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D2.1: Usage Scenarios and Application Requirements

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Summary

The objective of this deliverable is to identify the usage scenarios for wireless broadband services that will be offered over wireless mesh networks, and the corresponding service and application requirements and functionalities that the EU-MESH system should support. We first start by discussing the evolution of relevant technologies and identify key trends in telecommunications. Next we identify the services and applications that will be supported in future wired/wireless networks, and the classes of users that will use then and can obtain benefits from the EU-MESH system. Based on the services/applications and user classes, we next identify representative usage scenarios, and from these the corresponding high level user and applications requirements. Additionally, we identify the requirements from the network and service provider's side. Based on the high level requirements, technical requirements and functionalities related to QoS, mobility, security, resource management, and cross-layer monitoring are described. This deliverable will provide input in terms of technical requirements and functionalities for the architecture design task, and input in terms of the usage scenarios to the experiment and trial scenario definitions.

1. INTRODUCTION

1.1 Overview

The main objective of this deliverable is to understand the requirements from both the service/application side, but also from the particular usage of services and applications. Therefore, the deliverable focuses on the following two directions: i) identification of the community of users that could derive social and economical benefit from the EU-MESH system, and ii) definition of the technical requirements and functionalities (e.g., in terms of QoS, mobility, and security), that the EU-MESH system should provide in order to support services and applications.

The user and application requirements from the evaluation of the envisioned operational scenarios of the EU-MESH system, and the relevant applications and service needs (e.g., VoIP, video streaming, video surveillance, etc) are derived. To ensure a realistic specification of the requirements, the information from users' classification is taken into account, and the most interesting services for the experiments and trials are identified.

The results from this deliverable, and in particular the technical requirements and necessary functionalities will be the input to the architecture design task (Task 2.2 of Work Package 2), while the usage scenarios will be the input to the experiment/trial scenario definitions (Tasks 6.2 and 6.3 of Work Package 6).

1.2 Methodology

The methodology used in the deliverable is depicted in the following flow graph.

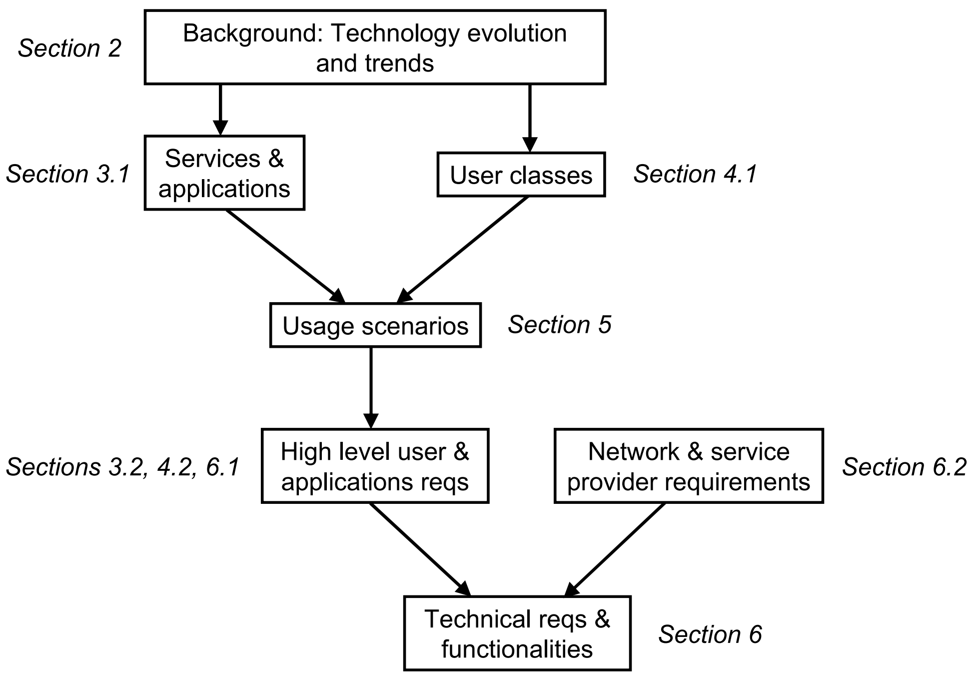

Figure 1 Methodology

We first start by identifying some background in the evolution of relevant technologies and identify key trends in telecommunications. Next we identify the services and applications that will be supported in future wired/wireless networks, and the classes of users that will use such services and applications. Based on the services/applications and user classes, we next identify representative usage scenarios, and from these the corresponding high level user and applications requirements. Additionally, we identify the requirements from the network and service provider's side. Based on the high level requirements, technical requirements and functionalities related to QoS, mobility, security, resource management, and cross-layer monitoring are described in more detail.

1.3 Features of the EU-MESH system

In this section we describe the features of the EU-MESH system, which constitute key advantages for satisfying requirements of existing and innovative future applications. EU-MESH is a multi-radio multi-channel mesh network for providing access to both fixed and mobile users.

Key features of the EU-MESH system include the following:

- Low-cost and fast infrastructure deployment, flexibility, and scalability through efficient location-aware self-configuration procedures
- Low operation and management cost through efficient utilization of both wireless (spectrum) and wired resources (provider-owned backhaul links and subscriber broadband access lines)
- High and symmetric downlink and uplink speeds through aggregation and efficient use of wired backhaul links
- Service to both fixed and mobile users over the same converged wireless and wired infrastructure
- Seamless application layer handoffs in single- and multi-operator environments
- Enhanced security through combination of both proactive and reactive mechanisms
- Reliability by exploiting multiple available paths to multiple fixed network gateways

2. TECHNOLOGY EVOLUTION AND TRENDS

2.1 Technology evolution

2.1.1 Evolution of network access technologies and architectures

In this section we discuss the development and evolution of various network access technologies, including both fixed wired and mobile/wireless technologies. An important performance metric for the various access technologies is the downlink and uplink speed in absolute and relative terms. A comparison for some current and future wired and mobile/wireless access technologies is shown in Figure 2.

3G technologies operating in 5 MHz channel bandwidth, such as UMTS, HSPA+, achieve peak speed of 42 Mbps in the downlink and 11.5 Mbps in the uplink, while technologies operating in 10 MHz channel bandwidth, such as WiMAX (IEEE 802.16) achieve peak speeds of 46 Mbps in the downlink and 14 Mbps in the uplink. Further improvements in speed, such as with 3GPP's LTE [Rys07] and IEEE's 802.16m [802.16m] will be achieved mainly by exploiting MIMO techniques and larger channel bandwidth, typically up to 20 MHz. On the other hand, IEEE 802.11n achieves speeds of 160 Mbps in both directions (shared), utilizing 40 MHz channel bandwidth, which however is in the unlicensed band; the lower efficiency of 802.11n is mainly due to the overhead of its distributed medium access control protocol. Moreover, note that work on 3GPP LTE and IEEE 802.16m is undergoing, and their deployment is expected to start beyond 2010; on the other hand, draft implementations of 802.11n are currently available.

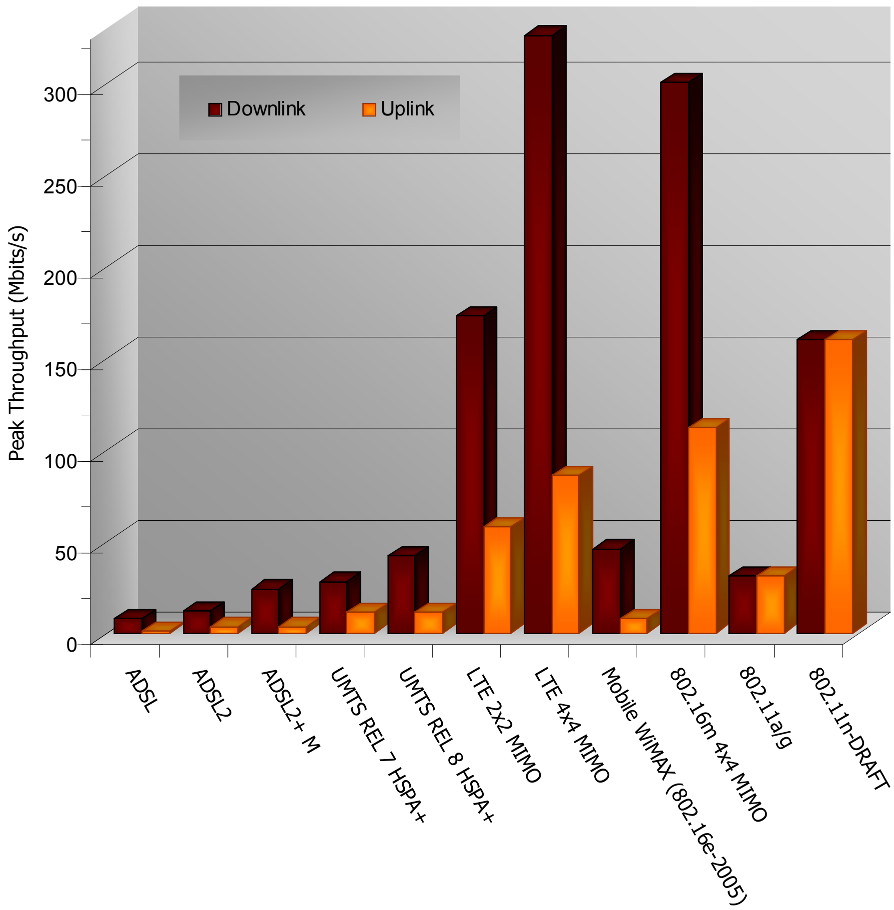

Figure 2 Downlink/uplink peak user speed for various access technologies

Fixed wired broadband access

Asymmetric Digital Subscriber Line (ADSL) is a modem technology that uses existing twisted-pair telephone lines to transport high-bandwidth data. It does this by utilizing frequencies that are not used by a voice telephone call. Because phone lines vary in quality and were not originally engineered with ADSL in mind, a long telephone line may attenuate ADSL signals at 1 MHz by as much as 90 dB. Therefore, ADSL can generally only be used over short distances, typically less than 5 km. The distinguishing characteristic of ADSL over other forms of DSL is that the volume of data flow is greater in the downlink (direction from the network service provider to the subscriber) than in the uplink direction. The main strength of ADSL in a techno-economic sense is the considerably lower initial investment compared to technologies that require a new physical infrastructure. Additionally, due to the star-based topology of the DSL access network, each customer gets a dedicated connection to the aggregation node in the DSLAM.

ADSL2 adds new features and functionality that improves the performance and interoperability of ADSL. Among the changes are improvements in data rate and reach performance, and rate adaptation. ADSL2 has been specifically designed to improve the rate and reach of ADSL largely by having better performance on long lines in the presence of narrowband interference, Table 1. ADSL2 achieves this by improving modulation efficiency, reducing framing overhead, achieving higher coding gain, improving the initialization state machine and enhanced signal processing algorithms.

ADSL2+ extends the capability of ADSL2 by doubling the number of downstream bits. The data rates can be as high as 24 Mbps downstream and 1 Mbps upstream, depending on the distance from the DSLAM to the customer's home. ADSL2+ is capable of doubling the frequency band of typical ADSL connections from 1.1 MHz to 2.2 MHz. This doubles the downstream data rates, but like the previous standards its rate decreases with the distance, Figure 3[1]. ADSL2+ allows port bonding, where multiple ports are physically provisioned to the end user and the total bandwidth is equal to the sum of all provisioned ports. So if 2 lines capable of 24 Mbps were bonded the end result would be a connection capable of 48 Mbps. However, not all DSLAM vendors have implemented this functionality.

Standard name	Common name	Downstream	Upstream
ANSI T1.413-1998 Issue 2	ADSL	8 Mbps	1.0 Mbps
ITU G.992.1	ADSL (G.DMT)	12 Mbps	1.3 Mbps
ITU G.992.3/4	ADSL2	12 Mbps	1.0 Mbps
ITU G.992.3/4 Annex J	ADSL2	12 Mbps	3.5 Mbps
ITU G.992.5	ADSL2+	24 Mbps	1.0 Mbps
ITU G.992.5 Annex L[MK00]	RE-ADSL2+	24 Mbps	1.0 Mbps
ITU G.992.5 Annex M	ADSL2+M	24 Mbps	3.5 Mbps

Table 1ADSL downstream/upstream theoretical rates

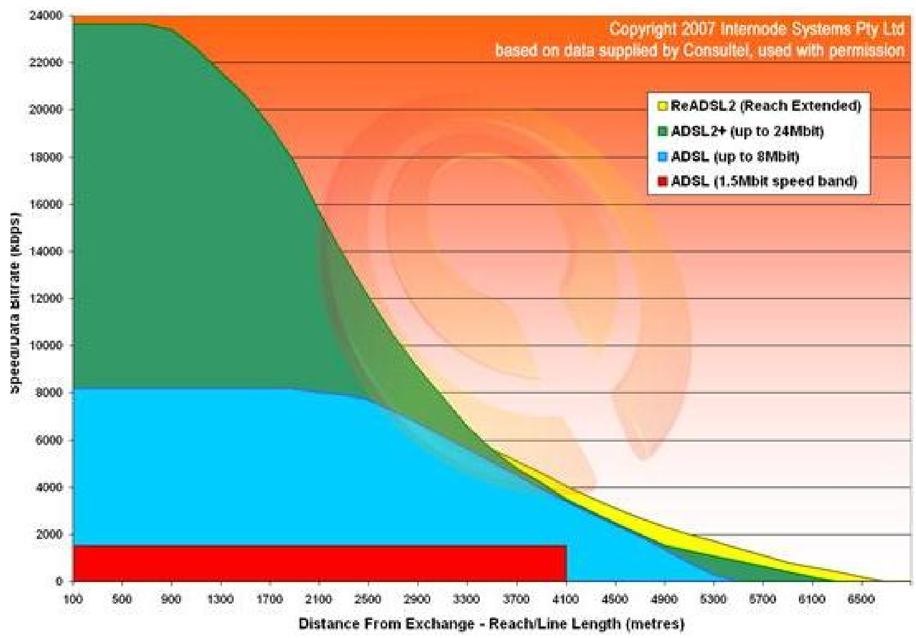

Figure 3 Dependence of ADSL speed with distance

[1] Source: http://www.internode.on.net/residential

VDSL technology resembles ADSL to a large degree, although ADSL must face much larger dynamic ranges and is considerably more complex as a result. VDSL transmits high-speed data over short distances of twisted-pair copper telephone lines, with a range of speeds depending on the actual line length. The maximum downstream rate is between 51 and 55 Mbps over lines with length up to 300 m. Downstream speed typically reduce to 13 Mbps for line lengths above 1500 m. Upstream rates are asymmetric, as in ADSL, at speeds from 1.6 to 2.3 Mbps. Both data channels will be separated in frequency from bands used for basic telephone service and Integrated Services Digital Network (ISDN), enabling service providers to overlay VDSL on existing services. At present the two high-speed channels are also separated in frequency. VDSL, as ADSL2+, will typically be used with fibre infrastructures, in FTTN/FTTC deployments.

Cable Internet access refers to the delivery of Internet service over cable television infrastructure. Bit rates of business cable modem service typically range from 2 Mbps up to 50 Mbps or more. The upstream rate on residential cable modem service usually ranges from 384 kbps to 20 Mbps or more. A fixed channel capacity is shared by a population of users (in the case of cable Internet, users in a neighbourhood share the available capacity provided by a single coaxial cable line). Therefore, service speed depends on how many people are using the service at the same time.

Fibre (FTTN,FTTC,FTTB,FTTH/FTTP) deployment in access networks is termed FTTx. FTTx covers several architectures and protocols such as fibre-to-the-home (FTTH) and fibre-to-the-premises (FTTP), fibre-to-the-building (FTTB), fibre-to-the-curb (FTTC), and fibre-to-the-node (FTTN). FTTH/FTTP pushes fibre all the way to individual residential homes or business premises. FTTH does not utilize copper, and typically support rate 50 to more than 100 Mbps. FTTB provides a dedicated fibre to each building or block of buildings, where it terminates at a remote terminal (RT), which is an active device requiring power and security. If the building is outfitted with CAT5 cable to each individual home, an Ethernet LAN is installed to provide shared bandwidth of 10 or 100 Mbps. If twisted pair is only available, the RT is a digital subscriber line access multiplexer (DSLAM) and is installed to provide required bandwidth services offering up to 50 Mbps. Most of today's FTTB deployments are providing about 10 Mbps. FTTC typically pushes fibre to about 150 to 300 meters from the subscriber, terminating at an RT and serving 8 to 12 subscribers. FTTN is similar in architecture to FTTC except that the RT is positioned much further from the subscribers -up to 1500 meters- and will serve 3 to 500 subscribers. Both utilize existing twisted pair outside plant to connect to the customer. Bandwidth is dictated by DSL technology and copper loop length. Very-high-data-rate DSL (VDSL) and VDSL2 works best at longer loop lengths and is predominantly used for FTTN, while asymmetric DSL2 (ADSL2), 2+ are being used in today's FTTC systems.

A key observation from Figure 2 is that both fixed wired access technologies, such as ADSL, and mobile/wireless wide area access technologies, such as UMTS and WiMAX, provide asymmetric downlink and uplink speeds. This is unlike 802.11-based wireless access, which supports symmetric downlink and uplink speeds.

Mobile/wireless broadband access

Next we discuss the evolution of mobile and wireless broadband access technologies. The development of current and future (4G) technologies, with their capabilities in terms of mobility and speed are shown in Figure 4. 3.9G technologies include UMTS's LTE (Long Term Evolution) and WiMAX.

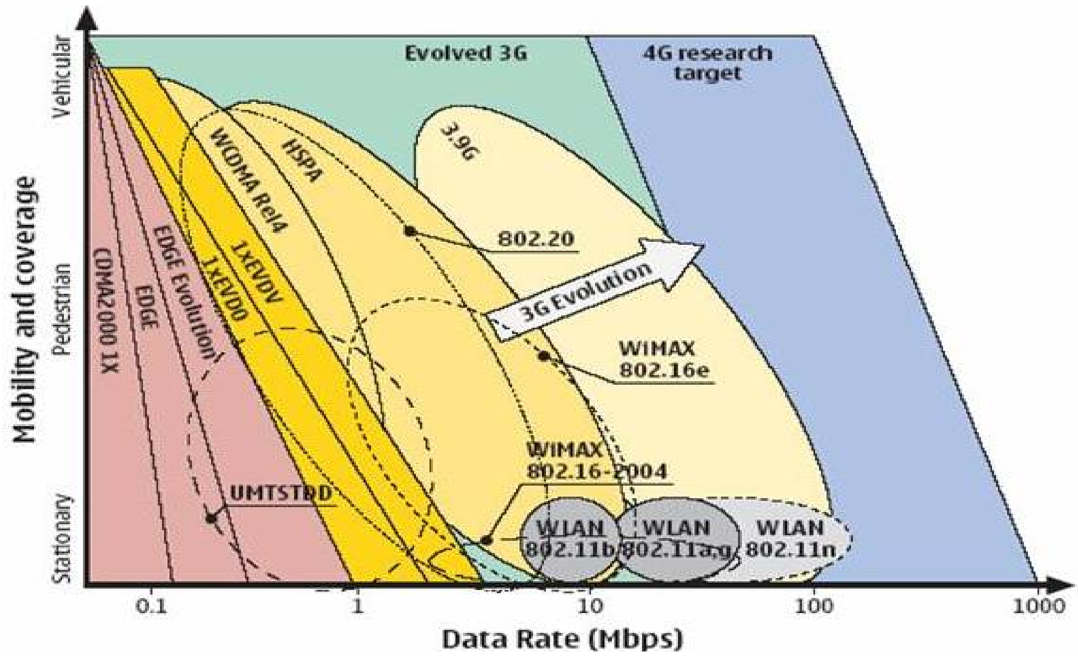

Figure 4 Development of mobile and broadband technologies

An important observation is that even current generation UMTS and WiMAX technologies have highly optimized physical layers, which suggest that there is not much room for improvement from a link layer perspective [Rys07]. Rather, rate improvement will be achieved primarily by using larger channel bandwidth, which is related to availability and cost (when using licensed spectrum).

*GSM (*Global System for Mobile communications) is currently the most popular standard for mobile phones. GSM differs from its predecessors in that both signaling and speech channels are digital, and thus is considered a second generation (2G) mobile phone system. GSM also pioneered the Short Message Service (SMS), which is now supported on other mobile standards as well.

Today, most GSM networks support *EDGE,* which is an enhancement to GSM's IP-based packet data service *GPRS*. The same data architecture is preserved in UMTS and HSPA networks, discussed below. The throughput per GSM timeslot at the link layer with EDGE can vary from 8.8 kbps under adverse conditions to 59.2 kbps with a very good Carrier to Interference (C/I) ratio. GSM with EDGE can theoretically provide 59.2 kbps in each of eight timeslots, for a maximum total peak network rate of 473.6 kbps in eight timeslots. Today's devices aggregate up to four timeslots and result in peak user-achievable rates of 200 kbps, measured at the application level, and typical data rates in the 120 to 180 kbps range.

UMTS (Universal Mobile Telecommunication System) *is* a technology that matured and benefited from research and development that began in the early 1990s. With the addition of HSPA (High Speed Packet Access) it can support much higher data access speeds compared to GPRS/EDGE [HTRP07]. Operators can use a common core network that supports multiple radio access networks, including GSM, EDGE, HSPA, and evolutions of these technologies. In UMTS (Release 99), the maximum theoretical downlink rate is just over 2 Mbps. Although exact throughput depends on the channel sizes the operator chooses to make available, the capabilities of devices, and the number of users active in the network, users can obtain peak throughput rates of 350 kbps in commercial networks. Peak downlink network speeds are 384 kbps. Uplink peak network throughput rates are also 384 kbps in newer releases. UMTS has lower network latency than EDGE, with about 100 to 200 msec measured in actual networks.

HSDPA (High Speed Downlink Packet Access) is a performance upgrade for packet data in UMTS that supports peak theoretical downlink speeds of 14 Mbps. HSDPA also supports lower latency, of the order of 70 msec. HSUPA (High Speed Uplink Packet Access) is an upgrade to improve uplink performance, which can reach 5.76 Mbps, and support a latency of 50 msec, which can be further reduced to 30 msec. Current devices can support a peak throughput of over 1 Mbps, while future category 6 devices with interference cancellation that boosts SNR values will be able to reach 5 Mbps. Combination of HSDPA and HSUPA are referred to as HSPA (High Speed Packet Access). Evolved HSPA or HSPA+ in newer releases of UMTS (Rel. 7/8) support 42 Mbps in the downlink and 11.5 Mbps in the uplink.

