Nº 5

Report from the UMTS Forum

Minimum spectrum demand per public terrestrial UMTS operator in the initial phase

UMTS Forum

This report is produced by the UMTS Forum, an association of telecommunica-tions operators, manufacturers and regulators active both in Europe and other parts of the world that share the vision of UMTS as a concept which will move mobile communications forward from second-generation systems into the Information Society and deliver voice, data, pictures, graphics and other wide-band information direct to people. The conclusions and recommendations in the report are supported by all operators and manufacturers in the UMTS Forum. The National Administrations that are members of the UMTS Forum have actively supported the development of the report. However, the views expressed do not necessarily represent the views of the Administrations. Therefore the Administrations cannot be bound by the detailed recommendations contained in the report.

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Executive Summary

This report, prepared by the Spectrum Aspects Group of the UMTS Forum, studies the minimum spectrum demand per UMTS operator up until the year 2005. In a previous report from the UMTS Forum in 1997 the overall spectrum demand was addressed.

UMTS, the Universal Mobile Telecommunications System, is recognised as the main opportunity to provide broadband mobile multimedia services for the future mass market. UMTS will offer user bit rates up to 2 Mbit/s.

It should be noted that this report focuses on the 15 member states of the European Union (EU15) and many of these assumptions and therefore conclusions may well not be valid for countries outside of Europe.

This investigation into the minimum spectrum demand per UMTS operator relates to public terrestrial UMTS networks in the EU 15 states and is based upon UMTS market and spectrum estimates made previously by the Market Aspects Group and Spectrum Aspects Group of the UMTS Forum.

In this report the main emphasis has been in determining the minimum spectrum with which an operator can build a 'real' UMTS network, this means that there should be sufficient spectrum to facilitate building a network capable of providing all expected UMTS services. The defined scenarios were tested against the traffic forecasts based on market studies and previous UMTS reports.

It should be noted that the conclusions made in this report are dependent upon market data for the years up to the year 2005 and the assumptions made. For example, it is assumed that 90% of the total speech and low speed data traffic will be carried over existing second generation networks within this period, that 60% of the indoor traffic will be carried over licence-exempt networks, and that high (2 Mbit/s) and medium (384 kbit/s) multimedia services are packet services which are tolerant of delay. It is important to note that although the majority of users will continue to use speech most of the capacity is needed for multimedia services. As identified in earlier work by the Spectrum Aspects Group the market is expected to continue to grow strongly after this date and additional spectrum will be required in the future.

The requirements arising from the symmetric and asymmetric nature of the future traffic are uncertain, but within the assumptions made the recommendations allow for the asymmetry forecasted in the market studies until the year 2005 to be handled.

The study looks at eight deployment scenarios for UMTS and examines each of them for their viability in terms of the cell loading and levels of service capabilities for each of the hierarchical layers. Whilst recognising that the situation can vary within the EU15 (the 15 members states of the European Union) the following recommendations are made:

Recommendation 1

Based on the assumptions made, the UMTS Forum recommends 2x15 MHz (paired) + 5 MHz (unpaired) as the preferred minimum spectrum requirement per public UMTS operator in the initial phase. The allocation of unpaired spectrum is foreseen to handle asymmetric traffic in an optimised way. However, depending on country specific situations, other spectrum allocations per operator may be more appropriate.

Recommendation 2

The UMTS Forum recommends to study further the flexible use of TDD and FDD techniques, with the aim of improving the efficient use of spectrum.

Recommendation 3

The UMTS Forum recommends that administrations and other relevant authorities take timely action to make sufficient spectrum available for UMTS in the initial phase to satisfy market demand.

1. Introduction

The UMTS Forum has previously estimated the overall spectrum demand [1,4] for satellite and terrestrial UMTS. This estimated spectrum will not be available in the initial phase of UMTS. In a number of countries, the start-up spectrum will be limited and there will be different needs in relation to countries economic developments and telecommunication infrastructures. To give guidance, the UMTS Forum has carried out a study on minimum spectrum bandwidth per UMTS operator (up to the year 2005) taking into account all presently known criteria. The task was undertaken by the Spectrum Aspects Group (SAG) as the responsible Working Group within the UMTS Forum.

UMTS is now recognised as the main opportunity to provide mobile broadband multimedia services for the mass market in the future, emphasising their broadband capability. There is an increasing focus on packet switching and Internet protocol techniques offering higher capacity and efficiency. In many regions, by the time the introduction of UMTS there will be a substantial penetration by 2 nd generation radio systems. It is becoming accepted that UMTS will concentrate on offering the new high bit rate multimedia applications in addition to speech services as a first phase. For existing 2nd generation operators who gain a UMTS licence then it is anticipated that this will be an adjunct to their 2nd generation systems which will continue to provide the major part of the total capacity for the basic telephony and lower data rate services

UMTS will offer the transmission of data rates up to 2 Mbit/s. The support of 384 kbit/s for high-mobility applications in micro and macro cellular environments is required. Packet data will be required to offer high data rate services in a spectrally efficient manner. There will also be licence-exempt applications in office and home environments, which are not considered in this study.

The investigation on minimum spectrum per UMTS operator relates to public terrestrial UMTS networks in the EU 15 states. This study takes as a starting point the UMTS market and spectrum estimates from the UMTS Forum report "A Regulatory Framework for UMTS", Report Nº1, June 1997 [1], and also takes into account the UMTS Terrestrial Radio Access (UTRA) Decision [8] to calculate the minimum spectrum required by a public UMTS operator. For this report UMTS is understood to be the UMTS standard as being developed by ETSI.

The latest discussions on the flexible use of paired and unpaired bands to support future traffic, some of which is expected to be asymmetric, by UTRA [17,18,19,20] are also reflected. Because UMTS is primarily envisaged for multi-service environments, inhomogeneous traffic distributions are expected. However UMTS networks can also carry dedicated speech services - when for instance a new operator comes into the market. As higher service bit rates

are expected to play a significant role from the year 2005, these bit rates should be technically available from the outset. Furthermore the Market Aspects Group of the UMTS Forum has forecast that high bit rate services will be highly asymmetric. These effects have to be considered in the estimation for minimum spectrum per UMTS Operator. It should be noted that estimates derived in this report are based on market forecasts for the year 2005. As identified in earlier work by the SAG [22] the market is expected to continue to grow strongly after this date and additional spectrum will be required in the future.

The report studies the following issues associated with the minimum frequency bandwidth per operator:

- Market forecasts
- Spectrum availability constraints
- Traffic requirements

1.1 Report Structure

The report is organised as follows. Some points of the market forecasts for UMTS services [21,24] that are relevant for spectrum estimation are presented in chapter 2. Chapter 2 presents the traffic calculated in [22], which is used in to derive Table 7 in chapter 4.

In chapter 3 the global availability of spectrum is considered.

In chapter 4 the technical assumptions are discussed along with a discussion on the hierarchical deployment of cells for UMTS. In 4.3 the eight scenarios considered are introduced along with the differences between these scenarios. The difference between the scenarios is shown in Table 11. This table is derived from the methodology outlined in Annex 2. A calculation of the effects of distributing the traffic more evenly, also taking into account quality of service factors, is shown in Table 12.

The technical investigation explores different deployment scenarios taking into account the requirements of providing wide-area coverage with 384 kbit/s and 2 Mbit/s in hot spot and indoor areas with hierarchical cell structures. As the standardisation process is still ongoing some technical assumptions are made which are considered to be reasonable.

In chapter 5 the eight scenarios are considered in detail and discussed from their feasibility point of view.

Chapter 6 follows on from the discussions in chapter 5 to make detailed conclusions.

1.2 General Assumptions

The following item list shows the general assumptions made in this investigation:

· UMTS Market forecast and traffic volumes according to market study for EU 15 states, Analysis/Intercai 1997 [21]: split into packet switched traffic and circuit switched traffic;

· the estimation from a market point of view is based on the figures available from [1,4,21,22];

· for the years 2002 until 2005 services carried over UMTS networks will be mainly focussed on Multimedia. Speech + low speed data are used mainly in 2nd generation systems, with 10 % of the speech and low data rate services carried in the UMTS bands (i. e. 90% on 2nd generation systems);

· three radio environments determine the spectrum requirement: Urban pedestrian, urban vehicular, central business district/indoor. Suburban and rural are not critical in this respect;

· ETSI Air Interface standard according to high level UTRA requirements [8] 5 MHz carrier spacing; Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes;

· the maximum available data rate is 384 kbit/s for macro and micro cells with full mobility. 2 Mbit/s for micro- and picocells with low mobility;

· each operator has exclusive spectrum (i.e. no frequency sharing);

· market shared equally between all operators. This assumption ignores the fact that an operator could have a greater share of the market. It was felt impractical to use other assumptions, but this fact should be taken into account;

· fixed hierarchical cell structures are used with traffic assigned to specific layers;

· only spectrum demand for public operator licensed use is considered;

· 155 MHz is available for terrestrial UMTS as identified in CEPT ERC/DEC/(97)07 on the introduction of UMTS, i.e. 1900 - 1980 MHz, 2010 - 2025 MHz, and 2110 - 2170 MHz [27].

Further detailed technical assumptions are made and shown in chapter 4.

1.

2. Market forecast for UMTS Services

2.1 Symmetric and Asymmetric Spectrum use

It is anticipated that UMTS high multimedia and medium multimedia traffic will be asymmetric in data flows between up-link and down-link, and the remainder of the traffic will be symmetric (see Table 1), leading to different requirements for radio spectrum in the two directions. However, before much can be decided about how the spectrum might be configured to take account of such factors, it is necessary to consider what is meant by asymmetry in this context.

The spectrum asymmetry can be defined as the ratio of transmitted down-link bits to transmitted up-link bits in a given integration time. The integration time is all-important as the picture changes depending on the observation window.

Within quasi-instantaneous timescales (say "10 seconds), all traffic, including speech, would undoubtedly be found to be highly asymmetric. In speech conversation generally only one party speaks at once. Even in video conferencing situations, visual activity is normally associated with the currently active participant. Messaging and file transfer services will clearly be asymmetric in these timescales. However, whilst the asymmetry will be of a high order within these short timescales, for some services (speech, video conferencing, etc) the direction of the asymmetry will keep reversing.

