates that mobile WiMax can achieve are higher than those which HSPA offers, however, the latter is better able to achieve relatively uniform coverage of users over a wider area at speeds that are comparable to first generation DSL services;
- Trade-offs between capacity (data rate) and coverage should be carefully reviewed by operators in making comparative assessments of wireless technologies to determine which is best suited to supporting their business models, especially since the nature and impact of these trade-offs are often neglected or presented very inadequately in technology comparisons that focus on only one parameter or figure of merit (typically peak data rate);
- Mobile WiMax networks based on emerging implementations of the technology which have limited mobility management capability are better suited to providing fixed and nomadic services than truly mobile services comparable to traditional cellular networks, while at the same time their voice traffic capacity - in particular mobile voice - is also limited. Hence operators whose business models depend on voice revenues, whether fixed and/or mobile, to achieve a satisfactory return on investment may find a commitment to WiMax hard to justify; and
- Mobile WiMax may also be attractive for delivering fixed and nomadic services up to and including broadband access in parts of the world where the fixed network infrastructure is very inadequate, although these opportunities may be shrinking as cellular infrastructure spreads rapidly over the next few years, even in traditionally telecommunications-poor countries.

Longer Term

- In the longer term broadband wireless systems are expected to be based on technologies such as OFDMA and MIMO which are being actively pursued by all key players in the wireless industry, including 3GPP and 3GPP2 as well as WiMax;
- The question of which and how many “flavours” of these basic technologies for broadband mobile wireless networks will eventually be deployed commercially on a significant scale will depend on several developments which will unfold between now and into the second decade of this century, such as:
  - On the WiMax side whether WiMax equipment captures large enough revenues in the interim to support its continued development by major vendors, and whether key aspects of a full network and services architecture such as roaming capabilities are implemented successfully;
  - On the 3GPP side how rapidly and successful the 3GLTE program moves ahead and 3GLTE equipment and systems become available;

- Commercial and business decisions by major technology suppliers that affect their development and market priorities and stimulate further initiatives in terms of suppler consolidation and/or realignment which can affect the outcome of whether there will be convergence or continued separation of the major broadband wireless development groups; and last but by no means least
- The environment for and investment appetite of mobile operators based on their experiences and initiatives both to ensure their influence over their equipment and systems suppliers, and in launching new business models that are more open and "internet-like" than the traditional cellular model, stimulate demand for even more broadband wireless channels, and involve a much wider variety of user devices than handsets.

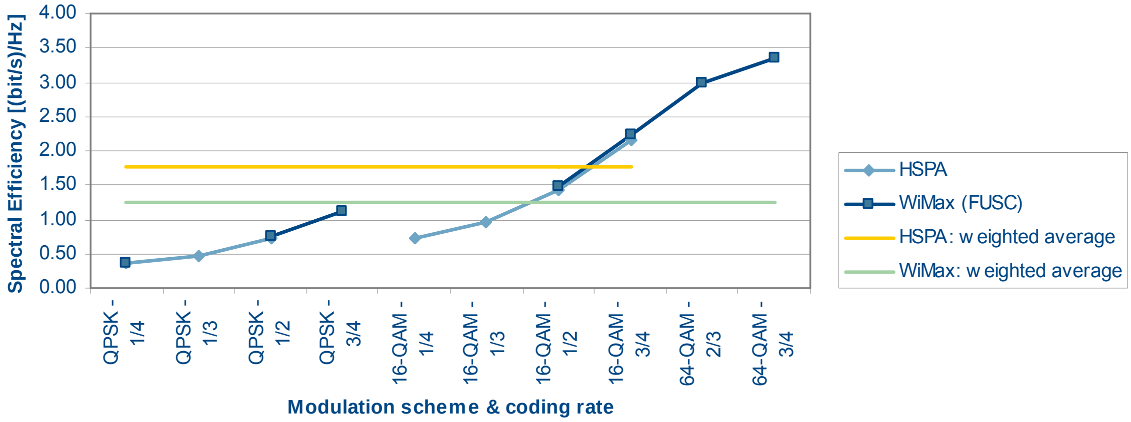
6. Appendices

6.1 Spectral efficiencies

The model permits the calculation of spectrum utilization in terms of coverage (spectral efficiency multiplied by site coverage area) and density (spectral efficiency per km²). These figures give an indication of combined spectral efficiency and link budget for coverage and capacity limited scenarios, respectively.

Figure A1 shows that with an even physical distribution of users throughout a cell HSPA actually achieves a higher weighted average spectral efficiency thanks to its ability to reach a higher proportion of users at relatively high data rates.

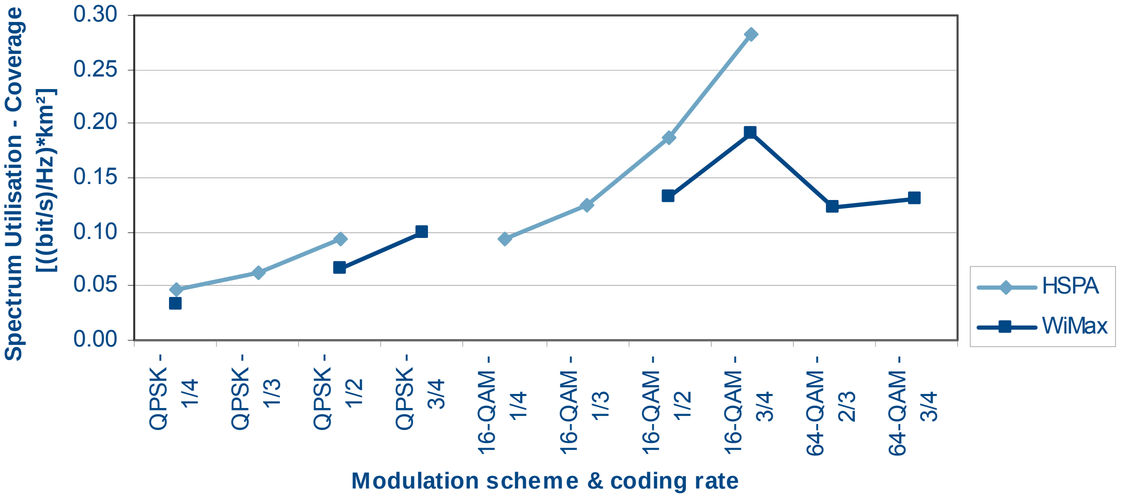
Figure A1: Nominal spectral efficiency (per modulation and coding scheme)



