A Review of Spectrum Requirements for Mobile WiMAX™ Equipment to Support Wireless Personal Broadband Services

September 2007

Executive Summary

Wireless Personal Broadband provides a new category of services that are enabled by the availability of affordable broadband connectivity at home, at work and on the go. Today, fueled by the widespread adoption of affordable broadband connectivity to the home, we are seeing new media rich applications emerging such as IPTV, user generated content, and social networking services. This is in addition to the emergence of new delivery initiatives such as Direct to Customer (D2C) media content, online synchronized games, music and video on demand, and also quad-play, which bundles TV, broadband with both fixed and mobile voice service. Tomorrow, as technologies such as WiMAX™ make "mobile" broadband connectivity affordable, broadband services will become personal much like the personalization of the cell phone today; hence the term Wireless Personal Broadband services.

The driving force behind the availability of Wireless Personal Broadband services is the convergence of fixed and mobile telecommunications coupled with the media content industry. Many service providers are already positioning themselves to offer a wide range of next generation media rich applications and services. Over the next few years we can expect:

- Broadband usage to move from wireline to wireless as subscribers demand everywhere connectivity.
- New media rich applications will place a high demand on bandwidth.
- High traffic loading on the networks as larger media rich files are transferred.
- Higher demand on uplink channels as users generate media rich content.
- A combination of users including those who regularly subscribe to services, and casual users with no monthly subscription.
- A greater selection of devices that provide a range of broadband connectivity options, allowing the user to choose their preferred network at will.
- A transition from household and business broadband connections to Wireless Personal Broadband where users stay connected regardless of location.

These changes require new, advanced, technologies such as Mobile WiMAX™, to be deployed in order to provide affordable broadband connectivity to people on the go. They also place an increased demand on spectrum available to deliver these broadband services. To determine the amount of spectrum necessary for delivering this new generation of Wireless Personal Broadband services, the WiMAX Forum® has solicited input from two globally recognized analyst firms, namely Informa Telecoms & Media® and The TeleCompetition Group®.

The prime aim of this paper is to determine the minimum spectrum requirement for widespread deployment of Mobile WiMAX systems primarily in developed countries that already demonstrate mature markets for both broadband and mobile communications services.

The key conclusions from this analysis include:

- The growth of Wireless Personal Broadband is highly dependent on the rate of convergence between fixed and mobile telecommunications and media industries. Rapid convergence leads to wider availability of services and high competition between the industry players, which also leads to higher subscriber adoption.

- WiMAX technology is being used by greenfield service providers to offer broadband services in competition with traditional mobile and fixed service providers. WiMAX technology is also being deployed by traditional fixed and mobile service providers as a complementary service offering to their subscribers.

- In order to meet predicted demand in the medium term, the early release of spectrum to support broadband technologies and particularly Wireless Personal Broadband services is essential for sustained market and economic growth.

- The forecasting of spectrum needs is far more challenging in a multimedia environment than for voice systems. The services offered by service providers to different market segments are expected to vary considerably. For example, a content based service provider may focus on providing video and TV services, whereas another service provider may offer ubiquitous Internet connectivity to enterprise subscribers. The range of services being offered has a major impact on the amount of spectrum required for cost-effective deployment. The WiMAX Forum believes that if a wide range of personal broadband services are to be offered to subscribers, a minimum of 30MHz of TDD spectrum is required per operator to realize the full potential of Mobile WiMAX[1].

- 30MHz per operator is not a unique answer. A range of scenarios needs to be considered and certain operators may require additional spectrum to establish a viable business case.

- Depending on local conditions, additional spectrum may also be required to account for inter-operator issues, co-existence, guard channels and other restricted channels. These issues are not considered further in this paper.

- There may be special circumstances where a viable business case could perhaps be established to roll-out WiMAX technology using spectrum allocations less than 30MHz per operator. In such circumstances a Service Provider may not be able to offer a full suite of broadband services or may only be able to support a smaller number of subscribers. These factors depend on prevailing local conditions are not considered further in this paper.

[1] This assessment is based on asymmetric utilization of spectrum to match traffic conditions . In the event a service provider has FDD spectrum, a larger amount of spectrum would be required to handle the downlink traffic which is expected to dominate.

Table of Contents

1 Introduction

WiMAX technology is a key enabling technology that promises to provide cost effective broadband connectivity to a wide range of devices both fixed and mobile. Extending affordable broadband connectivity beyond the boundary of the home, office and public hotspots is expected to have a profound impact on business productivity and the way in which consumers interact and utilize the Internet. A new class of service is emerging, commonly referred to as Wireless Personal Broadband services which analogous to the concept of a personal cell phone, is the concept of personal connectivity to Internet services.

The primary objective of this paper is to provide information to regulators, spectrum managers and other parties that are interested in understanding:

- The significant market interest in the new class of Wireless Personal Broadband services being delivered by WiMAX technologies.

- The reasons why the WiMAX Forum is advocating a market driven, regulatory framework to stimulate next generation wireless broadband technologies.

- The reasons why operators typically require a minimum of 30MHz of TDD spectrum to construct a viable network for offering Personal Wireless Broadband services.

Over the past 5 years, there has been significant speculation on the adoption of wireless broadband services. Today however, there are clear market indicators that help us better understand and hence predict the needs and requirements for wireless broadband communications. These indicators include the significant penetration and usage of fixed (wired) broadband services, together with a high adoption of wireless broadband in the home and office and the growing use of wireless public hotspots.

To quantify the future spectrum requirements for delivering this new generation of Wireless Personal Broadband services, the WiMAX Forum has solicited input from two globally recognized analyst firms; Informa Telecoms & Media and The TeleCompetition Group. These analyst companies took divergent approaches to assessing the market, but both forecasted subscriber and traffic levels which were surprisingly closely aligned. The WiMAX Forum members have built on the foundation laid by these analysts to project the spectrum required by service providers to offer subscribers the full capabilities of Wireless Personal Broadband services. This paper includes detailed subscriber and traffic forecasts from Informa Telecoms & Media and The TeleCompetition Group, and the spectrum requirements assessment carried out by the WiMAX Forum.

In assessing the spectrum requirements for Wireless Personal Broadband services, a structured methodology was followed which broke the assessment into smaller work items. This document presents each of these work items, starting with a description of the services and applications through the detailed subscriber and traffic forecasts, to the spectrum requirements.

Section 2 describes the Wireless Personal Broadband (WPB) applications and likely evolution of services from 2007 to 2020.

Section 3 quantifies the expected number of Wireless Personal Broadband subscribers.

Section 4 estimates usage of Wireless Personal Broadband applications in a range of scenarios.

Section 5 builds on the earlier sections to provide detailed traffic assessments. Consideration is given to regional differences, Quality of Service aspects and time of day usage.

Section 6 presents a model for quantifying spectrum requirements. Two scenarios are modeled determining a range of spectrum needs.

Section 7 draws conclusions in terms of required spectrum.

Section 8, presents a Service Providers perspective on delivering Wireless Personal Broadband services to their subscribers using WiMAX technology.

2 Wireless Personal Broadband Services

WiMAX technology gives subscribers the ability to make use of an "always on" IP connection at broadband speeds at home, at work and on the move. When the flexibility of wireless is combined with the capability to access the Internet and other network services at broadband speeds at mass-market pricing, a new category of services starts to emerge. These are called Wireless Personal Broadband (WPB) services.

2.1 Major Industry Drivers

There are several major technological advances happening that are enabling the provisioning of these new Wireless Personal Broadband (WPB) services. To help understand these services, one must first look at these advances. These include:

- OFDMA becomes the access technology of choice for wireless broadband.

  Orthogonal Frequency Division Multiple Access (OFDMA), which is the basis for Mobile WiMAX (as well as other advanced broadband wireless technologies such as the proposed LTE and EVDO-Rev C work items), is not only more spectrally efficient for wireless broadband data than previous access technologies it is also capable of scaling to wide bandwidths and hence higher data rates. Insufficient allocation of spectrum for wireless broadband going forward will have not only an impact on the number of subscribers that can be supported, but will also have a restricting impact on the data rates that can be provided to subscribers.

- Range of consumer devices.

  It used to be that subscribers had one handset to connect to the mobile networks and, as we integrated more and more into the device, many believed that subscribers would have one device that does everything, phone, pictures, music play, web connectivity movies, etc.. Today we understand that consumers will have multiple consumer electronic devices and that network connectivity is an important part of the functionality of these devices. It is foreseeable that every appropriate electronic device will include a wireless radio and consequently connectivity to the Internet.

- Multi radio devices

  Today there are mobile handsets that make voice calls over cellular networks and which are also equipped with a Wi-Fi radio, which can be used are used to make voice calls over Wi-Fi networks in the home and in the office. The integration of multiple radios into single device means that users will have access to broadband everywhere. Users will be able to access the same services using the same device whether at home, in the office or on the move.

- Personal broadband.

  Cellular technologies are widely utilized today by all household members. People have individual mobile numbers with personalized ring tone, rather than a shared home or office phone number. The vision for the future is that people will have a unique IP address or user name that provides a personalized Internet experience regardless of their location. For example, we can expect to see social networking applications such as "MySpace", which allows people to share personal information with friends, including knowledge about where friends are currently located and there accessibility.

The impacts of "always on" social networking applications are expected to be significant for both consumer and enterprise users.

- Always on connectivity.

  As convergence continues between fixed and mobile networks, service providers will be able to provide seamless connectivity for users wherever they are. Significant effort has been made in recent years to enable interworking between Cellular and Wi-Fi technologies such that seamless handover between these networks is now possible. This trend is expected to accelerate as work progresses to provide seamless transition between wireline and wireless technologies including wide area broadband networks. We shall migrate from an environment of finding a network to access email and information, to one where we are "always" connected to the Internet, able to send and receive multimedia rich content as it is being created.

- High performance low power devices.

  There is a continued trend to high performance processors with lower battery consumption and smaller form factors. So today we are seeing the emergence of new devices which can make full use of wireless broadband connectivity, full PC capabilities, and be able to still operate for several hours without need to be recharged. These new devices will improve the users experience and make always on broadband connectivity a reality.

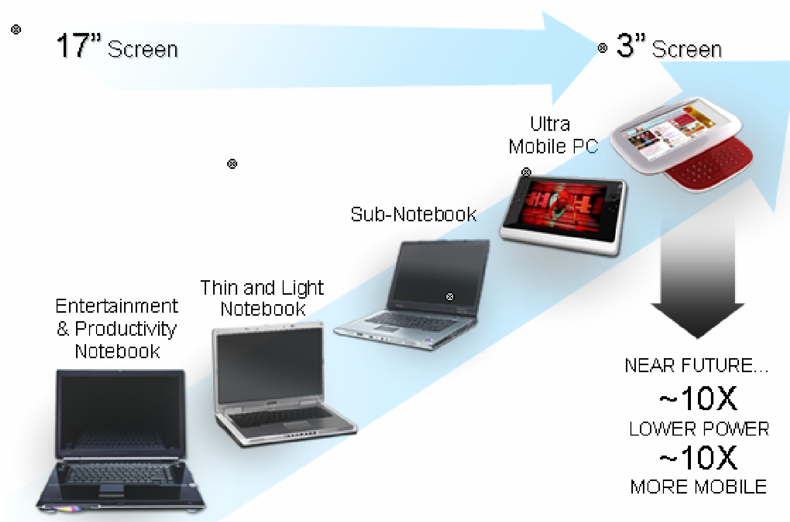


Figure 1: Moore's Law for Mobile Internet in Your Pocket[2]

- Extended use of Web services.