Over the duration of a multimedia session (defined as the multimedia equivalent of a "call"), the session asymmetry can be very different to the quasi-instantaneous values. Integrated over these longer timescales, normal speech conversation would be considered symmetrical, as might videoconference sessions. However, messaging, file transfer and information-gathering transactions would continue to have a high degree of asymmetry in the information content.

Over a long period of time (day, week or month) and integrated over all customers using the UMTS network, there will be an overall net degree of asymmetry in the number of bits flowing in the up-link and down-link channels. This will be averaged over the mix of services being used by customers and the net balance of session asymmetry in the calls completed. It is this net degree of asymmetry that is primarily of concern to the spectrum planners. The net

asymmetry is expected to be greater than unity, i.e. the totality of downlink traffic will require more spectrum capacity than the totality of up-link traffic.

The development of the UMTS spectrum requirements within the UMTS Forum is based on 6 market "environments", ranging from the Central Business District (CBD) to Rural. For any of the defined UMTS service groups (simple messaging, high multimedia etc.) the degree of asymmetry in the traffic being generated in each of these environments may vary, because the tasks that people will want to do with UMTS will vary.

The comments above relate to the degree of asymmetry within the end user traffic. Transactional asymmetry can be very high at this level. The UMTS Forum figures for "medium multimedia" and "high multimedia" services are ~40:1 and 200:1 respectively. However, the transmission of this information over a mobile network requires that additional system information be added in to cope with packet transmission, error handling and protocol overheads. These additional overhead signals will have a proportionally greater effect on the low data rate direction of an asymmetrical traffic flow, and will have the effect of reducing the overall asymmetry. Simple estimates based on fixed network hardware capabilities suggest the actual worst case asymmetry might be about 10:1 (e.g. ADSL technology). Studies based on the World-wide Web indicate similar ratios (supported by an investigation in [26] but other studies dealing with other market segments may indicate other ratios, which may be closer to unity. This can be called the "network level asymmetry" and the spectrum will need to be tailored to this requirement. A more detailed discussion of traffic asymmetry can be found in [5,6,25]. Traffic asymmetry has been allowed for in these calculations and therefore should not be a problem in the initial years of the UMTS rollout.

2.2 Service classes and switching modes

In its report "Spectrum for IMT-2000" the SAG converted the UMTS multimedia applications described in the Analysis/ Intercai Report from 1997 [21], which were based on a variety of future applications for data users, into a limited number of UMTS service classes, see Table 1. These service classes allow spectrum calculations independent from the various applications the user may have. They define the basic capacity requirements for the UMTS spectrum calculations. Response and delay time requirements from such applications were not taken into account. However they will affect the mode of operation on the Air Interface and will consequently impact the efficiency of the Air Interface.

Table 1: UMTS service classes and characteristics

Services	User net bit rate [kbit/s]	Coding factor	Asymmetry factors [s]	Effective call duration [kbit/s]	Service bandwidth[1] UL/DL	UMTS Switch Mode[2]
High interactive MM	128	2	1/1	144	256/256	CS
High Multimedia (MM)	2000	2	0.005/1	53	20/4000	PS
Medium Multimedia	384	2	0.026/1	14	20/768	PS
Switched data	14.4	3	1/1	156	432/43.2	CS
Simple messaging	14.4	2	1/1	30	28.8/28.8	PS
Speech	16	1.75	1/1	60	28.8/28.8	CS

1 The service bandwidth is the product of columns 2,3 and 4
2 CS is circuit switched and PS is packet switched

The asymmetry factors in Table 1 are taken from [22] The service classes have different characteristics. High interactive multimedia services e.g. video telephony require isochronous transmission, also switched data and speech services and they are therefore calculated as circuit switched services. This means that the average call duration time corresponds to the actual connection set-up time, the effective call duration depends on the occupancy factor, which is e.g. for speech 0.5, for video telephony 0.8. For packet switched services, the call duration is calculated as the sum of time intervals, where data are actually transferred via the Air Interface. Thus, the occupancy factor in this scenario is equal to one (see Figure 1).

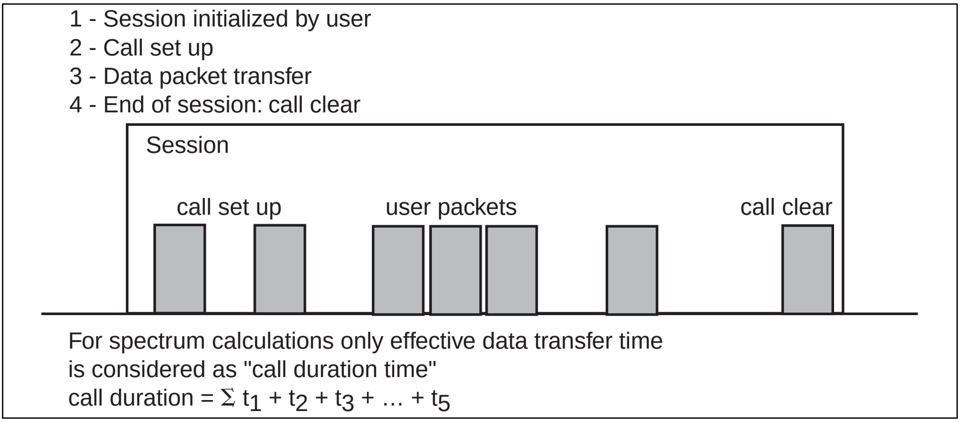
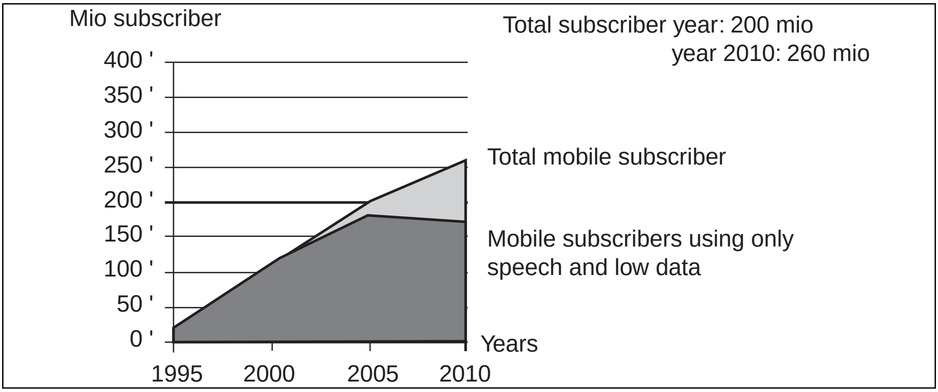


Figure 1 Packet transmission over the UMTS Air Interface

Quantitative Subscriber Estimates for the years 2005, 2010

Figure 2 shows the forecast for the EU 15 States. In 2005, there will be 200 mill. mobile users, thereof 32 mill. using Multimedia services including 12 mill low speed data and 20 mill high to medium multimedia service users. For the year 2010, there will be 260 mill in total, thereof 90 mill. multimedia service users including 10 mill low speed data and 80 mill high to medium multimedia.

Figure 2 EU15: UMTS and GSM/ DECT Subscriber Forecast (Private and Public) from the UMTS Forum Report №1 1997



The market forecast of the UMTS Forum shows 16% multimedia users for the year 2005 and 30% for the year 2010. These figures are low in contrast to speech. However - the picture becomes different, when we consider the traffic volumes. Here, multimedia dominates by far over speech in the year 2010. This can be seen in the traffic calculations of the SAG Report on UMTS spectrum estimates [22]. It can also be seen there, that multimedia traffic has high asymmetry regarding uplink and downlink. In this context asymmetry has to be seen as an overall net degree of asymmetry in the number of bits flowing in the uplink and downlink channels [5]

The UMTS spectrum which will be available in the year 2002 must be sufficient to handle the UMTS traffic up to the year 2005 in order to give operators confidence in the possibilities to develop and introduce UMTS.

2.3 Assumptions for the UMTS Market

The UMTS Forum's spectrum estimates from the year 1997 [1] show, that speech and low data rate services can remain in 2nd generation networks, if all 2nd generation spectrum identified for GSM and DECT is allocated. In this context it should be noted that new entrants, who do not have an existing 2nd generation network, may also gain a UMTS licence, in which case a higher focus on providing speech and low rate data services as well as multimedia may occur. The existing 2nd generation operators who gain a UMTS licence may also have a high interest in providing speech services because of a lack of capacity in their 2nd generation networks. It has been assumed in this study that the traffic is shared equally between all the operators. It has also been assumed that 90% of the total speech traffic will remain on 2nd generation systems in the initial phase. This is difficult to estimate, especially in the light of dual mode GSM/UMTS terminal development, which will allow for a long time the combined use of GSM and UMTS networks. Therefore, in the first part of this study, it has been assumed that most speech services as well as low speed data services, will be switched via GSM radio networks in the respective GSM spectrum.

This assumption of 90% of speech and low data on existing GSM networks recognises the existing success of GSM and that this will continue. It must also be remembered that GSM will probably continue to offer the better wide area coverage for speech and low data users up to at least the year 2005.

It should be noted however that the 10% assumption is for up to the year 2005. After 2005 it can be expected that the number of subscribers using only speech and low speed data will reduce in favour of subscribers taking up the whole range of applications from speech to multimedia.

Then, a calculation can be made for the required UMTS spectrum, which deals mainly with medium to high-speed multimedia services. An estimated division of the market forecast for the years 2005 into service classes is made in Table 4. It results in a UMTS scenario with 20 mill. medium/high multimedia and 17 mill speech users for the year 2005 (EU15).

Table 2: Forecast UMTS usage (multimedia users with low to high bit rates and speech)

Service users	Bit rate	Subscribers (EU 15) Year 2005 (millions)
High Interactive MM [1)]	128 kbit/s	2
High MM	2 Mbit/s	6
Medium MM	384 kbit/s	12
Speech/ low speed data	16/14.4 kbit/s	17
Total		37

1) Videotelephony, Telepresence

Table 3: 2nd Generation usage (speech and low speed data)

Service users	Bit rate	Year 2005 subscribers in EU15 (millions)
Speech	16 kbit/s	151
Low speed data	14.4 kbit/s	12
Total		163

2.4 Traffic capacity requirements in urban environments

In the spectrum calculations for UMTS six potential user environments were considered, see [4,22]

The analysis of the population distribution in Europe shows, that 50 – 60 % of the population are in the urban area. Further, the peak of spectrum demand comes from the urban pedestrian environment. This is further explained in Annex 1.