Source: Arthur D. Little / Altran Telecoms and Media analysis

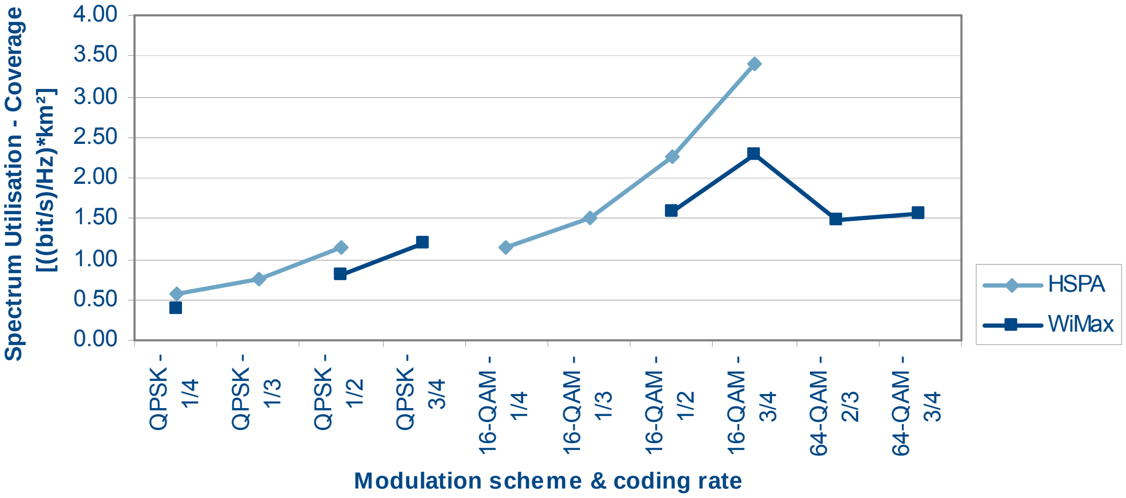
Figure A2-Figure A4 present the spectrum utilization of the two wireless technologies by area type, i.e. the spectral efficiency multiplied by the area covered. In coverage-limited scenarios higher spectrum utilization is better. These three figures indicate the general superiority of HSPA over mobile WiMax in these circumstances.

Figure A2: Spectrum utilization – coverage – urban areas (per modulation and coding scheme)



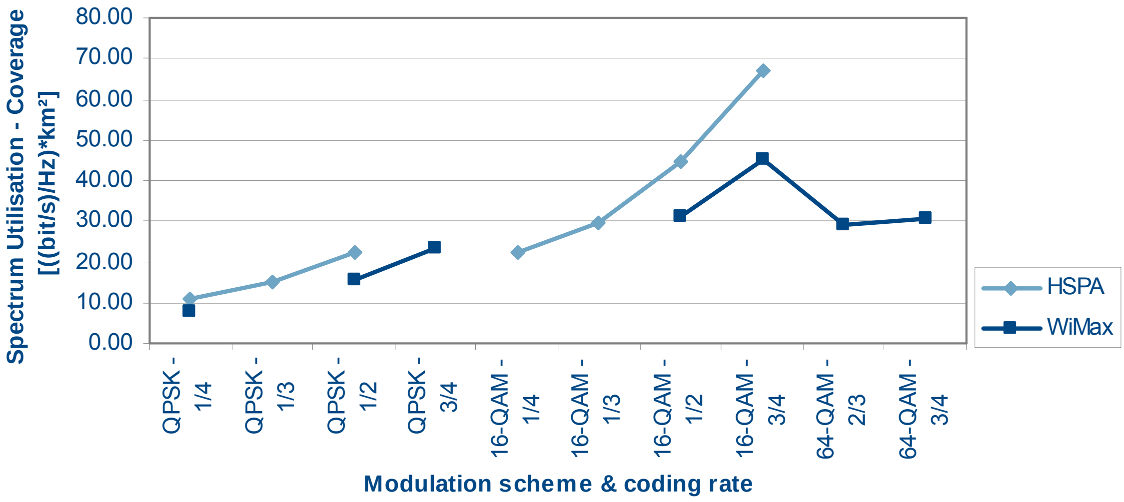
Source: Arthur D. Little / Altran Telecoms and Media analysis

Figure A3: Spectrum utilization – coverage – suburban areas (per modulation and coding scheme)