CDMA2000, is a hybrid 2.5G/3G technology of mobile telecommunications standard that uses CDMA. The CDMA2000 standards CDMA2000 1xRTT (2.5G), and CDMA2000 EV-DO and CDMA2000 EV-DV (3G) are approved radio interfaces for the ITU's IMT-2000 standard. *CDMA2000 EV-DV* (Evolution-Data/Voice) supports downlink (forward link) data rates up to 3.1 Mbps and uplink (reverse link) data rates of up to 1.8 Mbps. *CDMA200 EV-DO (Evolution-Data Optimized or Evolution-Data)* is a telecommunications standard for the wireless transmission of data through radio signals that uses CDMA as well as Time division multiple access (TDMA) to maximize both individual user's throughput and the overall system throughput. CDMA2000 EV-DO support downlink speeds of up to 2.4 Mbps with Rev. 0 and up to 3.1 Mbps with Rev, while the corresponding uplink speeds are 153 kbps and 1.8 Mbps, respectively.

*3G LTE (*Long Term Evolution) is an ongoing project of 3GPP that supports higher peak throughputs in higher spectrum bandwidth [Eks06]. 3G LTE will support downlink peak data rates from 172.8 Mbps up to 326 Mbps, with 20 MHz channel bandwidth; in comparison, UMTS releases up to HSPA+ (Rel 7/8) utilize 5 MHz channel bandwidth. Uplink peak data rates will be from 57.6 Mbps up to 86.4 Mbps, with 20 MHz channel bandwidth. Additionally, 3G LTE will reduce latency to 10 msec (round-trip time between user equipment and the base station).

IEEE 802.16, often referred to as *WiMAX* (Worldwide Interoperability for Microwave Access), is a set of standards aimed at providing wireless access over long distances to both fixed and mobile users. The 802.16-2004 enhanced the original standard by supporting point-to-multipoint communication, operation in channels below 10 GHz (both licensed and unlicensed), and non-line-of-sight. The IEEE 802.16e-2005 (also referred to as Mobile WiMAX) enhancement added support for mobility. IEEE 802.16e-2005 can achieve speeds of 46 Mbps in the downlink and 14 Mbps in the uplink. Work within the IEEE 802.16m Task Group is towards defining an advanced air interface targeting to support speeds above 130 Mbps in the downlink and above 56 Mbps in the uplink, utilizing 20 MHz channel bandwidth.

IEEE 802.11, often referred to as *WiFi (Wireless Fidelity),* is a set of standards for wireless local area network (WLAN) computer communication, developed by the IEEE LAN/MAN Standards Committee (IEEE 802) in the 2.4 GHz and 5 GHz unlicensed spectrum bands. The 802.11b standard amendment support transmission rates up to 11 Mbps, while the 802.11g (operating in the 2.4 GHz band) and 802.11a (operating in the 5 GHz band) supports rates up to 54 Mbps. The 802.11n standard which is under development will support transmission rates of up to 289 Mbps (20 MHz channel) and 600 Mbps (40 MHz channel). In addition to physical layer specifications, there are other specifications for supporting QoS (802.11e), dynamic frequency selection and transmit power control (802.11h), monitoring (802.11k), etc.

Satellite Internet employs a satellite in geostationary orbit to relay data from the satellite company to each customer. Satellite Internet providers offer three types of broadband Internet access service. The first one serves IP-multicast data, audio and video over a one-way multicast link from the satellite to the client stations. This type of service provides no way to upload information from client stations to the satellite and thus is not well suited for interactive applications. The second type of satellite Internet access uses a satellite link for the downlink while uplink data are sent through the PSTN network infrastructure using dial-up. The third type of service provides two way satellite Internet access. Two-way Satellite Internet access service is a completely autonomous set up, and supports downlink speeds from 512 kbps up to 2 Mbps and uplink speeds from 128 kbps up to 1Mbps. The main disadvantage of satellite Internet is the very high latency, which can be as much as 500 milliseconds to 900 milliseconds, thus making satellite Internet unsuitable for real time applications.

Access network topologies

Next we discuss the topologies for access networks, which connect end-user devices with core networks. When user devices connect to the access network through an air interface, as in the case of mobile networks, the access network is referred to as radio access network (RAN). Radio access networks are also referred to as cellular backhaul.

Radio access networks represent a significant percentage of the over network costs, which is typically in the range of 25-50%, hence their efficient operation is important [GDBD04]. Moreover, the importance of the access networks is justified by the fact that there is not much opportunity for significant improvements at the link layer. The above, in addition to the need for supporting increasingly high bandwidth creates the following requirements for future access networks [Ots01]:

- High data rates and capacity
- High reliability and QoS support
- Lower cost
- Flexibility and reconfigurability to adapt to increasing demand
- Incremental deployment and scalability
- Spectrum efficiency and efficient usage of backhaul capacity
- Seamless inter-working with multiple (heterogeneous) radio technologies

The above requirements translate to the following trends for future radio access networks [Yam00,BCR04]:

- High density deployment of base stations (microcells). This reduces the distance between end-user devices and base stations, hence reduces the corresponding path loss. On the other hand, higher densities mean higher costs, thus increasing the importance of cost-effective operation of radio access networks.
- Evolution towards packet switched IP-based nodes. This allows utilization of open interfaces, which eventually leads to reduced cost for the radio access network.
- Shifting all or most radio functions to base stations, i.e. the devices to which the end-user devices directly connect to.
- Sharing of the radio access network between multiple providers.
- Flat/distributed architecture, with peer-to-peer (or many-to-many) connections between nodes. This reduces the cost for each node, enables higher flexibility, scalability, redundancy, and reliability.
- Distributed control. This avoids single points of failure, hence increases the access network's reliability.

Next we present an overview of the various topologies for radio access networks (RANs), for various mobile/wireless technologies in current use or under development. The topologies discussed are the following:

- Hierarchical tree or star
- Star with wireless multi-hop relaying
- Single-hop mesh
- Multi-hop mesh

Hierarchical tree or star

With this topology base stations (in GSM/2G), Figure 5, or node B's (in UMTS/3G networks), Figure 6, are connected to Base Station Controllers (BSCs in GSM/2G networks) or Radio Network Controllers (RNCs in UMTS/3G) in a star topology. A single BSC (or RNC in UMTS/3G) controls multiple base stations or Node B's, but each base station (or Node B in UMTS/3G networks) is connected to one BSC (or RNC in UMTS/3G). The connection between a base station and a BSC is typically a TDM-based T1/E1, microwave (30-40 GHz), or fibre link. BSC's and RNC's are then connected to the core network, hence the hierarchical structure of such architectures.

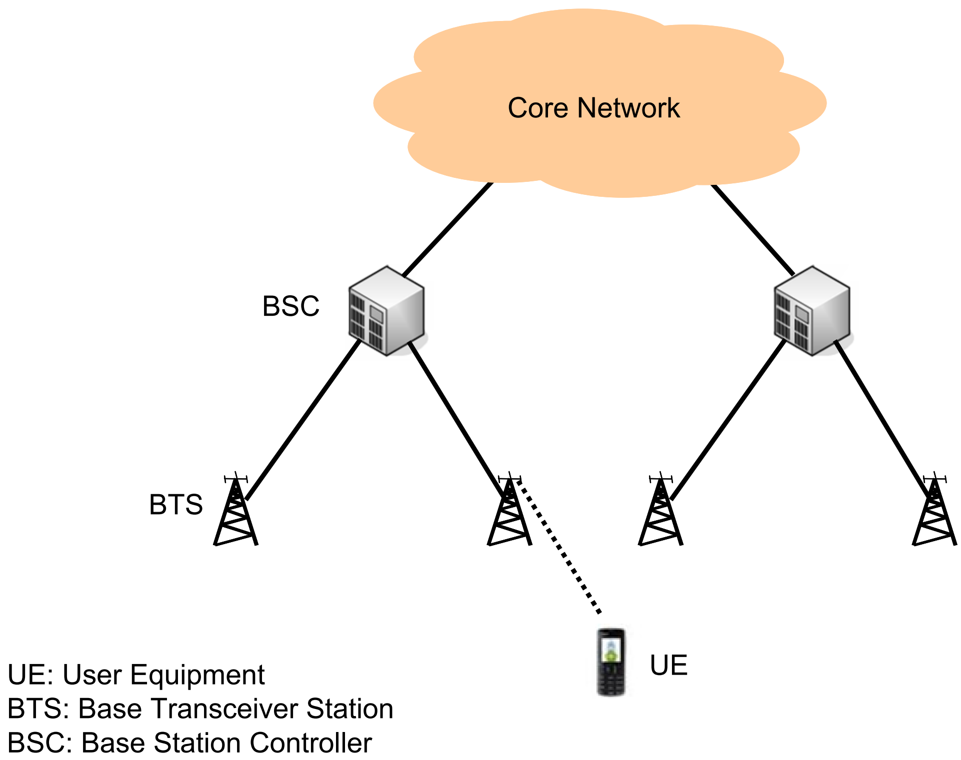

Figure 5 GSM/2G RAN topology

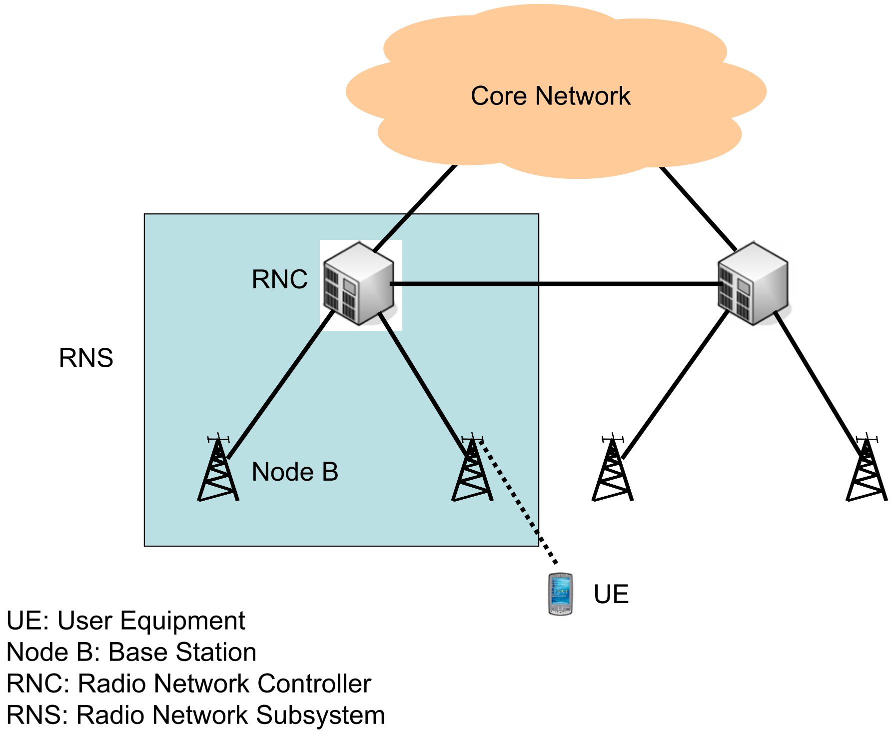

Figure 6 UMTS/3G RAN topology

A WiMAX radio access network has a similar hierarchical tree or star topology, Figure 7. Similarly, infrastructure-based IEEE 802.11 wireless LANs and hotspots have a star topology.

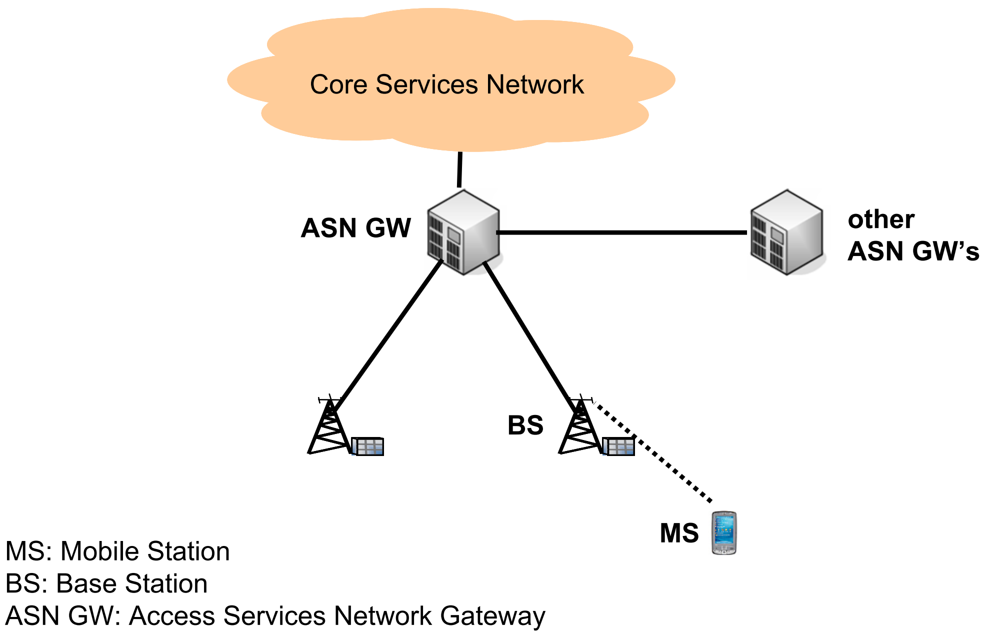

Figure 7 WiMAX RAN topology

Disadvantages of the hierarchical or star topology and the corresponding access technologies include the following [KY02]:

- There exists a single point of failure, which can be the sole link connecting a base station or the sole controller to which a base station connects to.

- The interface between the radio access network and an IP-based network requires a heavyweight gateway.
- It is difficult to incrementally deploy such an access network
- Spectrum management is hindered by lack of common mechanisms for handling similar functions such as mobility.

Star with wireless multi-hop relaying

In a star topology with multi-hop relaying, multiple base stations connect to a gateway either directly or through one or more wireless relays, Figure 8. Such a topology can reduce the cost and extend the coverage of a radio access network [YAM02, P++04]. Note that there is a single path from each base station to gateway.

This architecture is supported by WiMAX's mobile multi-hop relay mode under development in the IEEE 802.16j standard.

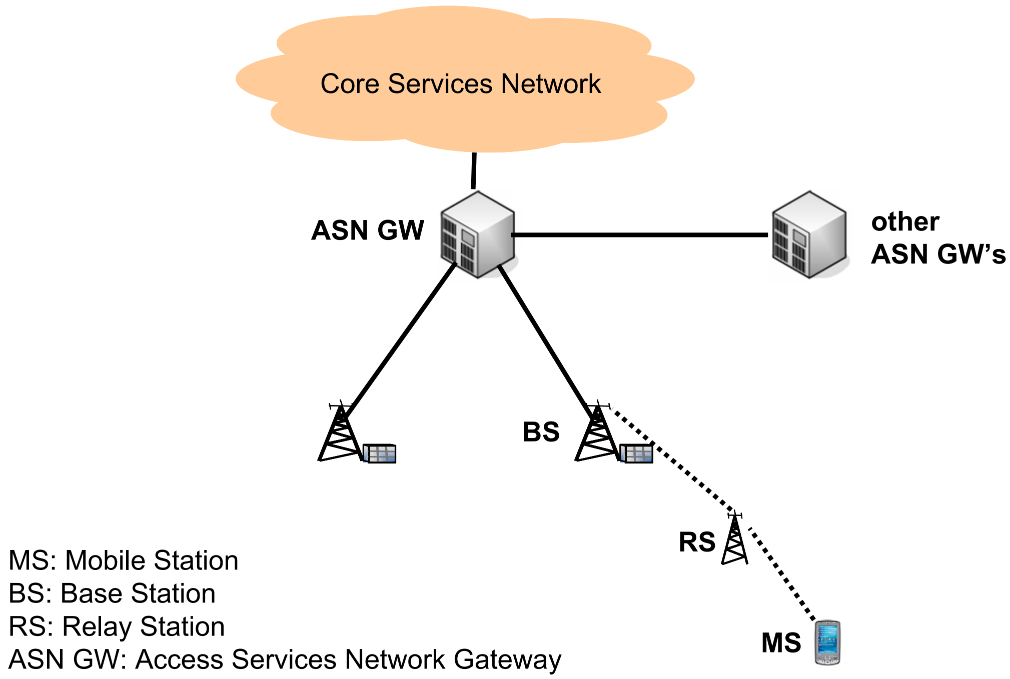

Figure 8 WiMAX RAN with relaying topology

Single-hop mesh topology

The Enhanced UTRAN (Universal Terrestrial Radio Access Network) of 3GPP's Long Term Evolution (LTE) work defines a single hop mesh topology, Figure 9, where base stations (termed enhanced Node B's or eNB's) have a many-to-many mesh connection with access gateways (aGW's). This minimizes the single point of failure for links between eNB's and the core network. Additionally, an eNB has a direct connection to other eNB's; this facilitates among other fast handoffs and radio resource management functions. Finally, all nodes are IP-based and all radio-related functionality has moved to the radio access network, which enables RAN sharing among multiple providers.

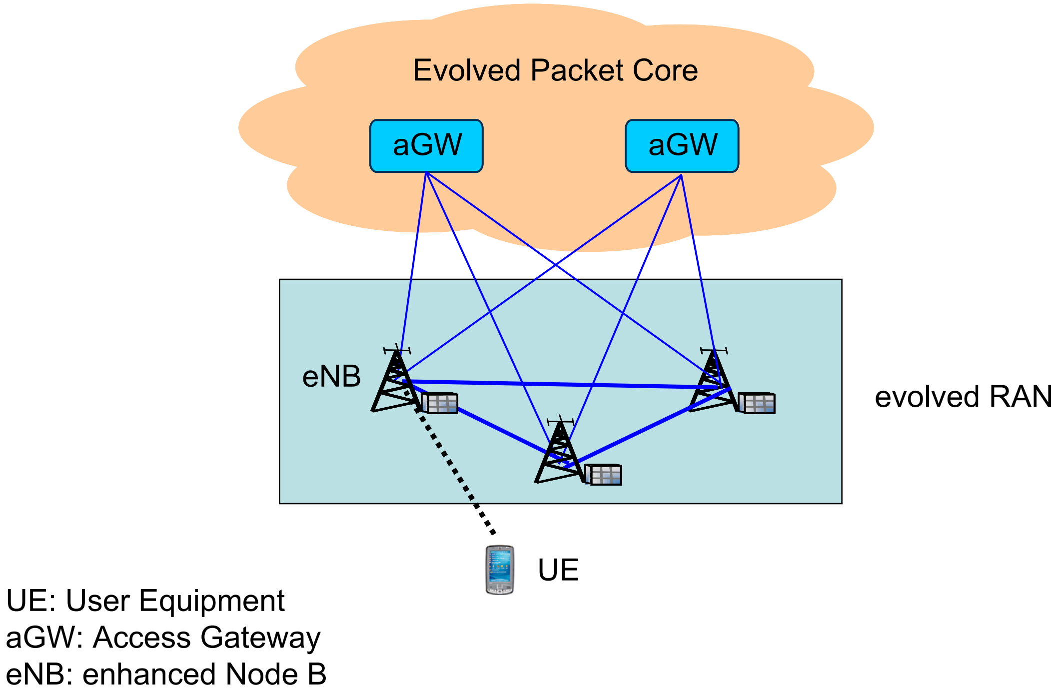

Figure 9 UMTS/LTE RAN topology with single-hop mesh connectivity

Multi-hop mesh topology

A key difference between a wireless multi-hop mesh topology and the single-hop mesh topology identified above is that the end-user access nodes connect to core network nodes through one or more nodes in the radio access network through multi-hop wireless links, Figure 10. Wireless links between access network nodes can be optical links (free space optical technology at 785 or 850 nm – infrared, or 1550 nm near-infrared), microwave (30-40 GHz), multimeter wave (60 GHz), and links in unlicensed bands (802.11b/g, 802.11a, etc).

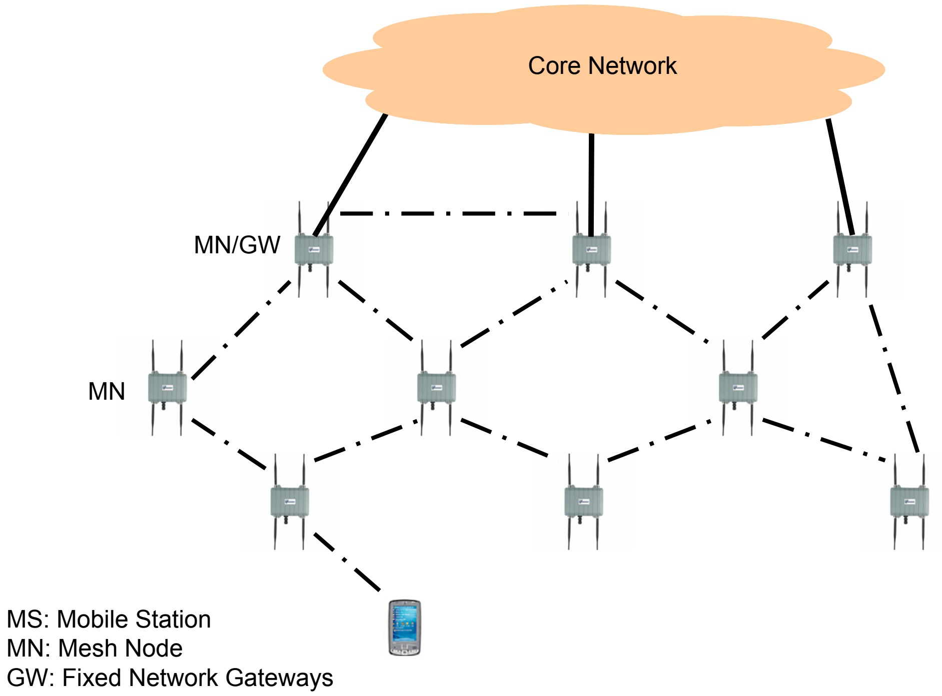

Figure 10 Wireless multi-hop mesh topology

A multi-hop mesh topology further enhances the reliability compared to the single-hop mesh topology discussed above, since an end-user access node is not only connected to multiple core network nodes, but additionally there are multiple paths between an end-user access node and a core network node. The existence of multiple makes routing important; this is not the case with wireless multi-hop relay topologies, where there is a single path between access and gateway nodes. The advantages for such a topology of the radio access network has been identified in previous works, e.g. [Whi00, GDBD04].

Mesh topology is also used in community, municipal, and commercial city-wide deployments that utilize commodity 802.11 hardware. A mesh topology is also considered in WiMAX's 802.16a mesh mode, which allows the connection between a mobile station and a base station through other mobile stations. Related protocols for supporting mesh connectivity with 802.11 wireless links is being defined in the 802.11s task group. Indeed, the trend towards mesh and multi-hop connectivity within the radio access network has been identified in a number of papers, e.g. [Whi00], [B++04], [GDBD04], [GBD05].

The above is the topology considered by the EU-MESH system.

2.1.2 Evolution of end-user devices

Computer power and mobility are the main factors determining the evolution of mobile devices. Computing power influences data speed, usability, storage, media and other functions, whereas mobility affects portability and data transmission while on the move. Handheld devices can be classified into two categories: PDAs and smartphones. Even though these two device types originated from different sectors, PDAs from the computer/laptop industry and smartphones from the mobile telephone industry, there is a clear trend for their convergence.