  For many years the trend has been to provision services over the web leveraging IP based technologies, protected by firewalls. The availability of wireless broadband connectivity enables these "Intranet type" services to be extended to groups and individuals away from the office such as mobile

[2] Source: Intel Corporation

work force, community groups. They can be connected to share a common rich multi-media environment no matter where they are located.

- M commerce is coming to maturity.

  Over the past few years, new forms of trusted intermediaries have started to emerge, enabling on-line payments and other forms of m-commerce. Coupled with the increases in advertising and marketing via the Internet, it is clear that ubiquitous wireless broadband connectivity will have a significant impact on how commerce and trade is conducted.

2.2 Application User Categories

Over the past few years several new and unpredicted Internet applications have emerged, such as MySpace, YouTube and eBlogger which have reached significant subscriber penetration. MySpace has 100M users, YouTube has 100M clips being viewed per day, and eBlogger has had 18.5M visitors. The WiMAX Forum believes that the emergence of Wireless Personal Broadband will further expand these services, and prompt new and again unpredicted applications to be introduced. It is therefore important when forecasting user traffic demands to employ a simplistic but meaningful application framework.

For the analysis presented in this paper, the WiMAX Forum has elected to use the following application user classification (based on a proposal by Informa Telecoms & Media).for Wireless Personal Broadband services. Informa Telecoms & Media categorize application users into four main categories: a general business category[3] and three consumer categories[4], communications, information and entertainment. Table 1 provides a description of these categories and highlights some of the services Informa Telecoms & Media expect to flourish.

Application user category[5]	Description	Service types
Business	Communication and information, intranet/extranet access being an important feature	Mobile office: This segment includes entry level communication applications such as email, messaging, and Internet/intranet access. Mobile workforce: These services represent an extension of communications applications with scheduling and other management functionality and software. Enterprise solutions: These involve middleware solutions and modifications to existing back office systems giving full integration of mobile platforms with solutions such as Enterprise Resource Planning, Customer Relationship Management and Supply Chain Management

[3] Business sector applications are paid for by the end user's employer.
[4] Consumer sector applications are those which are paid for by the end user.
[5] User-generated applications and online community applications, together with mobile commerce and location-based services are 'horizontal' applications which are integrated with each of these three consumer sector categories.

Communication	Including email, VoIP and messaging.	Today's key services: Short messages, instant messaging, and email. New developments: This include consumer push email, as used in the new iPhone from Apple, which is likely to drive a major uptake in these services, More advanced variations: For example video mail and video conferencing.
Information	Research and information gathering.	As the power of devices increases, and improves, research and information gathering will become a major activity, enabling access: Web-based services and information. Mobile content and downloads. Sports and weather news. Today's services will also the user-friendliness of mobile internet sites be expanded by adding location-sensitive services such as city guides and detailed personal satellite navigation applications available on demand.
Entertainment	Including music, games, interactive TV and radio	Games: Including online and downloaded games, in single player and multiplayer format. Music: For example downloads of music clips or longer full-track downloads; streaming audio; MP3 and similar format playback and other value-add services such as song collections which can be 'side-loaded' (synchronized) from the network on to a mobile device TV and video: These services can either be delivered from a single point, or can be created and shared by users. In each case, content can either be delivered in real time or offline and either downloaded or streamed Gambling: This includes sports betting, lotteries and casino-type gaming.

Table 1: The Major Wireless Personal Broadband Service Categories[6]

[6] Source: Informa Telecoms & Media

2.3 Application Positioning in 2015

Five years ago the wireless industry's view of next generation wireless services was focused primarily on communications such as video calls, and providing access to web pages. Today, however, with the rise of affordable broadband connectivity in the home, new models are emerging including Direct-to-Customer (D2C) advertising and sales, and the next generation Internet where significant content is generated by users.

It is interesting to consider the changing expectations for future traffic, and how this relates to the availability of next generation broadband wireless technologies such as WiMAX technology. Figure 2 shows Informa's positioning of the main applications user categories in 2015. The two axes indicate the extent of mobility as against the degree to which WiMAX technology is expected to penetrate the application categories by 2015.

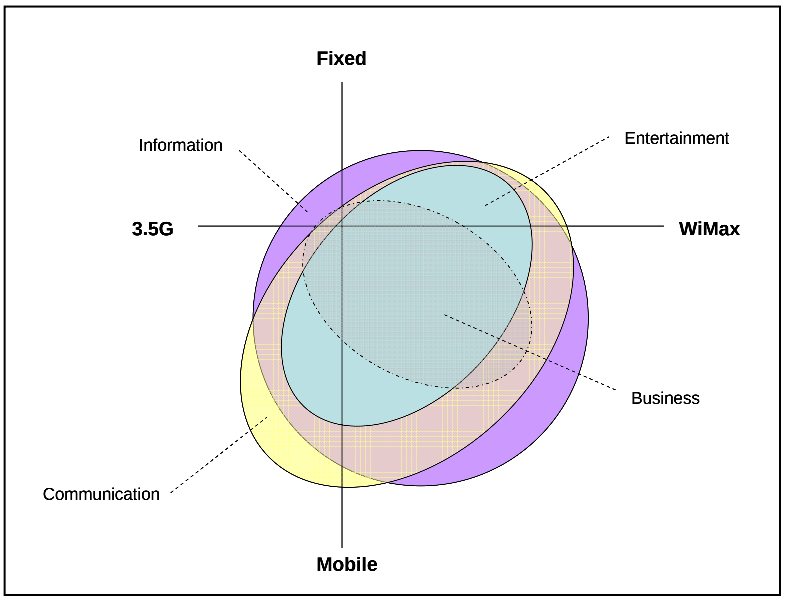


Figure 2: Personal Wireless Broadband expected Application Positioning by 2015[7]

The size of each 'bubble' shows the relative size of the subscriber base for each of the application areas (actual forecast numbers are provided in the subsequent sections). The overlap between the bubbles represents the common ground in the market between consumer and business applications as many users will be tapping into both consumer and business applications. Subscribers will also typically deploy several applications (especially in the consumer sector).

[7] Source: Informa Telecoms & Media

3 Wireless Personal Broadband Subscribers

3.1 Subscriber Forecast

A forecast of future subscriber numbers is a critical first step in determining traffic and spectrum needs. To gain an independent assessment of the likely numbers of subscribers, the WiMAX Forum solicited input from two globally respected analyst companies, namely: The TeleCompetition Group which is a US based company; and Informa Telecoms & Media which is a UK based company. Each took a different approach in assessing the number of subscribers. The results can be found in the charts below where it will be seen that both companies predict a broadly similar growth pattern for long term growth in the worldwide personal broadband addressable market.

The TeleCompetition Group forecast[8] shown in figure 3 predicts the number of worldwide Wireless Personal Broadband subscribers as just over 900 million by 2015, rising to almost 1350 million by 2020. From The TeleCompetition Group, the addressable market is based on their predicted base of WiMAX enabled CPE, including laptops. The TeleCompetition Group generated the near term data using ABI Research® forecasts of WiMAX enabled CPE cross referenced with their internal data, and also data from Point Topic and Maravedis Inc.. The TeleCompetition Group extrapolated the growth to the year 2020 using their internal models.

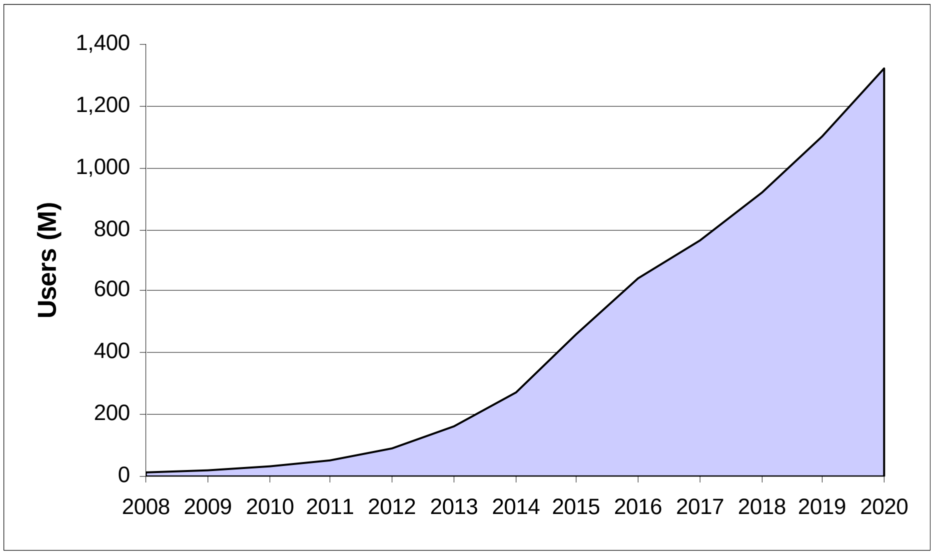


Figure 3: Worldwide Personal Broadband Addressable Market 2008-2020[9]

Informa Telecoms & Media forecast two possible scenarios for growth in Wireless Personal Broadband. A conservative scenario shows worldwide WPB subscribers increasing from 57.8 million in 2007 to 875.1 million in 2015[10], see figure 4.

[8] This analysis is based on both internal data and cross references with previously published reports from ABI Research and Maravedis.
[9] Source: The TeleCompetition Group
[10] Informa Telecoms & Media subscriber forecasts are based on a combination of WiMAX, HSPA and LTE, EV-DO and UMB.

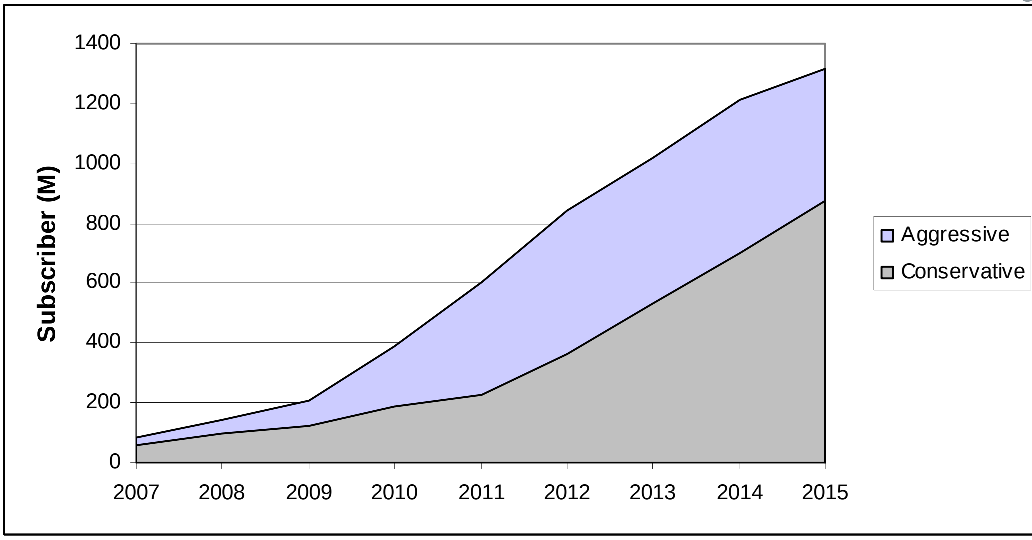


Figure 4: Wireless Personal Broadband subscribers worldwide 2007-2015[11]

Figure 5 contrasts the subscriber forecast between Informa Telecoms & Media and The TeleCompetition Group. Both analysts forecast a similar growth curve and the variance between the two forecasts is attributed to a combination of:

- The forecast from Informa Telecoms & Media is based on a combination of WiMAX, HSPA and EV-DO and the evolution of these technologies, namely 3GPP Long Term Evolution (LTE) and Ultra Mobile Broadband UMB, whereas the forecast from The TeleCompetition Group is based on the expected base of WiMAX enabled CPE, including laptops.
- The rate of adoption is highly dependent on the rate of convergence between the fixed and mobile telecommunications with the media sector. This is discussed further in the following subsection.