Source: Arthur D. Little / Altran Telecoms and Media analysis

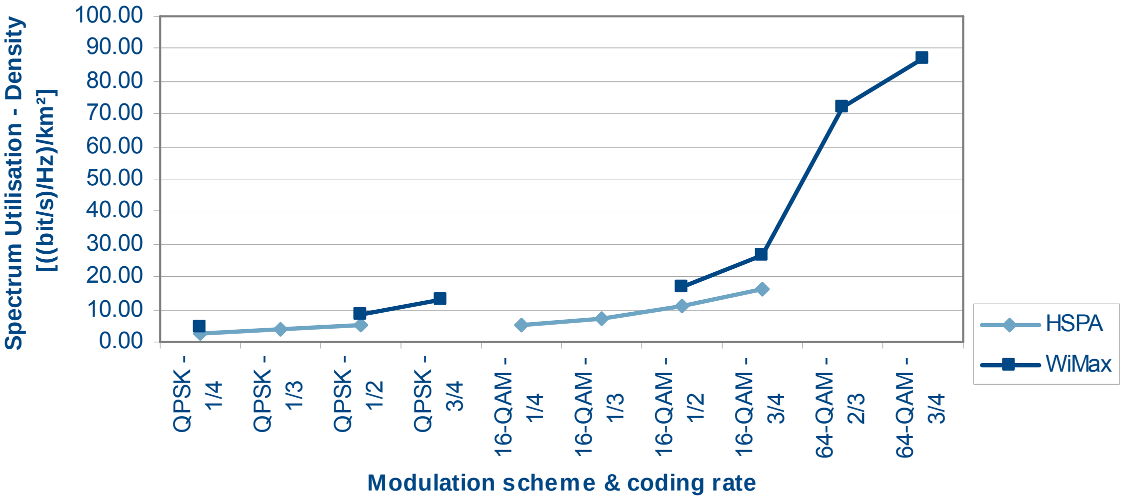
Figure A4: Spectrum utilization – coverage – rural areas (per modulation and coding scheme)



Source: Arthur D. Little / Altran Telecoms and Media analysis

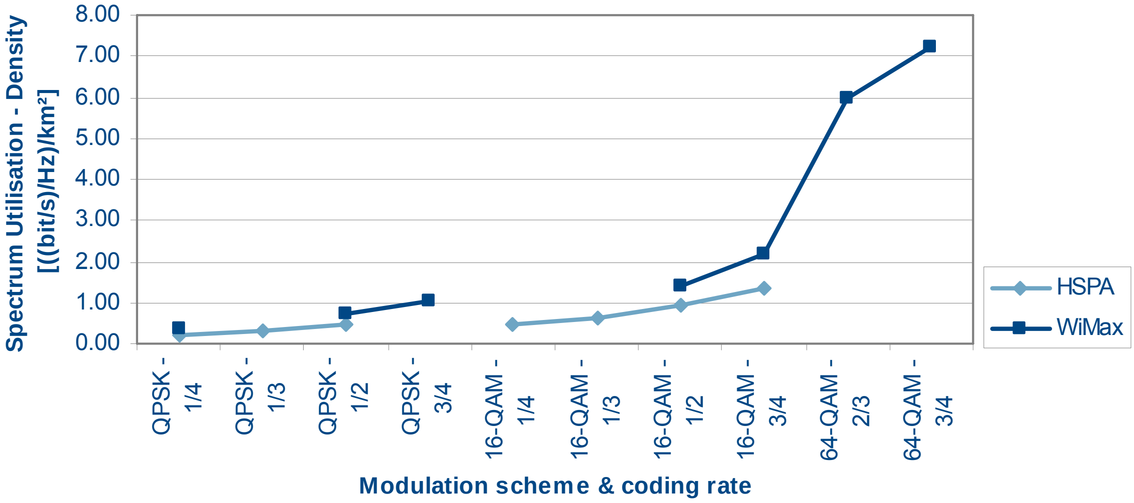
In contrast, in capacity-limited situations the figure of merit is spectral efficiency divided by the area covered, since the higher this is the more data capacity is available to users. Figure A5-Figure A7 demonstrate the expected superiority of mobile WiMax in these circumstances, especially if propagation conditions permit the use of the highest level 64 QAM modulation which WiMax but not HSPA currently supports.

Figure A5: Spectrum utilization – density – urban areas (per modulation and coding scheme)



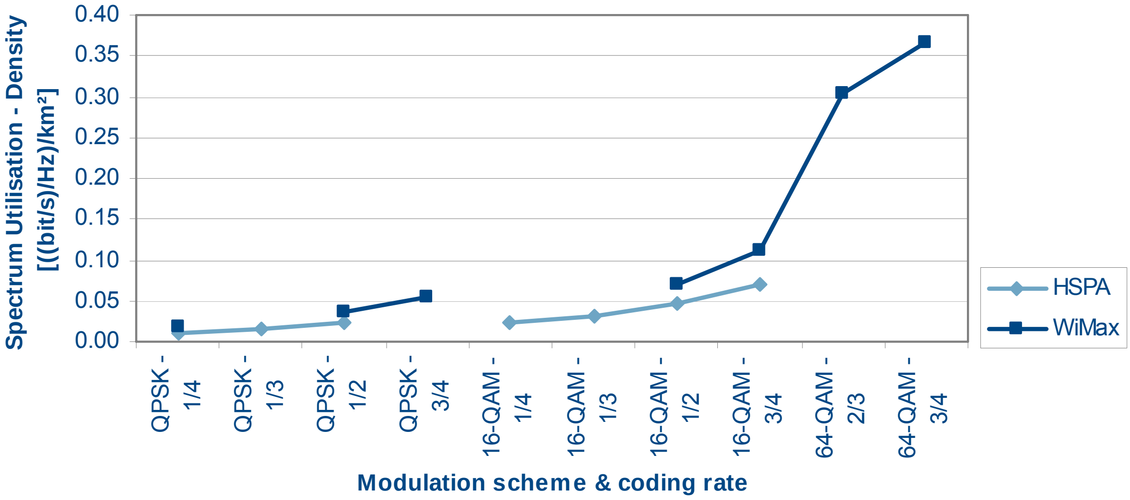
Source: Arthur D. Little / Altran Telecoms and Media analysis

Figure A6: Spectrum utilization – density – suburban areas (per modulation and coding scheme)



Source: Arthur D. Little / Altran Telecoms and Media analysis

Figure A7: Spectrum utilization – density – rural areas (per modulation and coding scheme)



Source: Arthur D. Little / Altran Telecoms and Media analysis

6.2 Qualitative interview questionnaire

Introduction

We have been retained by the GSMA to produce an independent and impartial view of the respective roles of mobile WiMax and 3G+ (namely HSPA) network technologies on a global basis. The intention of the GSMA is to make the findings of our work public through various media. It is usual practice for these reports to be published and placed in the public domain.