PDAs are handheld computers, which have become much more versatile over the years. They have computing and audio capabilities, enabling them to be used as mobile phones, web browsers, or portable media players. Many PDAs support natively Bluetooth, WiFi, Wireless Wide-Area Networks (GSM/GPRS/UMTS/HSDPA), GPS, on a single device, and employ touch screen technology.

Smartphones are mobile phones offering advanced capabilities beyond a typical mobile phone, often with PC-like functionality. Unlike the low-cost cell phone market, where devices have the sole capability to make and receive calls, the key characteristic of smartphones is the support for multiple functions. They can have QWERTY keyboard/touch screens, built-in cameras, accelerometers, built-in navigation hardware and software, documents management (PDF or Microsoft Office), media software for playing music, browsing photos and viewing video clips, Internet browsers or even just secure access to company mail.

The most common operating systems used in both PDAs and smartphones are:

- Palm OS. This is an embedded operating system with a touchscreen-based graphical user interface. The currently licensed version is called "Garnet OS".
- Windows Mobile. This is based on the Microsoft Win32 API for desktop computer and it comes in two flavours: Smartphone and Pocket PC editions (the first takes an "Always on" approach to power management, while Pocket PC not). The current version is Windows Mobile 6.

- BlackBerry OS. This is a proprietary multi-tasking operating system designed for the BlackBerry line of handheld devices, which makes use of the device's specialized input devices. The current version is OS 4.
- Linux. Linux is used as a basis for a number of different platforms. Examples include Access Linux Platform (referred to as a "next-generation" version of the Palm OS), Android (the software platform for mobile devices developed by Google that will be released within 2008), Openmoko (a project designed to provide end users with the ability to modify the operating system and software stack), ITOS (Internet Tablet OS, based on Debian), and LiMo.
- Symbian OS. This is a proprietary operating system mainly used by Nokia, Ericsson and Sony-Ericsson. Symbian OS is the leading OS in the 'smart mobile device' market. The current version is OS 9.5.
- Apple's iPhone OS. This is the operating system developed by Apple Inc. for the iPhone and iPod touch, derived from Mac OS X. The latest released version of iPhone OS is 1.1.4.

In the evolution of both mobile devices, some common technological trends can be distinguished:

1. Chipset: chip manufactures such as Intel and Qualcomm are developing and launching chips with increasing support for multimedia, camera, and other enhanced phone functions, in addition to 3/4G support. Moreover, the trend is to have one chip that handles multiple functions.
2. Multiple air interfaces. The mobile terminals often include more than one wireless interface: cellular (i.e., UMTS), medium range wireless interface (e.g., WLAN, Bluetooth) and short range wireless interface (e.g., RFID). GPS is another interface that is being increasingly supported, which will in turn drive more and more location-based services (e.g., social networking and advertising) in 2008.
3. Storage: the trend is towards expanding the capacity and minimizing the size. However, as various applications are being provided in the same device and multimedia functions are enhanced, the required capacity is increasing, as is the demand for a removable storage.
4. Screen size. Displays are gradually increasing their resolution and size. However, when considering portability and mobility, the size cannot be expanded indefinitely.
5. Battery life: There are significant improvements in this direction, with standby times ranging from 150 to 400 hours, and talk time up to 7 hours for smartphones.
6. Camera resolution: most of the devices have a 2.0 megapixels colour camera (PDAs support up to 3.0 megapixels). In addition to uploading and sharing photos directly over cellular networks, people can take pictures of ads to get coupons sent to them via SMS or get product information by taking a shot of a barcode.
7. Size: mobile devices are evolving into miniaturized and multi-functional devices.

All the above features lead to what seems to be the key element of all new mobile devices: the convergence towards a unique type of device - the smartphone. Music and video players and recorders are giving in much of their market-share in favour of a "one-device-does-it-all" type of informational, entertainment and communication product. The latest generation of game consoles (XBox 360, Sony Play Station 3 and Nintendo Wii) and hand-held game devices (Nintendo DS and Sony PSP) are network ready: they are able to connect to the Internet through their built-in/external 802.11b/g Wi-Fi or through a USB-to-Ethernet adapter.

Apple is another example of this trend: its iPod is likely to be fully replaced in the future by the iPhone. Other devices that smartphones are likely to supersede are messaging terminals, digital cameras, electronic train tickets, security badges, digital diaries, data loggers, health monitors, alarm clocks, navigation guides, interactive newspapers, and so on. All this functionality is integrated and supported by the low-cost high-performance core computing intelligence at the heart of the device. This demonstrates the trend towards convergence, bringing multiple opportunities for ground-breaking new products and services arising from the overlaps of these previously separate devices.

Besides the technological enhancements described above, there are practical factors that are driving convergence.

First of all, it is more convenient to carry a single device. When a user is highly mobile, navigating airports, hotels, business sites, and rental car agencies, space comes at a premium, and weight always matters. Since advances in mobile electronics have made it practical to add more powerful computer functions to the smaller and lighter cell phone, pure PDAs are becoming less attractive. Moreover, a single device takes up less pocket space than two devices, and a single electrical charger takes up less travelling space than two chargers.

Furthermore, smartphones are an evolution of an existing device that is already highly popular - the mobile phone. Smartphones can therefore take advantage of what's been called "the power of the mainstream". Mobile phones are ubiquitous, and people are well accustomed to using them. They also exhibit usefulness and, as such, they continue to appeal the mass market, while PDAs only really appealed to technology enthusiasts. In addition, the huge size of mobile phone industry means that strong learning effects and economies of scale operate, driving down costs even further.

Another development that is fuelling convergence is the addition of significant storage in the hybrid devices. PDAs tend to have more storage compared to cell phones. This difference in storage capacity is expected since PDAs are used for storing much more information than cell phones. However, for a hybrid device to offer true PDA functions, it will have to have a faster processor, more internal ROM and RAM storage, and most importantly ample external storage expandability. In this regard, the capacity of SD and miniSD cards has increased significantly, and such cards offer a solution to the storage capacity issue. There has even been some discussion of putting micro-drives in PDAs and hybrid devices, but their current power requirements and relative cost make them inappropriate.

Finally, smartphones have an open programmable nature that easily allows new navigation and control mechanisms to become available, improving the user interface for different use cases and addressing diverse user needs.

2.1.3 Evolution of customer premises equipment

Service providers desire to supply equipment that offers high-speed Internet access with close to zero initial investment from the consumer. The service provider recoups this investment through the commitment of a customer to a long-term contract. Thus, the suppliers of the “gateway” systems are under extreme pressure to minimize system cost. This drives the need to implement low-device-count solutions on low-cost printed circuit boards.

On the other hand, the emerging nature of this business is driving set-top-box manufacturers to be flexible enough to support the broad range of I/O interfaces being proposed for home local area network (LAN) connectivity, including wired and wireless. Filling the above needs requires an integrated communications processor, which combines a processor core with a myriad of on-chip communications peripheral interfaces. It also requires high performance, low power and a small footprint that is highly configurable to many CPE solutions aimed not only for supporting current CPE protocols and services, but also for supporting increased flexibility in order to embrace future requirements.

The CPE has evolved from a simple modem to a multi-functional gateway, with increasing functionalities such as wireless and VoIP support. Modems that only facilitated Internet access, have now been replaced by these gateways. According to a report by In-Stat, shipments for broadband routers were recently up by 11%, boosted by shipments of routers with VoIP capability.

Indoor CPEs are becoming increasingly efficient and multi-functional. It is now possible to have indoor CPEs that provide not only LAN ports but also FXS (Foreign Exchange Station) and FXO (Foreign eXchange Office) [P03], which are the most common interfaces found in analog telephony environments and facilitate various voice functionalities more economically. Moreover, most of CPEs have a built-in WiFi module in order to share bandwidth wirelessly with other PCs. Several modulation schemes are also provided by such gateway CPEs, with increasing support for QoS and service differentiation.

Outdoor CPEs support long-distance, possibly Line-of-Site (LOS), wireless connections. Outdoor CPEs often integrate POE (Power over Ethernet). POE technology is useful for powering IP telephones, wireless LAN access points, network cameras, remote network switches, embedded computers, and other appliances where it would be inconvenient, expensive or infeasible to supply power separately. Such devices also support bi-directional QoS, static/NAT router, DHCP Server/Client and ACK control. Outdoor CPEs achieve higher performance in terms of connectivity speed and communication range, compared to indoor CPEs, at the expense of less flexibility (since they are static devices) and increased cost.

2.2 Telecommunication trends

In this section we first discuss separately the trends related to mobile and wireless services, and the trends related to fixed broadband access services. A major trend for both is the convergence of fixed and mobile sectors. Converged services deliver ubiquitous and personalized services across multiple domains, offering the same quality level to users, whether they are at home, at work, or on the move. Fixed-Mobile Convergence (FMC) enables providers to move beyond traditional boundaries, and exploit new revenue streams. This is important for both pure mobile and wireless providers, as well as pure fixed broadband access providers. For the former, even though there has been a significant growth in the mobile industry for the past several years, in many situations it is reaching a saturation point, especially for voice-centric services and revenues [FMC07]. On the other hand, fixed telephony providers are experiencing a significant reduction in their traditional voice subscriber base due to VoIP. Also, fixed broadband access providers have seen a reduction of their revenue margin, and over the last years are exploring directions for offering bundled services, from double-play to triple- and quad-play, in order to exploit new revenue streams.

2.2.1 Mobile and wireless service trends

Two main factors are currently driving developments in the mobile services market:

- The enlargement of subscriber bases in the developing economies, particularly in the major emerging markets.
- The growing importance of data services, which now account for 18% of mobile revenues in Western Europe, 19% in the US and 32% in Japan.

Subscriber base growth

During the period 2002-2006, mobile subscriber bases expanded at an annual rate of 21-26%[2]. The number of mobile subscribers passed the 2-billion mark during 2005 and the 3-billion mark during 2007, with a large part of the increase being fuelled by the developing countries. By the end of 2007, 70% of the world's mobile subscribers will be in a developing country, compared with 50% at year-end 2003. Particularly strong growth is displayed by the major emerging economies of Asia (China, India, Indonesia, Pakistan), Latin America (Brazil, Colombia) Europe (Russia, Ukraine, Turkey) and Africa (South Africa, Algeria, Nigeria).

On the other hand, among industrialised countries, Western Europe has experienced a sharp decline in revenue growth, which is expected to be under 2% in 2007 (down from 9% in 2004, 3% in 2006). This has resulted from market saturation and cuts in termination rates, partly offset by increase in mobile data revenues. The US mobile market, which is relatively less saturated, remains much more dynamic in terms of value growth (+10% in 2006 and 2007). But evidently, subscriber growth is reaching a plateau (19 EU countries posted mobile telephony penetration more than 100% in 2007) and further market growth has to come from innovative services and applications.

3G adoption

Japan – and to a lesser extent, South Korea – are leading the way when it comes to the spread of 3G. In these two countries 3G, including both CDMA 2000 and WCDMA technologies, already represents 40% of mobile customers.

The start-up of 3G in Western Europe has been relatively slow compared to expectations set in the early 2000s, with 45 million customers at the end of 2006, a little more than 10% of the entire mobile customer base. Italy is ahead in Europe (16.6 million 3G subscribers at the end of 2006), led by the new entrant, Hutchison, which banked on video services to differentiate itself.

Analysts have termed 2007 as the year when 3G data services have finally taken off. After years of waiting, mobile broadband in many EU Member States is now a reality thanks to investments in high speed Internet access and flat-rate charging mechanisms. For the first time this year, there are more 3G networks offering commercial services than 2G networks. 86 operators are now offering 3G on a commercial basis, up from 70 last year, and 3G services are now available in all EU Member States. In fact, there is now more than one 3G operator offering such services in each Member State.

Applications

With the arrival of 3.5G (HSDPA) , which nearly three fourths of the WCDMA network operators in the world (128 out of 174) had introduced by mid-2007, true mobile broadband finally appears to be available in large cities, with speeds greater than 1 Mbps downstream. In addition, the gradual implementation of HSUPA will increase upstream speeds starting this year. Though HSDPA in Korea is already based on mobile handsets suited for video telephony and VoD, the service is sold in Europe using PC cards, mainly targeting businesses.

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[2] Data in this section are taken from:

- PROGRESS REPORT ON THE SINGLE EUROPEAN ELECTRONIC COMMUNICATIONS MARKET 2007 (13th REPORT)
- http://www.umts-forum.org/
- http://www.3gamericas.org

Rates are still relatively high compared to flat rate offers that consumers are accustomed to from the fixed Internet access. Operators have not yet opted to extend ‘free riding’ on the Web, even though agreements between their own portals and the Internet giants (GoogleMaps, MSN etc.), and UGC (User Generated Content, e.g. Facebook, YouTube) sites are becoming more frequent. However, the spread of convergent offers should strengthen the connection between fixed and mobile Internet business models.

Finally, the growth in data revenue and services now associated with 3.5G will endanger the control of current voice ARPU. The growth in traditional voice traffic may potentially be attacked by the rapid expansion of VoIP. Voice ARPU is already negatively impacted by VoIP enabled smartphones. Nevertheless, operators have started to respond with targeted ‘unlimited offers’, ‘home zoning’ (which could be extended by femtocell architectures), and of course FMC offers, in particular for operators who don’t have fixed infrastructure or who are in the process of building one.

The case for Femtocells

Femtocells are small, low-cost, low-capacity residential 2G or 3G base stations which enable users to communicate across any IP access network using a standard mobile handset. In terms of appearance and price there are significant similarities to wireless routers or WiFi access points.

Architecturally, residential femtocells are connected via the customer’s broadband DSL and by using broadband as the backhaul, the femtocell is able to provide voice and data services in the same way as a regular base station, but with the benefits of a simple and cheap installation, low unit cost and scalable design.

This far, most focus has been on UMTS 3G femtocells, though the technology can also be applied to CDMA-2000, 2G and WiMAX standards. There is, however, a key reason why 3G femtocells have drawn most attention: 3G does not work well in residential areas, which represents a significant factor in the poor levels of 3G take-up and usage to date. Femtocells, by adding coverage inside the building, are highly effective at improving indoors signal reception.

While a lack of agreed standards and outstanding technical issues may inhibit major femtocell rollouts in 2008, a ramp up in adoption should be expected in 2009/2010.

The femtocell business model allows for attractive home tariffs, such as cheap mobile voice calls and unlimited data packages. Once customers have been signed up, it is thought that the way will be clear for operators to tempt them to try new offerings - such as Mobile TV and music downloads - with attractive prices, perhaps including flat rate or ‘all you can eat’ data tariffs. The thinking is that once customers acquire a taste for 3G-based high-speed data services in the home they will then replicate this usage in the outdoor environment, finally increasing overall revenues.

At the same time, mobile operators will be in a powerful position to take call revenues from fixed-line operators. The potential for femtocells to facilitate low-cost mobile calls in the home (quite possibly at fixed-line equivalent rates), means that mobile operators can very reasonably expect to see substitution of fixed call revenue leading to higher levels of ARPU.

The argument can be made also that despite the potential for significant disruption, operators who do not deploy femtocells could be placed at disadvantage relative to their competitors in terms of network cost, breadth of services and end-user experience.

2.2.2 Broadband access service trends

The fixed line broadband access service has changed dramatically since its introduction in the late '90s. During its relatively short life, the changes we have seen in the broadband market itself have been particularly marked: today there is strong competition delivering a wide range of products spanning many price points, and available to most consumers in the EU. Consumers continue to see broadband services with steadily falling prices and rapidly increasing speeds. These services have profound impacts on society and economy by changing the way people conduct business, entertainment and education.

As consumers are increasingly experimenting with a diverse range of new applications and services over their broadband connections, such as video content, their expectation of services is moving beyond the relatively low speed or "best effort" network applications that are currently the norm. Faster speeds capable to sustain new services are needed and current network operators are challenged to address these needs with investments in new technologies. At their core networks they are deploying NGNs (Next Generation Networks), while at the same time they are beginning to employ Next Generation Access networks (NGAs) at the edge.

Cable and DSL were the first and are still the dominant broadband access technologies worldwide. Currently in EU, DSL is the most popular with 79.9% of total broadband connections, whereas cable leads in the United States, Canada and South Korea, with market shares ranging from 52.3% to 35.3%, as compared to 15.3% in the EU. In Japan, 36% of all broadband connections are provided through fibre optics, whereas 30.9% of all South Korean broadband Internet users use FTTH, compared to 1.3% in the EU. (PROGRESS REPORT ON THE SINGLE EUROPEAN ELECTRONIC COMMUNICATIONS MARKET 2007, 13th REPORT)

The fact that 58% of the broadband connections in EU are between 2Mbps and 10Mbps, shows that the first generation DSL networks (ADSL, ADSL2) are still being converted to ADSL2+ (24Mbps), in an effort to utilise more efficiently the existing copper networks. But even with these upgrades, the existing xDSL networks will ultimately be limited in terms of the combination of speed and coverage they can provide. More importantly, these technologies currently provide much slower uploading speeds than downloading speeds. Until recently, customers were seen as passive consumers of services and content on the Internet, downloading material to their computer, so that what really mattered was the download speed which would determine. The upload speed was very much a secondary consideration, since most of the material uploaded was very low bandwidth, such as e-mail or text for a web site or weblog. This is changing fast. Increasingly users are active producers or creators of content, uploading photographs, video clips and even short films to the Net, and they are using peer-to-peer and interactive services which require high up-load speeds. In this environment, upload speeds matter as well and the asymmetry between download and upload speeds becomes a real factor for customers.

In practice, most domestic consumers will not necessarily need upload speeds as fast as their download speeds, but they will certainly want much faster upload speeds than is currently available. So arguably for such consumers what is really important is faster upload speeds in absolute terms, rather than relative to the download speed. However, symmetric services are definitely important for businesses.

The most effective, but also the most expensive, solution to these increasing needs is to replace copper with fibre. Although FTTx access networks are currently deployed in small scale (1.3% of European broadband connections) or in trials, it is expected that their popularity and availability will rise, provided that the investment and regulatory environments become adequate.

From the consumers' point of view, FTTx access technologies provide two options:

- Fibre to the cabinet (FTTC): fibre runs from the local exchange to the street cabinet and active electronics are installed in the cabinet. The link from the cabinet to the customer's home remains the existing copper loop. Depending on the deployment option used, this model could deliver speeds of up to 100Mbit/s in both downstream and upstream directions.
- Fibre to the home/building/premises (FTTH/B/P): fibre runs all the way from the local exchange to the customer's home. This allows virtually limitless access speeds to be offered.

These different options involve different costs and operational factors to the providers and different access speeds to the customers. FTTH is regarded as more secure than FTTC as it does not require active street cabinets, while the long term operating costs would be lower than hybrid copper-fibre solutions. However, the upfront costs of deploying point-to-point fibre, would be significantly higher, because the principal cost of deploying fibre networks is the civil engineering cost (digging and pulling the fibre), which might account for even 80 per cent of the total.

The foreseeable future of broadband access can be summarised as follows:

- Existing copper infrastructure will continue to provide access in the short term future. ADSL2+ is still being deployed.
- Cable can be utilised for a little longer time span than copper (e.g., DOCSIS 2.0), but since its availability has always been scarce in Europe, its effect in broadband connectivity is also minimal.
- Parts of the copper and cable network will begin to be substituted or complemented with fibre. Due to lower upfront costs, FTTC technologies are expected to become popular in the medium term future.
- Further consumer demand for bandwidth, in conjunction with adequate investment and regulatory environment will drive the adoption rate of point-to-point fibre technologies. FTTx technologies will start replacing copper.

2.2.3 Fixed-mobile convergence

Fixed-Mobile Convergence (FMC) is the term used to describe a wide range of mobile services that converge the elements of fixed communications infrastructure to complement the core mobile service, by blurring line between fixed telephony using PSTN or broadband, and mobile telephony using a cellular network. There are lots of different interpretations of FMC and its implementation approach.

One of the major drivers of FMC is significant growth of wireless services. There are about 300 million mobile users and about 850 million subscribers connected to the PSTN (Public Switched Telephone Network). However, cellular subscriber growth is almost four times the rate of fixed-line subscriber growth. In addition, cellular operators continue to move fast into areas like data services and the Internet, once the sole domain of the fixed-line provider.

The aim of FMC is to provide both (fixed and mobile) services with one phone and to address an increased demand for mobility and anywhere access. Using a mobile phone more than the desk phone can introduce added costs to users and enterprises. FMC can reduce the number of cellular minutes occupied because it uses existing infrastructure such as WLANs, that are providing both, mobility and anywhere (in the building, on the campus, etc.) access.

One of the key challenges of FMC is indoor coverage. This challenge may be addressed by deploying WLAN infrastructure or by improving cellular network coverage through the deployment additional base stations. These are two considerably different and almost opposite strategies, and these strategies are driven by two different goals. The goal of the user or enterprise is to lower the cost of the cellular network usage. The goal is cellular operator is keep its customer on their network by extending indoor coverage.

The implications are different interpretations of FMC and its implementation approaches. One of the implementation approach is using dual mode devices which have separate Wi-Fi VoIP stacks and cellular radios allowing users to place VoIP calls when in hotspots, but without handoff - a call is either entirely VoIP or entirely cellular.

The other popular approach is using a hybrid phone, which is similar to dual mode, but can handoff between Wi-Fi and cellular networks. This approach is supported by the Unlicensed Mobile Alliance (UMA) and 3GGP's VCC for IMS [3GPP TS 23.206 V7.5.0, (2007-12), Voice Call Continuity (VCC) between Circuit Switched (CS) and IP Multimedia Subsystem (IMS), Stage 2, (Release 7)]. It should be noted that this standards provide support for voice services only.

Newer work at 3GPP is extending this standard to cover multimedia communications [3GPP TR 23.893 V1.2.1 (2008-03), Feasibility Study on Multimedia Session Continuity; Stage 2,(Release 8)].