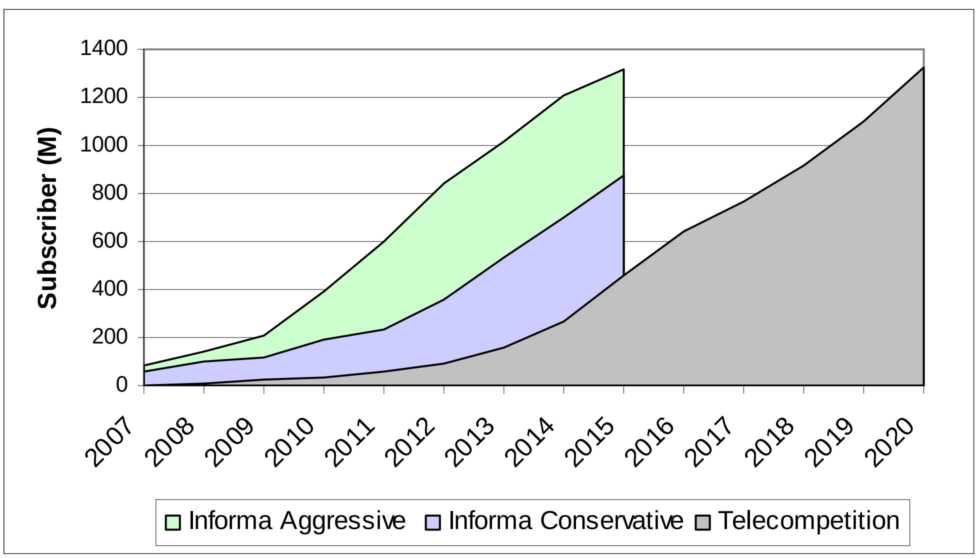


Figure 5: Contrasting The TeleCompetition Group's WiMAX forecast and Informa Telecom & Media's total WPB market forecasts 2007-2015[12]

[11] Source: Informa Telecoms & Media
[12] Source: Informa and The TeleCompetition Group

3.2 Availability of New Services

There is a linkage between subscriber growth and the availability of affordable media-rich services and devices. One of the key industry trends impacting the availability of personal broadband services is the convergence of fixed and mobile communications along with media content (notably broadcasting). The WiMAX Forum believes that this is a primary factor in determining subscriber growth over the next few years. If convergence happens quickly and results in a highly price competitive environment, we could experience a rapid take up of new services and result in the subscriber growth predicted in Informa's aggressive scenario. If convergence happens more slowly and affordable services are slower in becoming available to consumers, then we could experience the subscriber growth predicted by The TeleCompetition Group.

Today we are just beginning to experience the convergence of fixed and mobile communications along with media content. New devices are emerging, such as a single subscriber handset that works on both the cellular and Wi-Fi networks, and the capability to both download and upload video clips to handheld devices. Figure 6 provides a conceptual graphical picture of how convergence in the telecommunications industry is evolving over time.

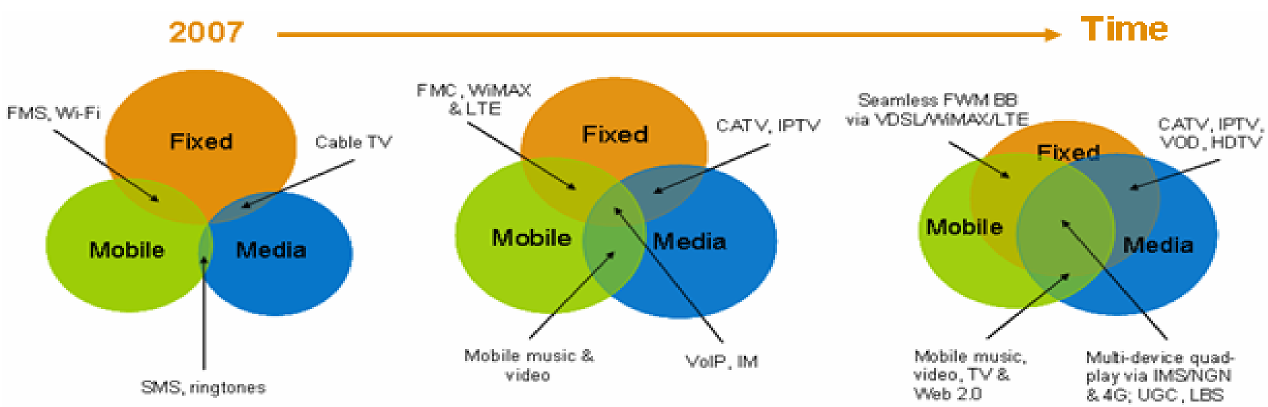


Figure 6: Impact on Convergence on Service Availability[13]

The rate of convergence is a key factor in determining the growth of Wireless Personal Broadband services. In countries and regions where a convergence happens quickly, the WiMAX Forum believes we will see growth as predicted in Informa Telecoms & Media aggressive forecast. In countries and regions where convergence is slow then, Informa Telecoms & Media conservative data and The TeleCompetition Group growth figures are more likely. The WiMAX Forum considers that there are five main factors influencing the rate of convergence:

1. Market penetration of VoIP.

   The penetration of VoIP continues to grow. Subscribers are migrating basic service away from a simple mobile voice model, to an environment where VoIP is bundled into information and entertainment services, and is similarly bundled with business collaboration services.

[13] Source: Informa Telecoms Media

2. Early adoption by consumers.

   Historically enterprise users are the first to adopt new wireless services due to the higher price points. Consumers tend to adopt later as prices fall. Today however, service providers are marketing new services directly to consumers, especially the younger generation. For example in Asia "buddy location" services, which map the location of a subscriber's buddies to local maps, is being integrated into other popular web services, for example, the local equivalent of MySpace.

3. Device evolution.

   The availability and versatility of new devices has a major impact on subscriber adoption. Wireless broadband devices if constrained in terms of battery life, display size and processing capacity will limit user experience and take up of new services. As the industry overcomes these technical challenges, a new breed of consumer electronics devices with integrated wireless connectivity is starting to emerge. However we are currently witnessing the coming to market of highly battery efficient computing and communications devices with wireless broadband capabilities. Wireless connectivity is starting to be a "must have" feature is order to enable the new generation of consumer electronics that encompass either interactive content and/or the creation and sharing of personal content.

4. Affordable wireless broadband.

   Service providers have tended to steer away from eat-all-you-can price models for wireless services in favor of data based pricing with caps. Pricing caps discourage subscribers from utilizing media rich applications and services. Today there are service providers that are planning leverage the WiMAX technologies to offer pricing on par with fixed broadband services in their country, and a few service providers are planning to actually offer eat all you can pricing. In addition some countries, such as Singapore and Australia, are starting to view broadband as a utility and governments are looking to take proactive steps to ensure affordable nation-wide availability of broadband.

5. Alternative content / video.

   Historically media content has primarily been created and controlled by large studio and production companies. More recently there is an increasing amount of content being created by individuals (independent, amateur, and academic) and shared on sites such as Google Video and YouTube. Also there is significant free content created by governments and public broadcasting companies. As camera and video recorders continue to be integrated into wireless devices, there is a potential that significant traffic may result from this alternative content. Together, this alternative content may lead to a new marketing and advertising model, representing an alternative to subscriber monthly fees as a source of revenue for service providers.

   The WiMAX Forum believe that the subscriber growth figures shown in Informa Telecoms & Media aggressive scenario will be typical in markets where regulation permits open competition between service providers and deployment of next generation technologies such as WiMAX technology is actively encouraged. In more restricted or controlled markets the WiMAX Forum believes that The TeleCompetition Group forecast is more likely to prevail.

4 Wireless Personal Broadband Usage

The previous sections considered the types of Wireless Personal Broadband services and the number of subscribers. The next step is to look at application usage. This section outlines the approach taken by The TeleCompetition Group and Informa Telecoms & Media and presents their respective assessment of application usage.

4.1 Informa Telecoms & Media Methodology

To assess application usage, Informa Telecoms & Media mapped Wireless Personal Broadband subscribers into application user categories and into user device categories. This provides a balance for assessing user demand for applications and the availability of user devices[14] that have the capability to support these applications.

- Application user categories

An individual WPB subscriber is likely to use many different consumer and business applications. An individual that uses WiMAX technology at work and at home will be included in “both” the business and consumer segments. This means that each individual WPB subscriber will typically appear in multiple WPB application user categories. In other words, an individual WPB subscriber can in theory be included in all WPB application users categories used in this study: consumer information application users, consumer communications application user, consumer entertainment application user, and business application user. Consequentially the number of WPB application users detailed in this section is far greater than the number of WPB subscribers detailed previously.

- User device category

Subscribers are further segmented into another set of user categories based on the type of WPB device used to access WPB services. The reason for this segmentation is that the type of end-user device has a major impact on how often a subscriber accesses a WPB network, and how much traffic they generate while accessing the network. The segments used by Informa Telecoms & Media are shown in Table 2.

Device Category	Device size	Time online	Traffic per hour
Fixed	Large	High	High
Portable	Medium	Medium	Medium
Mobile	Small	Low	Low

Table 2: Wireless Personal Broadband Device User Categories[15]

[14] WPB device unit sales forecasts are largely derived from existing ITM data and forecasts for the three main device categories: fixed, portable and mobile.
[15] Source: Informa Telecoms & Media

4.2 Informa Telecoms & Media Usage Forecast

Informa Telecoms & Media forecasts for the total number of WPB application users worldwide[16] for the aggressive scenario and conservative scenario are shown in figures 7 and 8 respectively. Although the number of users is similar in the early years of the forecast period, by 2015 there is a significant variance, with 7.7 billion WPB application users in the aggressive scenario compared to 2.7 billion in the conservative scenario.

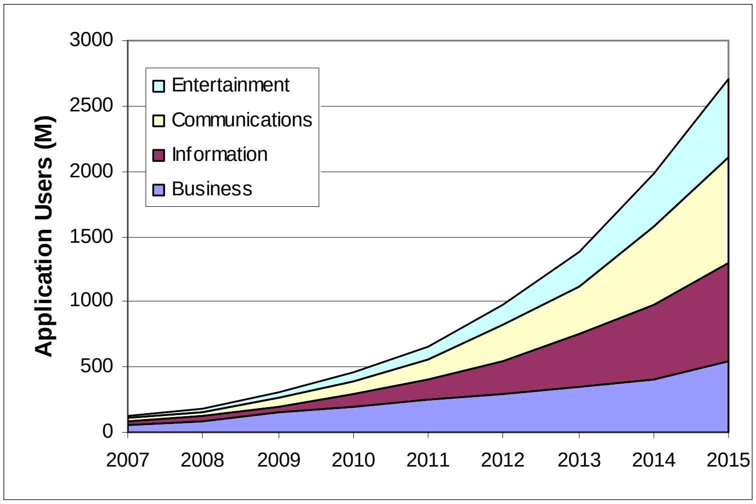


Figure 7: WPB Application Users Worldwide – Conversation Scenario[17]

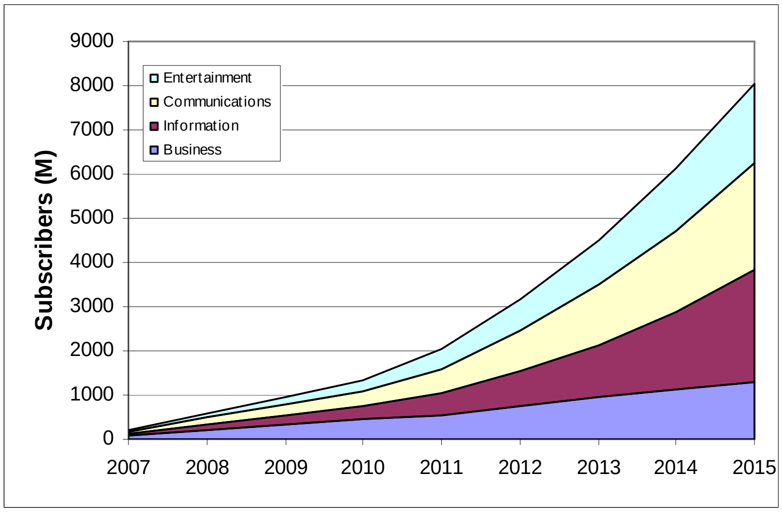


Figure 8: WPB Application Users Worldwide – Aggressive Scenario[18]

[16] The forecasts for application categories & application user segments are built on Informa Telecoms & Media existing database and in-house expertise, together with original research of public domain information and high-level industry interviews.
[17] Source: Informa Telecoms & Media
[18] Source: Informa Telecoms & Media

Informa Telecoms & Media analysis shows:

- Consumers are expected to be the main sector by 2015, driven by new forms of enhanced email combined with multimedia forms such as voice and video clips, and the integration of web-enabled services with 'rich voice' applications.