We recognize that this topic is a key item on the agenda of many CXOs in the telecommunications sector, and opinions, claims and counterclaims vary widely. Hence we are trying to seek information and judgments from a very wide variety of interested parties to gain a 360 degree view of the market place.

Our focus is on the next 5 years and the goals are to assess as objectively as possible

- What will be the respective roles of these technologies in a variety of circumstances including: (a) urban, suburban, and rural deployments; (b) countries with well developed fixed broadband infrastructure and countries with very limited fixed (wired) networks; (c) operators planning greenfield wireless network deployments and operators with existing 3G networks?
- Will these two technology streams be mainly competitive or complementary?
- How will the prospects for these two technologies be affected by the characteristics of overall demand for services (two-way versus predominantly one way, medium (up to about 1 Mbps) versus high bandwidth (multi-megabit per second), truly mobile versus nomadic applications)?
- As the newcomer compared to large existing cellular networks pursuing a path of successive upgrades, is WiMax likely to (a) be restricted to small niche deployments, (b) achieve a significant but still modest market share, or (c) become a major player in broadband wireless networks for mobile and nomadic use?

To help answer these questions, we would be grateful to hear your opinions and receive any information you think is relevant with respect to a number of technical, market, and/or demand issues and any other factors you believe are significant in terms of the decisions network operators will take in choosing the broadband wireless network technologies in which they will invest for forthcoming deployments. Please feel free to address only those questions or comment only on those topics where you feel comfortable, bypassing the rest.

Please indicate whether you wish your responses and submissions to be:

a) Identified by:

Individual	Company	Equipment Vendor, Handset supplier, mobile operator etc.
		(Specify)

b) Kept anonymous except for a statistical reference (e.g. x out of y respondents expect the following to occur).

Basic respondent information

Name:	
Position:	
Company	
Date of Interview	
Time of Interview:	
Interview Method (face-to-face, telephone etc.)	

Infrastructure technology

Question One: What we are hearing is a number of different viewpoints as to whether WiMax (802.16e) has the basis for a competitive advantage versus HSPA … what are your views on this subject?

Probe for answers on the following if not covered:

- RF performance (spectral efficiency of OFDMA)
- Use of smart antennas

Question Two: How large do you think this advantage may be in terms of performance metrics relevant to users (capacity, latency etc.)

Question Three: How clear or well proven is it that any such potential advantages or benefits will be realizable in a wide area, multi-cellular mobile environment

Probe – is this 'gut feel', intuition or supported by 'hard data' (if so, what is the source)

Question Four: Could you share your views on the structure and organization of handoff protocols within mobile WiMax and their standardization?

Question Five: In terms of timing, firstly, how important is, or will be, that the radio transport is IP based (i.e. no overhead) today, in three and five years time?

Time Period	Essential	Very Important	Neutral	Nor Very Important	Not Essential	Don't Know
Today						
3 Years						
5 Years						

Question Six: Turning to IMS, will the timing of the implementation of IMS have a significant effect upon adoption of WiMax?

Question Seven: Thinking about the implementation of IMS, there are different views as to whether it might facilitate the implementation of an all-IP environment across fixed and mobile networks earlier than might otherwise be the case, with corresponding savings in overall CAPEX and OPEX and the ability to offer new and/or a more coherent suite of services across different access networks. What are your thoughts?

a) Impact on Implementation
b) Savings & Coherent Services

Question Eight: We have heard a range of views as to whether interoperability issues between equipment from different WiMax vendors have been resolved or will persist, and if they do persist where they will create the greatest obstacles. What are your thoughts on this issue?

Question Nine: How confident are you that any interoperability resulting from needing to use equipment from different vendors will be resolved before acquired by operators?

Question Ten: There also seems to be some debate as to whether the WiMax, GSM, CDG technology streams will effectively merge by 2011-12 or some later date. Given what you know about the roadmaps of 3GPP (e.g. LTE) and 3GPP2 (e.g. EV-DO Rev. C) do you think that the merger will occur, or will significant differences still remain, and if so in what respects?

(Probe:)

- MIMO
- Adaptive antennas
- Coding schemes

Thank you for addressing those points, I'd now like to turn to the areas of Network Equipment and Coverage

Question Eleven: There appear to differing claims for the number of base stations required to achieve different coverage requirements. We recognize that the number of BTS required will depend on type of clutter and terrain to be covered not just on area, but could you share your thoughts on the expected coverage area per BTS[18] (assuming 2.5 and 3.5 GHz for WiMax **and/or** 2.5 GHz for HSPA) in the following environments: *(ignoring capacity requirements for now)*

Scenario	WiMax Yes/No	HSPA Yes/No	Comments
(a) dense urban area –multiple high rise buildings side-by-side			
(b) an urban area – mostly high rise buildings, not side-by-side			
(c) a suburban area (1 -3 storey buildings, mix of residential and business)			
(d) a rural area – 1-2 storey buildings sparsely spaced with large open areas in between			

Question Thirteen: Do you have any representative estimates of the numbers of BTS[1] for WiMax and/or HSPA likely to be required for the following scenarios - relating them to any assumptions made about numbers of subscribers, oversubscription, and data rate per subscriber, assuming a 2.5GHZ deployment for both technologies.