Femtocells are another approach to FMC, wherein the cellular carrier equips the homeowner or enterprise with a private cellular base station to provide RF coverage in the subscriber's building. The femtocell sends the cellular traffic from normal cell phones back to the wireless carrier over the subscriber's broadband connection, such as DSL, as depicted in the figure below

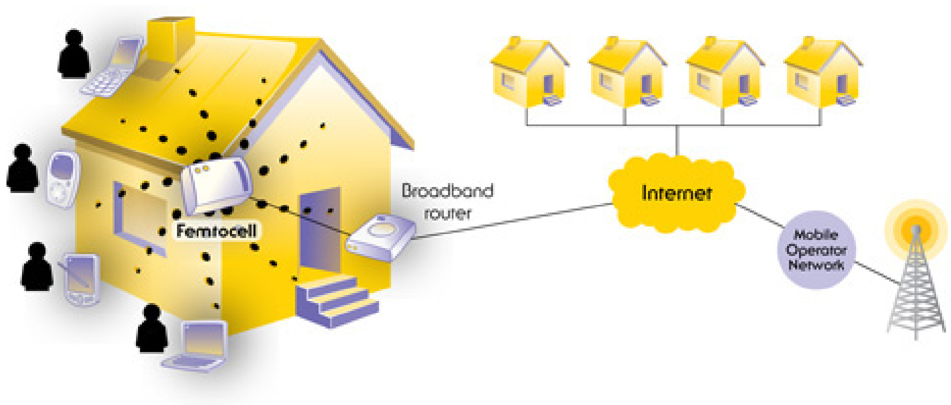

Figure 11 Femtocell network architecture (Source: Femto Forum)

There was a lot of hype over the femtocells in the recent years, but also a lot doubts because a lack of interoperability, as number of companies were independently building different solutions, due tothe lack of standards. In July 2007, the Femto Forum organization was founded to promote femtocell deployment worldwide and interoperability. It seems that initial focus of femtocell have been on UMTS only (a single mode handset), however, later it was recognized that the concept of femto cells is applicable to all air-interfaces. Currently, femtocells are also under development for GSM, TD-SCDMA, WiMAX and LTE. 3GPP LTE study group have identified femtocells ("Home eNode B") as a priority area, and started to produce new standards to enable interoperability with other wireless interfaces.

3GPP defines Generic Access Network (GAN) (also known as Unlicensed Mobile Access (UMA) prior 4/2005, and also as Universal Mobile Access), as a telecommunication system allowing seamless roaming and handover between local area networks and wide area networks using a dual-mode mobile phone. The GAN is an evolving wireless communications standard/system in which mobile phone sets function seamlessly between local area networks and wide area networks, as described in 3GPP TS 44.318 V8.1.0 (2008-03) [Technical Specification, Generic Access Network (GAN); Mobile GAN interface layer 3 specification (Release 8) and 3GPP TS 43.318 V8.1.0 (2008-02) [Technical Specification, Radio Access Network; Generic Access Network (GAN); Stage 2 (Release 8)].

Just recently (February 16, 2008), the 3GPP completed the work to add the Iu interface to the UMA/GAN standard, allowing UMA to become the standardized protocol between femtocells and the core network. This allows operators to buy femtocells and femtocell controllers from separate suppliers. This is very good news for FMC market. The figure below depicts this new 3GPP architecture.

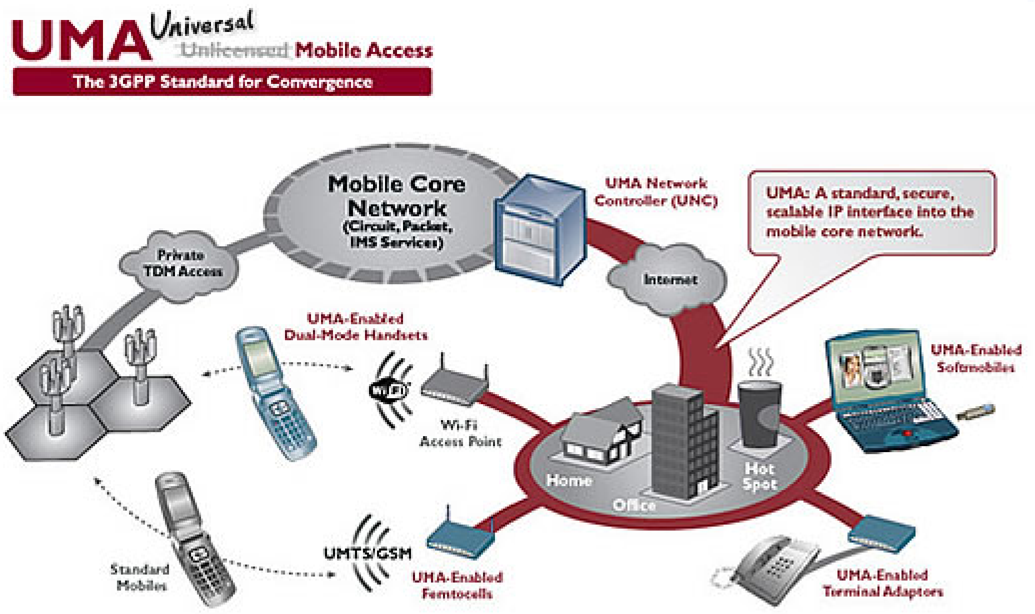

Figure 12 3GPP UMA architecture

Some analysts such as, In-Stat, believe that by 2010 the FMC and femtocell market segments will evolve to form a new fully-converged services market segment, based on Internet protocols that seamlessly enable voice and data communications across home, mobile, and work. Within this new environment, a mixture of equipment, in the legacy fixed and mobile networks will exist. FMC requires interoperability across all this equipment, starting from the handset or other user devices, to a converged fixed-mobile core network, to enable innovative applications, such as quad-play/multi-play services. This transformation will introduce horizontal choice of services in contrast to today's vertical business models.

Ib-Stat suggests that current unlicensed mobile access (UMA) and IMS-based FMC services, which emphasize cheap phone calling, will be marginalized. Likewise, operators that deploy femtocell-based services using the same cut-rate calling value proposition will be short-lived. Converged services that emulate the home telecommunications experience will emerge because they will be more highly-valued by consumers than are individual services.

Moreover, the trend towards FMC is expected to generate more than $35 billion in revenue worldwide for service providers and hardware vendors over the next five years, as shown in the figure below.

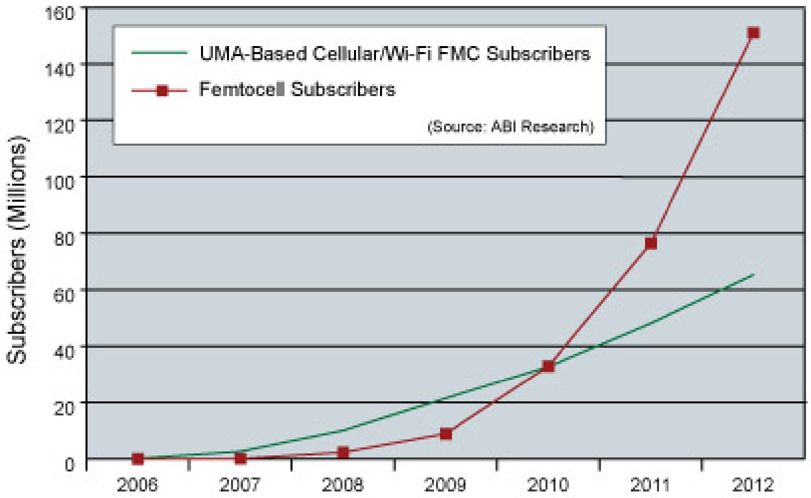

Figure 13 FMC subscriber growth

EU-MESH must consider market directions and applicable business models when designing EU-MESH convergence solution.

2.2.4 Traffic and application trends

Despite early predictions that the Internet would collapse ("gigalapse"[3]) from the accelerating traffic growth, during the last 5 years annual traffic growth rate is decreasing and is currently hovering between 50-60%[4].

In the last decade, typical equipment network access speeds have increased 100x (from 10Mbps to Gbit Ethernet, from ISDN to ADSL2 etc.). Applications greedy in terms of throughput, like Peer to Peer applications, video streaming and IPTV have begun to challenge the traditional Web/FTP/e-mail usage.

A recent study focusing on protocol type distribution in Germany[5] (Figure 14) proves that P2P traffic dominates the use of Internet. About ¾ of the whole traffic is P2P traffic, while HTTP is the second most important traffic protocol (about 1/10).

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[3] Bob Metcalf, Infoworld, December 1995 Issue

[4] Minnesota Internet Traffic Studies (MINTS) project, http://www.dtc.umn.edu/mints/home.html

[5] Internet study 2007, ipoque GmbH

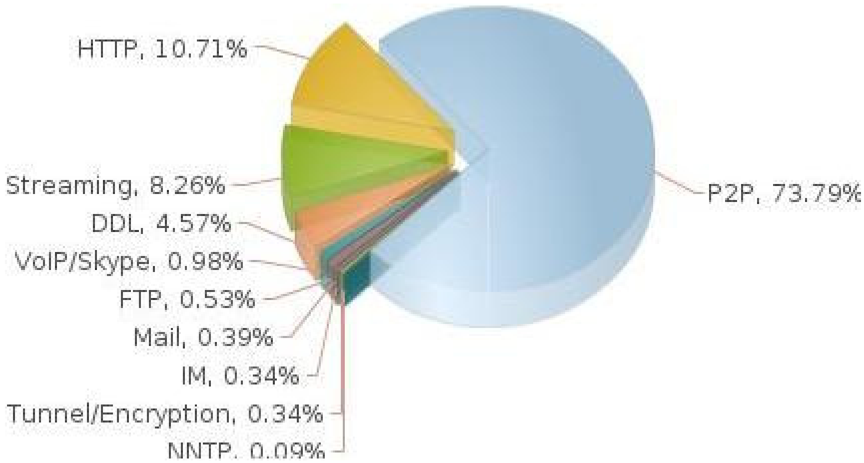

Figure 14 Protocol type distribution in Germany (2007)

Although a visit to popular Bittorent trackers proves that most of the content delivered via P2P networks is copyrighted material (TV shows, DVDs, Audio etc.), P2P is currently being legitimately and most successfully employed by:

- Linux distributions that are being developed by volunteer communities
- Skype VoIP telephony network
- Joost and Vuze TV-alike clients
- Various companies to deliver software updates (NOKIA, Blizzard)

In the above cases, P2P networks substitute or alleviate the need for large datacenters. This specific advantage will be most important in the near future for media content companies, as high-quality broadcast video will be significant driver of traffic. As video quality gets higher and the shows become longer-form, media companies will be faced with high bandwidth and infrastructure costs and will be forced to move to a decentralized P2P model. That, in turn, will create tremendous pressure on last-mile ISPs to reconfigure their networks to be more symmetrical.

Finally, the inevitable advent of NGNs, NGA and 3G networks, in conjunction with the continuously broadening variety of IP-enabled devices, is not expected to have a significant effect on the current traffic growth rate, but will definitely change the protocol distribution[6] in the following 3-4 years:

- IP traffic will nearly double every two years through 2011. Driven by high-definition video and high-speed broadband penetration, consumer IP traffic will bolster the overall IP growth rate so that it sustains a fairly steady growth rate through 2011, growing at a compound annual growth rate (CAGR) of 46 percent and nearly quadrupling the monthly traffic run rate from 2007 to 2011.
- Consumer IP traffic will grow faster than business IP traffic. Consumer IP traffic will keep growing at a CAGR of 52 percent, compared to 29 percent for business IP traffic. Mobility traffic will grow at a CAGR of 116 percent.
- Consumer IP traffic generated by the transport of cable and IPTV video-on-demand (VoD) content will grow faster than consumer Internet traffic.

[6] "Global IP Traffic Forecast and Methodology, 2006-2011", Cisco Systems Inc

- Peer-to-peer traffic still dominates Internet traffic and growth is not slowing. Instead, it will nearly quadruple, driven by the global increase in high-speed broadband penetration, the increasing use of peer-to-peer for standard-definition video file exchange, and the advent of high-definition video file exchange and television content via peer-to-peer.
- Internet video will account for 30 percent of all consumer Internet traffic. Internet video-to-PC will make up the majority of Internet video at 19 percent of total Internet traffic, but Internet-video-to-TV will grow rapidly to 10 percent of the total.
- Internet video-to-TV will keep increasing by more than a factor of 12. Internet video-to-PC will nearly quintuple over the same period. Internet-enabled set-top boxes are currently available for purchase by consumers, and will be increasingly deployed by IPTV and (later) cable providers. While Internet video-to-PC is dominated by short-form and lower-quality content, video-to-TV traffic will be composed by longer-form and higher-definition content, which means that the far smaller number of video-to-TV streamers and downloads will generate a larger amount of traffic than the greater number of video-to-PC viewers.
- Business Internet traffic will grow fastest in developing markets and Asia-Pacific. North America, Western Europe, and Japan will have slower growth rates. In volume, North America will continue to have the most business IP traffic, followed by Western Europe and Asia-Pacific.

2.2.5 Technologies and standards

EU-MESH network architecture will take for consideration evolving standards for Next Generation Network (NGN) defined by ITU-T, ETSI, and by other standards developing organizations.

In the Next Generation Network (NGN), defined by ITU-T and ETSI, a variety of the existing and new wired/wireless access network technologies are supported, such as WLAN, xDSL, and 2G/3G mobile networks etc., as shown in the figure below. Each of the access networks is connected to the NGN core network (CN), to provide the same set of services for users, preferably independently of the access network type. EU-MESH's focus is on access networks that should be seamlessly integrated with NGN's core network for end-to-end management and control.

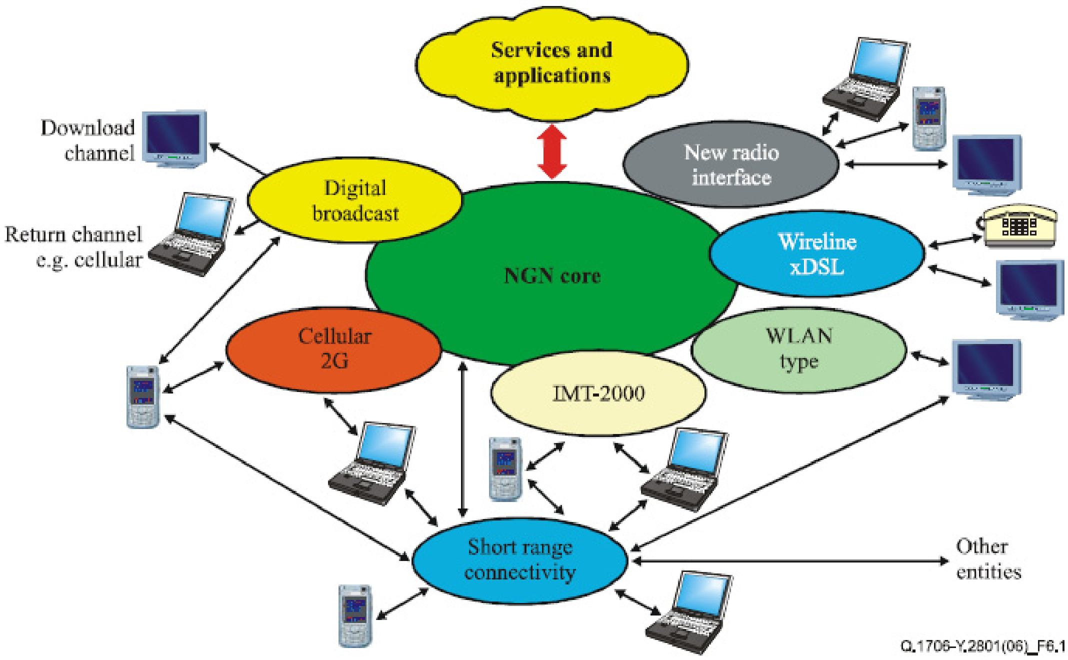

Figure 15 Envisioned network environment of NGN (source ITU-T Q.1706/Y.2801)

It is recognized that new capabilities will need to be developed to enable realization of EU-MESH's vision. These new capabilities and enhancements will be contributed to various standard organizations to promote interoperability and to stimulate market acceptance, thus resulting in lower implementation, operational and maintenance costs.

These management and control capabilities will be built on the base of the existing technologies and architectures to ensure interoperability. Specifically the EU-MESH configuration and management architecture will follow and will be integrated into the NGN architecture defined by ITU-T, as depicted in the figure below.

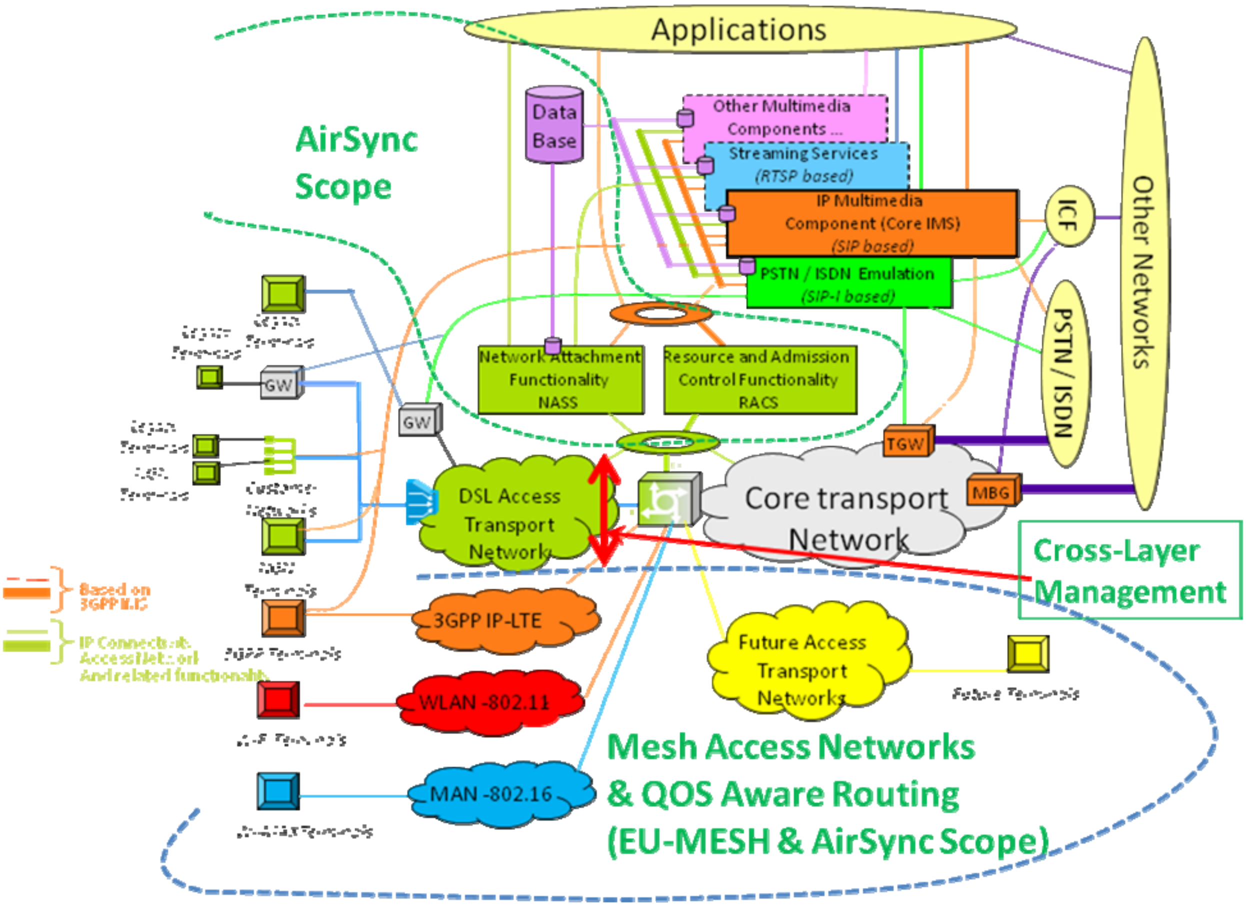

Figure 16 EU-MESH alignment with ITU-T NGN architecture

Within the NGN architecture, the resource and admission control functions (RACF) act as the arbitrator between service control functions (SCF) and transport functions for QoS related transport resource control within access and core networks. The policy decisions made by the RACF are based on transport subscription information, SLAs, network policy rules, service priority, and transport resource status and utilization information. Proximetry's AirSync policy based management system is aligned with ITU-T NGN architecture and capabilities, and it will provide cross-layer management capabilities to the EU-MESH system and QoS-aware routing.

Network attachment control functions (NACF), in the above architecture, provide dynamic provision of IP address and other user equipment configuration parameters, authentication of user access network, prior or during the IP address allocation procedure, authorization of user access network, based on user profiles (e.g., access transport subscription), access network configuration, based on user profiles, location management, and other control functions. It is expected that EU-MESH developed security procedures and mechanism will augment NACF capabilities.

Within the EU-MESH architecture, the RACF functionality should be expanded to provide an abstract view of access network infrastructure to the SCF and makes service providers agnostic to the details of transport facilities such as network topology, connectivity, resource utilization and QoS mechanisms/technology, etc. The RACF will interact with the SCF and transport functions for a variety of applications (e.g., SIP-based calls, video streaming, etc.) that require the control of NGN transport resources, including end-to-end QoS control.

RACF executes policy-based transport resource control upon the request of the SCF, determines transport resource availability, makes admission decisions, and applies controls to transport functions for enforcing the policy decisions. The RACF will interact with transport functions for the purpose of controlling bandwidth reservation and allocation, packet filtering; traffic classification, marking, policing, and priority handling.

RACF will take into account the capabilities of transport/access networks and associated subscription information for subscribers in support of the transport and access resource control. RACF will interact with network attachment control functions (NACF), including network access registration, authentication and authorization, parameter configuration, etc.

Specifically, the existing and emerging standards that will be included (but not limited too) for consideration in the overall architecture and EU-MESH capabilities are listed in Sections 9.1 (ETSI standards) and 9.2 (ITU Recommendations).

Wireless Access Technologies

Traditional wireless access technologies such as 2G and 3G can be considered as legacy technologies. Emerging wireless access technologies are appearing in both Wireless Local Area Networks (WLANs) and Broadband Wireless Access (BWA) networks. The EU-MESH system considers a wireless mesh network for providing access to both fixed and mobile users. Hence, it is not tied to a specific link layer technology. The above technologies will play an important role in the fixed-mobile convergence architecture as discussed in Section 2.2.3

The IEEE standards that should be considered when designing EU-MESH architecture and capabilities for wireless access are listed in Sections 9.3 and 9.4. In order to facilitate a better understanding of scope of each document, a short overview of the most relevant IEEE 802.11 standards and amendments is provided in this section.

IEEE P802.11s/D1.09 Draft STANDARD (March 2008) Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment: Mesh Networking.

This amendment defines an IEEE 802.11 Wireless LAN (WLAN) Mesh using the IEEE 802.11 MAC/PHY layers that supports both individually addressed and group addressed delivery over self-configuring multi-hop topologies. The networks described in this amendment make use of layer-2 mesh path selection and forwarding (that is, a mesh network that performs routing at the link layer). Mesh networks have advantageous properties in terms of robustness, range extension and density, but also have potential challenges such as power consumption and security. This amendment is specifically designed to address these challenges.

This is a key standard amendment that defines wireless mesh LANs. The current Draft (P802.11s/D1.1) has been approved for letter ballot comments. This ballot closes on May 3rd 2008.

This amendment specifies enhancements to the following draft standard and draft amendments, in order to support mesh networking:

- IEEE P802.11-2007
- IEEE P802.11k D11.0
- IEEE P802.11r D9.0
- IEEE P802.11y D7.0
- IEEE P802.11w D5.0

- IEEE P802.11n D3.03
- IEEE P802.11u D1.0
- IEEE P802.11p D3.0

Below is a short description of each above listed standard amendments.