Only the urban environments (CBD, pedestrian and vehicular) are considered now for calculating the spectrum requirement for the UMTS radio network as it is expected that the highest traffic densities and consequently the highest bandwidth requirements are in dense urban areas. In this study it is assumed that 60% of the in-building traffic originates from licence-exempt networks [6] Hence only 40 % of the traffic forecasted for CBD is considered in this calculation. The calculation uses the assumptions from [22]. The result for traffic per

km2 (aggregate traffic before adjustment for quality of service parameters (QoS)) is shown in the following Table 4.

Table 4: Traffic calculation for UMTS Services

Service class [2]	Aggregate traffic in the busy hour (Mbit/s/ km2) [1] Year 200 Uplink CBD(40%)	Urban	Downlink CBD(40%)	Urban
HMM 2 Mbit/s	0,15	0,1	30,6	22
MMM 384 kbit/s	0,06	0,05	2,5	1,8
HIMM 128 kbit/s	1,1	0,4	1,1	0,4
Speech/low speed data	2,5	2,3	2,5	2,3
Sum	3,8	2,85	36,7	26,5
All Environments	6,65		63.2	

1) Aggregate traffic includes the net bit rate, coding factor, uplink/downlink factor, and a 20% signalling overhead. For CBD the cell size is smaller than that for the other environments. Therefore an equivalent traffic value based on the cell sizes of the urban pedestrian and vehicular environment is used in order to simplify the conversion into spectrum demand in Table 4.
2) HMM = High Multimedia, MMM = Medium Multimedia, HIMM = High Interactive Multimedia

HMM and MMM both belong to packet switched services, while HIMM to circuit switched services (see Table 1). The traffic figures in Table 4 show, that packet switched services will dominate. The UMTS Air Interface should be designed to support circuit and packet oriented services efficiently.

The traffic figures can be converted into spectrum requirements. In [22] it is assumed, that the spectral efficiency of the UMTS Air Interface will be the figure from GSM, which is 53.8 kbit/s/ MHz per cell, including the coding factor 1.75, it is 94.15 kbit/s/ MHz per cell. In addition a spectral efficiency improvement factor is used. The average cell radius is assumed to be 75 m for the CBD environment and 0.7 km for the urban environments. The calculation result is shown in Table 5. It is taken over from the previous SAG report [22].

Table 5: Spectrum for UMTS Services in CBD and Urban environments (40 % CBD, pedestrian, vehicular)

UMTS Service	Spectrum Requirements (MHz) Year 2005			
	Uplink		Downlink	
	CBD 40 %	Urban	CBD 40%	Urban
HMM 2 Mbit/s	0.01	0.45	1.4	89.65
MMM 384 kbit/s	0.004	0.19	0.12	7.3
HIMM 128 kbit/s	2.0	12.36	2.0	12.36
10 % Speech/low speed data	1.9	10.2	1.9	10.2
Sum (rounded)	3.91	23.20	5.42	119.5
All Environments	27.1	124.9		

These calculations were based on average cell sizes of 2nd and 3rd generation services. This is sufficient when calculating the total spectrum demand. However this report has to analyse the viability of a number of scenarios for UMTS, in view of the available spectrum for the operators and the characteristics of the traffic and has to use other assumptions concerning cell sizes and service classes for UMTS only. Possibilities to combine the use of different transmission modes also have to be taken into account, i. e. FDD and TDD, in order to cope with the asymmetry in the traffic evident from Table 1 and discussed in chapter 2.

3. World-wide spectrum availability

The spectrum available for operators is for most of the world-wide regions and areas the spectrum identified for IMT-2000 at WARC-92 and in the ITU Radio Regulations. Figure 3 shows the IMT-2000 spectrum situation in some countries and areas.

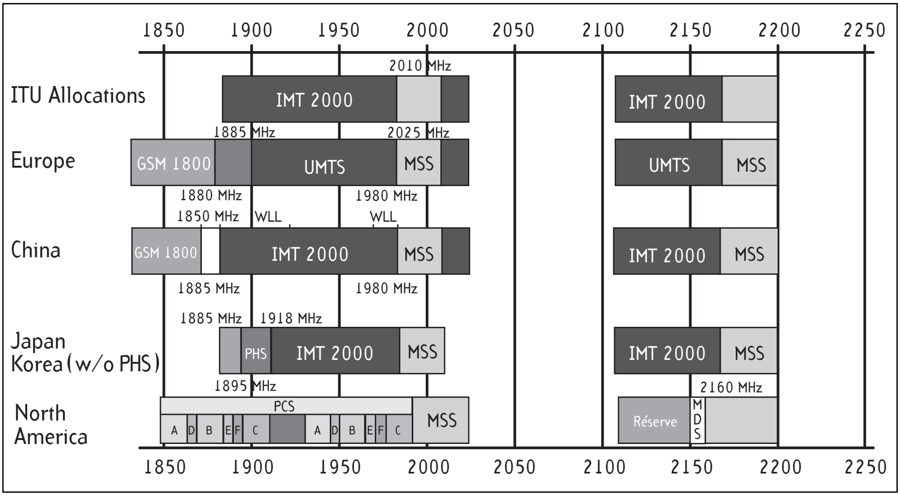


Figure 3: Frequency bands for IMT-2000

As shown in Figure 3 some countries have not converged fully in the direction of the WARC-92 agreement.

3.1 European Spectrum for UMTS

The European spectrum designation is defined in the ERC Decision on the introduction of UMTS; CEPT ERC/DEC/(97)07, CEPT ERC decision. A total of 15 CEPT states have at this time signed up to this ERC Decision. It is anticipated that more countries will sign in the future. In total 155 MHz could be made available up to 2005 subject to market demand. The bands for terrestrial UMTS identified in the ERC Decision are 1900 - 1980 MHz, 2010 - 2025 MHz, and 2110 - 2170 MHz. For the year 2002, the spectrum designations will probably differ from country to country. The ERC also decided that at least 2 x 40 MHz should be available to operators in this year. As a consequence different operator scenarios developed in this report may help to deal with such situations.

The UMTS operator may have to be able to work with the allocated bandwidth for a number of years beyond 2005. There is uncertainty as to when and if more spectrum will be available for UMTS. This has to be taken into account for spectrum requirements per operator in such a way, that an operator gets a limited spectrum reserve for traffic capacity beyond the figures shown in chapter 4.

It is further expected that more spectrum could become available after 2005 and more operators could be licensed after this date. This extra spectrum could also be assigned to the existing operators.. The number of operators depends more on non-technical issues, such as economic issues and the availability of additional spectrum.

CEPT in Europe can make available all ITU spectrum except 15 MHz which are already used for DECT. This results in 155 MHz of spectrum for terrestrial services with an additional 60 MHz identified for UMTS satellite services within the 2 GHz MSS bands.

3.2 Asia/Pacific

The spectrum allocation in the Asian Pacific states will probably be similar to those in Europe. Japan is expected as the first state allocating spectrum for IMT-2000, probably one year earlier than in Europe. Most of the countries are expected to make paired and unpaired bands available. Therefore, similar operator scenarios will appear, as in Europe.

The recent discussion of the UMTS Forum in China reflects the ITU allocations as being quite similar to those in Japan and Korea. It may be assumed that the major part of the ITU bands could be made available, however, no detailed plan or decision has been published.

The Japanese Ministry of Post and Telecommunications, MPT, is planning to designate the WARC-92 spectrum for third generation systems in the same way as the Europeans with the difference, that the frequency band 1895 MHz to 1918.1 MHz is already allocated to PHS services.

Korea already indicated spectrum allocations for IMT-2000 in line with spectrum identified for IMT-2000 in the ITU Radio Regulations

3.3 North America

There is a different situation in North America. The introduction of PCS services and the auctioning led to a split into licenses of 2 x 15 MHz and 2 x 5 MHz up to 1990 MHz. This differing spectrum utilisation leads to questions as to how IMT-2000 services can be implemented and how radio equipment could be harmonised with IMT-2000 services in Europe and in Japan and in the rest of the world.

As it is shown in Figure 3 North America can use only 5 to 15 MHz frequency blocks in the PCS bands. Therefore the 5 MHz minimum bandwidth per Operator is an important requirement for the standard; it has also to include guard band. The upper part of the IMT-2000 spectrum from 2110 to 2160 MHz could potentially be used by IMT-2000/UMTS.

In the USA the PCS bands are already available to operators. Canada has kept the C and E frequency blocks as a reserve for later allocations. The spectrum policy will be reviewed at the end of 1998.

3.4 South America

The South American spectrum situation differs slightly from that in North America and future plans for 3rd generation mobile systems are not yet known.

3.5 African and Arab States

The African and Arab states are following the ITU discussions and the developments in the other regions and countries. Active participation in conferences dealing with spectrum indicates their high interest in being involved in the future preparations on spectrum issues. It may therefore be assumed, that these states will follow the world-wide moves on spectrum allocations to operators.

3.6 Other regions

The remaining regions and countries in the world may continue with the WARC-92 decision. There are no indications in a different direction, which means that the ITU objective, of a world-wide harmonised IMT-2000 spectrum allocation, is still valid for the most parts of the world.

4. Minimum spectrum per operator from a technical point view

This chapter states the simplifications and approximations used in the spectrum calculations and defines some deployment scenarios. The reader is referred to section 1.2 where general assumptions are listed.

4.1 Technical assumptions

As the UTRA standardisation process has not been completed yet, it is only possible to use preliminary data for detailed spectrum calculations. In this study, several assumptions have been made regarding the capabilities of the technology, the size of the market and the development and take up of new services. Some of these assumptions may turn out to be pessimistic or optimistic. No tele-traffic models are currently available to the Forum for multimedia networks carrying mixed data rate traffic of both circuit and packet switched services. The calculations used in this report initially derive the traffic loading per carrier without any allowance for quality of service (QoS). A factor is then applied to the cell loading to allow for the aggregate quality of service requirements across all services.