Scenario	WiMax - Number of Base Stations (Also add assumptions)	HSPA – Number of Base Stations (Also add assumptions)
Dense urban area of 4 sq. kms		
Urban area of 8 sq. kms		
Suburban area of 100 sq. kms		
Rural area of 500 sq. kms		

Question Fourteen: Some of the people we have spoken have commented on 3.5GHz's ability to provide reasonable indoor coverage. What are your views and/or experience?

Many industry observers and commentators have highlighted the success that handsets & devices have played in the success of the mobile industry to date. I'd like to close this section by exploring this area:

Question Fifteen: What differences, if any, do you anticipate in terms of weight, volume, and battery life between WiMax and HSPA handset devices?

Element	WiMax	Comments	HSPA	Comments
Weight				
Volume				
Battery Life				
Other (Specify)				

Question Sixteen: What other "form factors" or device configurations do you consider will be significant for broadband wireless connections, e.g. in-car installations, vertical industry-specific devices?

Question Seventeen: What are your thoughts as to whether WiMax and HSPA devices will have to be dual-mode to provide sufficient geographic coverage, e.g. WiMax/EV-DO; HSPA/UMTS/WiMax/HSPA

Market and demand for services

I'd now like to move our discussions to the market place and the end-user demand for services.

Question Eighteen: Firstly, how do you see the expected demand for broadband "untethered" access develop along the following dimensions?

Dimension	Comments
Fixed versus Nomadic versus Mobile at vehicular speeds	
The need for geographic coverage/interoperability at different levels	(Probe for) local, regional, national, international levels
Data/video only versus Data/video and VoIP	
Device form factor i.e. Handheld; Laptop; other	
Download-dominated; Upload/download balanced	
Entertainment	
Business Applications	
Information Retrieval	
Are there any other dimensions you feel are as, or even more important?	

Question Nineteen: A classic chicken and egg argument is whether increasing bandwidth triggers the development of new applications or services or demands for new applications/services stimulate increases in bandwidth. Whatever the case may be, where do you think discontinuities lie in terms of broadband speeds beyond which significant new applications services and hence markets open up, that cannot be effectively addressed at speeds below that level?

Probe the following:

Speed	Comments
300/400 kbps versus 1Mbps	
1 Mbps versus 3 Mbps	
3Mbps versus 10 Mbps	
10Mbps versus 30 Mbps	
Other critical speed levels	

Question Twenty-three: In your view, is true broadband defined as 500 kbps+ or 1 Mbps+ or some other speed for user data rates, and how will this change over the next 5 years?

2006		2008		2011	
Mobile	Fixed Line	Mobile	Fixed Line	Mobile	Fixed Line

Other factors affecting choices of broadband wireless network technology

Coming to the end of the interview, I'd like to spend a little time exploring the other factors that could influence the choice of broadband wireless network technology

Question Twenty-four: How do you see the price and price evolution of base stations (BTS) for mobile WiMax and HSPA?

WiMax	HSPA

Question Twenty-five: How will this vary by frequency band (2.3/2.5 and 3.5 GHz for WiMax, and 900MHz/1.8/2.1 GHz for HSPA)?

Question Twenty-six: What would you estimate to be the delta increase in costs over the existing 3G network by deploying HSPA?

Question Twenty-seven: Similarly What would you estimate to be the delta increase in costs over the existing 3G network by deploying WiMax?

(Probe for:)

- OSS
- Additional transceivers
- Additional backhaul
- Additional base stations

Question Twenty-eight: If performance and/or cost differences in network equipment alone are not sufficient in your situation to make the choice clear, what other factors, which might differentiate in, practical terms between the value of these alternative technologies will play important roles in your decision-making process?

Influence	Prompted	Unprompted
Availability of external financing for one or the other choice (e.g. vendor financing,		
Government-guaranteed financing)		
Regulatory decisions (other than spectrum allocation), such as obligations and rules regarding roaming and interconnection agreements imposed upon other operators and treatment of VoIP		
Ability to offer "bundled" i.e. multi-access/FMC services by cooperating with other operators or with other business units in your organization		
Timing of decision to implement IMS (IP Multimedia Subsystem)		
Availability and prices of user devices		
Rules about allowable subsidies for user devices		
Availability and price of billing and/or other operational and business support systems		
Availability of applications and services running over the network and of an ecosystem of developers providing a flow of enhanced and new applications and services		
Interest of influential third parties such as Google, Microsoft, Yahoo! in offering their services over the network		
Lower royalty payments for WiMax equipment as compared to HSPA		
Other.		

Question Twenty-nine: For an existing 3G network and assuming you are planning significant network investments in the next 3 years. Despite any uncertainties about market demand for services are the performance and/or cost differences between WiMax and HSPA network equipment sufficient on their own to make the choice between them?

Question Thirty: What if you do not own any existing wireless infrastructure?

Question Thirty-one: And could, or might, the answer to the preceding question differ if you are an operator in the U.S., Western Europe, Central/Eastern Europe (including Russia and former Soviet countries), Japan, China, India, Brazil, any other countries you think are significant?

Question Thirty-two: Does HSPA have an advantage compared to WiMax because there are more applications and services available for HSPA networks today

Question Thirty-three: How do you see the average selling price evolve for: (a) handsets; (b) data cards; (c) "built in" wireless for: (i) WiMax and (ii) HSPA

WiMax only		HSPA & 3G		WiMax & 3G	
Handsets		Handsets		Handsets	
Datacards		Datacards		Datacards	
"Built-in" Wireless		"Built-in" Wireless		"Built-in" Wireless	

Question Thirty-four: In your view, will there be significant differences between WiMax and HSPA in the impact of royalty fees upon device costs?