IEEE Std 802.11-2007 [Previously known as P802.11-REVma 9.0) Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

This revision gives users, in one document, the IEEE 802.11 standard for wireless local area networks (WLANS) with all the amendments that have been published to date. The original standard was published in 1999 and reaffirmed in 2003. The following documents have been rolled into this revision and are, therefore, now retired along with the original, reaffirmed edition of IEEE Std 802.11:

1. IEEE Std 802.11a™-1999 (Amendment 1)
2. IEEE Std 802.11b™-1999 (Amendment 2)
3. IEEE Std 802.11b-1999/Corrigendum 1-2001
4. IEEE Std 802.11d™-2001 (Amendment 3)
5. IEEE Std 802.11g™-2003 (Amendment 4)
6. IEEE Std 802.11h™-2003 (Amendment 5)
7. IEEE Std 802.11i™-2004 (Amendment 6)
8. IEEE Std 802.11j™-2004 (Amendment 7)
9. IEEE Std 802.11e™-2005 (Amendment 8)

IEEE P802.11k/D13.0, Draft STANDARD (March 2008), Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 1: Radio Resource Measurement of Wireless LANs

Radio Resource Measurement is a key enabler to the next generation of Wireless Local Area Networks (WLAN). Radio Resource Measurement addresses some of the existing issues in using unlicensed radio environments to meet the requirements of emerging technologies. In addition, Radio Resource Measurement provides knowledge about the radio environment to improve performance and reliability. The following request/report measurements are specified:

- Beacon
- Frame
- Channel Load
- Noise Histogram
- STA Statistics
- Location Configuration Information
- Neighbor Report
- Link Measurement
- Transmit Stream/Category Measurement

IEEE P802.11n/D3.03, Draft STANDARD (Feb 2008), Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 4(# 933): Enhancements for Higher Throughput

This amendment defines modifications to both the 802.11 physical layers (PHY) and the 802.11 Medium Access Control Layer (MAC) so that modes of operation can be enabled that are capable of much higher throughputs, with a maximum throughput of at least 100Mb/s, as measured at the MAC data service access point (SAP).

IEEE P802.11pTM /D3.03, Draft STANDARD (February 2008), Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 9: Wireless Access in Vehicular Environments (WAVE)

This amendment specifies the extensions to IEEE Std 802.11™ for Wireless Local Area Networks providing wireless communications while in a vehicular environment. WAVE is a mode of operation for use by IEEE Std 802.11™ devices in environments where the physical layer properties are rapidly changing and where very short-duration communications exchanges are required. The purpose of this standard is to provide the minimum set of specifications required to ensure interoperability between wireless devices attempting to communicate in potentially rapidly changing communications environments and in situations where transactions must be completed in time frames much shorter than the minimum possible with infrastructure or ad hoc 802.11 networks. In particular, time frames that are shorter than the amount of time required to perform standard authentication and association to join a BSS are accommodated in this amendment.

IEEE P802.11r/D9.0, Draft STANDARD (January 2008), Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 2: Fast BSS Transition

This amendment specifies the extensions to IEEE Std 802.11 for Wireless Local Area Networks providing mechanisms for Fast BSS Transition. The Fast BSS Transition mechanism allows a STA to establish security and/or QoS state at the target AP prior to or during reassociation, avoiding delays in connecting to the DS after transition. The amendment addresses solutions to two classes of network infrastructures from a QoS perspective: one where the transition-enabled AP is willing to provision QoS resources at reassociation time; and another where the AP needs to reserve the network infrastructure resources before transitioning.

IEEE P802.11u/D2.0, Draft STANDARD (January 2008), Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 7: Interworking with External Networks

This amendment specifies enhancements to the 802.11 MAC that support WLAN Interworking with External Networks. It enables higher layer functionalities to provide overall end-to-end solution. Main goals of 802.11u are enabling information transfer from external networks, aiding network selection, and enabling emergency services.

This standard also offers regulatory bodies a means of standardizing access to one or more frequency bands for the purpose of local area communication.

IEEE P802.11v/D2.0, Draft STANDARD (February 2008), Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 9: Wireless Network Management

This amendment provides Wireless Network Management enhancements to the IEEE 802.11

MAC, and PHY, extending radio measurements to effect a complete and coherent upper layer interface for managing IEEE 802.11 devices in wireless networks. In addition to providing information on network conditions, Wireless Network Management also provides a means to exchange location information, provide support for multiple BSSID's on the same wireless infrastructure, more efficient delivery of group addressed frames, and enable a sleep mode in which a STA can sleep for long periods of time without receiving buffered frames from the AP. Specifically, Wireless Network Management service includes:

- BSS Transition Management
- Co-located interference Reporting
- Diagnostic Reporting
- Event reporting
- Location Services
- Maximum Multicast Rate processing
- Multicast Diagnostic reporting
- Multiple BSSIDs
- Proxy ARP
- Sleep Mode
- STA Diagnostics
- TIM Broadcast
- Traffic Filtering Service
- Traffic Generation

IEEE P802.11w/D5.0, Draft STANDARD (February 2008), Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 4: Protected Management Frames

This amendment specifies the extensions to IEEE Std 802.11 for Wireless Local Area Networks providing mechanisms for protecting management frames.

The IEEE 802.11 standard has been used in a wide range of mainstream business and personal applications. The success of products has resulted in an increased dependency of IEEE 802.11 as a primary method for the interconnection of networking equipment. This increased dependence has resulted in a need for increased assurance that the system will not be disrupted by the actions of unauthorized equipment. Such disruption can be caused by malicious systems generating false information and impersonating valid equipment. The current IEEE 802.11 standard addresses security of data frames but systems are still vulnerable to malicious attack because management frames are unprotected. At the same time, there is an increased dependence on management frames as a result of IEEE 802.11 amendments. The purpose of this amendment is to reduce the susceptibility of systems to such attack.

IEEE P802.11.2/D1.01, Draft STANDARD (February 2008), Draft Recommended Practice for the Evaluation of 802.11 Wireless Performance

Recommended practices for evaluating and measuring the performance of IEEE Std 802.11 Wireless Local Area Network (WLAN) devices and networks at the component and application level are described. A set of performance metrics, measurement methodologies and test conditions are provided that enable such measurements to be made and permit prediction of the performance of installed WLAN devices and networks. Three principal usage cases are covered by this recommended practice, as follows

a. data-oriented usage case

b. streaming media usage case

c. latency sensitive (i.e., bidirectional real-time communications) usage case

2.3 Socio-economic trends

Trends of economies and societies have influenced the development of communications, their applications and the level of ICT penetration into customers. Some of the main trends that lead societies towards adoption of broadband services are mentioned within the subsections below.

2.3.1 Globalization

Globalization in literal sense is the process of globalizing, transformation of some things or phenomena into global ones. It can be described as a process by which the people of the world are unified into a single society and functioning together. This process is a combination of economic, technological, socio-cultural and political forces. Globalization, as a term, is very often used to refer to economic globalization, which is the integration of national economies into the international economy through trade, foreign direct investment, capital flows, migration, and spread of technology. The word globalization is also used, in a doctrinal sense to describe the neo-liberal form of economic globalization. Globalization has various aspects which affect the world in several different ways such as industrial, economic, financial, political, cultural, ecological, social, transportation, legal/ethical. Moreover, globalization effects include:

1. *Informational* - increase in information flows between geographically remote locations
2. *Technical* - Development of a global telecommunications infrastructure and greater trans-border data flow, using such technologies as the Internet, communication satellites, submarine fibre optic cable, and wireless telephones
3. *Standardisation* - Development of universal standards are more than necessary in order to assure interoperability and interconnectivity across different technologies. Copyright laws, patents, telecommunication standards, world trade agreements, EU directives, can be considered as major effects of the trend towards globalization and stronger international co-operation.
4. *Competition* - Among other effects, globalization is pushing Small-Medium-Enterprises to compete with wider range of competitor companies, while in the same time it opens the opportunity to address wider markets through the use of modern Internet technology and e-commerce practices. Henceforth, competitiveness and increased quality of products are more than important that ever for business activites to sustain.

2.3.2 Use of Internet for both work and entertainment / leisure

Now, it is the case that Internet penetration has reached very high levels in most EU countries, and it is of great importance that its use is spread across different activities. When advent of Internet started it was mostly used for email and web from home and for business purposes (mostly in big firms). Now it is an enabling tool for SMEs to increase competitiveness, to deploy innovative business scenarios, to address new markets. In order for businesses and citizens to fully realize the importance of broadband technology, there must be compelling reasons for people to use it. Applications such as functional websites, emails, and online citizen services profoundly impact the way a process takes place, and thereby serve to drive demand for the technology. Business use of internet applications to improve efficiency and increase productivity is on the rise across countries worldwide. Additionally, a significantly share of businesses are using the internet for operational applications, such as tracking inventory, controlling and manufacturing process or conducting online meetings, monitoring etc. as well as for promotion and advertising. There is a clear proportionate relationship between growth in GDP and access to information and communications technology.

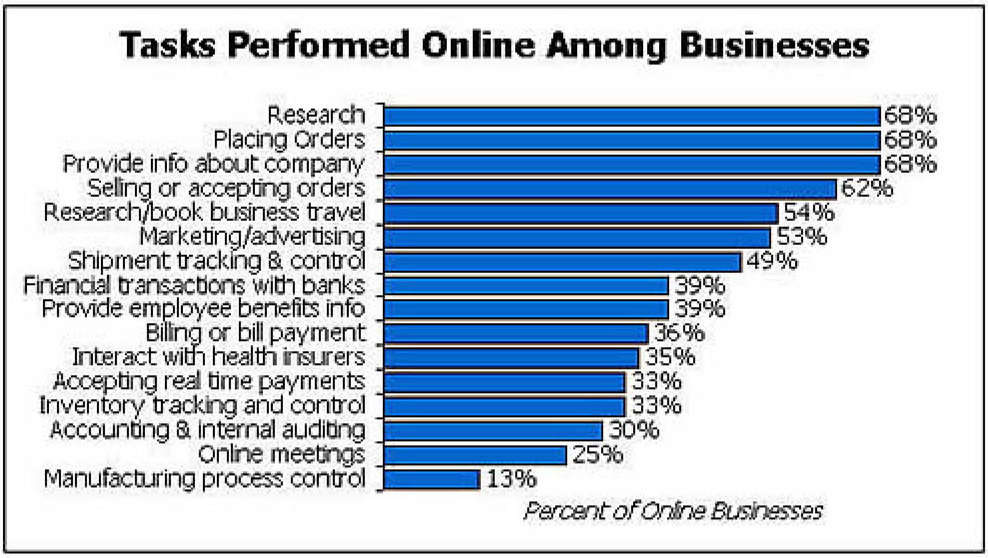

Figure 17 Tasks performed online among businesses

The Internet is used most often by businesses for research, buying selling, and providing the world with general information about the company. Moreover, the reasons for increased Internet usage at homes have changed. Electronic commerce within various domains, e-government and electronic payment facilities, electronic ticketing, entertainment (Video-on-Demand, IPTV, online music, etc), distant learning have changed the role of Internet at homes from surfing in general to specific and targeted usage, and brought the benefit of doing thing without the need to move. Even teleworking, which is enabled via broadband, when normally balanced with the social and family life can bring gains into quality of life. A benefit which is essential for congested urban areas, for distant rural communities and for the environment and the quality of life in general.

2.3.3 Mobile lifestyle

Mobile phones were traditionally designed with the comfort of the ear in mind. If we look at how the market has evolved today, the design requirements are very different because phones are as much about visual activities like texting, email, photos and web pages as they are about the traditional function of voice. When we consider the ratio of screen size versus the overall 'face' area of the device, Over time, displays have come to dominate the main interaction surface of the mobile phone. If one could track this ratio over the lifetime of the mobile industry, it would show a steadily increasing trend, starting with the single line 'dot matrix' displays of the 1980s and rising through to the massive screens of the iPhone, Prada phone, Viewty and HTC Touch.

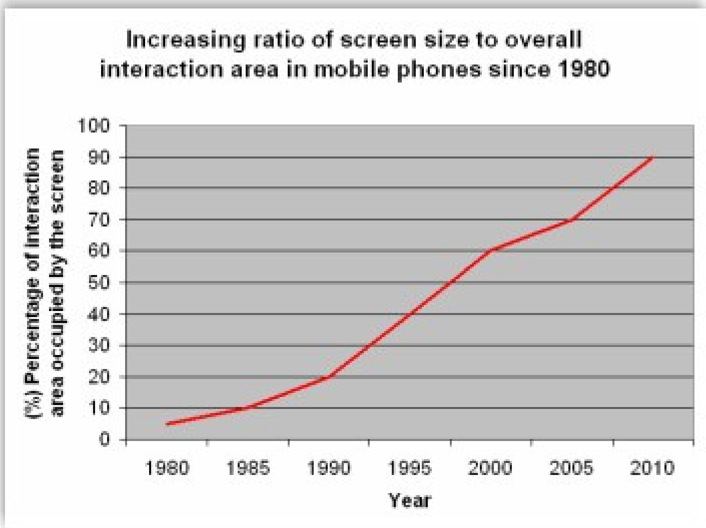

Figure 18 Increasing ratio of screen size in time

The iPhone and its touchscreen have ushered in a boom for the UI design industry. Faced with Apple as a new competitor, rival handset manufacturers are recruiting UI experts as never before. Spurred in to action by the fear of being left behind, management teams throughout the device business are now mandating a selection of touchscreen products in their portfolio. iPhone sales volumes may still be less than a single digit percentage of the market, but there is no doubting the device has established a new design benchmark. This sudden willingness to embrace the touchscreen is providing UI designers with more scope than ever before to create flexible interaction layers which adapt to provide the best interface method for individual applications.

Finally, the role of the mobile device is starting to change. Driven by applications like mapping, music, video and tele-conferencing, the handset is increasingly migrating from our palms and finding a new place in the environment around us. We are starting to see phones attached to the car dashboard or pumping out music from the bookshelf of a teenager's bedroom. They are being propped up on tables so kids can watch videos on holiday and plugged in to TVs to drive photo slideshows. Over time, the average interaction distance between the users and their phones will increase significantly from the few centimetres we see today. Interaction designers can no longer take it for granted that the user will be holding the device in their hand, with their face close to the screen.

The industry faces a real and complex challenge over the next few years. On the one hand, device manufacturers must grapple with the immediate competitive implications of the iPhone and the growth in touchscreen devices. On the other, companies throughout the industry are seeking to expand the role of the phone into every area of our daily lives, including many scenarios where the handset will actually no longer be held in our hands.

So it is sure, that the mobile lifestyle and fashion will continue, though services that will be available, will not be mostly oriented only to the teenagers, but will also serve the needs of in-vehicle activities, of the tourist, distant learning, tele-working and many other social activities. *In this context, wireless ubiquity and new handsets (iPhone…) can have an effect on separation between work and personal life: the "anywhere, anytime" culture wireless technologies are spawning, hit the differentiation between work and personal life.*

2.3.4 Impact of broadband on quality of life

Broadband and its associated technologies go far beyond economic development. Broadband technology and integrated community networks enable a richer quality of life for the public through enhanced education, improved health care, more efficient and democratic government, and instant connection across the country and around the globe. Hospitals can use broadband to connect doctors to each other, within their community, and across the world, to serve patients better. Schools use broadband to create distance learning programmes for students in rural areas and for those with physical limitations. Government uses broadband to offer licence renewal, from the comfort of a citizen's home or office. Broadband enables citizens to foster closer relationships from city to city and across the world through email, radio, online chatting, personal websites, online photographs, video streaming, and countless other ways. Providing access to broadband technology through infrastructure build-out is the first step for a community in progression toward realizing the benefits of broadband deployment. In most large communities within Europe, the adoption of broadband is on pace with the colour TV.

2.3.5 Digital divide

While numbers can be promising signs of technological advancement, the situation is not uniformly spread. The disparity in the availability of broadband service between urban and rural geographic areas is significant, or between countries. However, governments have embarked ambitious projects of increasing the availability of an internet broadband infrastructure to the rural communities. International policies are also encouraging and funding activities for rural broadband facilities to serve telemedicine and tele-education projects, as well as show benefits of broadband access to low-developed countries. So, digital divide is a socioeconomic fact that is being addressed by various policies and initiatives as well as technologies that enable cheaper and more flexible network deployments.

Bridging the digital divide has long been at the top of every socioeconomic development agenda, and an increasing number of studies and reports are confirming that universal access to mobile communications is the most effective way to achieve it. Many governments have realized how important access to mobile technology is to their citizens. In India, for example, the universal access policy has been backed up with financial support for mobile telephony infrastructure. People in Asian, African and Latin American countries are all looking into how mobility can be used to reduce poverty and how they can use mobility to go beyond their traditional challenges and provide access to information for all. It is part of a sincere quest for a more equal society.

2.3.6 E-Commerce

In terms of citizens using the internet for purchasing, EU citizens have been fairly consistent over the past several years, resulting in billions of euros being spent over the internet. Clearly, online shopping is continuing to exemplify one of the most popular web-based applications. Without broadband technology, online shopping can be an agonizingly slow process. Electronic commerce can be considered as an important economic factor, bringing new opportunities for small companies to address bigger markets and internationalize their products and services.

2.3.7 E-Government

Online delivery of public services to the citizens and the business is reaching an increasing level across EU countries. The most important anticipated benefits of e-government include improved efficiency, convenience, and better accessibility of public services. There are many considerations and potential implications of implementing and designing e-government, including disintermediation of the government and its citizens, impacts on economic, social, and political factors, and disturbances to the *status quo* in these areas. Though policies are favouring the advancement of e-government methods in all interfaces of the public, it has been recorded that public online service for business are still much more developed than those for citizens. Therefore, attention within EU should be paid into developing further the level and coverage of electronic services into areas that improve quality of service, increase speed of procedures where interaction of the citizen with the public is necessary. For instance, in many countries, it has been monitored that electronic services for collection of taxes have been well advanced while services for registrations and permits have ot reached the same level. In countries such as the United Kingdom, there is interest in using electronic government to re-engage citizens with the political process. In particular, this has taken the form of experiments with electronic voting, aiming to increase voter turnout by making voting easy. The UK Electoral Commission has undertaken several pilots, though concern has been expressed about the potential for fraud with some electronic voting methods. While the situation of e-government practices differ from country to country, it is globally recognised that from year to year, more services will be available online and as Internet users are becoming more and broadband access cheaper, e-government will penetrate the volume of transactions in the future and gear the efficiency of public service organisations.

2.3.8 Increased mobility

Apart from mobile lifestyle, life itself has increased needs for mobility. Increase of trade and tourism as well as globalization increases mobility and transportation needs. In that context, and having fixed broadband access as a main tool for business and leisure activities, it is desirable to reach seamless level of broadband availability and quality within the mobile part of the user experience.

2.3.9 Criminality increase

While criminality seems to increase in various regions and countries, a sense of security, as well as practical means to monitor and guarantee safety, must be well adopted into the everyday life of people. Broadband technologies seem to provide useful application that respond to such need.

3. SERVICES AND APPLICATIONS

3.1 Service and application categories

Next we present a categorization of services and application based on some common features. Our categorization is a superset of the user-perspective QoS classes identified in [ITU-R M.1079-2], [ITU-R M.1822], [3GPP TS 23.107] (equivalent to [ETSI TS 123 107]), which differentiates classes based on how delay sensitive the corresponding application is, Table 2. Moreover, the ETSI NGN (Next Generation Network) QoS framework is based on [ETSI TS 123 107] (equivalent to [3GPP TS 23.107]), and a review of the IMT-2000 QoS class framework and other proposals is contained in [ETSI TR 102 479].

QoS class of service	Conversational class of service Real-time conversation	Interactive class of service Interactive best effort	Streaming class of service Real-time streaming	Background class of service Background best effort
Fundamental characteristics from the user perspective	– Preserve time relation (variation) between information entities of the stream – Conversational pattern (stringent and low delay)	– Request response pattern – Preserve payload content	– Preserve time relation (variation) between information entities of the stream	– Destination is not expecting the data within a certain time – Preserve payload content
Example of the application	– Voice	– Web browsing	– Streaming video	– Background download of e-mails

Table 2 IMT-2000 QoS classes from a user perspective

A short description of the various QoS classes follows:

- Conversational class: This involves real-time communication between peers (or groups) of live (human) end-users. The communication can involve audio, video, or text. This class has the most stringent requirements in terms of end-to-end delay.
- Interactive class: This involves the online requesting of data from an end-user (human or machine) to a remote server. The primary performance metric for this class is the response time.
- Streaming class: This involves real-time transmission audio or video streams to end-users, which are assumed to be human. The main performance metric for this class is the delay variation of the transmitted traffic.
- Background class: This involves the transmission of data in the background. This class does not impose any requirements in terms of delay.

The categorization presented below, firstly differentiates basic Internet services, and includes new services/application categories, namely multimedia sharing and context-based information services, which are expected to play a significant role in emerging ubiquitous broadband access networks.

- Basic Internet services
    - Web browsing
    - Email, multimedia messaging (transmission of messages that include multimedia objects - images, audio, video, rich text - and not just text as in Short Message Service - SMS)
    - File transfer
    - Telnet
- Conversational services
    - VoIP, video-telephony
    - Tele/video-conferencing
    - Instant Messaging (IM): Real-time communication between two or more people based on typed text.
    - Online chating: includes Internet Relay Chat (IRC), online forums/virtual communities, social networking
- Streaming services
    - IPTV: Transmission of digital television over an IP network infrastructure.
    - Mobile TV: Transmission of TV content to mobile devices.
    - Interactive TV: Transmission of TV over an IP network with the support of a direct feedback channel from the users/viewers to the operator. This feedback can be used for voting, sending messages, etc.
    - Internet radio: Transmission of radio broadcasts over an IP network.
    - VoD (Video on Demand) SD (Standard Definition)/HD (High Definition): Transmission of user-selected video content.
    - On-demand streaming media – MoD (Media on Demand): Transmission of user-selected multimedia content, such as music and video clips.
    - Video surveillance: Transmission of video signals to monitor and record for security purposes.
- Interactive services
    - Interactive gaming: Involves data transfer between multiple users and a server, or directly among multiple users. A subcategory termed real-time gaming (e.g., first person shooter) will have stricter delay requirements.
    - Voice mail/messaging.
    - Collaborative working: Includes application sharing, collaborative workspace and document management, etc.
    - ASP services: server-based execution of word processors, spreadsheets, ERP, etc
    - E-commerce: Involves client-server communication for buying and selling products and services.
    - Control of remote devices
- Multimedia sharing
    - Peer-to-peer file sharing: Sharing of files according to the peer-to-peer (P2P) model, where users both consume (download) and provide (upload) files.
    - User-created content sharing: Communication of users with the network (e.g., to a server) in order to share multimedia content (photo, video, audio).
- Context-based information services (context: location, presence, profile, behavior, etc)
    - Location-based multimedia broadcast: One-way location-based broadcasting of local news, travel information, advertisement, etc.