- The business sector is expected to increase with the merging of fixed and mobile functions (as seen in the BT Fusion service currently), incorporating features such as single number calling, intelligent conferencing and location sensitive applications.

- Communications and information services are major drivers for growth in consumer application users in both the conservation and aggressive scenarios. Driven by seamless connection and features such as 'click to web' and 'click to email' coming into the mass market, and enabling growth in online shopping for both digital and 'real world' goods and services.

- In the aggressive scenario, consumer usage far outstrips that of business and is buoyed up by widespread adoption of services offering multi-function capability (email with voice/video annotation, location-sensitive information services).

4.3 The TeleCompetition Group Methodology

The TeleCompetition Group has developed a traffic forecasting model called TrafficSTATs®. This model takes a "bottoms up" approach to predicting offered traffic loads, considering a number of service traffic characteristics. Service traffic characteristics includes all traffic that end users would offer the network based upon baseline location and subscriber profiles plus seven service variables and states. This is the unconstrained traffic offered to the network.

Eight service variables are considered for each service activity:

- Location profile (EU25)
- Subscriber profile (Age, Occupation, Industry, Income)
- Market segment (Consumer, Business; Casual User; Contract Subscriber)
- Media Type (High, Medium, Low)
- Network cases (WiMAX to WiMAX; WiMAX to Fixed; Fixed to WiMAX)
- Contact type (one-to-one; one-many;)
- Transmission mode (one way; two way)
- Service level (Normal; Restricted)

The TeleCompetition Group methodology identifies significant service activities and then models each one individually, considering all the parameters listed above. In total, over 40 individual activities are modeled using these eight service variables and other traffic characteristics. The TrafficSTAT model details out uplink and downlink traffic, symmetry, and other traffic parameters, then aggregates the result for a geographic area. The output provides both aggregate traffic information as well as "per subscriber" detail.

4.4 The TeleCompetition Group Usage Forecast

The TeleCompetition Group break down the consumer and business segments into specific services, such as file upload and download, and then make various assumptions regarding usages of these services. The usage assumptions are derived considering previous forecasts of offered traffic for users of mobile (UMTS) services published by the UMTS Forum, as supplemented by recent research on user trends and applications.[19]

Consumer		**2010**	**2015**	**2020**
File UL/DL - Podcast				
	# Users	3.8	33.7	75.1
	Sessions per month	15	23	45
	Max file size	2,594	41,500	41,500
Consumer Video/Audio Streaming				
	# Users	3.8	33.7	75.1
	Sessions per month	8	11	23
	Max file size (kB)	20,250	54,000	108,000
Web Browsing / Shopping/Email				
	# Users	3.8	33.7	75.1
	Sessions per month	28.5	42.8	85.5
	Max file size (kB)	13,608	36,288	72,576
MM download (Music or Video)				
	Adoption rate	5%	10%	20%
	Max sessions per month	15	23	45
	Max file size (kB)	10,125	27,000	54,000
Gaming / Gambling				
	Adoption rate	5%	10%	20%
	Max sessions per month	8	11	23
	Max file size (kB)	7,200	7,200	7,200
IP TV (Server-based and P2P)				
	Adoption rate	5%	10%	20%
	Max sessions per month	8	11	23
	Max file size (kB)	253,440	253,440	253,440
Consumer Multimedia Messaging				
	# Users	4.2	67.0	171.7
	Sessions per month	330	330	330
	Max file size (kB)	150	300	450
Consumer Multimedia Conferencing				
	Adoption rate	5%	10%	15%
	Session per year	6	12	12

Table 3: Key Consumer Activity Usage Assumptions[20]

[19] Table 3: Magic Mobile Future 2010 – 2010, UMTS Forum, 2005
[20] The TeleCompetition Group

Business		2010	2015	2020
Business File Upload/Download				
	Adoption rate	100%	100%	100%
	Max sessions per month	88	79.2	61.6
	Max file size (kB)	7,896	7,896	7,896
Webcast_Video/Audio Streaming				
	Adoption rate	100%	100%	100%
	Max sessions per month	18	26	44
	Max file size (kB)	4,410	4,410	4,410
Intra/Extra_Web Browsing_EmailMgt				
	Adoption rate	100%	100%	100%
	Max sessions per month	70.4	70.4	70.4
	Max file size (kB)	6,101	6,101	6,101
Business Messaging				
	# Users	6.1	44.7	114.5
	Sessions per month	80	159	159
	Max file size (kB)	150	300	450
M2M: Batch File Download/Upload				
	Adoption rate	10%	30%	80%
	Max sessions per month	22.0	22.0	22.0
	Max file size (kB)	0.5	2	5
Business - Realtime Collaborative Work				
	Adoption rate	5%	10%	15%
	Max sessions per year	12	12	12
	Max minutes per session	60	60	60
Personal and Asset Tracking (Business)				
	Adoption rate	10%	15%	25%
	Average sessions per month	120	120	120
	Max file size (kB)	400	400	800
Business Simple Voice				
	Adoption rate	2%	5%	20%
	Call per month	120	120	120
	Minutes per call	5	5	5

Table 4: Key Business Activity Usage Assumptions[21]

[21] Source: The TeleCompetition Group

5 Traffic Estimates

Both Informa Telecoms Media and The TeleCompetition Group took very different approaches to forecasting analyzing and segmenting the Wireless Personal Broadband market. However there is close alignment between their subsequent traffic assessments. This section details the traffic estimates made by these two different analyst companies and draws initial conclusions.

5.1 Informa Telecoms & Media Traffic Estimates

The Informa Telecoms & Media traffic model provides conservative and aggressive forecasts of traffic by number of events and throughput volume, and by application type. Figure 9 below compare Informa Telecoms & Media conservative and aggressive traffic growth and traffic between 2007 and 2015. The aggressive scenario forecasts 32.2PB per year growing to 1,491.70PB per year in 2015.

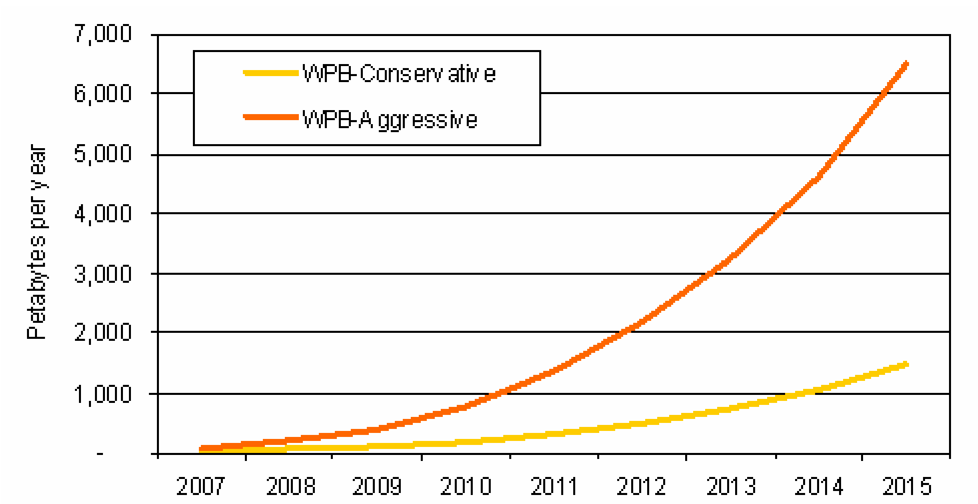


Figure 9: WPB Conservative & Aggressive Total Traffic 2007-2015[22]

Tables 5 and 6 provide a break down of the total worldwide traffic by region. In the aggressive scenario Europe increases from 17.2PB in 2007 to 1,481.3PB in 2015. The forecast for Europe will be used later in this document for comparison with the figures from The TeleCompetition Group analysis of the European market.

[22] Source: Informa Telecoms & Media

	2007	2010	2015
Region	PB/year	PB/year	PB/year
North America	12.9	68.1	471.4
Latin America	1.7	9.4	67.9
Asia Pacific	11.7	68.8	532.6
Europe	5.3	41.5	363.5
Africa/Middle East	0.8	6.5	56.4

Table 5: WPB Traffic per year by Region – Conservative Scenario[23]

	2007	2010	2015
Region	PB/year	PB/year	PB/year
North America	31.7	264.9	1,779.70
Latin America	5.9	49.2	380.2
Asia Pacific	28	259.4	2,602.20
Europe	17.2	161.1	1,481.30
Africa/Middle East	3	31.9	272.2

Table 6: WPB Traffic per year by Region – Aggressive Scenario[24]

5.2 Informa Telecoms & Media Busy Hour Traffic

Informa Telecoms & Media research indicates around 68% of business traffic is generated between 9am and 5pm, which for many businesses corresponds to the working day. Nevertheless, there is a substantial amount of traffic generated after working hours from those who work late, travelers and business commuters, small businesses that do not follow the office working pattern and from international data communications. There is also traffic generated overnight, between the hours of 1am and 9am, both by automatically generated data exchanges and by business travelers and commuters.

Consumer data traffic is more evenly spread throughout the day with families at home and children arriving home in the afternoon. It is heaviest in the evening between 5pm and 1am but there is also a significant amount of traffic that takes place overnight. This is higher than overnight business traffic and represents a mix of automatically generated data (downloads/uploads) programmed to take place at the quietest time of day, and enthusiastic interactive application users such as online games players, gamblers, music and video fans, etc.

While it is recognized that there may be changes in the time of day distribution over time, Informa Telecoms & Media believe that these percentage splits represent a sound basis for estimating time of day traffic levels and have been maintained throughout the period. This is shown in figure 10.