The Forum believes that a QoS factor of about 3 is sufficient to allow for acceptable blocking of circuit services and reasonable delay constraints on packet switched services. Once the QoS targets for UMTS services are better understood this allowance may need to be reviewed.

The following assumptions are made:

1. The technology will support a channel spacing of 5 MHz. This channel spacing includes all necessary guard bands assuming the same spectrum efficiency. It is therefore assumed that 12 FDD and 7 TDD carriers are available.

2. The maximum available data rate for a carrier in FDD-mode (2x5 MHz) is 2 Mbit/s (uplink/downlink) capacity for low mobility or 384 kbit/s (uplink/downlink) for full mobility. The maximum available data rate for a carrier in the TDD mode (5 MHz) is 2 Mbit/s uplink or downlink (but not simultaneously) for low mobility applications.

3. Cell types, mobility classes and maximum data rates (user bit rates) are assumed according to Table 6.

Table 6: Maximum available data rates

Cell type	Mobility class	Max. available user net bit rate
Macro	High	384 kbit/s
Micro	high/low	384 kbit/s / 2 Mbit/s*
Pico	Low	2 Mbit/s

*2 Mbit/s (low mobility only) may be possible close to the base station

4. Scenarios assume that 60 % of CBD traffic is carried in licence exempt networks.
5. CEPT in Europe can make available all ITU spectrum except 15 MHz which are already used for DECT. This results in 155 MHz of spectrum for terrestrial services with an additional 60 MHz identified for UMTS satellite services within the 2GHz MSS bands.

6. High and medium multimedia are assumed to be tolerant of reasonable delay .

The reader is also referred to section 1.2 General assumptions.

It should be noted that;

· If the spectrum efficiency factor is higher than assumed the spectrum per operator could be less.

· The minimum economic cell size may be larger than assumed, particularly for micro cells. In this case the spectrum requirement per operator could be increased;

· The packaging options evaluated here are based on a fixed hierarchical structure. Other possible deployment scenarios could lead to further packaging options, e.g. it may be possible in the future to reuse the same carrier for different cell layers such as the same carrier to support an FDD macro cell outdoors and a FDD pico cell indoors;

· If the spectrum demand proves to be greater than that derived within this report, this could lead to either a need for more total spectrum for a given number of operators or for a given spectrum allocation a reduction in the number of operators per country.

In Tables 7 to 9 all numbers used for the calculations in Table 11 are stated. These have been taken from [22]. A carrier bandwidth B = 4,4 MHz is used. Furthermore it is assumed that

90 % of the total speech according to the market forecasts is carried within the GSM network. The remaining 10 % are shared equally among all UMTS operators. The HMM traffic is distributed among micro- and picocells. The HMM traffic predicted for the urban-vehicular environment will be added to the traffic in medium multimedia service. This follows the assumption that a user in the urban-vehicular environment will accept a lower data rate if the maximum data rate is not available. In Table 9 it is assumed that macro cells are tri-sectored whereas micro - and pico cells are omni-directional.

Table 7 Offered Bit Quantity [kbit/h/km2] in downlink for year 2005

Service	CBD	Urban-p	Urban-v
HIMM	9,56E+06	1,53E+06	2,62E+03
HMM	2,76E+08	7,86E+07	1,35E+05
MM	2,21E+07	6,42E+06	1,10E+04
Switched data	8,73E+06	2,62E+06	4,50E+03
Simple messaging	2,76E+06	8,29E+05	1,42E+03
Speech	2,18E+08	7,84E+07	2,02E+06

Table 8 Asymmetry factors and spectral efficiencies

Service	A_S	Se_S [kbit/s/MHz/cell]	
		Macro	Micro, Pico
HIMM	1,000	80	200
HMM	0,005	80	200
MM	0,026	80	200
Switched data	1,000	80	200
Simple messaging	1,000	80	200
Speech	1,000	80	200

The UTRA specification is based on 4.096 Mbp/s chip-rate and offers a maximum service net bit-rate up to 2 Mbp/s assuming a coding factor of 2 (aggregate bit-rate = 4 Mbp/s). This service bit-rate has to be understood as a peak value, whereby the actual capacity of the air interface depends on a number of criteria, mainly on the transport layers 1 and 2. For the actual capacity guaranteed during the busy hour estimates have to be made based upon the present level of knowledge on the UTRA specification.

The spectrum efficiency figures given in Table 8 are intended to represent what can be achieved in 2 x 5 MHz (FDD) and 5 MHz (TDD) channels under "busy hour" conditions in practical embedded cell deployment scenarios. The "busy hour" assumption implies that all nearby cells contributing to the wanted cell's interference environment are reasonably heavily loaded. The above spectrum efficiency figures are the gross bit rates without coding or signalling overheads. Coding factors are 1.75 for speech and 2 for all other services except switched data which has a factor of 3 [22]. A 20% signalling overhead is also assumed.

Table 9 Assumed base stations distances and cell areas

	Distance [km]	Cell area [km²]
Macro	1	0,288
Micro	0,4	0,138
Pico cell	0,075	0,005

It should be noted that all cell areas assumed in table 9 for macro and micro cells differ from the ones for urban-vehicular and urban-pedestrian environments in [22] This comes from the fact that the calculation is now made on the basis of a hierarchical cell structure whereas the calculation in [22] was based on market environments assuming average cell sizes for all environments. Furthermore different spectrum efficiency figures are used, because here UMTS only is considered, whereas in [22] a mixture of 2nd and 3rd generation systems was considered.

4.2 Spectrum Allocation and Deployment Scenarios

In order to realise the benefits of the Information Society as soon as possible, and for UMTS to be a mass market global solution, every effort will be needed to make UMTS as commercially attractive as possible. To do this requires that operators can make the optimum use of the scarce resource of spectrum. They should be given the maximum flexibility to cater to the possible different customer/market requirements. UMTS will make use of advanced cellular structures aimed at maximising network capacity. Such network structures are generally called hierarchical cell structures and can be implemented according to the specific operator's needs.

For an optimal UMTS radio network, it is proposed, that UMTS be planned using a hierarchical cell structure, see Figure 4, using micro, macro, and pico cells. Consideration needs to be given as to which element of UTRA (FDD or TDD) should be employed for which type of cell. Below is shown a possible use of this hierarchical cell structure, where high traffic demand could require 3 layers. With flexible deployment it could be possible in some locations for an operator to re-deploy picocell channels for macro cells outside of urban areas.

All CBD HMM traffic is assigned to the picocells, whereas all urban-pedestrian HMM traffic is allocated to in micro cells (partly at a lower data rate) and all HMM urban-vehicular traffic is carried by macro cells at a lower data rate.

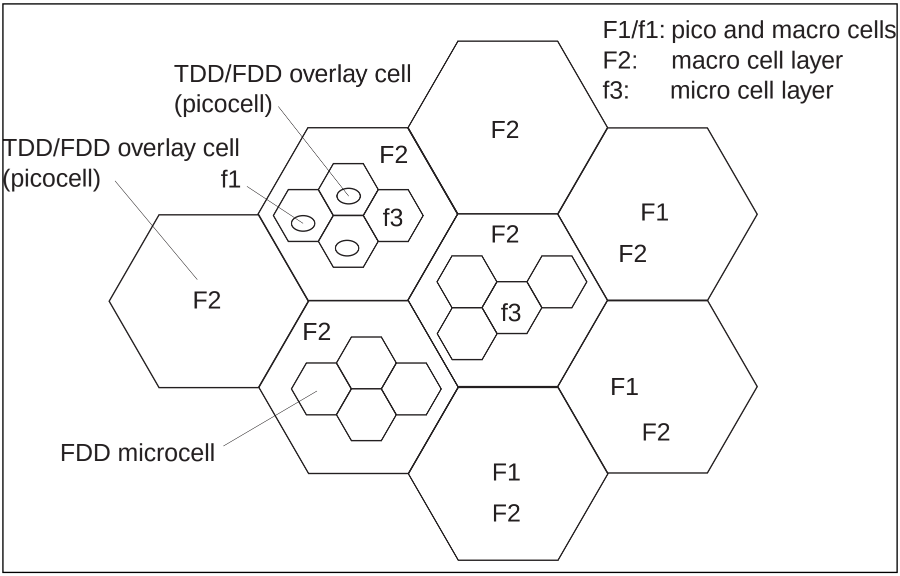


Figure 4: Flexible UMTS three layer network

The FDD macro cell provides the wide area coverage and is also used for high-speed mobiles. The micro cells are used at street level for outdoor coverage to provide extra capacity where macro cells could not cope. A cluster of them is shown here, although they could be deployed singly. It would seem likely that these microcells would not be hexagonal in shape but canyon-like, reflecting the topography of a street and be perhaps 200 – 400 m in distance. This

would be very specific to the city type.

The picocell would be deployed mainly indoors, in areas where there is a demand for high data rate services such as laptops networking or multimedia conferencing. The way in which these picocells can be deployed would be dependent on their maximum range in given environments (indoor and outdoor). Such cells may be of the order of 75 m in distance. A limiting factor will be the range of these terminals when used for high data rate services given the high demand this will place on batteries.

As a basis for a network operator an allocation of paired frequencies for FDD operation is necessary.

· 2 x 5 MHz will allow a single layer only; a hierarchical cell structure is not feasible in this case;

· 2 x 10 MHz gives room for a two-layer structure, e.g. a macro cell layer together with either a micro cell layer or picocell;

· 2 x 15 MHz allows the deployment of a complete hierarchical cell structure where the traffic demand is high or a mix of layers such as one macro cell and two micro cells;

· 2 x 20 MHz allows increased flexibility and additional capacity.

In addition to the allocation of paired frequencies an operator may need an allocation of unpaired frequencies for TDD operation, in particular for low mobility applications indoors.

· 5 MHz may be required in order to give satisfactory capacity for asymmetric traffic;

· 10 MHz would give more flexibility and additional capacity for asymmetric traffic.

4.3 Viability of scenarios

Eight scenarios were selected to study their ability to cater for the projected demand for UMTS services. These eight varied from 2 x 5 MHz to 2 x 20 MHz paired + 5MHz unpaired spectrum. Table 10 below defines the 8 scenarios with the different allocations per operator. The total predicted traffic is assumed to be equally shared between each operator.