- Location-based interactive multimedia: Transmission of multimedia content that also involves user feedback.
- Location-based on demand services: On demand transmission of information such as service discovery, positioning, travel directions, localized maps
- Presence-based applications: user/device tracking
- Alert/notification, advertisement services
- Personalized content: information based on user profile and behaviour

The above characterization is of course not unique; Services can also be categorized in terms of other features, such as real-time/non-real-time, user-generated/server-generated content, and symmetric/asymmetric requirements for downlink and uplink. Additionally, there is no strict differentiation between categories: for example, web browsing can be considered an interactive service.

Innovative services and applications which can benefit from the EU-MESH system include the following:

- Multimedia sharing applications which involve sharing of user-created content. Such applications require high uplink throughput, and ubiquitous broadband access.
- Seamless service delivery across different access technologies: The EU-MESH system involves integration of wireless with wired infrastructures, thus provides benefits in this direction.
- Increased mobility: EU-MESH targets at supporting seamless mobility through application-layer mechanisms, in multi-operator environments while guaranteeing the required QoS.
- Context-dependence: Such services can benefit from the EU-MESH system, through support of ubiquitous broadband access services for both fixed and mobile users.

In addition to the above, all services and applications can benefit from the EU-MESH system in terms of reduced cost, enhanced availability and coverage, and enhanced reliability and security.

3.2 Service and application requirements

The major groups of applications in terms of QoS requirements are shown in the following table [ITU-R M.1079-2]:

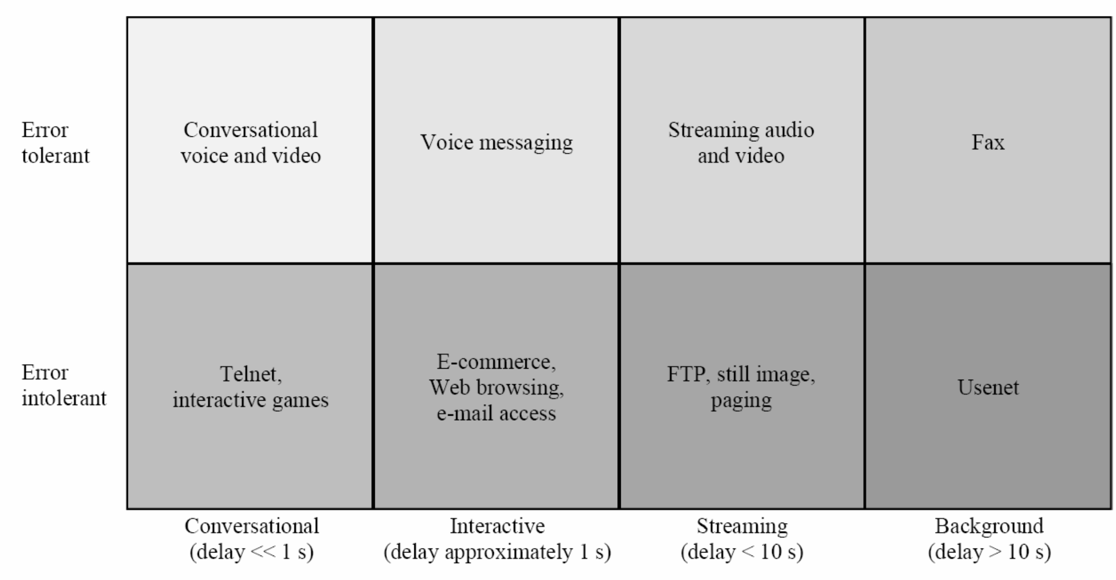

Figure 19 Major application groups in terms of QoS requirements

The table below identifies the requirements for the services and applications identified in the previous section. The requirements for a subset of the services are based on [ITU-R M.1079-2], [3GPP TS 22.105], whose key performance parameters are aligned with [ITU-T G.1010].

Services/ Applications	Downlink/ uplink traffic ratio	Downlink speed	Uplink speed	Interactive	Performance parameters			Location-dependence	Transmission mode
					One-way delay	Delay variation	Loss ratio		
Basic Internet Services									
Web browsing	>>1	>500 kbps	4-25 kbps	Yes	<2s/page (acceptable <4s/page)		0%	No	Unicast
Email	1	>500 kbps	>500 kbps	No	<2s (acceptable <4s)		0%	No	Unicast
File transfer	>>1	>1Mbps	4-25 kbps	Yes	<15s (acceptable <60s)		0%	No	Unicast
Telnet	1	4-25 kbps	4-25 kbps	Yes	<250 ms		0%	No	Unicast
Conversational Services									
VoIP, tele-conferencing	1	30-50 kbps	30-50 kbps	Yes	< 150ms (limit <400ms)	<1ms	<3%	No	Unicast/ multicast
Video-telephony/ video-conferencing	1	32-384 kbps	32-384 kbps	Yes	< 150ms (limit <400ms)	<1ms	<1%	No	Unicast/ multicast
Instant messaging (IM)	1	4-25 kbps	4-25 kbps	Yes	<250 ms		0%	No	Unicast
Online chating	1	4-25 kbps	4-25 kbps	Yes	<250 ms		0%	No	Unicast

Streaming Services									
IPTV	>>1	1-3 Mbps		No	<10s	<2ms	<1%	No	Broadcast
Mobile TV	>>1	28-512 kbps		No	<10s	<2ms	<1%	No	Broadcast
VoD (SD)	>>1	1-3 Mbps	<8 kbps	Yes	<10s	<2ms	<1%	No	Unicast
VoD (HD)	>>1	6-10 Mbps	<8 kbps	Yes	<10s	<2ms	<1%	No	Unicast
On-demand streaming media (MoD)	>>1	32-384 kbps	<8 kbps	Yes	<10s	<2ms	<1%	No	Unicast
Internet radio	>>1	16-64 kbps			<10s	<2ms	<1%	No	Broadcast
Video surveillance	>>1	32-384 kbps	<8 kbps	Yes	<2s	<2ms	<1%	No	Unicast
Interactive Services									
Interactive gaming	1	4-25 kbps	4-25 kbps	Yes	<250ms		0%	No	Unicast
Real-time gaming	1	32-64 kbps	32-64 kbps	Yes	<75ms		0%	No	Unicast
Voice mail	1	30-50 kbps	4-25 kbps	Yes	<2s		<3%	No	Unicast
Collaborative working	>>1	>500 kbps	4-25 kbps	Yes	<2s/transact.		0%	No	Unicast
ASP services	>>1	>500 kbps	4-25 kbps	Yes	<2s/transact.		0%	No	Unicast
E-commerce	>>1	>500 kbps	4-25 kbps	Yes	<2s/transact.		0%	No	Unicast
Control of remote devices	1	<28 kbps	<28 kbps	Yes	<10s		0%	No	Unicast
Multimedia Sharing									
Peer-to-peer file sharing	1	>500 kbps	>500 kbps	Yes	<15s (acceptable <60s)		0%	No	Unicast
User-created content sharing	<1	32-64 kbps	>500 kbps	Yes	<2s/upload		0%	No	Unicast
Context-based Information Services									
Location-based multimedia broadcast	>>1	32-384 kbps		No	<10s		<1%	Yes	Broadcast
Location-based interactive multimedia	>>1	32-384 kbps	<8 kbps	Yes	<10s			Yes	Unicast
Location-based on demand services	>>1	32-384 kbps	<8 kbps	Yes	<10s		<1%	Yes	Unicast
Alert/notification, advertisement services	>>1	<28 kbps		No	<10s		0%	Yes	Multicast
Presence-based applications	>>1	<28 kbps	<28 kbps	Yes	<10s		0%	Yes	Unicast
Personalized content	>>1	32-64 kbps	<8 kbps	Yes			0%	Yes	Unicast

Table 3 Requirements for services and applications

Mobility requirements

Related to mobility, the original IMT 2000 minimum requirements were the following:

- Vehicular high-speed: 144 kbps
- Medium-speed: 384 kbps
- Indoor, low-speed: 2.048 Mbps

Current technology has surpassed the above, and the target for IMT-Advanced (4G) technologies for deployment after 2010 are the following [ITU-R M.1645]:

- High-mobility: 100 Mbps
- Low-mobility: 1 Gbps

4. USER CLASSES AND GAINS

4.1 User classes

Requirements do not depend solely on the service/application performance requirements, but also on the specific characteristics of user classes (or groups), as well as the usage of the particular service/application. Depending on user class and usage, there can exist a different tradeoff between cost, security, mobility, and performance. This is further motivated by the high interest for personalized and location-dependent services, but also the exploitation of new revenue streams through satisfaction of the needs of particular (niece) user groups, and even individual users.

The boundary between user classes is not strict, and is becoming increasingly blurred as the need for mobility increases, and as technology convergence enables new markets and new habits. The following table illustrates various groups of users, according to different categorization criteria.

Users Grouped By	Groups Identified
Type of Customer	Home/residential Business users (individual) Private organizations: o SOHO (Small Office Home Office) o SME o Large enterprises Public organizations Value added service providers
Usage Type	Fixed: single location. Connection through an outdoor or indoor CPE Mobile: vehicular speeds. Connection through a wireless interface located on the end-user device Nomadic (also referred to as “portable” mode): stationary or moving at pedestrian speeds. Connection through a wireless interface on the end-user device
Type of Device	Laptop PDA Smartphone Set-top-Box Personal Computer Smart Objects (*like SPYKE Robot from Meccano with M2M*) Standard Phones with WiFi/WiMAX/3G functionality
Purpose of Usage	Business Critical – business, telephone calls, monitoring, security sensitive Entertainment – IPTV, VoD Leisure – Web surfing, tourism guidance Learning – mobile learning Medical – telemedicine application Social Communication – audio/video calls, multimedia sharing
Type of Traffic	See Table 3

Table 4 User classes

Of course, users can be also classified according to other criteria, such as gender, age, average income or other elements of his/her personal profile. However, this categorization is more relevant to the needs for an analysis of behaviours and habits of broadband users. In the EU-MESH case, user classification is mainly necessary in order to:

- *Identify user needs in various contexts* – For instance, the needs of a user on the move are very different from that of a stationary/indoor user. Moreover, business usage imposes different needs than home usage. EU-MESH, as a technology for both indoor and outdoor access, should consider the various contexts of usage and types of users, in order to address their current and emerging needs and requirements.
- *Identify difficulties in broadband adoption* – User classification into urban, suburban and rural areas is important, as the wireless mesh architecture approach influences the level of the investments that are necessary in order to increase network coverage across these areas. In many countries, rural and suburban areas are facing significant difficulties and delays in developing broadband access networks. New technologies such as EU-MESH should be competitive in terms of deployment and maintenance cost, in order to address the digital-divide across areas and countries.

Depending on usage type, a user can select a different tradeoff between cost, security, mobility, and performance. This leads to the requirement for personalization of services. Usage types will be further utilized in the context of usage scenarios. High level user requirements are the following.

- QoS
- Service reliability and availability
- Operation friendliness and ease-of-use (convenience)
- Low cost/Affordability
- Security & privacy
- Uniform access anytime, anywhere (ubiquitous service availability and seamless service delivery), and from any device over different wired and wireless access technologies
- Full range of services – one contract/bill (one-stop shop)
- Localization
- Personalization
- Device awareness

4.2 User class gains

In this section we discuss the potential benefits (social and economic) of the various user classes that can be achieved by the EU-MESH system.

Operators & Policy makers gain

As discussed above, the EU-MESH system proposes a cost-effective way for delivering broadband access to all. There is already a push from some stakeholders for national governments to fund high-speed access to all homes and business premises. The belief is that such investment will lead to greater economic wealth and social fulfilment - and if not acted upon soon, some of the opportunities, especially related to industrial competitiveness, will be either lost or not exploited to the fullest extent. However, high-speed broadband investment, such as deployment of fibre, can run into billions of euros, and the real benefits can be hard to quantify and prove.

Addressing the digital divide across areas

In addition to the direct benefits of broadband access, the indirect socio-economic benefits of broadband access are equally significant. Increased competitiveness, greater attractiveness to foreign investment, greater use of e-services such as e-government, e-health, e-education and tele-working all bring economic and/or social benefits to a country. Such benefits can often only be maximised through extensive broadband coverage and availability. A US Department of Commerce study in 2006 determined several positive effects of broadband, including growth in employment levels and business establishments. Interestingly, it also found that weaker economic regions were just as likely to benefit from having access to broadband, while in some cases the positive impacts were greater. However, there are still large sections of any country that cannot get or believe they do not want/need broadband access. Addressing such unbalance is among any government's prime objective. Within this context, EU-MESH addresses the issue of easiness to reach adequate coverage in both urban/suburban and rural areas. Furthermore, it brings gains to the providers who are interested to expand their reach ability and markets, through the provision of services to both stationary and mobile users. EU-MESH enables providers to bypass lack of necessary wired infrastructure in certain areas, and expand their service area and their target markets. To make the most out of the benefits of broadband, it is important to bring it to all inhabitants of a country. The advantage of wireless technology is that it is often the only way to quickly and cost-effectively reach those in rural areas or areas with little or no fixed infrastructure.

Services towards improved quality of life, security and growth

As EU-MESH raises the uplink speed limits, it brings broadband connectivity to a symmetric level, which enables user-generated content applications to reach an acceptable level of performance. These applications enable applications such as remote surveillance, tele-working, tele-conferencing, and social networking to become more popular. Such applications address the socio-economic need for improved quality of life and security. Moreover, broadband improves many aspects of our daily lives, providing access to healthcare and education, as well as information and entertainment. It stimulates entrepreneurial activities, facilitates industrial growth, and can enable a more sustainable society. If broadband is to be enabled for everyone, then combining existing fixed broadband with wireless technology can achieve this goal in an efficient manner.

Affordability and value for money

When a market becomes bigger, and the deployment of wireless access becomes even more cost-effective, and users can further improve performance due to economies of scale. EU-MESH is aligned to this goal, which is to bring cost-effective broadband access to a wider scale.

Mobility supports quality of life and business

EU-MESH is empowering the capabilities of broadband mobile networks, contributing to the gains achieved through the extensive usage of broadband access within nomadic and mobile usage scenarios. People who get connected to mobile communications obtain gains (sometimes location and context-based) that is not available as quickly or dependably by any other means. Farmers and fishermen with mobile phones can use mobile technology to find out the current prices for their crops. This influences the autonomy of their business enormously, as they can effectively increase their bargaining power with the middlemen and make sure the crops are sold at a fairer price. Tourists can have location-based guidance within an urban environment. Other areas where mobile broadband provides information include healthcare and personal security, though these do not form the most obvious benefits of mobility. It becomes possible to call a doctor or relative in an emergency, something that is taken for granted in developed countries. Some clinics have also set up automatic SMS systems to send reminder messages to patients when they need to take their medicine, ensuring more effective treatment of ailments. Meanwhile, citizens who live in less secure areas - or areas prone to natural disasters - can also obtain through ubiquitous and dependable broadband access..

A seamless network with no boundaries

As broadband technologies are advancing and operators are developing new methods and new products/services for fixed and mobile broadband, interoperability and seamless networking is the most important features that will assure user complacency within a wide environment. EU-MESH is addressing the multi-provider seamless connectivity, based on advanced hand-over techniques, so that the user can gain a unified networking environment with less boundaries. Seamless access for wireless connectivity can provide

- secure access, as it uses recognized security standards,
- simpler access, as it provides a common, easy to use login scenarios, and
- seamless access as it support carrier roaming agreements and potential one-bill service.

The advantages of technologies such as EU-MESH, that enable a seamless network environment inside home, business and at the mobile environment, are set to drive broadband to a true global mass market - and turn millions of users into billions.

Efficient spectrum management is a factor of economy

To deliver the full potential of mobile broadband and enable true wide-area mobility in a cost-effective manner, sufficient radio spectrum needs to be allocated. Once globally harmonised, technology and standards then need to be selected. When technologies reduce interference, spectrum management becomes easier and spectrum can be efficiently utilized. EU-MESH aims to reduce interference through algorithms that combine channel access with power and channel control. Though a technological gain, it can be considered also as an economic one, as spectrum management can gear mobile broadband business opportunities. It is estimated that by 2010 more traffic will be generated by data services than by voice in mobile networks. The unprecedented demand for mobile-broadband services means additional radio spectrum is going to be critical. The International Telecommunication Union estimates that around 700 - 1200 MHz of additional spectrum is needed to handle public mobile-broadband services up to 2020, meaning that current levels of available radio spectrum need to be doubled or almost tripled.

To summarize, the following user classes can gain benefits through the EU-MESH system:

a. *home users* – broader coverage, cost-effective services, seamless and high quality service
b. *business users and SMEs* – broader coverage, cost-effective services, seamless and qualitative service
c. *tourists and mobile users* – innovative location based services, seamless roaming across different providers
d. *network providers* – cost effective network deployment and operation, expanded market range, efficient spectrum management, competitive QoS.

5. USAGE SCENARIOS

This section describes usage scenarios that involve services and applications provided over the EU-MESH system. Each scenario can involve more than one service or application, while each scenario demonstrates one or more of the advantages of the EU-MESH system.

5.1 Usage scenario template

Each scenario is described using a template that includes the following fields:

- Title
- Description
- Application and services used
- User type
- Usage type
- Requirements

The following template will be used hereinafter for concisely describing each usage scenario. In the next subsection, following the concise description of the scenarios, we discuss each scenario in more detail.

Title of Scenario	Short Title
Description	One paragraph overview of the scenario
Applications & Services used	Services and applications that are used within the scenario
User Type	home/business/other
Type of Usage	fixed/nomadic/mobile
Requirements	Main user and network provider requirements necessary to support the application and usage

Table 5 Scenario template

5.2 Usage scenarios

5.2.1 Overview of the usage scenarios

We consider the following eight usage scenarios:

1. Mobile business user
2. Nomadic business user
3. Gaming user
4. Home user – leisure activity
5. Home user – entertainment activity
6. Tourist / attraction visitor
7. Video surveillance – home monitoring
8. Mobile commerce

The above eight usage scenarios are summarized in the tables below.

Title of Scenario	**Mobile Business User**
Description	A business user who is on the move, either in a car, walking, or in a train, utilizes his device and the available broadband access in order to access corporate data, work remotely, receive and send email, receive news, as well as make phone calls and conferences with colleagues at the office.
Applications & Services used	VoIP, real-time and streaming audio, e-commerce transactions, web/mail/corporate intranet access
User Type	Business
Type of Usage	Mobile
Requirements	Efficient and scalable QoS, tsecure and fast handoff, re-authentication during handover, virtual private networking, reliability/availability, cost effectiveness

Table 6 Mobile business user scenario

Title of Scenario	**Nomadic Business User**
Description	A business user who is moving from place to place, at intermediate stops utilizes broadband access in order to access corporate data, work remotely, receive and send email, receive news and watch video, and make audio/video-conferences with colleagues at the office.
Applications & Services used	VoIP, real-time audio / video, e-commerce transactions, streaming audio and video, web/mail/corporate intranet access
User Type	Business
Type of Usage	Nomadic
Requirements	Efficient and scalable QoS, high-speed access, virtual private networking, reliability/availability, cost effectiveness

Table 7 Nomadic business user scenario

Title of Scenario	**Online Gaming User**
Description	This involves a user playing online games. The user can be stationary, playing for example at home, or nomadic, playing from different locations.
Applications & Services used	Online games, real-time audio / video, e-commerce transactions, peer-to-peer communication

User Type	Gamer
Type of Usage	Fixed, Nomadic
Requirements	High downlink/uplink rates, predictable QoS, delay and jitter constraints

Table 8 Gaming user scenario

Title of Scenario	**Fixed Home User - Leisure Activity**
Description	This is the case of a typical Internet user sending/receiving mails, searching the web, and conducting e-commerce/e-government transactions. A more advanced home user can access more demanding services such as VoIP, multimedia content sharing, peer-to-peer file sharing, participation in online communities and other, tele-working
Applications & Services used	Web, email, VoIP, p2p
User Type	Home
Type of Usage	Fixed
Requirements	High downlink/uplink rates, predictable QoS, cost-effective service

Table 9 Fixed home user – leisure activity scenario

Title of Scenario	**Fixed Home User – Entertainment Activity**
Description	The same fixed home user, possibly through a set-top-box, watches on-demand audio/video content or real-time TV broadcasts. The user has various functionalities available related to catch-up TV, time-shifted programmes, subscription packages, etc.
Applications & Services used	IPTV, Video/Music On Demand
User Type	Home
Type of Usage	Fixed
Requirements	real-time and predictable QoS, SLA, high downlink rates, cost-effective service

Table 10 Fixed home user – entertainment activity scenario

Title of Scenario	**Tourist / Attraction Visitor**
Description	A visitor/tourist receives on his mobile device information related to his current location. Such information can include guidance, weather, local advertisements, discovery of people/places of interest, etc.
Applications & Services used	Web/weather/traffic information, location-based information services, RRS feeding, proximity-based alerting, routing guidance
User Type	Tourist, citizen
Type of Usage	Mobile, nomadic
Requirements	Location awareness, high availability and coverage, personalized services, cost effectiveness, seamless QoS, easy access

Table 11 Tourist / attraction visitor scenario

Title of Scenario	**Video Surveillance / Home Monitoring**
Description	Owners of multiple buildings use video surveillance technology in order to monitor all floors and rooms of the various buildings. Monitoring is necessary from various points including parts of the building, at home and outdoor.
Applications & Services used	Surveillance applications, streaming video, image frame transfer, VoIP
User Type	Premises Owner / Security Company Provider
Type of Usage	Nomadic
Requirements	Low setup and maintenance cost, high downlink/uplink bandwidth, indoor/outdoor mobility, high coverage

Table 12 Video surveillance / home monitoring scenario

Title of Scenario	**Mobile Commerce**
Description	M-commerce refers to a set of applications offered to mobile users that allow them to buy goods and services via wireless access
Applications & Services used	Electronic purchase of tickets, goods, local merchant payments, stock trading, local information services
User Type	Business, mobile/nomadic tourist, visitor
Type of Usage	Mobile, nomadic
Requirements	Privacy, mobility, efficiency, scalable QoS, secure and fast

	handoff, re-authentication during handover, virtual private networking, reliability/availability, cost effectiveness

Table 13 Mobile commerce scenario

5.2.2 Mobile business user scenario

The Mobile business user scenario involves access to services and applications by business users that are on the move. According to the ITU definition, user mobility refers to the ability of a user to maintain the same user identity irrespective of the terminal used and its network point of attachment. The key characteristic from the user point of view is seamless mobility; the user/terminal is able to change the network access point, as he/it moves, without interrupting the current service session, i.e. handovers are possible.

In the "mobile usage" case, the user is moving at a pedestrian/vehicular/train speed and has active service sessions. We can distinguish the pedestrian/vehicular case from the train case. In the first situation, as they cannot pay too much attention to the mobile device, the users can use their smart-phones or PDAs for making VoIP calls or for accessing streaming audio from anywhere, and any time. In the second case, as they can work while moving, users can use their laptops (smart-phones or PDA as well) for accessing not only the previous services but also a full range of corporate services and information, or for running real time multimedia application (video and audio). Consequently, employees, partners, suppliers and customers gain the ability to access or update critical data and complete commercial transactions through wireless devices.