[23] Source: Informa Telecoms & Media
[24] Source: Informa Telecoms & Media

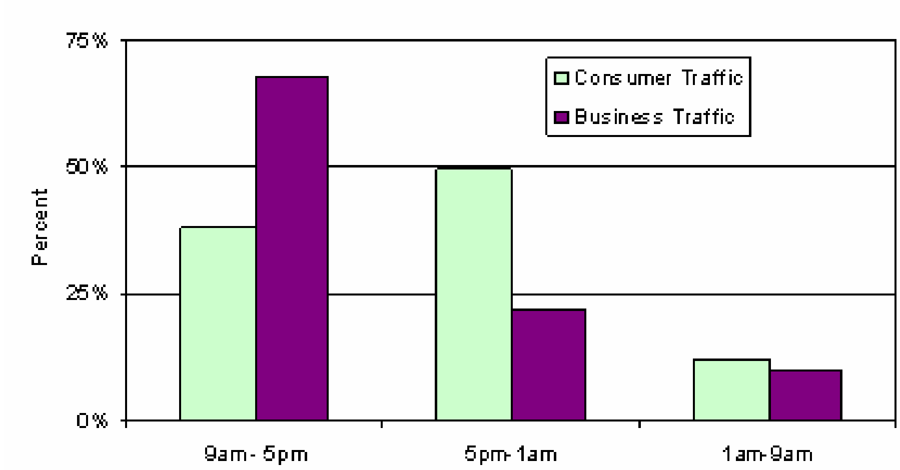


Figure 10: Traffic Time of Day Breakdown[25]

Tables 7 and 8 provide Informa Telecoms & Media estimate of total traffic. For the year 2015, Informa Telecoms & Media project Busy Hour traffic worldwide of 285.4TB in the conservative scenario, and 1,181TB in the aggressive scenario.

	2007	2010	2015
Consumer/Business	**PB/year**	**PB/year**	**PB/year**
09.00 – 17.00	20.4	121	833.3
17.00 – 01.00	8.5	53	494.2
01.00 – 09.00	3.3	20.3	164.3

Table 7: Traffic Time of Day– Conservation Scenario[26]

	2007	2010	2015
Consumer/Business	**PB/year**	**PB/year**	**PB/year**
09.00 – 17.00	54.5	468	3448.9
17.00 – 01.00	22.4	217.4	2333.2
01.00 – 09.00	8.9	81.1	733.3

Table 8: Traffic Time of Day– Aggressive Scenario[27]

[25] Source: Informa Telecoms & Media
[26] Source: Informa Telecoms & Media
[27] Source: Informa Telecoms & Media

5.3 TeleCompetion Traffic Forecast for Europe (EU25)

The TeleCompetition Group have modeled and forecasted the traffic expected to be generated by Wireless Personal Broadband users within the 25 countries that make up the European Union (EU-25). The 25 EU countries represent a region with nearly 450 million people. The TeleCompetition Group model produces local demand for services based on worldwide inputs and local propensity to buy. Demographic and other factors specific to the EU-25 region were used to determine the Wireless Personal Broadband addressable market, see figure 11. TeleCompetion estimate that the annual traffic in Europe generated by Personal Wireless Broadband services is 1,832PB, see Table 9.

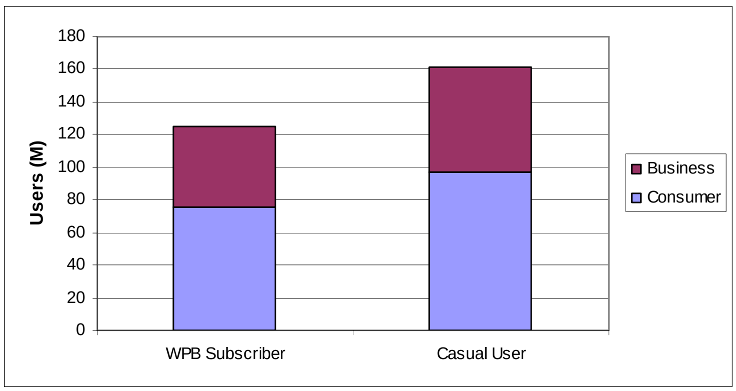


Figure 11: European (EU-25) Personal Broadband Addressable Market 2020, by Segment[28]

Segment	Days used per month	Daily Traffic (TB)			Annual Traffic (TB)		
		2010	2015	2020	2010	2015	2020
Consumer	30	50	4,306	28,277	17,869	1,550,276	10,179,714
Business	22	345	1067	3,298	91,174	281,782	870,656
Total		395	5,374	31,575	109,042	**1,832,058**	11,050,370

Table 9. Daily and Annual Traffic for EU 25: 2010, 2015, 2020[29]

[28] Source: TeleCompetition Group including review of ABI Research and Point Topic forecasts 2006.
[29] The TeleCompetition Group

5.4 Contrasting Traffic Densities Estimates

Both Informa Telecoms and Media and The TeleCompetition Group have provided analysis covers a range of geographical locations (national characteristics, developed/under-developed countries, urban, suburban, rural etc), a range of customer categories (business, consumer, casual etc) together with a wide range of applications and services (voice, multi-media etc) in different scenarios (fixed, mobile, nomadic etc). However Informa Telecoms & Media and The TeleCompetition Group took very divergent approaches to the task of estimating the traffic generated by Personal Wireless Broadband services.

- Informa forecast are based on device forecasts and expected usage of these devices. The TeleCompetition Group forecasts are based on a detailed analysis on the applications and the expected traffic per application.

- Informa Telecoms & Media was asked to provide worldwide forecasts. The TeleCompetition Group was asked to focus primarily on the EU25 countries

Despite these vastly divergent approaches to assessing traffic densities. The results to these two forecasts are surprisingly aligned.

TeleCompetion estimate that the annual traffic in Europe is 1,832PB, see Table 9. This is within 20% of the Informa Telecoms & Media aggressive estimate for Europe of 1,481PB, see Table 6. Indeed The TeleCompetition Group figures are actually larger that Informa Telecoms & Media aggressive scenario. Due to the close alignment of The TeleCompetition Group figures to the Informa Telecoms & Media aggressive scenario, the WiMAX Forum considers that Informa Telecoms & Media aggressive scenario is more likely than their conservative scenario.

5.5 Traffic Distribution

The TeleCompetition Group forecasts show the change in overall traffic distribution from 2010 to 2020, see figure 12. The most dominant activities in 2010 subsequently decrease as a percentage of total traffic over the forecast period. File upload/download, Web browsing, shopping and email collectively comprise over 80% of total traffic. By 2020, these two activities only contribute slightly over 50%. All other activities increase as a percentage of total traffic from 2010 to 2020, especially IPTV, video conferencing and collaborative work. This reflects the shift in consumer and business activities from text-based, non interactive sessions towards visual and media based information that are more interactive, more “real time”. This will result in a requirement for higher bandwidth.

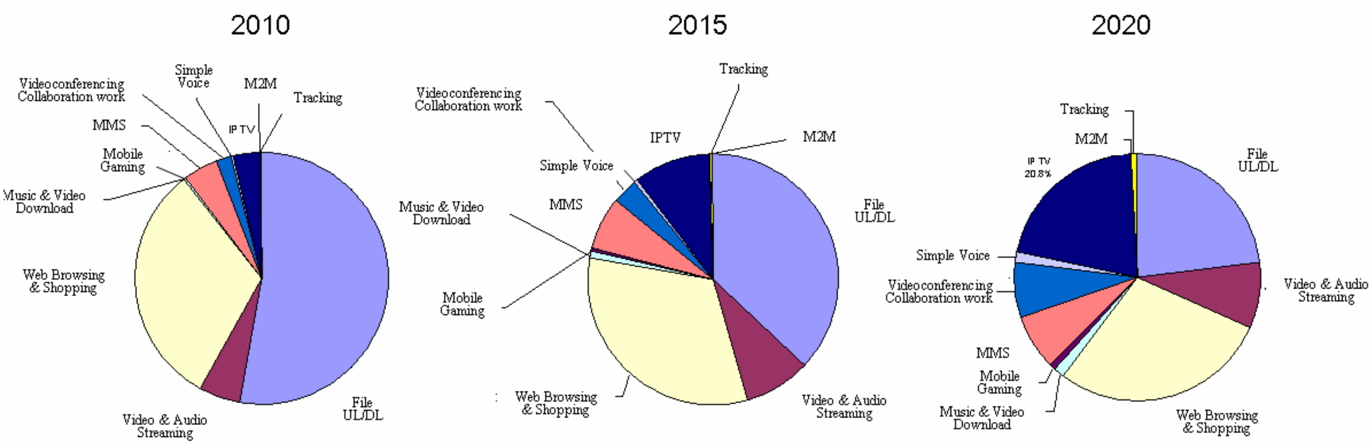


Figure12: Predicted Traffic Distribution by WPB Application 2010-2020[30]

The change to visual and media based information is also illustrated in the changes in the traffic distribution across QoS classes. Figure 13 shows that conversational and streaming traffic collectively increases from 11% of total traffic in 2010 to 39% in 2020.

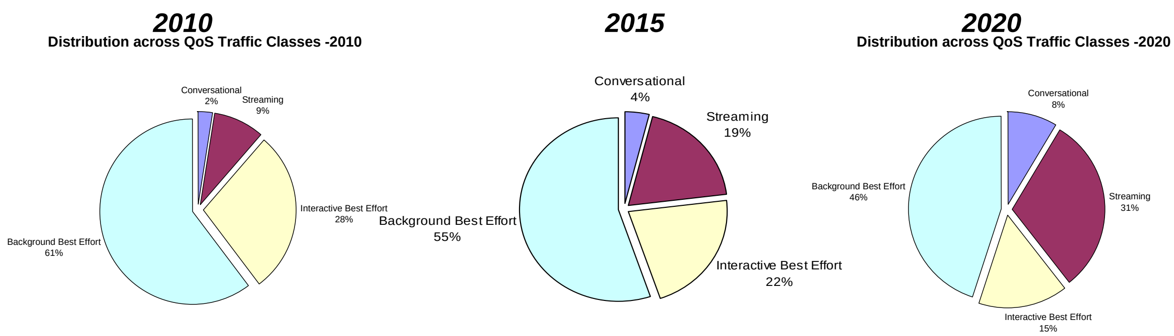


Figure 13: Predicted Traffic Distribution by QoS Classes 2010-2020[31]

These transitions are conceptually aligned with the earlier discussion of convergence between the fixed/mobile telecommunications and media industries, reference figure 6.

5.6 TeleCompetion Busy Hour Traffic Estimates

The TeleCompetition Group derived the Busy Hour (BH) for each activity, as shown in Table 10. These figures show uplink and downlink traffic in the busy hour, including consumer and business segments for both Personal Wireless Broadband subscribers and casual users.

[30] The TeleCompetition Group
[31] The TeleCompetition Group

Busy Hour Traffic (TB) EU25	2010			2015			2020		
	UL	DL	Total	UL	DL	Total	UL	DL	Total
File Upload/Download	3.5	14.3	17.8	12.5	126.5	138.9	44.8	482.7	527.6
Video / audio streaming	0.1	1.8	1.8	1.3	33.7	35.0	7.8	195.9	203.7
Web browsing and shopping	1.3	9.2	10.5	15.1	105.8	121.0	81.7	571.9	653.6
Music and video download	0.0	0.1	0.1	0.1	2.8	2.9	1.4	34.7	36.1
Mobile gaming	0.0	0.0	0.0	0.0	1.1	1.2	0.6	13.9	14.4
MMS	0.5	0.9	1.4	15.0	29.5	44.6	57.7	113.5	171.2
Videoconferencing / Collaborative Work	0.2	0.5	0.7	6.0	16.1	22.1	43.9	119.5	163.4
Simple voice	0.1	0.1	0.1	1.6	1.6	3.2	16.5	16.5	33.0
IP TV	0.0	1.1	1.1	3.9	32.4	36.4	49.7	429.2	478.9
M2M	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.7
Tracking	0.0	0.1	0.1	0.3	1.9	2.2	2.3	16.1	18.4
Total Coincident Traffic	5.6	28.1	33.7	**55.9**	**351.5**	**407.4**	306.8	1,994.3	2,301.0

Table 10: Overall busy hour traffic by activity for EU25[32]

Busy hour is the peak hour of traffic during a day[33]. In theory, each activity type has peak traffic that varies by time of day, day of week and even by season. Prior research by The TeleCompetition Group showed that, for a service provider offering a full range of services, differences in diurnal variations in busy hour by service are not significant enough to invalidate a simple summation of individual peak traffic loads during the course of a day. This is referred to as the Total Coincident Traffic in table 10.