Table 10: Deployment Scenarios

Scenario	Paired frequencies allocated to one operator	Unpaired frequencies allocated to one operator	Max. number of operators	Traffic per operator /Mbp/s/ km2 uplink	Traffic per operator /Mbp/s/ km2 downlink	Traffic per operator /Mbp/s/ km2 Total	Spectrum not allocated [MHz]
1	2x5 MHz	-	12	0.55	5.3	5.85	35
2	2x5 MHz	5 MHz	7	0.7	9.2	10.1	50
3	2x10 MHz	-	6	1.1	10.5	11.6	35
4	2x10 MHz	5 MHz	6	1.1	10.5	11.6	5
5	2x15 MHz	-	4	1.6	16	17.6	35
6	2x15 MHz	5 MHz	4	1.6	16	17.6	15
7	2x20 MHz	-	3	2.2	21	23.2	35
8	2x20 MHz	5 MHz	3	2.2	21	23.2	20

In addition, it should be noted that other countries and regions in the world will probably have different market demands and requirements and therefore other scenarios for minimum spectrum per operator may also be relevant.

From a previous report [22] the overall number of information bits required to be carried was calculated for the three critical environments that contribute to the total spectrum requirements, namely the central business district (CBD), urban pedestrian, and urban vehicular. The values are shown in Table 7. The traffic was then divided equally between the assumed number of operators. This assumption ignores the fact that an operator could have a greater share of the market and traffic. It was felt impractical to use other assumptions but this fact should be taken into account when considering the conclusions of this report. The initial spectrum for an operator should allow for this, and not severly constrain an operator through lack of spectrum.

Using the methodology outlined in Annex 2 the projected traffic is distributed over the assumed hierarchical cell structure. This process leads to a required number of bits to be carried by each cell. This requirement is then divided by the capacity of the cell which gives a cell loading value (cl %), which is calculated for the uplink and downlink separately to account for traffic asymmetry. In a TDD cell, the capacity of 13 timeslots are considered for the downlink and 1 timeslot for the uplink.

This cl % value is the net percentage of the channel used in the busy hour, when no account has been taken of the Quality of Service (QoS). Various QoS demands, such as assured low delay and near real-time delivery, will significantly increase the loading. A factor of three has been assumed to be necessary to assure required QoS.

The results of this calculation are shown below in Table 11. The assumed cell hierarchy is given in the second column (M=macro, m=micro, and p=pico). The loading presented in the table is cl %.

In the calculations an assumption is made as to the amount of traffic that will be carried in licence exempt networks. This is necessary because the market study used does not differentiate between public licensed and licence exempt networks. It is assumed that 60% of CBD traffic is carried on licence exempt networks.

Table 11 Net cell loading for different scenarios without QOS considerations.

Layer Scenario	Cell layers*	Macro (M) cell_load, UL/%	micro (m) cell_load DL/%	Pico (p) cell_load, UL/%	cell_load, DL/%	cell_load, UL/%	cell_load, DL/%
1	M	48	221	-	-	-	-
2	M,pTDD	40	309	-	-	1	6
3a	M,p	46**	361**	-	-	<1	4
3b	M,m	<1	1	36	322	-	-
4	M,m, pTDD	<1	1	9	69	<1	7
5	M,m,p	1	2	13	104	<1	5
6	M,2m, pTDD	1	2	6	52	1	10
7	M,2m,p	2	3	9	69	<1	7
8	M,2m,p, pTDD	2	3	9	69	<1	5

*) M: FDD-Macro-cell; m: FDD-Pico-cell; p: FDD-Pico-cell; pTDD: TDD-Pico-cell
The assignment of the second/additional carrier to particular layers is only representative; flexible assignments to other layers should be possible
**) in scenario 3a all traffic from urban-p environment is carried in Macro-Cells

The figures in Table 11 rest on the assumption that all traffic originating in one environment is carried in only one of the cell layers. As can be seen, this in some cases results in one layer being overloaded while others are under-utilised. This is not spectrally efficient.

In order to explore the possibility to distribute the traffic more evenly, another calculation has been done with the assumptions

1. All HMM traffic is carried in the pico-cell layer;
2. The pico-cell layer is assumed to have been built out so it can carry 25 % of all other traffic;
3. The remaining traffic is distributed to get as far as possible similar load in the macro- and micro-cell layers.
4. That for QoS a multiplier of 3 is used on the net cl % to give the effective cl %.

For details of the calculation, see Annex 2. The result of the calculation is shown in Table 12.

The loading presented in the following tables is cl % x 3. This is the effective cl %. A figure of 100% for effective cl means that the channel is fully loaded.

Table 12 Effective cell loading with flexible distribution of traffic between network layers with QoS factor of 3.

Scenario	Macro layer Load DL	Load UL	Micro layer Load DL	Load UL	Pico layer Load DL	Load UL
1	NA	NA	249%	31%	NA	NA
2	NA	NA	54%	33%	14%	6%
3	NA	NA	63%	38%	15%	1%
4	56%	45%	52%	30%	16%	7%
5	60%	45%	82%	49%	23%	1%
6	48%	35%	42%	25%	25%	11%
7	55%	41%	57%	34%	31%	1%
8	55%	41%	38%	23%	33%	15%

NA = not available.

As can be seen, a more evenly distributed loading has been achieved. Still, in some scenarios the micro-cell layer is overloaded or close to overloaded. In reality the possibilities to redistribute traffic between layers is limited by its characterisitics (such as speed and response time). Fast moving mobiles should not be handed over to the micro-cell or pico-cell layer. Therefore a loading close to 100% will limit the flexibility of the network. If re-distribution of traffic on to the pico cell layer is inappropriate the problem could be resolved in some areas by reducing micro cell sizes.

5. Minimum Spectrum per operator
an overall view and a feasibility study

In chapter 3, eight deployment and allocation scenarios have been introduced, which have been discussed from a technical point of view. Based on these scenarios the maximum number of operators for each scenario is derived in Table 10, taking into account the spectrum availability situation in Europe. In addition to the frequencies allocated in the different scenarios there may be some spectrum of that decided in the ERC Decision in reserve, depending on national constraints. From the analysis of the market situation in chapter 2 it was concluded that a technical deployment with the assumptions made in [15] and [22] is not possible. For this reason all scenarios are examined taking into account the results from chapter 4 assuming different parameters for cell sizes and spectrum efficiency figures than used in [22].

Using these values for each scenario the different services and environments are assigned to cell layers. It is then evaluated whether it is possible to carry the traffic with the deployed scenario. The methodology is described in more detail in Annex 2 of this report. The loading of the different cell layers should to be below 100 % if the scenario is feasible to carry the traffic as required, with some provision for quality of service. The cell sizes (see Table 9) are selected as close as possible to those values from [22]. Improved spectrum efficiency figures are obtained based on the results of the ETSI-simulations [13,14]. As the most critical situation is in dense urban areas the three environments CBD, urban-pedestrian and urban-vehicular are considered only. All assumptions and figures used for this calculation are included in Annex 2 of this report.

5.1 Scenario 1:

The Federal Communications Commission (FCC) in the USA requires the minimum bandwidth per public operator to be 2x5 MHz. UMTS will allow the deployment of a one layer network. A calculation has been made of the consequences of such an allocation. As can be seen from Table 12, with the assumed cell size the capacity will not be sufficient to carry the traffic load forecast for the EU15.

Furthermore, in order to be able to deliver the 2 Mb/s service in combination with all other types of services in an actual traffic situation, two layers of micro-cells are necessary. One layer has to be reserved for the 2 Mb/s service, the other serves other customers. It will probably be necessary to temporarily remove all other users from the carrier in the vicinity of the 2 Mb/s user. This makes a second micro-cell layer necessary. In this scenario with only one carrier no 2 Mb/s service can be delivered. The flexibility to serve different kinds of users at

the same time will also be diminished. It will also be very complicated and expensive to achieve seamless coverage without a macro cell layer.

Scenario 1 are not feasible from a technical point of view, as it will not provide the full range of UMTS services. Without a macro cell layer it will be virtually impossible to cater for fast moving mobiles, and make it very difficult for UMTS operators to provide coverage comparable with that expected by GSM customers today in rural and urban areas. Therefore this scenario is not recommended.

5.2 Scenarios 2 and 3:

Even if the addition of a pico-cell layer increases the capacity to more or less the required level, the problem to deliver the full range of UMTS services in all areas still remains. The pico-cells will only have a limited coverage, indoors and in hot-spots. Whilst these scenarios can cater for the traffic load predicted for the EU15 countries, they still suffer from not having a macro cell layer.

Without a macro cell layer it will be virtually impossible to cater for fast moving mobiles, and make it very difficult for UMTS operators to provide coverage comparable with that expected by GSM customers today. Therefore these scenarios is not recommended.

5.3 Scenario 4:

This scenario can handle all traffic. Scenario 4 would work with 5 operators as well as with 6 operators, because there is the required 20 % spare capacity (see Table 12). That is each operator has sufficient spare capacity to handle 20% extra traffic with the spectrum assumed for each in this scenario, which would enable 5 operators to carry all the traffic, even though 6 operators are assumed here.

However having only 1 channel per cell layer may not provide the flexibility that is required. There may be problems delivering high data rate services in some areas.

Due to the disadvantages of this scenario it is not a preferred solution.

5.4 Scenario 5:

The deployment situation is similar to the situation in scenario 4, except that paired bands instead of unpaired bands are used for pico cells. However the situation is worse because the total spectrum assumed to be allocated to operators is less than in scenario 4. The loading on the micro cell layer(downlink) is increased significantly over all scenarios (except 1).. This scenario also does not have the benefit of TDD spectrum, which makes the efficient handling of asymmetric traffic difficult. Again as in scenario 4 this solution may lack in flexibility. Due to the disadvantages of this scenario it is not a preferred solution.

5.5 Scenario 6:

This scenario is the preferred solution for the minimum spectrum required by a public UMTS operator.

The scenario with full functionality that occupies the least amount of spectrum per operator is Scenario 6. It allows for one macro-cell layer, two micro-cell layers and one pico-cell layer.