The network requirements derived from this scenario are:

- Efficient and scalable QoS support. This includes prioritization, controlled jitter and latency and improved loss packets for voice and multimedia traffic.
- Network traffic monitoring and tuning to provide the requested Quality of Service by an estimation of the network's load.
- Mechanisms for secure and fast handoffs between heterogeneous networks and different operators.
- Mechanisms for (automatic) re-authentication during handover. This requirement applies particularly to the VPN services scenario.
- Reliability/availability. The system should be able to adapt to varying network conditions and should provide security mechanisms to ensure high reliability and availability.
- Scalability.
- Cost effectiveness.

EU-MESH benefits for mobile use are mentioned below:

- EU-MESH shall provide enough bandwidth to allow smooth service delivery, with strong delay and jitter constraints (especially for VoIP).
- Cost effectiveness
- Fast and effective handover:
    - within the same access technology (like a Wifi network using the same backhaul)
    - within a network using different kind of technology access (like 3GPP / Wifi roaming).

5.2.3 Nomadic business user scenario

Nomadic business users are people moving from place to place, that require information exchange and communication services available for business purposes when they stop moving. In this case, they have to suspend an application or a session and resume it when they connect at a new access point.

Whilst nomadic business users increasingly need access to their corporate networks, it is the small and medium sized businesses that recognise the immediate benefit. Many of these businesses are either being operated from home, or are businesses with customers, premises and collaborators in multiple urban locations.

The network requirements derived from this scenario are listed below:

- Efficient and scalable QoS support. This includes prioritization, controlled jitter and latency and improved loss packets for voice and multimedia traffic.
- Network traffic monitoring and tuning to provide the requested Quality of Service by an estimation of the network's load.
- Mechanisms for fast (automatic) re-authentication between different operators. This requirement applies particularly to the VPN services scenario.
- Reliability/availability. The system should be able to adapt to varying network conditions and should provide security mechanisms to ensure high reliability and availability.
- Scalability.
- Cost effectiveness.

EU-MESH benefits for nomadic use are the following:

- EU-MESH shall provide enough bandwidth to allow smooth service delivery, with strong delay and jitter constraints (especially for VoIP).
- Cost effectiveness.
- Network service delivery equivalent to a fixed business user.

5.2.4 Gaming user scenario

Online games are played over some form of computer network, typically on the Internet. Online gaming offers the ability to play against human opponents (multiplayer games), although single-player online games are quite common as well.

Different genres of online games exist, the most common being:

- First person shooter games
- Real-time strategy games
- Massively multiplayer games, including role playing games, social games etc.

Cross platform online games are also possible, allowing users of different kind of platforms (Xbox, PS2, DS, PC…) to connect to the game.

Users playing online games need a broadband connection with adequate throughput, low latency and jitter. A typical online gamer using EU-MESH would be:

- playing at home (fixed home user).

- playing at another place (at school, in a restaurant/bar, at some friend's place), hence being a nomadic user.

The network requirements derived from this scenario are:

- low delay and low jitter
- higher uplink rates
- predictable QoS

Through EU-MESH, the main advantages are:

- ability to play efficiently due to adequate throughput and low delays
- provision of high uplink rates
- network service delivery equivalent to a home gamer

Additionally, wireless mesh networking supporting geo-localisation services, could support novel forms of gaming such as playing with/against locally connected players.

5.2.5 Fixed home user – leisure activity scenario

EU-MESH can serve the typical needs of the Internet user at home. However, usage at home can differ from case to case, based on the different needs and habits of each specific user. The average low usage level is that of the occasional user who sends and receives mails as well as browses the web and sometimes concludes e-commerce or e-government transactions. And this does not happen necessarily on a daily basis. On the other side, an advanced user has increased requirements in terms of performance and traffic load. The services he is using go far beyond the web, and include Voice over IP telephony, sharing of multimedia content, peer-to-peer, participation into online communities etc. To be more specific, we assume the following user scenario:

- The user arrives home after a vacation. As soon as he enters his apartment, his mobile phone switches from GSM network to his residential WiFi Access Point and logs-in to his own SIP server/gateway. The message waiting indicator on his phone blinks, after all these days of absence he has a lot of messages stored in his telephone appliance.
- Our user is utilizing a GSM/WiFi phone with a SIP telephony client. He has also installed at home an IP telephony appliance and has a subscription to a VoIP provider. The connection of this appliance to the VoIP provider needs VoIP class QoS.
- He turns on his internet stereo and tunes to some jazz music before browsing his voice messages. His stereo utilizes a smart p2p client that at the same acts as a relay for other users. His music provider is employing p2p networking in order to both reduce his own infrastructure costs and at the same time provide better quality to the end users.
- He fires up his computer to check his social networking website. He decides to update his blog about his vacation. While writing, he uploads photos and videos from his camera to accompany the text.

Through EU-MESH, the main advantages can be:

- higher uplink rates compared to fixed broadband access technologies (xDSL, cable),
- the ability of network operators to make discount/special agreements with their fixed customers in exchange for sharing their unused bandwidth with other customers or partner operators.

5.2.6 Fixed home user – entertainment activity scenario

Broadband access in fixed environments, is increasingly utilised for activities related to entertainment, mainly music, television over IP and video (streaming or on demand). Both the technological and the market trend lead the way towards increased penetration of triple-play services, which can also be envisaged within the cases of EU-MESH. A usage scenario for EU-MESH can include the case of the fixed home user that

- has the necessary IP-enabled multimedia equipment (STB, Set-Top-Box) at his home to view videos, TV programmes and listen to music,
- has on-demand access to multimedia (movies, music etc) content through content providers, and
- has access to streaming content and time-shifting viewing capabilities.

The network requirements derived from this scenario are listed below:

- High downlink speeds, with prioritization and controlled jitter
- Efficient and scalable QoS support
- Availability
- Scalability
- Cost-effectiveness

The EU-MESH network infrastructure in mainly advantageous in provisioning speed and cost efficiency.

5.2.7 Tourist / attraction visitor scenario

The tourist info system / attraction visitor scenario delivers services and free (or flat low cost) public access based on the location information and the user personal profile. It also allows people to share their multimedia files (photographs, video, textual notes, etc) with locations on electronic maps with other users. A user can add pictures to a certain point of the map by clicking on the map and browsing the image files corresponding to this location. Dynamically, the user can add, modify, or delete comments on a certain multimedia file, change its permission, and rate its content. Most importantly, the system allows file-sharing with other users. A user can search for multimedia files using criteria based on location and rating. The local user can view the files, reviews and rates included in the response of another user.

Example of services proposed to the user are:

- Multimedia content (music/photo/video) sharing both synchronously and asynchronously.
- Location-based on-demand services: nearby points of interest, search engines (transportation, restaurant, events, weather), travel directions, location discovery and localized maps.
- Proximity-based notification (push or pull). The latter includes push services such as targeted advertising (i.e., events, spots) or automatic airport check-in, and push/pull facilities like common profile matching (i.e., ad hoc grouping for visiting an exhibition) or buddy list.
- Proximity-based actuation (push or pull). These services concern payments based upon proximity, like electronic toll collection.

The tourist / attraction visitor scenario is a very relevant example of context-aware application for both nomadic/mobile users. The context variables that play an important role in this scenario are:

- Interest: the personal interest of the user that direct the search for relevant points of interest and events.
- Location: to find nearby points of interest.
- Visiting history: information about places that the user has already visited before.

From the user perspective, the requirements derived from this scenario are listed below:

- *Ubiquitous Access:* the network should be easily accessible from everybody.
- *Access Anytime – Anywhere:* network access is assured at all times and from all locations.
- *User mobility*

From the network perspective:

- User positioning. The system should autonomously detect the user position.
- High uplink speed. The system should support the transmission of large quantities of data.
- Resilience to operational anomalies and security attacks, as it should work in a multi-operator environment.
- High availability.
- Scalability.
- Cost-effectiveness.

5.2.8 Video surveillance / home monitoring scenario

Wireless Mesh Networks can be applied for video surveillance application as follows:

Consider a large apartment house, 6 floors, 3 stairways and entrances, underground parking garage. Most of the flats are owned by the inhabitants.

The owners deployed a new surveillance, monitoring equipment based on a new mesh network environment.

The preliminary requirements of the owners include the following:

- They need a cheap solution; therefore they want to save costs on the wires.
- An operator will be contracted to build and maintain the mesh network
- A large number of cameras are needed to provide enough coverage to track illegal activities
- They want a modern, digital system, no matter how the equipment works; it has to be digital, widely reachable, digitally achievable, etc.
- The digital recordings use high bandwidth to provide quality, 24 fps, video resolution (e.g., 640x480), multiple (~30) cameras.
- For cost savings, a group of owners will be selected as administrators of the system. These owners will be responsible to look back previous recordings or watch for real-time events if special conditions occur. The members of the administrative group might change in time, therefore a flexible solution is needed.
- Some of the administrators want to be able to watch for events in real time through the internet from their workplace
- An official security firm will be contracted to watch for security events with the usage of combined information of the video surveillance, fire protection and burglar alarm system

of the house. For this purpose, high speed connectivity with high upload rate should be provided by the house.

- Personnel of the security firm will patrol in the area and check the contracted buildings if needed. During the patrol, the personnel should have access to the camera video feed of any of the protected houses.
- In emergency conditions, the administrators of the system should be able to access the surveillance system through mobile computers throughout the house.
- At some places in the house, particularly in the underground garage, there is no GSM/3G coverage. The owners/administrators still want to get access to the internet and also to VoIP providers, therefore in emergency situations, they can report the event (to official emergency service, or just to the other administrators, local personnel, or contracted security firm) from every place in the house. (e.g., by Wifi based VoIP phones)
- High quality images from the cameras need high bandwidth for storing and for real-time delivery to remote and local users. This bandwidth is “upload” direction from the internal network.

To achieve these goals, a wireless mesh network architecture is established, with the following features and characteristics:

- Mesh routers are set up at every floor, they are interconnected through wireless links
- The network is built and maintained by a network operator. The operator provides access to the mesh network and the internet. The operator also provides the necessary security services, such as authorized access to the network resources.
- The mesh network operator provides services in multiple houses in the area, which are interconnected to each other providing extra bandwidth for mesh-internal resources, such as the surveillance system of the different houses.
- Every camera uses IP protocol to deliver pictures and they are connected to the next access point by wire or wireless manner.
- Central servers (PC computers) collect and store the incoming information through the mesh network
- The mesh network provides mobility. The security personnel of the security services company can access any of the video streams of any of the nearby houses. The video quality might be very high, especially in the houses who joined into a single mesh network in the area.
- Every flat owner can connect to the mesh network, the administrators are allowed to watch the real-time streams and stored recordings, the reconfiguration of the administrators is easy.
- The network is highly resilient. The lack a single mesh router, or a problem on a separate internet gateway does not harm the stability of the service, therefore it is more likely to be protected against direct attacks and occasional failures.
- The administrators with notebooks and VoIP based phones can roam through the house and are connected to the network, to the surveillance system and to the VoIP based phone service constantly.

The considered disadvantages for wired networks are:

- High installation costs
- No mobility throughout the house (moving clients)
- Expensive relocation/reconfiguration of the network
- Low upload speeds to administrators outside the house/ security firms
- Low resilience level, dependency upon a particular network provider
- No solution for telephony (VoIP/GSM) in uncovered areas such as underground places

- Low internal bandwidth; although most of the surveillance traffic is internal, in standard internet based solutions the bandwidth between nodes inside the house is very low and provided through the network operators city-wide peering network. (e.g., with ADSL upload rate)

Expected results of the established scenario include the following:

- Every flat owner is able to make connection to the mesh network, in a resilient way.
- Everybody, who needs access to the video surveillance service, connects directly to the internal mesh network, therefore a high bandwidth (both way) can be provided to internal users.
- The security personnel have mobile access to high quality video streams inside the mesh network. Therefore, the quality of the security services can be improved while maintaining a low cost factor.
- Support for guests and temporary users
- Internet users of the surveillance system can get high quality feed through the high bandwidth provided by the mesh network; meanwhile, the users in the house don't experience lack of bandwidth on their internet connectivity;
- High internal bandwidth for distributing real-time and stored material
- Mobility throughout the house and easy reconfiguration
- Resilient, dependable network (both against attackers and failures)
- High bandwidth and thus high quality images provided to the contracted security firm
- The security of the transport system is provided by the mesh network, possibly with no dependency on outsiders.
- Low establishment and maintenance costs
- Higher profit margin for the network operator due to the low costs
- Additional security for the residents by providing high quality video streams to the patrolling (mobile) security personnel.

5.2.9 Mobile commerce scenario

The term m-commerce refers to a set of applications offered to mobile users that allow them to buy goods and services using their handheld devices through wireless network access.

Example m-commerce applications include mobile ticketing, mobile coupons, information services, fleet-tracking, etc. All these applications require ubiquitous internet access; however this is quite expensive today for ordinary people. For this reason, m-commerce applications are currently mainly used by business users only. One of the main advantages of mesh networks is that they can provide ubiquitous Internet access at a reduced cost. Therefore, mesh networks can foster the wider deployment and usage of m-commerce applications. The following m-commerce usage scenarios are specific examples that the EU-MESH network can support:

- *Mobile ticketing:* The owner of a smart phone wants to buy a cinema ticket. The cinema complex provides its program through location based services. Thus, the customer does not have to search for the webpage of the cinema. Without staying in a queue at the box office, she selects the show that she is interested in, and buys the ticket using her phone and her wireless internet access provided by the EU-MESH network. The cinema can later validate the customer's ticket using inexpensive Wi-Fi connections at the gates.
- *Mobile coupons:* A chain of department stores wants to attract customers in its shops. In order to achieve that, it may disseminate electronic coupons near to its shops through the EU-MESH network. The prospective customers walking near to one of

the shop receive the electronic coupons in their handhelds. When they enter into any shops of the chain, they can validate their coupons. The chain of department stores can administrate the coupon dissemination in a centralized way and determine at which access points it wants to broadcast coupons. On the one hand, the mesh network provider can charge the chain for the usage of each access point. On the other hand, the chain can select the access points where the coupons are disseminated, which can be a larger area than the territory of the shops.

- *Information services:* Mobile users can receive a wide variety of information services through the EU-MESH network. The services can be location based, namely, local traffic information, weather forecast, news, etc.
- *Fleet-tracking:* The companies which can gain the most from the EU-MESH network are the dispatch-rider companies. Due to the fleet-tracking and ever-online possibilities of the EU-MESH network, the companies can follow where the employers are and give new destinations for the better utilization of resources. The companies can detect and take advantage of special situations. E.g., a company has two cars. One car goes to the destination of a delivery (place A). The other car goes from place B to C. The center gets an order to deliver a letter from A to a place near to C. As the center is aware of the position of the two cars and knows the destination of them, it instructs the first car to pick the letter up and meet the other car. The other car finally delivers the letter at place C, while the first car serves other orders. In addition, the drivers can call each other at a flat rate using VoIP services provided through the EU-MESH network.

The user and network requirements derived from this scenario are listed below:

- Privacy. No outsider or even none of the operators should be aware who buys what, what they are interested in, etc.
- Confidentiality and integrity of payment messages, as well as the content of the m-commerce services.
- Efficient and scalable QoS support. This includes prioritization, controlled jitter and latency and improved loss packets for multimedia traffic.
- Network traffic monitoring and tuning to provide the requested Quality of Service by an estimation of the network’s load.
- Mechanisms for secure and fast handoffs between heterogeneous networks and different operators during a transaction.
- Mechanisms for (automatic) re-authentication during handover.
- Reliability/availability. The system should be able to adapt to varying network conditions and should provide security mechanisms to ensure high reliability and availability.
- Scalability.
- Cost effectiveness.

6. TECHNICAL REQUIREMENTS

This section considers the high level requirements identified in the previous sections, in addition to the network and service provider requirements, and identifies the specific technical requirements and functionalities that the EU-MESH system must support in order to fulfil them.

6.1 User and application requirements

The user and application requirements based on the discussion in Sections 3.2 and 5 are summarized in the following table, together with the corresponding technical requirements and features that need to be supported by the EU-MESH system.

High-level user and application requirements	Technical requirements and functionalities
QoS	End-to-end QoS mechanisms to support the service and application QoS requirements identified in Section 3.2
High and symmetric uplink and downlink speeds	Efficient utilization of the aggregate backhaul gateway capacity, from both provider high-capacity links and subscriber broadband access lines
Seamless mobility	Fast, reliable, and secure handoffs supporting QoS in multi-operator environments Minimization of handover time to satisfy application specific delay bounds (e.g., <50 ms for VoIP) Ubiquitous coverage
Low cost, affordability	Efficient utilization of wireless and wired resources, and minimization of interference
Reliability	Exploitation of path redundancy and self-healing procedures

Security	• Authentication and access control for mesh clients:
	  o support for end-user mobility and QoS-aware applications
	  o must work in a multi-operator environment
	• Protection of wireless communications:
	  o confidentiality and integrity protection of messages at the link layer
	  o prevention of traffic analysis
	• Increasing the robustness of the networking mechanisms (especially the routing and the transport protocols):
	  o integrity protection and authentication of routing control messages
	  o detection of incorrect routing information as much as possible

	o robust error recovery procedures not exploitable by the adversary • Intrusion detection and recovery: o detection at all layers; combination of various misbehaviour detection modules in a cross layer approach o peer monitoring and exclusion of misbehaving mesh routers
Availability	Ubiquitous coverage Self-healing procedures
Location-based services	Position and presence information
Operation friendliness and ease-of-use	Service discovery and service availability Seamless service delivery Self-configuration
Full range of services – one contract	Integrated fixed, nomadic, and mobile services

Table 14 User & application requirements and functionalities

6.2 Network and service provider requirements

The network and service provider requirements, and the corresponding technical requirements and functionalities are summarized in the following table. The requirements and functionalities are further elaborated in the next two subsections.

Network and service provider requirements	Technical requirements and functionalities
Low-cost and fast infrastructure deployment	Fast and efficient self-configuration procedures
Low operation and management cost	Efficient utilization of wireless and wired resources
Flexibility and scalability	Fast and efficient self-configuration procedures Efficient utilization of wireless and wired resources, and minimization of interference
High and symmetric downlink/uplink speeds	Efficient utilization of wireless and wired resources, and minimization of interference
Service to both fixed and mobile	Converged wireless and wired infrastructure Seamless handoff
QoS and SLA support	End-to-end QoS and service/policy differentiation mechanisms Real-time monitoring of performance and available

	network resources, based on standard interfaces Fast and accurate identification of anomalies and security attacks
Seamless mobility	Fast, reliable, and secure handoffs supporting QoS in multi-operator environments Minimization of handover time to satisfy application specific delay bounds (e.g., <50 ms for VoIP) Ubiquitous coverage
Reliability and security	Exploitation of path redundancy and self-healing procedures Proactive and reactive security procedures Fast and accurate identification of anomalies and security attacks
Availability	Ubiquitous coverage Self-healing procedures Real-time monitoring of performance and available network resources, based on standard interfaces

Table 15 Network and service provider requirements and functionalities

6.2.1 Fixed broadband access provider

Comprehensive management of the broadband access infrastructure (network elements and services) is a fundamental requirement. Administrators and customers rely on this infrastructure where availability and performance are mandated, and problems should be quickly identified and resolved. Functions that are performed as part of network management include controlling, planning, allocating, deploying, coordinating, and monitoring the resources of a network, network planning, predetermined traffic routing to support load balancing, cryptographic distribution authorization, etc. FCAPS (Fault, Configuration, Administration or Accounting, Performance, Security) is the ISO Telecommunication Management Network model and framework for network management. Based on this model, the EU-MESH system should support the following functions:

- Fault management - The goal of fault management is to recognize, isolate, correct and log faults that occur in the network. Furthermore, it can use trend analysis to predict errors so that the network is always available. This can be established by monitoring the network performance in order to identify abnormal behaviour.
- Configuration management - The goal of configuration management is to track and modify configurations of network devices, in a simple and automated manner.
- Administration / Accounting management - The goals of administration management are to administer the set of authorized users by establishing users, passwords, and permissions, and to administer the operation of network devices, which includes performing software backup and synchronization. The goal of accounting is to gather usage statistics for users, which can be later used for billing, usage quota enforcement, and capacity planning.

- Performance management - The goal of performance management is to evaluate and report the behaviour of network equipment and the effectiveness of the network, to gather statistical information, maintaining and examining historical logs, determining system performance under natural and artificial conditions. Metrics that should be measured are
    - availability
    - bandwidth utilisation
    - packets per second
    - round trip time
    - jitter
    - packet loss
    - reachability
    - circuit performance
    - flow capacity
    - routing diagnosis
    - response time
    - connection rates
    - service qualities

  These metrics are fundamental for operations like capacity planning, usage-based billing, service contract negotiation, reporting, and provision of value-added services. The EU-MESH system should support standard interfaces (e.g., SNMP) in order to communicate with network management applications.
- Security management - Security management is the process of controlling access to network assets. Data security can be achieved with authentication, authorization, and encryption.

QoS and SLA (Service Level Agreement) support require both active mechanisms for service differentiation and policy enforcement, in addition to passive real-time monitoring of the offered performance and the available resources of the whole network. Also, QoS support requires reactive mechanisms that quickly and accurately identify performance anomalies, faults, and security attacks, which can trigger corrective procedures to overcome the problems and mitigate their negative effects.

6.2.2 Wireless access provider

From the wireless access provider side, technical requirements for the EU-MESH system include the following:

- End-to-end QoS and SLA support. These requirements are similar to those discussed in the previous subsection.
- Fast deployment, flexibility, and scalability. This requires efficient and automated self-configuration procedures. Automated configuration refers to both the wireless link layer (e.g., power and rate control, channel assignment), and the IP level (addressing and routing).
- Efficient operation and management. This includes minimizing wireless interference due to either external or internal sources (e.g., using power control and channel assignment), and load-aware procedures for access selection and routing. Load balancing should also be performed in the case of multiple fixed gateways, without

affecting the end-user service quality.

- Reliability and security. These require coexisting of proactive security mechanisms, for securing the exchange of control and routing information, and reactive detection and self-healing procedures for quickly and accurately identifying problems and minimizing service disruption.
- Availability and coverage. This requires real-time monitoring of the offered performance and the available network resources, in addition to reactive detection and self-healing procedures.

6.3 QoS and efficient network resource utilization

Quality of Service (QoS) support is of central importance for broadband wireless access systems. Intuitively, the goal of QoS is to provide statistical guarantees on the ability of the network to deliver predictable performance. More precisely, users' needs and preferences, together with application characteristics, form the set of application requirements demanded to the network services and protocols. Then, application requirements are translated into a set of qualitative and quantitative features that the network should guarantee. The system qualities that form the basis for the QoS requirements are several and include

- *Performance* – The set of system parameters used to quantitatively assess the application behaviour. Metrics that are commonly used are the desired application data throughput, the maximum end-to-end (from source to destination) delay for data packets, the delay variability, and the maximum packet loss rate.
- *Availability* – A measure of how often the system resources and services are accessible to end-users.
- *Scalability* – The ability to add capacity to the system over time, so that the system can support additional load from existing users or from an increased number of users.