[32] The TeleCompetition Group
[33] Busy intervals of 5 and 15 min are more desirable for data traffic analysis but this level of granularity is not currently available.

6 Spectrum Requirements for WiMAX® Technology

6.1 Approach to Assessing Spectrum Requirements

This section describes the approach taken by the WiMAX Forum in quantifying spectrum requirements for WiMAX systems to deliver Wireless Personal Broadband services. This assessment is divided into the following key elements:

- Service profiles

  Service profiles provide a description of the range of services being offered to the different market segments. Different service providers may offer different service profiles and hence their spectrum requirements may also be different. For example service providers that choose to promote IPTV and video streaming as their main services are likely to need more spectrum than another service provider who focus primarily on promoting ubiquitous Internet connectivity to enterprise subscribers.

  The WiMAX Forum's approach has been to consider a mix of Service profiles, based on the results identified by The TeleCompetition Group, see table 10.

- Traffic density forecasts (offered traffic)

  Here, Traffic density is defined to be the aggregate payload (Mbits per second) offered to all users during the peak busy hour (PBH) whilst located in a particular area, divided by the total area in question (square kilometers). Traffic density forecasts are derived from estimates of total traffic offered to an appropriate mix of Subscribers in particular, scenarios without any restrictions on the network's ability to transport the offered data, i.e. it is, the total offered traffic unfettered by hardware limitations or consideration of spectrum availability or suffering any degradation in quality of service, etc.

  Traffic densities have been calculated using forecasts of average traffic per Subscriber and predictions of Subscriber densities in various scenarios. Traffic density is given in Mbits per second per square kilometer.

- Spectrum requirements

  The spectrum required per operator must be sufficient to transport the offered data within agreed limits for quality of service (bit error rate, latency, etc). The amount of spectrum required by an operator is derived from a knowledge of the offered traffic density and the basic characteristics of the radio access system. In this regard, the characteristics of the WiMAX radio access system are defined in previously published WiMAX Forum papers, namely:

  - "Mobile WiMAX – Part I: A Technical Overview and Performance Evaluation"
  - "Mobile WiMAX – Part II: A Comparative Analysis"

The average busy hour calculation that follows represents a conservative approach to estimating busy hour and spectrum requirements. The WiMAX Forum chose this approach so that the results will be readily understood by regulators and less open to challenge. The approach calculates average per subscriber busy hour use, considering downlink traffic only[34].

6.2 Service Profiles

The TeleCompetition Group has analyzed a range of Wireless Personal Broadband (WPB) services. For each service they have estimated both the adoption rate and the busy hour offered traffic per subscriber for both subscription and casual users. This information for 2015 is summarized in table 11.

Activity / Service	% Rate of service adoption		Personal Broadband Traffic (MB)	
	Subscription Users	Casual Users	Subscription Users	Casual Users
Business				
Business File UL/LD	50%	100%	2.90	0.15
Webcast_Video/Audio Streaming	50%	100%	0.45	0.01
Intra/Extra_Web Browsing_EmailMgt	50%	100%	1.82	0.16
Business Messaging	100%	100%	0.34	0.34
M2M: Batch File Download/Upload	30%	30%	0.0001	0.0001
Business - Realtime Collaborative Work	5%	0%	19.42	-
Personal and Asset Tracking (Business)	15%	15%	0.003	0.004
Business Simple Voice	5%	5%	0.75	0.75
Consumer / Residential				
File UL/DL - Podcast	90%	100%	3.12	0.24
Consumer Video/Audio Streaming	90%	100%	0.68	0.27
Web Browsing / Shopping/Email	90%	100%	2.24	0.86
MM download (Music or Video)	10%	7%	0.68	0.27
Gaming / Gambling	10%	7%	0.27	0.11
IP TV (Server-based and P2P)	10%	7%	8.35	3.51
Consumer Multimedia Messaging - other	100%	100%	0.44	0.44
Consumer Multimedia Conferencing	10%	0%	0.13	-
Tracking Services - Consumer	15%	15%	0.21	0.21
Diagnostics (Machine to Machine)	30%	30%	0.00	0.00
Consumer Simple voice	5%	5%	0.46	0.46

Table 11: Forecasts for % Rate of Market Adoption and PBH Traffic per User in 2015[35]

It will be observed that the busy hour traffic varies service by service. Each service type has peak traffic that varies by time of day and day of the week. Research by the TeleCompetition Group concluded however that the diurnal variation in busy hour by service are not significant enough to invalidate a simple

[34] Downlink traffic is expected to be dominant with data-centric traffic as will be the case with Personal Broadband Services

[35] Source: The TeleCompetition Group, June 2007

summation of individual peak traffic loads during the course of a day. This is referred to as the Coincident Busy Hour (CBH).

Uplink and downlink busy hour traffic was calculated for each individual service/activity and for the entire EU-25 and is shown in Table12.

Busy Hour Traffic (Tbytes) EU25	2015		
Consumer	**UL**	**DL**	**Total**
File UL/DL - Podcast	5.3	97.6	102.9
Consumer Video/Audio Streaming	1.1	28.5	29.6
Web Browsing / Shopping/Email	12.1	84.8	96.9
MM download (Music or Video)	0.1	2.8	2.9
Gaming / Gambling	0	1.1	1.2
IP TV (Server-based and P2P)	3.9	32.4	36.4
Consumer Multimedia Messaging	9.9	19.5	29.4
Consumer Multimedia Conferencing	0.1	0.1	0.3
Tracking Services - Consumer	0.3	1.9	2.1
Diagnostics (Machine to Machine)	0	0	0
Consumer Simple voice	0.8	0.8	1.5
Business			
Business File UL/DL	7.2	28.9	36.1
Webcast_Video/Audio Streaming	0.2	5.2	5.4
Intra/Extra_Web Browsing_EmailMgt	3	21.1	24.1
Business Messaging	5.1	10	15.1
M2M: Batch File Download/Upload	0	0	0
Business - Realtime Collaborative Work	5.8	16	21.8
Personal and Asset Tracking (Business)	0.011	0.011	0.023
Business Simple Voice	0.8	0.8	1.7

Table 12: Busy hour traffic in 2015[36]

As previously stated, the total busy hour traffic will depend on the services offered by the service provider. However, as customer numbers increase one can reasonably expect that a broad mix of services will be taken up across the busy hour by different customers and the individual traffic requirements will begin to average out. Consequently it becomes possible to forecast a realistic figure for average traffic per customer arising in the busy hour. There is a significant difference in service use between business and consumer customers. Consequently, for the purpose of establishing spectrum requirements, two scenarios are considered for base station deployments.

- Scenario 1 describes a typical densely populated residential area with a preponderance of consumer customers (subscription and casual).
- Scenario 2 describes a typical dense urban environment with a preponderance of business users (subscription and casual).

[36] Source: The TeleCompetition Group, June 2007

The data from The TeleCompetition Group shows that there is effectively a 50:50 split between subscription users and casual users respectively in both business and consumer market segments. This allows the construction of two simple models, one for each scenario. The model for Scenario 1 assumes an 80:20 split for residential to business customers. The model for Scenario 2 assumes a 20:80 split for residential to business customers. Based on these assumptions and the forecasts shown in tables 11 and 12, the average downlink (DL) traffic that offered per customer in each scenario can be derived.

Based on the data in tables 11 and 12, the average DL traffic per user in 2015 for Scenario 1, a suburban residential area is 3.57 MB/hr and in Scenario 2, an urban commercial area, it is 2.26 MB/hr. Looking beyond 2015 to 2020 further increased the busy hour traffic in Scenario 1 from 3.57MB/hr to 8.92MB/hr, and for scenario 2 from 2.26 MB/hr to 4.21 MB/hr.[37]

6.3 Population and Traffic Densities

To quantify spectrum needs, it is necessary to ascertain how many potential customers are likely to be present in any given area during the busy hour and to consider how large this number might become per unit area. Reasonable estimates can be derived from knowledge of population densities applicable to these two scenarios together with a forecast of customer penetration in each.

Population density figures are surprisingly varied. Report No 6 from the UMTS Forum (UMTS/IMT-2000 Spectrum) evaluates spectrum requirements for macro/micro cells primarily for hand held voice terminals. In this report the UMTS define the population density of 108,000 potential users per square kilometer in urban pedestrian use and 180,000 potential users per square km in City Business Districts (CBD).

This report uses 40,000 potential subscribers per km^2. This figure is inline with the population density used in the UK for urban residential areas. These figures are believed to be representative of the situation for most of the service providers that are members of the WiMAX Forum.

Table 13 provides a comparison of traffic densities based on these population densities. Assuming a combined penetration rate for multiple operators of 30%, the traffic density for urban areas in 2015 is approximately 95 Mbits/s/km^2.

		Population per km^2	Year	DL traffic per user (MB/hr)	Traffic per km^2 (Mb/s/km^2)
UK Service Provider	**Urban residential**	40,000	2015	3.57	95
			2020	8.92	238

Table 13: Busy hour traffic densities for 2015 and 2020

Assuming a competitive environment in which three Service Providers are operating in the year 2015, then any one operator will be required to provide a radio access network with a downlink capacity capable of delivering an aggregate of 30 to 35 Mbit/s/km^2 during the peak busy hour.

[37] These numbers are conservative as they average out the usage amongst the entire addressable population. A higher busy hour figure would be obtained if all users of all services have the same busy hour. The WiMAX Forum has chosen to adopt the more conservative "average" usage in this report.

6.4 Mobile WiMAX® Spectrum Requirements

The paper, titled “Mobile WiMAX – Part II: A Comparative Analysis”, published by the WiMAX Forum in May 2006 provides details of spectral efficiency and net throughput for WiMAX Certified equipment. Table 14 provides an extract from this paper for a WiMAX system deployed utilizing a 10 MHz BW TDD channel for a single transmit antenna (1x2 SIMO) and multi transmit and multi receive antennae (2x2 MIMO) configuration with varied downlink to uplink traffic ratios and frequency reuse factor of 1.

Parameter		**SIMO**		**MIMO**	
		DL/UL=1	**DL/UL=3**	**DL/UL=1**	**DL/UL=3**
Spectral Efficiency (bps/Hz)	DL	1.10	1.23	1.71	1.91
	UL	0.69	0.61	0.94	0.84
Net information through-put per Channel/Sector (Mbps)	DL	5.9	9.1	9.2	14.1
	UL	3.1	1.6	4.2	2.2

Table 14: Mobile WiMAX Performance Characteristics

As is typically the case with any wireless service offering, deployments in the more densely populated areas will be capacity-limited rather than range-limited[38] and virtually any data density requirement, no matter how high, is theoretically achievable independent of spectrum availability, by deploying a greater number of base stations per unit area. Densely packed base stations however can have the following negative consequences:

- Increased base station to base station interference
- Base station deployment costs including backhaul, site acquisition and civil works can significantly impact the business case for the operator.
- The proliferation of base stations with highly conspicuous towers and antennas, particularly with multiple operators, can create an objectionable visual impact.