A possible distribution of carriers and of traffic between the carriers is shown in the following table. Pico cells has been built out to cover enough area to take up 25% of the traffic, which probably means not only hot-spots and some indoor areas, but also dense town centres.

Table 13: Possible Traffic distribution between cell layers

Service Class	Macro-cell layer	Micro-cell layer	Pico-cell layer
	Share	Share	Share
High MM	0%	0%	100%
MMM	5%	70%	25%
HIMM	5%	70%	25%
Switched Data	10%	65%	25%
Simple messaging	10%	65%	25%
Speech	10%	65%	25%
	1 FDD	2 FDD	1 TDD
	carrier	carriers	carrier
Loading of Downlink	48%	42%	25%
Loading of Uplink	35%	25%	11%

If a more limited build-out of picocells is desirable from an economic point of view, more spectrum for an extra micro cell carrier has to be found.

5.6 Scenario 7 and 8:

Also these scenarios allow for full functionality and have enough capacity to carry all traffic.

5.7 Summary

Scenarios 4 to 8 can be considered further. The choice of which scenario that should be preferred cannot be the same for all countries and markets. There will be a trade off between the cost of rolling out a network since extra spectrum (all other things remaining equal) should lead to a less costly roll out, and the benefits of having extra operators. This is not however a technical issue, and is therefore not discussed within this report. There are also issues concerning the flexibility with which an operator can deliver services and the realisation of a global mass market.

However the preferred solution is 2 x 15 MHz paired and 5 MHz unpaired for the minimum spectrum required by a public UMTS operator.

It is envisaged that by the year 2005 techniques will be available which will allow UMTS to exploit the spare capacity in paired channels due to traffic asymmetry. This will give an operator the required margin to continue catering for demand for some time past the year 2005. Sooner or later there will however be a need for more spectrum for UMTS.

5.

6. Conclusions

The analysis carried out in this document is to give guidance for the minimum spectrum demand per public UMTS operator in the initial phase. 8 scenarios are calculated and evaluated based on the market forecast for EU 15. The results of the evaluation suggest the UMTS service capabilities shown in Table 14.

Table 14: UMTS service capabilities

Scenario	Paired frequencies allocated to one operator	Unpaired frequencies allocated to one operator	UMTS Service capability
1	2x5 MHz	-	
2	2x5 MHz	5 MHz	limited
3	2x10 MHz	-	
4	2x10 MHz	5 MHz	some possible
5	2x15 MHz	-	restrictions
6	2x15 MHz	5 MHz	
7	2x20 MHz	-	full
8	2x20 MHz	5 MHz	

In addition the worldwide situation is reflected.

6.1 European Situation

Based on the assumptions in this report, including the practicality to distribute traffic loading relatively evenly between the hierarchical cell layers, and assuming that the use of TDD in the unpaired spectrum is the more efficient way of handling asymmetric traffic, the UMTS Forum considers that,

scenario 6 (2x15 MHz + 5 MHz) is the preferred minimum.

However, depending on country specific situations regarding, for example spectrum, operators, market, asymmetry and traffic, other spectrum allocations per operator may be more appropriate. Therefore, depending on spectrum availability, more paired or unpaired spectrum could be allocated to an operator if higher traffic demands it.

The 2 x 15 MHz (scenario 5) would be technically sufficient to allow a UMTS service to start up and offer the full range of services envisaged at this time, but may not provide a flexible deployment of hierarchical cells.

It has been shown that from a purely technical point of view the minimum spectrum requirement (by definition) is 2x10 MHz (FDD) + 5 MHz (TDD) (scenario 4). This scenario

provides sufficient capacity to carry the projected traffic for Europe and the full range of UMTS services, but may not provide a flexible deployment of hierarchical cells. There may be problems delivering high data rate services in some areas.

Scenarios 1 - 3 are not practicable as they do not provide the full functionality required.

Scenarios 7 and 8 allow for full functionality and have enough capacity to carry all traffic.

6.2 World wide situation

Considering the regional situations in other parts of the world, such as America or Asia, none of the scenarios could be excluded. The minimum spectrum requirement per IMT-2000 operator depends on the regional markets and the regional conditions.

6.3 Recommendations

Recommendation 1

Based on the assumptions made, the UMTS Forum recommends 2x15 MHz (paired) + 5 MHz (unpaired) as the preferred minimum spectrum requirement per public UMTS operator in the initial phase. The allocation of unpaired spectrum is foreseen to handle asymmetric traffic in an optimised way. However, depending on country specific situations, other spectrum allocations per operator may be more appropriate.

Recommendation 2

The UMTS Forum recommends to study further the flexible use of TDD and FDD techniques, with the aim of improving the efficient use of spectrum.

Recommendation 3

The UMTS Forum recommends that administrations and other relevant authorities take timely action to make sufficient spectrum available for UMTS in the initial phase to satisfy market demand.

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A.1 FULL AND LOW MOBILITY USE IN THE SELECTED ENVIRONMENTS

UMTS is a multi-service system with the focus on mobile multimedia.

The spectrum calculations for UMTS are based on service classes with bitrates up to 2 Mbps and based on environment definitions.

The calculation result for UMTS Spectrum in the years 2005 and 2010 shows, that the CBD/urban- pedestrian/vehicular environments define the total spectrum requirement for additional 185 MHz. Table 1 and 2 gives an indication, how the traffic will be shared between the UMTS services 'High Multimedia' (2 Mbit/s), 'Medium Multimedia' (384 kbit/s) and 'High Interactive Multimedia' (128 kbit/s) etc. The following analysis results in the possibility to develop a concept for spectrum use, which gives the UMTS operator more flexibility in the use of spectrum.

1. Analysis of the market forecast data

If we analyze the population distribution in EU15 countries (see Fig. 1), we recognize the following:

- 50 - 60 % of the population in EU15 is in the urban area, there lies the focus on the spectrum limitation.

- most of the spectrum needed for UMTS services comes from the urban/pedestrian environment. It has partly extreme asymmetric traffic, dependent from the applications (High MM, Medium MM). Symmetric traffic comes from circuit switched services, which are, for example speech, video telephony and data.

- The amount of paired spectrum for 0Full Mobility' applications (vehicular) may satisfy up to 3 000 - 10 000 potential users per km2. The higher user density up to 108 000 users/km2 deals only with 'Low Mobility' (pedestrian, office, home).

- Spectrum for rural areas cannot fully be utilized in average, only for exceptional cases e.g. traffic jam/accident on motorways. Therefore symmetric and asymmetric services can be served in paired frequency bands, although the spectrum will not be used to 100 % in both directions.

· for urban environments outdoor, it seems to be more efficient to reserve separate carriers for 'Low Mobility' use and 'Full Mobility ' use. Full roaming between both should be possible.

· the spectrum which is needed for uncoordinated indoor use has to be considered separately. It deals with user densities up to 180 000 users per km^2.

2. Recommendations

The UMTS operator gets a UMTS license with

a) carriers for full mobility applications;
b) additional carriers for low mobility applications.

· as it was simulated in ETSI-SMG2 on the UTRA proposals, we recognize, that for full mobility it allows bitrates up to 384 kbit/s. It enables the operator to provide country-wide coverage. Full and low mobility users can operate in this radio layer.

· additional carriers dedicated for low mobility allow up to 2 Mbit/s services. It provides higher spectral efficiency according to SMG2 work results (approximate factor 2 and higher compared to full mobility). It shall be used in areas, where the majority of users has low speed and where higher bitrates are required.

This recommendation gives better spectrum utilisation because it allows optimal spectrum usage tailored to the population distribution and to the user characteristics. It further makes use of the unpaired UMTS bands with the TDD mode of UTRA. If the TDD component of UMTS is used, the operator can also adopt varying asymmetry situations between mobile users and base stations.

3. Conclusion

It is recommended to give every UMTS operator licensed spectrum in paired and unpaired bands for the following reasons:

a) Paired bands are required for full mobility (vehicular) applications but low mobility

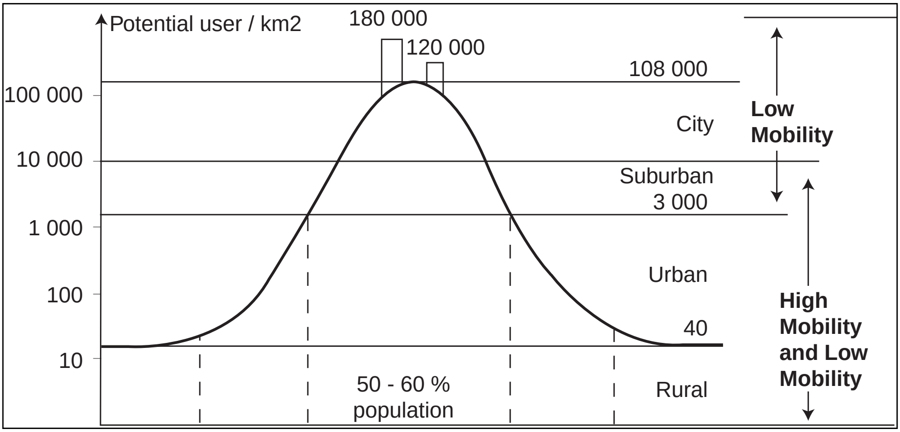
user traffic can also be included. They will be used for country wide coverage. In suburban and urban areas these bands will also be used for low mobility. In rural environments, sufficient traffic capacity can be provided for vehicular and pedestrian, symmetric and asymmetric service.

b) Unpaired bands, applied for low mobility only, shall be used mainly in the urban areas, where pedestrian communications dominate far beyond vehicular communications. Low mobility use of spectrum results in higher spectral efficiency and higher bitrate, thus better spectrum utilization will be achieved. Higher bitrates have asymmetric traffic characteristics and therefore, unpaired bands can be used.

c) To deal efficiently with the different traffic characteristics of the UMTS market, the TDD mode can be used for the low mobility applications and the FDD mode forthe full mobility and low mobility applications.

d) Radio network layers for full mobility and low mobility need to be separate, although users may roam between them. Therefore, separate carriers will be required to enable the operator a full UMTS service.

e) 2 Mbit/s services can only be offered in the low mobility case. Dedicated carriers for high bitrate services are necessary to avoid dynamic impacts on low to medium bitrates