WiMax-specific issues

Question Thirty-five: How difficult and expensive will it be to make the transition from a fixed WiMax (802.16d) to a mobile WiMax network (802.16e) – or do you think that most or all WiMax deployments should or will be based on 802.16e from the start (this question is not directly or exclusively dependent on handoff protocols but on the lower layers as well)?

Question Thirty-six: Do you think that lack of suitable spectrum will continue to be a substantial obstacle to WiMax deployment (Probe:)

- How much of a disadvantage will it be with respect to (a) CAPEX, given the number of BTS needed, and (b) in-building coverage if WiMax spectrum is only available at 3.5 GHz and not at 2.3/2.5GH

Question Thirty-seven: Is there anything else you'd like to add or comments you'd like to make?

6.4 Sources

General

Author	Title	Publisher	Year
Intel Corp.	Understanding WiMAX and 3G for Portable/Mobile Broadband Wireless	Intel Technical White Paper	2004
Kettani S.	Mobile WiMAX: A Complementary or Competitive Technology?	Bechtel Telecommunications Technical Journal, Vol. 4, No. 2	2006
Cardoso F.D., Taccori S., Correia L.M.	Initial Propagation Models	IST-2001-32125 FLOWS, Deliverable No. D4	2002
Abhayawardhana V.S., Wassell I.J., Crosby D., Sellars M.P., Brown M.G.	Comparison of Empirical Propagation Path Loss Models for Fixed Wireless Access Systems	IEEE 61st Vehicular Technology Conference, VTC 2005 Spring, Vol. 1, pp. 73-77	2005
Ranvier S.	Path Loss Models	Helsinki University of Technology	2004
Furuskär A.F., Almgren M., Johansson K.	An Infrastructure Cost Evaluation of Single- and Multi-Access Networks with Heterogeneous Traffic Density	IEEE 61st Vehicular Technology Conference, VTC 2005 Spring, Vol. 5, pp. 3166-3170	2005
Walden M.C., Rowsell F.J.	Urban Propagation Measurements and Statistical Path Loss Model at 3.5 GHz	IEEE Antennas and Propagation Society International Symposium 2005, Vol. 1A, pp. 363-366	2005
Huo D.	Issues on Path Loss Model	IEEE 802.20 Working Group on Mobile Broadband Wireless Access	2005
ArrayComm	Improving wireless economics through MAS software - MAS in Practice	http://www.arraycomm.com/serve.php?page=practice	2006
ArrayComm	Introduction to the Economic Drivers of Broadband Wireless	ATiS - World Telecommunications Day	2005
ArrayComm	Multi-Antenna Signal Processing: Drivers of Adoption in 3.5G, 3GLTE, and WiMAX	http://www.arraycomm.com/docs/ArrayComm_MAS_Adoption_Drivers.pdf	2006
Aarnikoivu S., Winter J.	Mobile Broadband Wireless Access	Helsinki University of Technology, Research Seminar on Telecommunications Business	2006
Katsianis D., Welling I., Ylönen M., Varoutas D., Sphicopoulos T., Elnegaard N.K., Olsen B.T., Budry L.	The Economic Perspective of the Mobile Networks in Europe	Natianal and Kapodistrian University of Athens	2001

Author	Title	Publisher	Year
Umehira M.	Research and Development of Broadband Wireless Access Technologies	NTT Technical Review, Vol. 2, No. 1, pp. 12-20	2004
Thelander M.W.	Ca-ching or Ker-plunk - The Dollars and Sense of 3G	Signals Research Group	2006
Matheson R.J.	A Survey of Relative Spectrum Efficiency of Mobile Voice Communication Systems	U.S. Department of Commerce, NTIA Report 94-311	1994
Walker M.	Pipes Galore	Vodafone, presentation at the IEE	2005
Smurna T.	Techno-economic Analysis of Telecom Investment Projects	Helsinki University of Technology	2006
Jenkins G., Uskola J.	At the Starting Line – The Race to Mobile Broadband	Deutsche Bank AG, London	2007

HSPA

Author	Title	Publisher	Year
Qualcomm	HSDPA for Improved Downlink Data Transfer	http://www.cdmatech.com/download_library/pdf/hsdpa_downlink_wp_12-04.pdf	2004
Dahlmann E., Ekström H., Furuskär A., Jading Y., Karlsson J., Lundevall M., Parkvall S.	The 3G Long-Term Evolution - Radio Interface Concepts and Performance Evaluation	IEEE 63rd Vehicular Technology Conference, VTC 2006 Spring, Vol. 1, pp. 137-141	2006
Cardona N., Navarro A.	The Influence of Propagation Model and Sectorisation over WCDMA Capacity	Proc. IASTED Intl. Conf. "Communication Systems and Networks", pp. 117-122	2002
Dinan E., Kurochkin A., Kettani S.	UMTS Radio Interface System Planning and Optimisation	Bechtel Telecommunications Technical Journal	2002
Pitsillides A.	Performance Evaluation of UMTS Outdoor Environments using a simulative approach	University of Cyprus, Dept. of Computer Science	2003
Correia L.M., Fledderus E.R., Meijerink E., Perera R., Serrador A., Türke U., van Uitert M.J.G., Winter T.	Identification of relevant parameters for traffic modelling and interference estimation	IST-2000-28088 MOMENTUM, Deliverable No. D2.1	2001