With greater spectrum availability, base station to base station spacing can be increased[39] to reduce the potential for interference, lower deployment costs, and mitigate the negative visual impact. However the WiMAX Forum recognizes that spectrum is a limited resource and must be carefully allocated to assure efficient utilization. It is the view of the WiMAX Forum that cells covering 1 square km (approximately 620 meter radius for a hexagonal cell) represents a good compromise between spectrum utilization and the factors cited above.

Based on the performance figures in table 14; by 2015, an operator deploying cells covering 1 square km would require three to four 10 MHz channels with (2x2) MIMO in urban residential areas. Therefore a

[38] This will typically be true for any band being considered for WiMAX between 2.0 and 4.0 GHz.

[39] The WiMAX Forum white paper, “A Comparative Analysis of Mobile WiMAX Deployment Alternatives in the Access Network”, provides a comparison of base station requirements for varied spectrum allocations and WiMAX advanced antenna alternatives.

Service Provider requires **a minimum of 30 to 40 MHz** of TDD spectrum to deploy the full range of Personal Wireless Broadband services in dense urban areas using 1 km^2 cells with advanced antennae[40].

In summary this analysis relates specifically to European urban areas and is based on the following assumptions:

- Broad range of Personal Wireless Broadband services as shown in Tables 3 & 4
- Typical usage profile for these services as shown in table 3 & 4
- Rate of service adoption services as shown in Table 11
- Number of subscribers as shown in Figure 3
- Traffic distribution changes from 2007 thru to 2020 as shown in Figure 12
- Estimate of busy hour traffic as shown in Table 10
- Dense urban population density of 40,000 per square km
- Service penetration of 30% divided between 3 service providers
- Throughput in a cell covering 1 square km is 14.1Mb/s using WiMAX technology with 2x2 MIMO

Each market and each service provider may require a different set of assumptions. Changes to any of these assumptions can have a significant impact on spectrum requirements. For example:

- A service provider may offer a different range of services, such as offering more bandwidth intensive services such as high definition video. This highly asymmetric traffic would increase the downlink (DL) busy hour figures substantially and, in turn, increase the spectrum requirements. By comparison, a service provider with a focus of business collaboration services would experience more symmetric traffic requirements and may be able to offer a high quality service experience using less spectrum.
- Markets in areas with limited wireline deployments may experience significantly higher adoption rates. This is likely to significantly increase the amount of file download traffic, which in turn increases the busy hour figures and the consequent demand for spectrum.

It is hoped that this analysis of a European urban environment can also be used as a basis for service providers and regulators to understand the spectrum needs in different scenarios. For example:

- In less densely populated areas, greater coverage can be attained by using advanced antennae to extend the range.
- In city business areas with higher population densities, smaller size cells may be deployed to increase capacity per sq-km.
- In developing countries and other situations where the business economics may not support the roll out of 2x2 MIMO and/or additional cell sites then the use of additional spectrum should be considered to provide a more cost effective solution. A full range of services in this case may require four or five 10 MHz channels.

Beyond 2015, as subscriber penetration and traffic per service grow, additional capacity can be attained by adding additional cell sites, moving to more advanced antenna systems such as higher order MIMO configurations and adaptive beamforming, and deploying advanced cell planning techniques such as fractional reuse.

[40] This assessment is based on a conservative DL:UL ratio of 3:1. Table 10 shows the potential for a DL;UL ratio of 8:1. Should the service provider use FDD spectrum, a minimum of 40 MHz would be required.

6.5 Conclusion

In the past five years, broadband connectivity has had a major impact on the way business is conducted and on changing consumer expectations. It is delivering services which vary from high resolution entertainment, unlimited access data, web conferencing, telemedicine, to distance learning. There is increasing recognition that deployment of broadband telecommunications services could bring about significant benefits to both consumers and to a country's economy.

The introduction of new technologies, such as OFDMA, enables higher data rate and hence broadband services to be implemented in a mobile environment anywhere, anytime. The market demand for these personal broadband services is expected to be considerable for both business users and consumers. The demand for new OFDM technologies like WiMAX technology introduce new issues for regulatory consideration and adopting the right policy framework to facilitate the growth of broadband technologies is perhaps the most pressing issue that Telecommunications Regulators are facing today including spectrum management and allocation

Traffic forecasts from independent analysts, Informa Telecoms & Media and The TeleCompetition Group, suggest that a 30 to 40 MHz spectrum allocation is necessary to cost-effectively roll out a comprehensive suite of personal wireless broadband services in an urban European environment. Details of the assumptions used are summarized in Section 6.4 above. However variances between regions can be significant. It is hoped that this paper will help regulators to better understand the different contributory factors. The WiMAX Forum recommends that regulators allocate spectrum blocks of a minimum of 30 MHz per operator to facilitate the timely and economic deployment of a full range of Personal Wireless Broadband services, with the caveat that local needs may require more spectrum to be allocated in some circumstances.

These conclusions are based on traffic forecasts for 2015. They rely on certain benefits being obtained from the timely introduction of advanced antenna technologies. Many licenses are likely to be awarded in the next year or two. It could be argued that spectrum requirements for initial roll-out may be less than 30 MHz per operator as traffic volumes begin to grow. Advanced antenna technologies are not immediately available however. Consequently it may be prudent to commence operations using 30 MHz per operator and assume that a trade-off will arise whereby the use of advanced antenna technology becomes viable in time to meet rising traffic demands.

7 A Service Provider Perspective

In additional to broadband connectivity on the move, WiMAX technology holds the promise of enabling the provisioning of low cost broadband connectivity to homes and businesses. This affordable connectivity is expected to enable a new category of services referred to as Personal Wireless Broadband services, which brings anywhere, anytime connectivity to the Internet. The previous sections provided forecasts on the expected growth of these services and concluded that service providers require 30MHz of spectrum to implement the full capabilities of Personal Wireless Broadband services. The purpose of this section is to provide some insight into how service providers are leveraging WiMAX technology to deliver Personal Wireless Broadband services today and their expectations for the next few years.

WiMAX equipment is being deployed today in diverse environments: From different geographical regions in the world, fixed to mobile, urban to rural, as a complementary service to competitive service. To capture these diverse perspectives, four service providers from different regions of the world were interviewed and asked about their service plans and expectations for the future. These service providers were:

- Pipex Communications, a entrepreneurial ISP in Europe
- Aircel a cellular service provider in India
- Sprint Nextel a major 3G service provider in the North America
- Korea Telecom is the first service provider to implement Mobile WiMAX

7.1 Pipex Communications

Pipex is an established Internet Service Provider (ISP) based in the UK that provides broadband services to homes and businesses. Through their Intel JV ‘Pipex Wireless’, they are in the early stages of deployment of Fixed WiMAX™ systems having put up their first base stations up in November 2006. The UK is a mature market with Asynchronous Digital Subscriber Line (ADSL) widely available. However, Pipex’s customer are already seeing advantages of Fixed WiMAX technology.

Firstly, WiMAX technology provides the opportunity to service markets that are further away from the exchange, and therefore unable to benefit from the higher ADSL data rates. Secondly, WiMAX provides a more symmetric uplink and downlink capability. This is important for home workers and small businesses which generally have a need send as well as receive data.

Pipex has over 600,000 wired broadband customers and as they add more capabilities to the network they can see subscriber behaviors changing. Graham Currier, Business Development Director at Pipex Wireless commented “basically as more bandwidth becomes available, people do different things with it”. In particular, the areas where Pipex Wireless are seeing the most change are:

- Media content is improving.
  As data rates increase, the size of files or transaction can increase allowing for richer music, media, streaming content to be downloaded.
- The number of People working from home is increasing.

As higher rates of connectivity between the home and office become available, more people are working from home.

Pipex sees these trends expanding with 802.16e WiMAX equipment and the availability of personal broadband. Their view is that we are moving to an increasingly connected world requiring broadband services to be available in more places than wired services. This provides business with new efficiencies and ability to work smarter, and provides consumers with new levels of social interaction. Graham Currier asserts “people want broadband on the go. People need this, the trends are clear, people want to walk around with devices, and people want more connectivity. These things are all clear. “

Looking forward, Graham Currier considers that there are two key spectrum considerations that are critical to enabling fixed wireless broadband.

- Ability of offer service to a high density of users from each base station site to recover the significant capital outlay involved. For a large number of subscribers to be serviced in a given area, a service provider must maximize the number of channel cards within the base station. Deployment of multiple channel cards requires the service provider to have rights to wide spectrum allocations.

- Ability of offer a service that meets the subscribers’ needs in terms of data rates and capacity. Service providers need the ability to offer data rate comparable to competitive products in the market. As the trend in the provisioning of ADSL and mobile data is increasing speeds, service providers need the capability to offer wider bandwidth solutions.

7.2 Aircel India

Aircel Business Solutions (ABS) is a subsidiary of the leading Indian cellular service provider Aircel. After researching and deploying commercial wireless broadband systems for several years, Aircel have elected to deploy WiMAX equipment as an overlay to their current cellular network infrastructure to quickly offer affordable broadband data services to Small and Medium Enterprise (SME) customers.

A key aspect of Aircel’s strategy has been the development of their own internal operational support systems, which includes OSS and BSS. This enables Aircel to distinguish themselves from other service providers. For example, they can connect and disconnect a customer online, and service provision a customer within 48 hours of the customer requesting service.

Initially Aircel deployed Wi-Fi hotspots with early 802.16 products providing backhaul capability. In 2003 they had implemented 500 hotspots across the major cities in India. Aircel found that it was difficult to get a broadband connection in the commercial areas in which they wished to provide services. In addition to these deployment problems, Aircel found the hotspot model had a very low and hence unprofitable ARPU. Today Aircel has refocused their efforts towards the deployment of WiMAX technologies. Aircel initial roll out is focused primarily on providing Internet connectivity to the IT sector, where Aircel sees a major demand for telecommuting services.

Telecommuting services are expected to grow substantially in major cities in India due to the high traffic congestion and the considerable distances between the local residential areas and the new high tech commercial regions. India in particular is renowned for its large software companies and the provisioning of international call centers. Today many employees in India commute 2 to 3 hours daily from their residencies to the commercial centers where they work. Telecommuting therefore offers major benefits both to enterprises and their employees.

Today telecommuting is not widely available due to the very low penetration of the Internet to homes in India, which is currently estimated at around two percent. Aircel believe WiMAX technologies can have a major impact on broadband availability and adoption in India. Ram Shinde, Head of Aircel's Business Solutions, commented that "we have seen what happens with other mobile services, such as GSM. Ten years ago landline penetration of telephony was very low, just 2 to 3% and now with mobile services, telephony penetration is now 30 to 40%. We believe that one of the key reasons why Internet penetration is low is because of low last-mile landline penetration. We expect deployment of WiMAX equipment to increase Internet penetration levels similar to the impact of GSM."

To provide telecommuting capabilities, Aircel plan to deploy WiMAX equipment city wide, providing assured quality of service broadband connectivity for both commercial centers and residential areas. Aircel started rolling out Fixed WiMAX equipment in the 2.5GHz band in late 2006 and offered commercial services in January 2007. Today Aircel provides connectivity to more than two hundred small and mid size enterprise customers.

In addition to expanding their Fixed WiMAX network, Aircel are looking to deploy Mobile WiMAX. However the spectrum allocation and regulations are still under discussion in India. The regulators in India have identified 100MHz of spectrum, with the possibility that it may be extended to 150MHz, in the 3.5 to 3.7GHz band. This is expected to be allocated to regional and national carriers across India. Ram Shinde expressed concern that the spectrum maybe allocated in relatively small packages, which would limit the broadband data rates achievable. Mr Shinde commented that "we estimate that we need a minimum of 30MHz of spectrum to roll out Mobile WiMAX and be able to provide broadband connectivity to our customers".