Spectrum Calculation for terrestrial UMTS

Services	CBD/Urban (in building)	Suburban (in building or on street)	Home (in building)	Urban (pedestrian)	Urban (vehicular)	Rural in- & out-doo
High interactive MM	4.94	9.89	2.4	9.89	2.47	2.47
High MM	0.02	0.55	0.6	0.45	0.0	0.0
Medium MM	0.008	0.14	incl.	0.19	0.0	0.0
Switched data	1.25	6.26	0.3	5.42	0.42	0.83
Simple messaging	0.04	1.16	incl.	0.94	0.0	0.0
Speech	4.82	28.3	0.3	97.7	4.25	5.38
Total per env. [MHz]	11.1	46.3	3.6	114.6	7.14	8.69

Table 1: Up link for the year 2005: The required spectrum for each operating environment [MHz]

Services	CBD/Urban(in building)	Suburban (in building or on street)	Home (in building)	Urban (pedestrian)	Urban (vehicular)	Rural in- & out-door
High interactive MM	4.94	9.89	2.4	9.89	2.47	2.47
High MM	3.61	109.6	6.2	89.5	0.15	0.26
Medium MM	0.29	5.48	incl.	7.3	0.01	0.01
Switched data	1.25	6.26	0.3	5.42	0.42	0.83
Simple messaging	0.04	1.16	incl.	0.94	0.0	0.0
Speech	4.82	28.33	0.3	97.7	4.25	5.38
Total per env. [MHz]	14.9	160.7	9.2	210.8	7.3	8.96

Table 2: Down link for the year 2005: The required spectrum for each operating environment [MHz].

A.2 METHODOLOGY TO EVALUATE SPECTRUM ALLOCATION SCENARIOS

In chapter 4 of the Report a number of possible spectrum allocation scenarios have been proposed. Also in this chapter the overall traffic demand is given. The traffic demand is expressed as offered bit quantity (OBQ). The following methodology is used to evaluate whether a certain scenario is adequate to satisfy the overall traffic demand. The feasibility of each scenario is checked by comparing the offered bit quantity per operator (OBQO) in each cell layer with the cell capacity in the same cell layer. (Cell capacity is specified by the carried bit quantity per operator CBQO; see section 2 of this Annex.) OBQO represents the market potential per Operator and CBQO represents the traffic that can be handled from a technical point of view. As the most critical area is the dense urban area only the CBD, urban-pedestrian and urban-vehicular environments are considered in the methodology. The flowchart of the methodology is shown in Figure 1 below.

1. Calculation of the offered bit quantity per operator and cell layer (CBQO)

Assuming that n operators share the market equally then the OBQOUL/DL,s,e for the service s in the environment e in uplink(UL)/downlink(DL) is given by

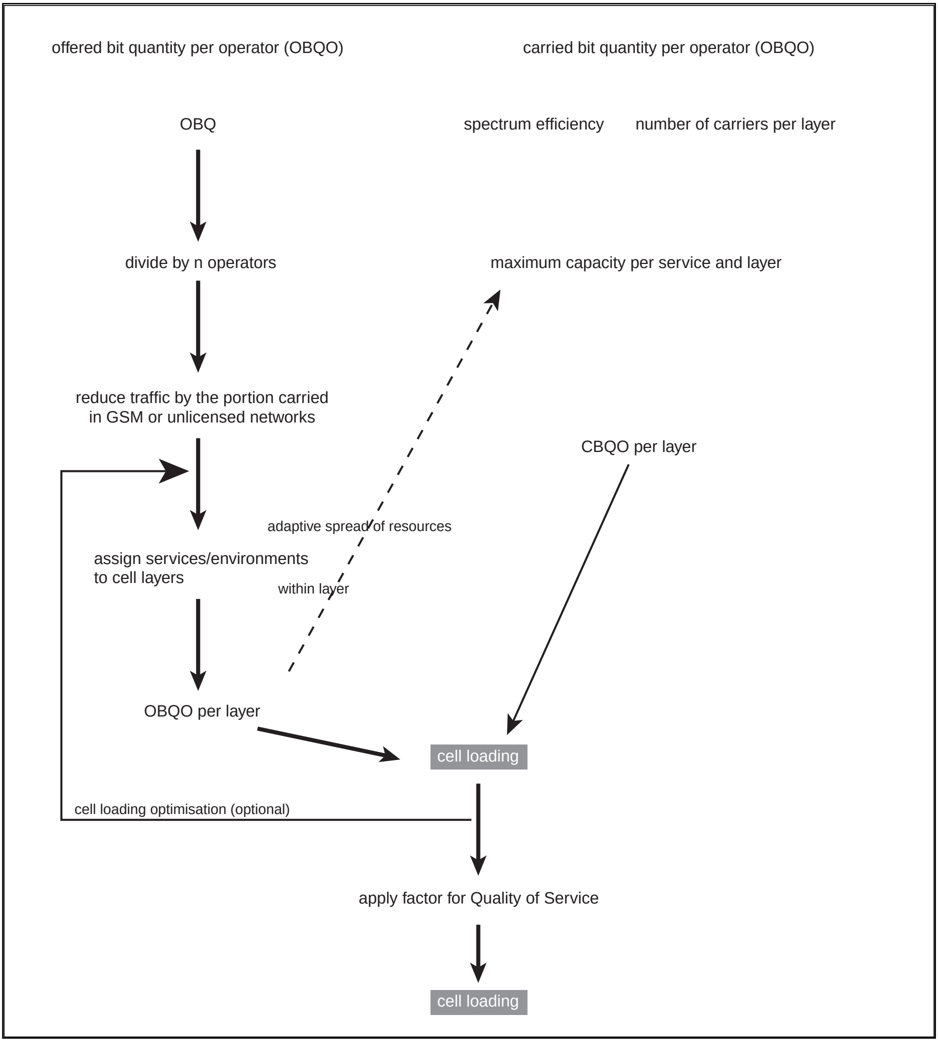
$$OBQO_{DL,s,e} = (OBQ_{s,e} \, (1-t_{GSM,s})\,(1-t_{unlic,s,e}))/n \qquad (1)$$

$$OBQO_{UL,s,e} = OBQODL_{s,e} \, a_s \qquad (2)$$

where $OBQs,e$ is the total offered bit quantity for s in e (downlink)
$t_{GSM,s}$ is the portion of the traffic carried in GSM-networks for s
$t_{unlic,s,e}$ is the portion of the traffic carried in licence-exempt networks for s in e
a_s is the asymmetry factor for s
s ∊ {HIMM,HMM,MM,speech, switched data, simple messaging}
e ∊ {CBD, urban-pedestrian, urban-vehicular}

When dividing the offered bit quantity by the number of operators trunking efficiency losses are ignored. Each service in a certain environment is now assigned to one cell layer l. For simplification speech, switched data and simple messaging services are aggregated to the service class speech/low date rate services as these services can be carried in GSM networks too. The $OBQO_{UL/DL,s,l}$ for a service s in the layer l is calculated as the sum of all $OBQO_{UL/DL,s,e}$ from environments e of s that are assigned to l. The $OBQO_{UL/DL,l}$ for the layer l is the sum of all $OBQO_{UL/DL,s,l}$ belonging to l, where l ∊ {macro, micro, pico}

Figure 1. Methodology to evaluate spectrum allocation scenarios



2. Calculation of the carried bit quantity per operator and cell layer (CBQO)

The maximum carried bit quantity per operator $maxCBQO_{s,l}$ for the service s in the cell layer l can be computed as

$$maxCBQO_{s,l} = N_l\, SE_s\, B \,/\, A_l \quad (3)$$

where	Nl	is the number of available carriers in l
	SE_s	is the spectrum efficiency for s
	B	is the carrier bandwidth
	A_l	is the hexagon area according to

$$A_{l,}omni = 0,866 * d^2 \quad (3a)$$
$$A_{l,}sector = 0,288 * d^2 \quad (3b)$$

and	d	is the distance between two base stations.

In order to calculate $CBQO_{s,l}$ it is necessary to assume a distribution of the carried traffic for each service within the same layer. It is assumed the resources within one layer can be allocated optimally. Optimally means that the portion ql,s of resources that is allocated for service s in l corresponds to the portion of offered bit quantity:

$$ql,s = OBQO_{UL/DL,l,s}/OBQO_{UL/DL,l} \quad (4)$$

therefore $CBQO_{s,l}$ is given by:

$$CBQO_{UL/DL,s,l} = maxCBQO_{s,l}\ \ q_{l,s} \quad (5)$$

The $CBQO_{UL/DL,l}$ for the layer l is the sum of all $OBQO_{UL/DL,s,l}$ belonging to l, where l $\in$ {macro, micro, pico}

3. Calculation of the cell loading of each layer

The ratio

$$cl_l = OBQO_{UL/DL,l} / CBQO_{UL/DL,l} \qquad (6)$$

is called cell loading and should be ideally below 100% in each cell layer for both uplink and downlink. This cell loading value is the net percentage of the channel used in the busy hour, when no account has been taken of the Quality of Service (QoS). Various QoS demands, such as assured low delay and near real-time delivery, will significantly increase the loading. Therefore are QoS factor is used to consider QoS yielding the effective cell loading:

$$cl_{l,effective} = QoS\ cl_l \qquad (7)$$

4. General Assumptions

In Table 1 to 3 all numbers used for the calculations in the example and in chapter 4 of the Report are stated. A carrier bandwidth B = 4.4 MHz is used. Furthermore it is assumed that 90 % of speech and low bit-rate is carried within the GSM network. It is assumed that 2 Mbit/s (HMM) is only possible in pico cells. Therefore the HMM traffic predicted for the urban-pedestrian and urban-vehicular environment will be added to the traffic in medium multimedia service. This follows the assumption that a user in these environments will accept use a lower data rate if the maximum data rate is not available. In Table 3 it is assumed that macro cells are deployed sectorized whereas micro - and pico cells are omni directional.