Several approaches have been investigated to provide QoS support in wired networks, such as routing enhancements (e.g., MPLS), advanced resource reservation protocols (e.g., IntServ), or traffic differentiation and prioritization (e.g., DiffServ). However over-provisioning of bandwidth and network resources still remains the most common solution for QoS management in wired networks.

The problem of providing QoS support in wireless networks, and ad hoc networks in particular, is even more challenging than wired networks due to the unique characteristics of the wireless medium. Specifically, the wireless channel is intrinsically unreliable and time varying, and subject to interference, multipath propagations, and burst channel errors, which make the bandwidth a precious and limited resource. In addition, although multi-hop communications are beneficial to improve network reliability and extend network coverage, they may also lead to severe performance degradations as the number of relaying nodes increases. For these reasons, in order to provide an effective QoS support in mesh networks, it is of paramount importance to design novel QoS models to ensure an efficient utilization of the available wireless resources, to improve the network capacity, and to increase the backbone scalability.

To address the above technical challenges the EU-MESH system will employ a multifaceted approach. Firstly, the EU-MESH system will utilize multi-radio and multi-channel capabilities, as well as directional antennas, to build the mesh network, which can enhance spectrum reuse and capacity by promoting channel diversity. Moreover, a multi-radio and multi-channel environment is more likely to experience path diversity, i.e., the existence of multiple paths between a pair for nodes that are independent in terms of interference and congestion, which is generally beneficial to provide more effective QoS support. The second strategy that will be adopted by the EU-MESH system to deal with the capacity limitations of typical broadband wireless access systems, is to fully integrate into the mesh backbone all the available fixed access technologies, namely both provider fixed broadband links (e.g., 802.16 BWA and fibre links) and subscribers access lines (e.g., ADSL). In this way, the EU-MESH capacity towards the Internet will not be restricted only to a few provider-owned Internet gateway connections, but it will consist of the aggregate capacity of subscriber access lines, which are now isolated and typically underused. Thus, the converged EU-MESH infrastructure can offer a virtual pool of communication resources to both local stationary users and remote mobile users.

The approach considered in EU-MESH to build ultra-high capacity mesh network opens up new avenues for optimized QoS support and more efficient network resource utilization, as well as new technical challenges. Specifically, to unleash the potential of the multi-user diversity that is provided by the use of multi-channel technologies, multi-radio capabilities and directional antennas it is necessary to design efficient policies to coordinate the use of the wireless and wired network resources. The methodology we will adopt is to understand the interactions of the various wireless control mechanisms, such as channel assignment, power control, coverage control (through beacon power control), and channel mechanisms (e.g., 802.11e, 802.11n), and quantify how each influences the overall performance. Such understanding will help to investigate joint procedures to optimize the wireless resource utilization. It is also intuitive to observe that the enforcement of QoS constraints cannot be achieved without considering the interdependencies existing between topology formation, channel assignment and routing. For instance, QoS-aware routing capable of discovering feasible paths that satisfy QoS constraints needs to take into account not only topology information, but also channel characteristics (i.e., channel allocation, link capacity, packet loss ratio, and interference), as well as traffic dynamics and distributions. To achieve the joint optimization of wireless resource utilization we advocate the use of cross-layer design, in order to allow the lower layers of the protocol stack to share information on the status of network resources. This can permit to devise coordinated operations among protocols belonging to different layers to realize an improved local and global adaptation.

6.4 Cross-layer performance monitoring

To support QoS while efficiently utilizing network resources, EU-MESH will develop a cross-layer architecture enabling measurement-based monitoring of relevant performance parameters across layer boundaries. This approach is based on the idea that every layer must cooperate to gather better results in terms of throughput, power consumption, routing, mobility support, etc. This cooperation can include joining of layers to super layers, inserting new layers with/without changing the primitives used in the old layers, and interaction between non-adjacent layers [SM05]. These changes make cross-layer design different from a layered architecture.

One extreme approach is to join all layers together to implement all duties within a monolithic program. Although this approach will have the advantage of working fast, its source code will be very large and complicated. In addition, it will have short-term performance gains only and is not advised for long-term gains [KK05]. So, we are not found of this approach.

We believe that problems should be solved where they appear. This can be achieved by maintaining the layered design of classical networks, but enable the interaction between different layers.

A recent trend in the literature is to use a parallel layer (like ATM Management Planes), which interacts with all the layers. This layer is called as "Optimizer Block" [SBY06], "Shared Database" [SM05], "Network Status Component" [CMTG04], and "State Manager" [CHL03] by different researchers. But the main idea is the same: "Let layers share information via a layer which can be interacted by all the layers. The OLD style of interaction between the layers must be preserved."

The main question here is "what/how information must be stored and shared within a cross-layer design principle?" References [SRK03] [RI04] [VAG05] list some possible interactions between the layers. We list 5 important points that must be considered when designing cross-layer solutions:

1. *Scope* of the exchanged information in cross-layer solution - The information exchange can be between the layers of the same host, it can be between neighbouring hosts, etc. Any solution will have implications on the data model for sharing information. Information exchange between two hosts or a group of host will probably be based on message exchange. Information exchange within a single host, offer in addition the possibility to implement shared memory concepts to react fast enough on dynamics of the network.
2. *Access rights* of the layers on the stored information - The information must be written, changed and read. It is possible to restrict some layers only for reading, other ones for just writing, etc. The access rights will ensure to avoid unstable control loops between the layers. Unstable control loops may occur, if multiple layers have write access on the same information. To disable control loops permanently may lead to performance degradations. It is an open question, at which conditions control loops should be enabled.
3. *Adaptation to current Management Information Base* (MIB) approaches to store and retrieve the information - Currently there are some RFCs which define MIBs for different layers of the TCP/IP protocol stack. For example, RFC 4022 [Rag05] defines an MIB for TCP, RFC 4113 [FF05] defines an MIB for UDP, RFC 4293 [Rou06] defines an MIB for IP, and RFC 2863 [MK00] defines an MIB for network interfaces. These MIBs must be investigated and necessary changes/additions must be done to include cross-layer design specific wireless meshed network information.
4. Possibilities of measurements of the *metrics* - Suppose that, interference level information is collected. Such information can be measured by different algorithms and results obtained by these different algorithms can be very different. Thus, *how* to measure a metric is as important as choosing *what* to measure.
5. *Metrics* for different network technologies - Bytes, packets, power levels, etc can be used as measurement metrics. WMNs will include heterogeneous network technologies. Thus, metrics must be chosen carefully. For example, 10 percent free capacity for a 64 kbps line is very different from 10 percent free capacity of a 10 Mbps line.

6.5 Seamless mobility

Global mobility is achieved when both *seamless vertical* (among different type of networks) and *horizontal* (among networks of the same type) *handovers* between *different domains* (inter-domain handoff or macro-mobility) *or inside the same domain* (intra-domain handoff or micro-mobility) are supported.

Handover is a process that involves a delay and the two main components that contribute to its value are the discovery and the re-authentication procedures.

The discovery phase, performed by a scanning, is triggered by the degradation of some physical parameters (like the signal-to-noise-ratio or the signal-strength) and determines a list of new networks to which to associate. The re-authentication step involves both authentication and association to the new selected network.

As depicted in the usage scenarios, a variety of applications can be supported by EU-MESH, each with different handoff delay bounds. For instance, real time applications with QoS constraints require a strict handoff delay (VoIP typically tolerates delays up to 150 ms in a single direction before the quality of the call is unacceptable), whereas elastic applications (like email with large attachment) are more sensitive to throughput rather than to delay. For time sensitive applications the objective is to minimize the handover delay, and schemas that attempt a handoff when a client's service degrades to a point where connectivity is threatened are clearly not suitable. Furthermore, it should be guaranteed that the handoff procedure do not incur in any packet loss.

To finalize the support for heterogeneous applications and user's demands, global mobility solutions need to meet the following requirements:

- backward compatibility with legacy systems and current standards;
- adaptability: the handoff schema should adapt to the different delay bounds of each application.

Fast handoff between heterogeneous networks and different operators involves reducing the two components (scanning and re-authentication) that contribute to the overall delay. This can be achieved by considering application layer solutions that do not introduce network overhead, and ensure portability and platform independency (i.e., not introducing any sub-layer nor requiring any operating system specific intervention). Furthermore methods proposed should self-tune and self-optimise a list of internal parameters that control the handoff procedure when the network's context changes (e.g., connectivity disruption).

Adaptation of the delivered QoS to changing network conditions could be achieved by cross-layer monitoring.

The handover process can be further optimized by using past experience that, through statistical measures of trend, will show anticipatory behaviours in order to predict the handoff decision or detect the optimal handoff trigger timing.

6.6 Proactive and reactive security

It is evident that in order to make business by deploying wireless mesh networks and providing Internet access and other services to customers, one needs to consider security issues seriously and address them appropriately. The reason is that it is relatively easy to carry out various attacks against mesh networks due to the wireless nature of the communication medium, and due to the lack of physical protection of the unattended mesh nodes. Furthermore, if security is not handled appropriately, then customers may prefer alternative technologies; this would hinder the adoption and wide-spread deployment of mesh networks, which in turn, would result in loss of business opportunities. Therefore, security is one of the focus areas in the EU-MESH Project.

In this section, we identify security requirements that are relevant for wireless mesh networks in general, and for EU-MESH in particular. We understand that some applications running on top of a mesh network may have highly application specific security requirements; we are not particularly interested in those requirements though, as they are difficult to identify without the specification of the application itself, and they can be best handled by the application anyway. Rather, we aim at identifying general security requirements of wireless mesh networks that are either independent of the applications or common to all applications.

Our approach will be the following: First, we recapitulate the system model, then we introduce an adversary model from which we derive a set of high level security requirements. A more detailed analysis and the refinement of the requirements into design criteria for security mechanisms will be carried out later in Work Package 5 where we will also develop specific security mechanisms that meet the identified design criteria.

6.6.1 System model

For the purpose of the following discussion in this section, we define the following high level model of the system. The mesh network consists of mesh routers that form a static wireless ad hoc network. Some of the mesh routers function as gateways to the wired Internet, and some of them function as wireless access points where mobile mesh clients can connect to the network. The sets of gateways and access points can overlap and they do not necessarily cover the entire set of mesh routers.

The mesh routers may be operated by multiple operators, but in this case, we assume that they cooperate in the provision of networking services to the mesh clients. This cooperation may be based on business agreements (similar to roaming agreements in the case of cellular networks). Mesh clients are mobile computers operated by end-users. End-users may be associated with one or more operators by contractual means.

Mesh clients use the services provided by the mesh network in order to run various applications. Typically, mesh clients use the mesh network to access the Internet, or they run applications that take advantage of the connectivity provided by the mesh network itself (e.g., mesh clients can communicate with each other through the mesh routers without using the Internet).

The mesh network supports QoS-based applications and mobility of the mesh clients. In other words, we assume that appropriate mechanisms are used within the network to provide services with QoS guarantees (e.g., the routing protocol uses QoS-aware routing metrics, and handles admission control and resource reservations), and to ensure seamless handover between access points for the mobile clients. Here, we are not considering the details of these mechanisms; we are interested only in their general security requirements.

6.6.2 Adversary model

As usual, the first step in the identification of security requirements is the understanding of the potential attacks against the system. This understanding is summed up in an adversary model that describes the following:

- classes of attackers,
- their objectives, and
- their means to attack the system.

Classes of attackers

Taking into account the system model described above, we identify three types of attackers:

- *External attackers:* These are attackers that have no legitimate access to the mesh network and its services, but they have appropriate equipment to use the wireless medium and interfere with the operation of the mesh network protocols. In addition, these attackers may have unsupervised physical access to some of the mesh routers that are installed in public areas, and they have the knowledge to modify the behaviour of these routers by installing rogue software on them.

- *Dishonest customers:* These are misbehaving end-users that have legitimate access to the mesh network services, and they try to take advantage of this in order to interfere with the operation of the network or to gain illegal access to its services (e.g., by impersonating another end-user).
- *Dishonest operators:* These are operators of the mesh infrastructure that do not honestly stick to business agreements.

Objectives of attacks

We identify the following main attack objectives:

- Unauthorized access to services provided by the mesh network (e.g., access to the Internet). Primarily, this objective is relevant for external attackers and dishonest customers. In the latter case, the dishonest customer may try to use services that are not included in his subscription.
- Unauthorized access to end-user data and meta-data. Here end-user data means the content of the messages exchanged in a service session, whereas meta-data refers to information on the end-user's location and service usage profile (e.g., which applications are used and how often). Thus, the first objective is related to violating the confidentiality, and the second is related to violating the privacy of the end-user. Primarily, this objective is relevant for external adversaries and dishonest operators.
- Denial of Service. This objective is related to degrading the QoS offered by the network (including the complete disruption of communication between some parts of the network). Primarily, this is relevant for external adversaries.
- Gaining advantage over competitors. For dishonest operators, the primary reason to mount attacks on the system (especially on those parts that are operated by other operators) is to gain some advantage over their competitors. This is achieved either by destroying the reputation of a competitor, or by dishonestly increasing one's good reputation.

Attack mechanisms

There are a multitude of attack mechanisms that can be used and combined in order to reach the goals described above. However, most of these mechanisms fall into either one of the following two categories:

- Attacks on wireless communications (including eavesdropping, jamming, replay, and injection of messages; traffic analysis; setting up wormholes; etc.)
- Setting up fake mesh routers or compromising existing mesh routers (typically by physical tampering or logical break-in). The behaviour of the fake or compromised mesh routers can be arbitrarily modified in order to help to achieve specific objectives.

6.6.3 Derived security requirements

Based on the adversary model described above, we identify the following main security requirements for wireless mesh networks:

- authentication and access control for mesh clients,

- protection of wireless communications,
- increasing the robustness of the networking mechanisms (especially the routing and the transport protocols),
- intrusion detection and recovery.

Authentication and access control for end-users

In order to prevent unauthorized access to services, mesh clients must be authenticated, and access control rules must be enforced in the system. Ideally, access control enforcement should take place at the access points such that unauthorized access attempts are denied as early as possible without affecting the rest of the network.

There are many options to satisfy this requirement in terms of available authentication protocols and authorization schemes. However, there are additional requirements that need to be satisfied, which may exclude some of those options. These requirements include the need to support end-user mobility and QoS-aware applications, and the need to work in a multi-operator environment.

Supporting user mobility and QoS-aware applications means that re-authentication of mesh clients and access authorizations should be fast such that the requirements of authentication and access control do not exclude the possibility of seamless handover between the access points. In addition, the multi-operator environment means that such handovers may occur between access points belonging to different administrative domains, and hence, the authentication and access control scheme must be ale to handle this situation.

Protection of wireless communications

It is well-known that wireless communications are vulnerable to jamming, eavesdropping, replay, and spoofing attacks. For this reason, wireless communications between mesh clients and mesh routers, as well as among mesh routers, must be protected. This includes the following requirements:

- The confidentiality and integrity of application data must be protected in order to prevent unauthorized access to end-user data. Ideally, this should be done in an end-to-end manner; however, some applications may not be prepared for this protection, in which case, it would be desirable to solve the problem transparently to the applications within the mesh network itself.
- Message integrity and authenticity must be provided ideally in a link-by-link manner such that fake, modified, and replayed messages are identified and removed as early as possible, and therefore, futile usage of bandwidth is avoided.
- Traffic analysis must be prevented as much as possible in order to prevent unauthorized access to meta-data of end-users, and hence, ensure some degree of privacy. Link-by-link encryption of messages can help in this regard, as it can hide end-to-end addressing information. However, link encryption does not prevent all kinds of traffic analysis attack.

Note that the above requirements do not address the problem of jamming attacks. Jamming is difficult to defend against in a proactive manner, therefore, we will handle the protection against jamming attacks as part of the requirements for reactive security measures later.

Increasing the robustness of the networking mechanisms

The easiest way to mount stealth denial-of-service attacks against a network is to manipulate its basic mechanisms such as the routing protocol. For this reason, it is important to increase the robustness of the basic networking mechanisms. In particular, the routing protocol must be strengthened with security measures in order to minimize the risk that the network ends up in an incorrect or highly suboptimal state, where some nodes cannot communicate or communication is possible only with a high amount of overhead.

In general, QoS-aware routing protocols provide three functions:

- proactive dissemination of routing information (e.g., link quality metrics) and local route computation, or on-demand route discovery (depending on the type of the protocol),
- resource reservation on selected routes (for the purpose of QoS guarantees),
- and recovery from errors during the data forwarding phase.

All of these three functions have their security requirements. Routing information dissemination and route discovery requires the authentication and integrity protection of routing control messages, in order to prevent their manipulation by external adversaries. In addition, in some protocols, special attention must be paid to the protection of non-traceable mutable information (e.g., the cumulative routing metric values) in routing control messages against misbehaving mesh routers. It may also be desirable to ensure non-repudiation of routing control messages in order to discourage operators to mount stealth attacks against each other, and to facilitate dispute resolution.

Resource reservation messages must also need to be authenticated in order to avoid resource blocking DoS attacks. Similarly, it must be guaranteed that resources do not stay reserved forever. Finally, error recovery procedures should not be exploitable by attacks aiming at the disruption of communication or increasing the message overhead in the network.

Intrusion detection and recovery

Due to the fact that our adversary model allows for dishonest operators and physical tampering of mesh routers by external attackers, we must assume that some fraction of the mesh routers may exhibit arbitrary Byzantine behaviour. It is more or less impossible to identify such misbehaving nodes by cryptographic means. Similarly, cryptographic solutions are ineffective against jamming attacks. Therefore, besides the proactive, cryptography based security measures that we have described above, one must also consider the application of some reactive, intrusion detection and recovery mechanisms.

As misbehaviour can happen at any layer of the communication stack, misbehaviour detection should be implemented in all layers; moreover, various misbehaviour detection modules can be combined in a cross layer approach to increase the effectiveness of the detection. Misbehaviour detection and recovery requires that the nodes can monitor the activity of each other (at least to some extent), they can identify suspicious activities, and they can make counteractions (e.g., they can exclude some nodes from the network). This also means that some level of cooperation must take place between the nodes. The challenge is that some nodes participating in the misbehaviour detection may themselves misbehave and try to mislead the other nodes.

7. ACRONYMS

3GPP	3rd Generation Partnership Project
3GPP LTE	3GPP Long Term Evolution
aGW	Access Gateway
AP	Access Point
ARPU	Average Revenue Per User
BSC	Base Station Controller
BWA	Broadband Wireless Access
CAGR	Compound Annual Growth Rate
CDMA	Code Division Multiple Access
CPE	Customer Premises Equipment
DHCP	Dynamic Host Configuration Protocol
DoS	Denial of Service
eNB	Enhanced Node B
FMC	Fixed-Mobile Convergence
FTTB	Fibre to the building
FTTC	Fibre to the curb
FTTH	Fibre to the home
FTTN	Fibre to the neighbourhood
FTTP	Fibre to the premises
FTTx	Fibre to the x
GAN	Generic Access Network
GSM	Global System for Mobile communications
HSDPA/HSUPA	High Speed Downlink Packet Access/ High Speed Uplink Packet Access
HSPA	High-Speed Packet Access
ISP	Internet Service Provider

LAN	Local Area Network
LOS	Line-of-Site
MAN	Metropolitan Area Network
MIB	Management Information Base
MIMO	Multiple-Input and Multiple-Output
MoD	Music/Multimedia on Demand
MPLS	MultiProtocol Label Switching
MVNO	Mobile Virtual Network Operator
NAT	Network Address Translation
NGA	New Generation Access
NGN	New Generation Network
PDA	Personal Digital Assistant
POE	Power over Ethernet
QoS	Quality of Service
RAN	Radio Access Network
RFC	Request for Comment
RNC	Radio Network Controller
SLA	Service Level Agreement
SME	Small-Medium Enterprise
SOHO	Small Office – Home Office
TD-SCDMA	Time Division-Synchronous Code Division Multiple Access
UMTS	Universal Mobile Telecommunication System
VoD	Video on Demand
VoIP	Voice over IP
WCDMA	Wideband Code Division Multiple Access
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access

WLAN	Wireless Local Area Network
WMN	Wireless Mesh Network
xDSL	x Digital Subscriber Line

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9. LIST OF STANDARDS

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ETSI ES 282 003 V1.1.1 (2006-06) ETSI Standard “Telecommunications and Internet converged Services and Protocols for Advanced Networking (TISPAN); Resource and Admission Control Sub-system (RACS); Functional Architecture”

Final draft ETSI ES 282 004 V2.0.0 (2007-11) ETSI Standard “Telecommunications and Internet converged Services and Protocols for Advanced Networking (TISPAN); NGN Functional Architecture; Network Attachment Sub-System (NASS)”

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ITU-T Q.3151 ATM and frame relay/MPLS control plane interworking: Client-server

ITU-T Q.3201 EAP-based security signaling protocol architecture for network attachments

ITU-T Q.3300 Architectural framework for the Q.33xx series of Recommendations

ITU-T Q.3301.1 Resource control protocol - Protocol at the Rs interface

ITU-T Q.3302.1 Resource control protocol - Protocol at the Rp interface

ITU-T Q.3303.0 Protocol at the interface between a Policy Decision Physical Entity (PD-PE) and a Policy Enforcement Physical Entity (PE-PE) (Rw interface): Overview

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This amendment specifies enhancements to the following draft standard and draft amendments, in order to support mesh networking:

— IEEE P802.11-2007

— IEEE P802.11k D11.0

— IEEE P802.11r D9.0

— IEEE P802.11y D7.0

— IEEE P802.11w D5.0

— IEEE P802.11n D3.03

— IEEE P802.11u D1.0

— IEEE P802.11p D3.0

IEEE Std 802.11™-2007 [Previously known as P802.11-REVma 9.0) Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

IEEE P802.11k™/D13.0, Draft STANDARD (March 2008), Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 1: Radio Resource Measurement of Wireless LANs

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IEEE 802.16Conformance01-2003 IEEE Standard for Conformance to IEEE 802.16 Part 1: Protocol Implementation Conformance Statement (PICS) Proforma for 10-66 GHz WirelessMAN-SC Air Interface

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IEEE 802.16Conformance04-2006 IEEE Standard Conformance04-2006 Part 4: Protocol Implementation Conformance Statement (PICS) Proforma for Frequencies below 11 GHz

IEEE 802.16e-2005 IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems Amendment for Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands.

IEEE 802.16f-2005 IEEE Standard for Local and Metropolitan Area Networks - Part 16: Air Interface for Fixed Broadband Wireless Access Systems--Amendment 1--Management Information Base

IEEE 802.16k-2007 IEEE Standard for Media Access Control (MAC) Bridges Amendment 2: Bridging of IEEE 802.16