Author	Title	Publisher	Year
Maidment D.	Understand HSDPA's implementation challenges	Mobile Handset Design Line	2005
Nortel Networks	HSOPA: The vision beyond 3G	http://www.nortel.com/solutions/wireless/collateral/nn114882.pdf	2006
Dulski A., Beijner H., Herbertsson H.	Rural WCDMA – Aiming for nationwide coverage with one network, one technology, and one service offering	Ericsson Review No. 2, pp. 79-85	2006
Valadon C.	HSDPA: Pushing the Limits of 3G for Enhanced Data Rates	http://www.ttpcom.com/en/downloads/TTPCom_Presentation_HSDPA_Pushing_the_Limits_of_3G_for_Enhanced_Data_Rates.pdf	2006
Haberland B., Bloch S., Braun V.	3G Evolution Towards High Speed Downlink Packet Access	http://www1.alcatel-lucent.com/publications/abstract.jhtml?repositoryItem=tcm%3A172-18051635	2004
Qualcomm Engineering Services Group	HSDPA Indoor Deployment Aspects	http://www.qualcomm.com/esg/media/pdf/HSDPA_IndoorDeploymentAspects.pdf	2006
Nokia	Nokia HSDPA Solution	http://www.nokia.com/NOKIA_COM_1/About_Nokia/Research/Demos/HSDPA/HSDPA_A4.pdf	2003
Shengyou W.	HSDPA Radio Network Planning	Huawei Technologies, Issue 19	2005
Lucent Technologies	More Efficient and Cost-Effective Use of Precious Bandwidth	Lucent Technologies White Paper	2005
Nortel Networks	HSDPA and Beyond	http://www.nortel.com/solutions/wireless/collateral/nn_110820.01-28-05.pdf	2005
Griparis T., Dinan E.	HSDPA Network Dimensioning Challenges and Key Performance Parameters	Bechtel Telecommunications Technical Journal, Vol. 2, No. 4	2006
Rysavy P.	Data Capabilities: GPRS to HSDPA and Beyond	http://www.rysavy.com/Articles/Rysavy_Data_Paper-Sept2005.pdf	2005

WiMax

Author	Title	Publisher	Year
Luntovskyy A., Gütter D., Schill A.	Models and Methods for WLAN / WiMAX- Network Design	IEEE CriMiCo Conference, Sevastopol, Crimea, Vol.1, pp.391-393	2006
Arthur D. Little	WiMAX vs. WiWAIT: Will Mobile Also Dominate Broadband?	http://www.adl.com/industries/time/report_mbwa.php	2004
Dineen R.	WiMAX anti-CLiMAX	HSBC Global Research	2006
OECD	The Implications of WiMAX for Competition and Regulation	Working Party on Telecommunication and Information Services Policies, DSTI/ICCP/TISP(2005)4/FINAL	2006
Kahn K.	Evolution of WiMax - Beyond Fixed Access Networks	Intel, Communications Technology Lab	2005
Kitchener D., Naden M., Tong W., Zhu P., Senarnath G., Zhang H., Steer D., Yu D.	BS-RS, BS-MS and RS-RS NLOS Multihop Path Loss Model	IEEE C802.16j-06/063	2006
Ericsson AB	WiMAX - Copper in the Air	http://www.ericsson.com/technology/whitepapers/3058_WiMAX_A.pdf	2006
Intel Corp.	Deploying License-Exempt WiMAX Solutions	http://www.intel.com/netcomms/technologies/wimax/306013.pdf	2005
Thelander M.W.	WiMAX - Opportunities and Challenges in a Wireless World	CDMA Development Group	2005
NEC Corporation	Technical Description on NEC's Broadband Wireless Access Products	http://www.neceurope.com/pdf/NEC_Mobile_WiMAX_Whitepaper_Ver-D1.4_060513.pdf	2006
Nortel Networks	Considerations for deploying mobile WiMAX at various frequencies	http://www.nortel.com/solutions/wimax/collateral/nn115440.pdf	2006
Smurna T.	Competitive Potential of WiMAX in the Broadband Access Market: A Techno-Economic Analysis	Helsinki University of Technology	2005
Cai S.	Enabling Technologies for WiMAX Deployment with Indoor Terminals	Global WiMAX Summit, China	2005
Ikeda T., Asa M., Saito K.	Comments on IEEE 802.16j Path-loss Models in IEEE802.16j-06/013	IEEE C802.16j-06/113	2006

Author	Title	Publisher	Year
WiMAX Forum	Mobile WiMAX - Part I: A Technical Overview and Performance Evaluation Mobile WiMAX – Part II: A Comparative Analysis	WiMAX Forum	2006
WiMax.com	Insight into Capital Expenses for WiMax Network	PBM Networks	2006
Richardson M., Ryan P.	WiMAX: Opportunity or Hype?	Advances in Telecom: Proc. 4th Annual ITERA Conf. (ITERA 2006), pp. 103-139	2006
Laine P., Boettle D., Boscher c., Feijt L.	WiMAX, making ubiquitous high-speed data services a reality	http://www1.alcatel-lucent.com/publications/abstract.jhtml?repositoryItem=tcm:172-44851635	2004
Nortel Networks	MIMO or AAS: Key technology choice in deploying WiMAX	http://www.nortel.com/solutions/wimax/collateral/nn118160.pdf	2006
Korhonen J.	WiMax - Threat or Opportunity for 3G?	TTPCom, http://www.ttpcom.com/en/downloads/TTPCom_Whitepaper_WiMAX.pdf	2005
Nortel Networks	Considerations for Deploying Mobile WiMax at Various Frequencies	http://www.nortel.com/solutions/wimax/collateral/nn115440.pdf	2006
WiMAX Forum	Fixed, Nomadic, Portable and Mobile Applications for 802.16-2004 and 802.16e WiMax Networks	WiMAX Forum	2005