Mr Shinde also mentioned the importance of interoperability between 2.3 and 2.5GHz both for global roaming and also to achieve the desired CPE price points. Mr Shinde remarked that today the price for CPEs in the 2.5GHz band is $70. To be able to justify WiMAX deployment in the 2.3GHz, it is important that CPE pricing in this band reach $50 in 2 to 3 years. These price points will enable subscriber to own there own equipment.

Aircel, like many service providers around the world are deploying WiMAX equipment as a complementary technology to cellular, and as a means to rolling out broadband services to their subscribers. In order to continue implementing advanced broadband services, Aircel is working with the India regulators to facilitate access to addition spectrum. Mr Shinda reaffirmed the importance of globally harmonized spectrum as a critical enabler to achieve lower product price points and hence enabling a viable business model for the India market.

7.3 Sprint Nextel

Some carriers are starting to see 3G and WiMAX equipment provide complementary service offerings. An analogy can be made to the early discussions on 3G and Wi-Fi. After initial concern, most service providers around the world now see 3G and Wi-Fi as complementary technologies. Today a handful of service providers recognize the value of intermixing the service offerings enabled by 3G and WiMAX technology. An example of a major carrier doing just this is Sprint Nextel.

Sprint Nextel is a US based company that has been operating a nationwide 3G network for several years and is the ARPU leader[41 i] in the delivery of data services. Going forward Sprint Nextel sees WiMAX

[41] CDG web site for web cast in Oct 2006

technology as a key enabler of their 'Internet everywhere' vision where mobility and the Internet intersect. Sprint Nextel anticipates spending US$3B on implementing a Mobile WiMAX network as the technology of choice to deliver mobile broadband services to subscribers.

The positioning of 3G and WiMAX services is unique for each service provider. In the case of Sprint Nextel, they plan to position 3G as enabling voice centric devices with a particular focus on enterprise subscribers. WiMAX technology is being positioned as providing more data centric complementary services, and also as the wireless radio of choice for embedding into consumer devices, such as mobile gaming devices.

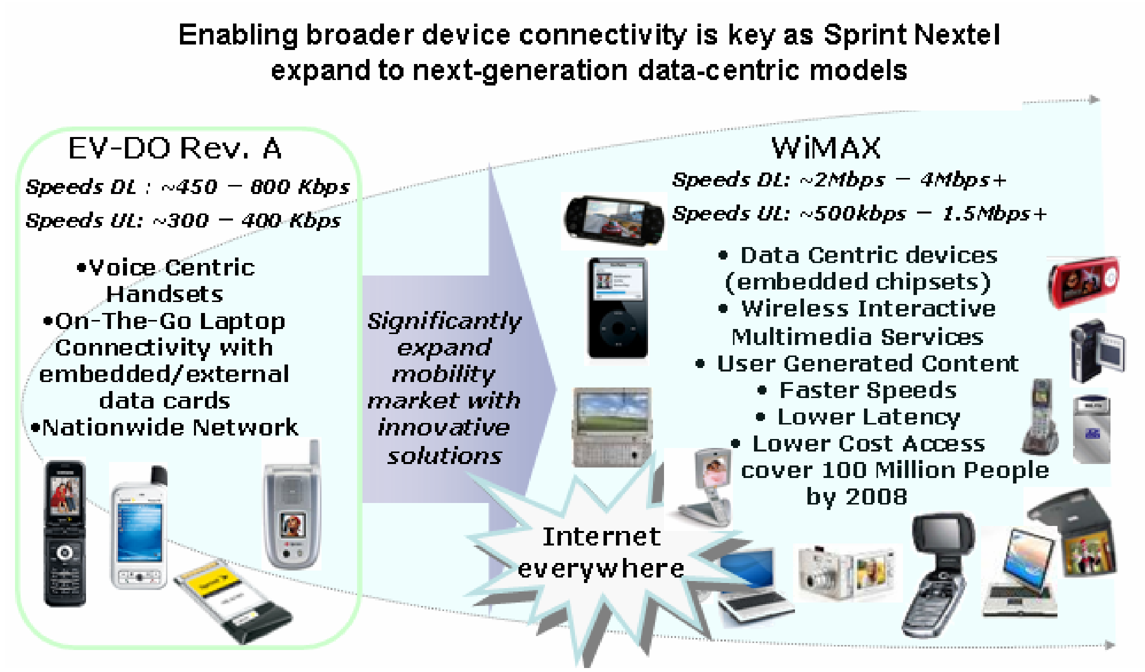


Figure 14: Sprint Nextel's Perspective on WiMAX Enables Services

Sprint Nextel also see WiMAX systems enabling multiple different service models such as: extending the delivery of mobile broadband services, ADSL replacement, and the solution that will meet the quality of service broadband needs of vertical services such as real-time videos of medical information.

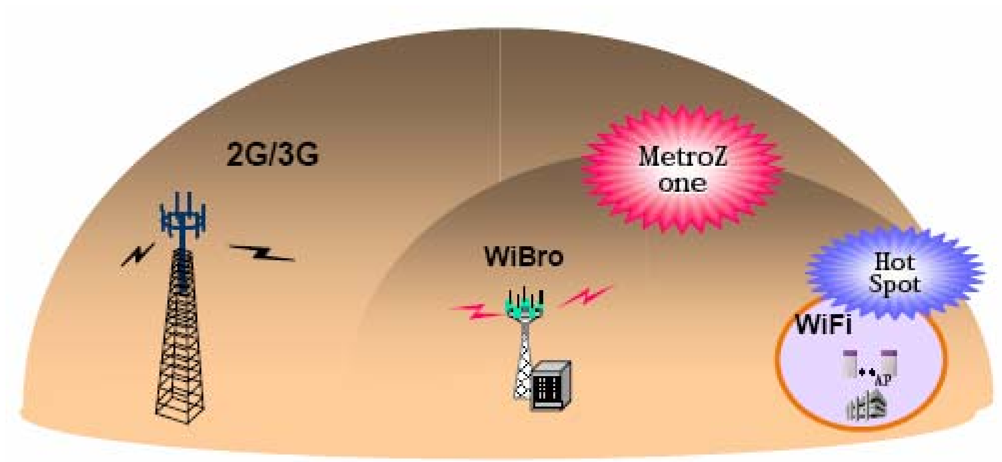
A key enabler for Sprint Nextel's complementary position of services has been the availability of spectrum. Sprint Nextel have both 3G spectrum at 1.9GHz and broadband wireless spectrum at 2.5GHz. Trey Hamberry, a senior executive from Sprint's government affairs department commented; "the U.S. FCC liberalized the spectrum framework by reconfiguring the band from its interleaved format and adopting a technology and service neutral framework, allowing companies to deploy WiMAX or other technologies, based on their evaluation of superior performance, cost, and marketplace demand."

7.4 KT (Korea Telecom)

In South Korea, regulators provided a vision and subsidies in certain broadband and wireless applications, and at the same time left service providers largely unregulated. This led to fierce competition, and today broadband penetration in Korea is the highest in the world. Now Korea is rolling out WiBro (wireless Broadband) service, a Korean standard, which was subsequently fully integrated into the global IEEE 802.16e-2005 standard. The creation of a supportive regulatory environment has enabled Korea to be the first country to roll out Mobile WiMAX.

KT is in the very early stages of deploying and optimizing a Mobile WiMAX network. Initially the network covered 5 major regions in the Seoul and Bundang areas plus the major transport routes between these areas. In April 2007, KT extended their Mobile WiMAX network to all the areas in Seoul and its environs, covering 25% of the country's population.

In addition to rolling out Mobile WiMAX, KTF, a subsidiary of KT, has their own 3G mobile network and is rolling out HSDPA (High Speed Data Packet Access). KT welcomes the coexistence and complementary nature of different wireless networks technologies, including 3G, Wi-Fi and WiMAX. WiMAX systems provide coverage in metro areas where Internet data demand is high, 3G provides ubiquitous coverage, and Wi-Fi provides localized coverage. KT's strategy is to enable seamless connectivity between networks.



2G/3G: Voice-oriented, nationwide, narrowband
WiBro: Urban cities, data centric
Wi-Fi: Hot Spot

Figure 15: KT's Complementary Market Positioning of Technologies

KT is providing a broad portfolio of services on their Mobile WiMAX network, generally referred to as WiBro (Wireless Broadband) services. These services are primarily targeted at the younger mass consumer and enterprise markets. Going forward, KT expects to see service adoption similar to the wired Internet. Dr. Hyun-Pyo Kim, Director of the Mobile WiMAX business unit at KT, explained that there has been great success with mini homepage and user created content portals in the Korean market. Pandora TV (which is similar to YouTube), one of the major User Created Contents (UCC) portals in Korea, receives 650,000 hits a day among its 10 million subscribers, Dr. Kim expects mobile media services to be one of the major growth areas.

Some examples of WiBro services are:

- Hot clip provides push services such as sports updates
- Communicator integrates all communications methods, including voice, video, email, SMS, white board

- mLog is a personalized media blog service
- Multi-Board provides single interface for data and multimedia communications
- PC Control allows subscribers to remotely access home and office PCs from their mobile device

Figure 16: KT's Broadband Multimedia Service Portfolio

As a result of these early mobile services, KT believes that the Internet of the future will be one where users generate most of the content. As part of this vision, KT considers the high rate uplink throughput, in addition to the downlink throughput, as an increasingly important enabler to allowing subscribers to *quickly* upload and share information in.

Annex A

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Annex B

Acronyms

3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
ADSL	Asynchronous Digital Subscriber Line
ARPU	Annual Revenue Per User
BH	Busy Hour
CATV	Cable TV
CPE	Customer Premises Equipment
D2C	Direct to Customer
DL	Downlink
DSL	Digital Subscriber Line
EU	European Union
EVDO	Evolution Data Optimized
FDD	Frequency Division Duplex
File UL/DL	File upload and/or download
FMS	Fixed Mobile Substitution
GSM	Global System for Mobile communications
HD TV	High Definition Television
HSDPA	High Speed Downlink Packet Access
HSUPA	High Speed Uplink Packet Access
IM	Instant Messaging
IMS	IP Multimedia Subsystem
ITU	International Telecommunications Union
IP	Internet Protocol
IPTV	Internet Protocol Television

LBS	Location Based Service
LTE	Long Term Evolution
M2M	Machine to Machine
MB	Mega Bytes
MIMO	Multiple Input, Multiple Output
MM	Multi-Media
MMS	Multimedia Messaging Service
NGN	Ext Generation Networking
OFDMA	Orthogonal Frequency Division Multiple Access
P2P	Person to person, peer to peer
PB	Peta Bytes
QoS	Quality of Service
SIMO	Single Input Multiple Output
SMS	Short Message Service
TB	Tera Bytes
TDD	Time Division Duplex
UGS	Unsolicited Grant Service
UL	Uplink
UMB	Ultra Mobile Broadband, formerly EV-DO Rev C
UMTS	Universal Mobile Telecommunications System
VOD	Video on Demand
VoIP	Voice over Internet Protocol
WPB	Wireless Personal Broadband
Wi-Fi	Wireless Fidelity

About the WiMAX Forum®

The WiMAX Forum is an industry-led, non-profit corporation formed to promote and certify the compatibility and interoperability of broadband wireless products using the IEEE 802.16 and ETSI HiperMAN wireless MAN specifications. The Forum's goal is to accelerate the introduction of these devices into the marketplace. WiMAX Forum Certified™ products will be interoperable and support Metropolitan Broadband Fixed, Nomadic and Mobile Applications.

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