6.5 Glossary of terms

1xRTT	One Carrier Radio Transmission Technology
2G	Second Generation
3G	Third Generation
3GPP	3G Partnership Project
3GPP2	3G Partnership Project 2
4G	Fourth Generation
AAS	Adaptive Antenna System
ADSL	Asynchronous Digital Subscriber Line
AGW	ASN Gateway
AMC	Adaptive Modulation and Coding
AMR	Adaptive Multi Rate
ASN	Access Service Network
BTS	Base Station
CDMA	Code Division Multiple Access
CP	Cyclic Prefix
CSN	Connectivity Service Network
dB	Decibel
DL	Downlink
EDGE	Enhanced Data Rates for GSM Evolution
EIRP	Effective Isotropic Radiated Power
ETSI	European Telecommunications Standards Institute
EV-DO	Evolved Data Optimized
FDD	Frequency Division Multiplex
FFT	Fast Fourier Transformation
FL	Forward Link
FTP	File Transfer Protocol
FUSC	Fully Used Sub-Carrier
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GSM	Global System for Mobile communication
GSMA	GSM Association
HLR	Home Location Register
HO	Handover, Handoff
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access

HSUPA	High Speed Uplink Packet Access
HTTP	Hyper Text Transfer Protocol
IMS	IP Multimedia Subsystem
IP	Internet Protocol
ITU	International Telecommunication Union
LAN	Local Area Network
LOS	Line of Sight
LTE	Long Term Evolution
MAC	Media Access Control
MAN	Metropolitan Area Network
MBS	Multicast and Broadcast Service
MIMO	Multiple Input Multiple Output
MMS	Multimedia Message Service
MS	Mobile Station
MSC	Mobile Switching Centre
NLOS	Non Line of Sight
OFDMA	Orthogonal Frequency Division Multiple Access
PER	Packet Error Rate
PHY	Physical layer
PSTN	Public Switched Telephone Network
PUSC	Partially Used Sub-Carrier
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Key Shifting
RAN	Radio Access Network
RF	Radio Frequency
RL	Reverse Link (also Radio Link)
RNC	Radio Network Controller
SGSN	Serving GPRS Support Node
SHO	Soft Handover / Soft Handoff
SIM	Subscriber Identification Module
SIMO	Single Input Multiple Output
SIP	Session Initiation Protocol
SM	Spatial Multiplexing
SMS	Short Message Service
SNR	Signal-to-Noise Ratio
SOFDMA	Scalable OFDMA

SS	Subscriber Station
STC	Space Time Coding
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telephony System
VoIP	Voice over IP
VPN	Virtual Private Network
WCDMA	Wideband CDMA
WiFi	Wireless Fidelity
WAP	Wireless Application Protocol
WiBro	Wireless Broadband
WiMax	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

6.6 About Arthur D. Little, Altran Telecoms & Media and Praxis

Arthur D. Little

Founded in 1886 in Boston by a pioneer chemist and MIT professor, Arthur D. Little is the world's first professional management consulting firm. Ever since its creation, it has proved able to evolve and adapt with a constant focus on answering our clients' needs and challenges and creating true partnerships with business leaders.

Together with its partners Altran Technologies and Cambridge Consultants Ltd. the firm has over 17.000 professionals at your disposal in more than 30 offices world-wide. Arthur D. Little's global leadership in management consulting is embodied both by its size and global presence, and by its innovation methodology, demonstrated by numerous standard-setting publications.

Arthur D. Little completes over 2000 projects every year serving the world's leading companies. This rate of activity has enabled Arthur D. Little to gain strong experience and a well established know-how which is highly valued by our clients.

The pioneer spirit of its founder is still a strong feature of Arthur D. Little today. Arthur D. Little people bring curiosity, creativity, integrity and analytical rigor to every job, which means fast and dramatic performance improvements. Our constant objective is to create value for our clients, placing innovation at the heart of our recommendations and fostering the use of new technologies and next generation processes.

Arthur D. Little teams work both with major multinational groups and smaller growth-driven companies (in the Biotech industry for instance). The firm has conducted projects with over 70% of Fortune 100 companies. The quality of our work is rewarded by our client's loyalty: approximately 70% of our worldwide revenue is generated by projects for companies that have been our clients for over three years.

The TIME practice (Telecommunications, Information, Media and Electronics) has unrivalled expertise in strategic and technological assistance of leading telecom players. Arthur D. Little helps major telecom operators, government agencies and equipment suppliers in the completion of their most sensitive projects. The practice has gained a true and precise knowledge of the sector and of its main players.

During the last few months, Arthur D. Little has assisted several major mobile telecom operators in the world in defining next generation mobile data offers and services. For further information consult the Arthur D. Little website at www.adl.com.

Altran Telecoms & Media

Altran Telecoms and Media UK&I is a business division of the Altran Group with focus on the UK and Ireland region. Our mission is to be trusted technology partners of our clients, recognized for providing innovative project solutions and specialized consulting assignments.

To achieve this, we work closely with our clients, telecom operators and vendors, to help them develop new products and services in a fast paced technology environment. With outstanding capabilities in Wireless Access Technologies, Technology Innovation and Product Validation, Altran Telecoms and Media have developed a strong reputation in the areas of Mobile Devices, Project Management, Test and Validation and Process Improvement.

Praxis High Integrity Systems Limited

Praxis is a systems engineering company founded in 1983 and specializes in mission-critical applications. Praxis leads the world in specific areas of advanced systems engineering specifically: ultra low defect software engineering, telecoms engineering, safety engineering for complex or novel systems, and tools/methods for systems engineering. Praxis offers clients a range of services including turn-key systems development, consultancy, training and R&D. Key market sectors are Aerospace, Defence, Air Traffic Management, Railways and Nuclear. The company operates internationally with active projects in the US, Asia and Europe. UK offices include London and Bath. It is wholly owned by Altran Technologies which is a global leader in innovation engineering and employs 16, 000 engineers across the world.

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