Table 1: Offered Bit Quantity [kbit/h/ km2] downlink for year 2005, no blocking adjustment for circuit switched services

Service	CBD	Urban-p	Urban-v
HIMM	9,56E+06	1,53E+06	2,62E+03
HMM	2,76E+08	7,86E+07	1,35E+05
MM	2,21E+07	6,42E+06	1,10E+04
Switched data	8,73E+06	2,62E+06	4,50E+03
Simple messaging	2,76E+06	8,29E+05	1,42E+03
Speech	2,18E+08	7,84E+07	2,02E+06

Table 2: Asymmetry factors and spectral efficiencies

Service	a_S	Se_S [kbit/s/MHz/cell]	
		Macro	Micro, PicoSe_S [kbit/s/MHz/cell]
HIMM	1,000	80	200
HMM	0,005	80	200
MM	0,026	80	200
Switched data	1,000	80	200
Simple messaging	1,000	80	200
Speech	1,000	80	200

Table 3: Assumed base station distances and cell areas

	Distance d [km]	Cell area Al [km2]
Macro	1	0,288
Micro	0,4	0,138
Pico cell	0,075	0,005

5. Example calculation

An example calculation is done for scenario 6. It is assumed that 60 % of the CBD traffic is carried in license-exempt networks, i.e. 40 % of CBD traffic will be carried out by public networks. In Table 4 the assignment of services and environments to cell layers are shown. This assignment is used by default, when no optimisation of cell loading is applied.

Table 4: Assignment of services and environments to cell layers

Service	CBD	urban-p	urban-v
HIMM	pico	micro	macro
HMM	pico	micro	macro (MM*)
MM	pico	micro	macro
speech/low data	pico	micro	macro

* In the urban-v environment it is assumed that the offered HMM traffic is delivered at lower data rates (MM)

The distribution of resources to uplink/downlink in the unpaired bands (Table 5) was done symmetrically as a first approximation. However this can be adapted to the real traffic asymmetry requirements if either the traffic in uplink or downlink is not satisfied.

Table 5: Allocation of carriers to layers

	Macro	Micro	Pico
number of paired carriers	1	2	0
number of un-paired carriers uplink	0	0	0.5
number of un-paired carriers downlink	0	0	0.5

Table 6: $OBQO_{UL,l}$ [kbit/h/ km²]

Service	Macro	Micro	Pico
HIMM	655	382500	956000
HMM	0	0	138000
MM	949	552500	57460
sp./low data	50648	2046225	2294900
sum	52252	2981225	3446360

Table 7: $OBQO_{DL,l}$ [kbit/h/ km²]

Service	Macro	Micro	Pico
HIMM	655	382500	956000
HMM	0	0	27600000
MM	36500	21250000	2210000
speech/low data	50648	2046225	2294900
sum	87803	23678725	33060900

Table 8: $CBQO_{UL,l}$ [kbit/h/ km²]

Service	Macro	Micro	Pico
HIMM	32746	738648	9402541
HMM	0	0	271454115
MM	1824816	41036014	21735999
speech/low data	2532145	3951478	22571016
sum	4389709	45726141	325163672

Table 9: $CBQO_{DL,l}$ [kbit/h/ km²]

Service	Macro	Micro	Pico
HIMM	32746	738648	9402541
HMM	0	0	271454115
MM	1824816	41036014	21735999
speech/low data	2532145	3951478	22571016
Sum	4389709	45726141	325163672

Table 10: Cell loading / %

Layer	cl,UL/%	cl,DL/%
Macro	1,19	2,00
Micro	6,51	51,78
Pico	1,05	10,16

6. Sensitivity Analysis

In this section the sensitivity of some important parameters (cell area, GSM-split, CBD-split and traffic asymmetry) on the traffic saturation is shown.

Cell Area

From equation (3) to (6) it can be derived that $cell\_loading_{,l}$ is proportional to A_l. Consequently a variation of the cell area by x % yields a variation of the cell loading figure

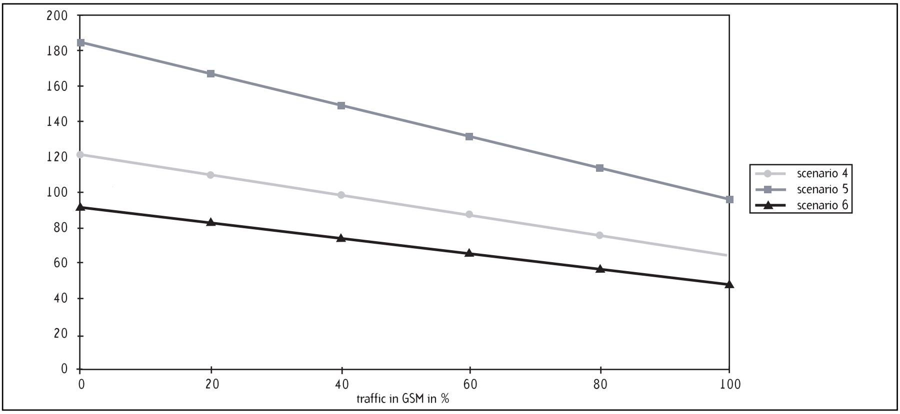
by the same percentage. However the necessary investment will increase if the cell sizes decrease.

CBD-split
In Table 9 calculations for a 60 % the portion of traffic carried in licence-exempt networks are shown. It is obvious that the critical layer is the pico-cell layer, which can carry all traffic even with only one frequency block. The micro and macro layer is insensitive to this parameter. Hence the results are stable in terms of CBD-split.

GSM-split
The critical layer in terms of the split of speech-traffic between UMTS and GSM is the downlink of the micro cell layer. Figure 2 shows the cell loading figures for three different scenarios (scenarios 4 and 7 result in identical curves).

Traffic asymmetry
The results based on this calculation method are also stable in terms of traffic asymmetry. From Table 9, which is calculated with high degree of traffic asymmetry, it can be derived that the traffic can be carried in the uplink even for completely symmetric traffic (assuming an asymmetry factor as = 1). This is due to the fact that in the asymmetric case reserves for the uplink are included originating from the use of mainly paired frequency bands. Another reason for these reserves are also the small cell sizes assumed in the calculation.

Figure 2: Cell loading as a function of speech traffic carried in the GSM network



7. Optimised traffic distribution

In the first approximation the distribution of traffic was done straightforward according to Table 4 assuming that all traffic originating in one environment is carried in only one cell layer. Consequently in some scenarios one layer can be overloaded while other are under-utilised. This is not spectrally efficient. In order to explore the possibility to distribute the traffic more evenly, another calculation has been done with the following assumptions:

· all HMM traffic is carried in the pico cell layer
· the pico cell layer is assumed to have been built out so it can carry 25% of all other traffic
· The remaining traffic is distributed to get as far as possible similar load in the macro and micro cell layers.

8. Results for all scenarios based on optimised traffic distributions

The results of the calculations are shown in tables, one for each scenario. For the first three scenarios the total carried traffic in the downlink is given, which is derived from Table 1, assuming that 60 % of the CDB traffic is carried in private networks. The total traffic for scenarios 2-8 are all the same. In the tables the share of the traffic carried by each cell layer is shown for every service class, together with the amount of spectrum required to carry the traffic in that layer (assuming that 90% of the speech and low speed data traffic is carried in GSM networks).

The total spectrum requirement for each cell layer is then calculated, and the loading of the cell layer is calculated as the required spectrum divided by the available spectrum in that layer.

In the calculations it has been assumed that all services can be delayed until free capacity can be found in a channel. In reality shorter delays are required. Therefore the loading of a channel cannot be 100 %. Experience from wired data networks suggest that when the loading exceeds 30 - 40 % problems will occur. Hence a Quality of Service factor of three is applied to indicate the real possibilities for loading the channel. The results of the calculations are summarised in Table 19.

Table 11: Effective cell loading for Scenario 1 (with QoS factor applied)

Service Class	Total traffic downlink	Micro
	Kbit/h/km2 x 105	Share
High MM	0	0%
MMM	2044.06	100%
HIMM	53.5662	100%
Switched Data	61.165	100%
Simple messaging	19.3442	100%
Speech	1676.2	100%
No of Carriers		1 FDD
Loading downlink		83%
Loading uplink		10%
Loading x 3 downlink		249%
Loading x 3 uplink		31%

Table 12: Effective cell loading for Scenario 2 (with QoS factor applied)

Service Class	Total traffic downlink	Micro	Pico
	Kbit/h/km2 x 105	Share	Share
High MM	1891.35	0%	100%
MMM	152.71	75%	25%
HIMM	53.5662	75%	25%
Switched Data	61.165	75%	25%
Simple messaging	19.3442	75%	25%
Speech	1676.2	75%	25%
No of Carriers		1 FDD	1 TDD
Loading downlink		18%	5%
Loading uplink		11%	2%
Loading x 3 downlink		54%	14%
Loading x 3 uplink		33%	6%

Table 13 Effective cell loading for Scenario 3 (with QoS factor applied)

Service Class	Total traffic downlink	Micro	Pico
	Kbit/h/km2 x 105	Share	Share
High MM	1891.35	0%	100%
MMM	152.71	75%	25%
HIMM	53.5662	75%	25%
Switched Data	61.165	75%	25%
Simple messaging	19.3442	75%	25%
Speech	1676.2	75%	25%
No of Carriers		1 FDD	1 FDD
Loading downlink		21%	5%
Loading uplink		13%	0%
Loading x 3 downlink		63%	15%
Loading x 3 uplink		38%	1%

Table 14: Effective cell loading for Scenario 4 (with QoS factor applied)

Service Class	Macro	Micro	Pico
	Share	Share	Share
High MM	0%	0%	100%
MMM	7%	68%	25%
HIMM	7%	68%	25%
Switched Data	20%	55%	25%
Simple messaging	20%	55%	25%
Speech	20%	55%	25%
No of Carriers	1 FDD	1 FDD	1 TDD
Loading downlink	19%	17%	5%
Loading uplink	15%	10%	2%
Loading x 3 downlink	56%	52%	16%
Loading x 3 uplink	45%	30%	7%

Table 15: Effective cell loading for Scenario 5 (with QoS factor applied)

Service Class	Macro	Micro	Pico
	Share	Share	Share
High MM	0%	0%	100%
MMM	6%	69%	25%
HIMM	6%	69%	25%
Switched Data	13%	62%	25%
Simple messaging	13%	62%	25%
Speech	13%	62%	25%
No of Carriers	1 FDD	1 FDD	1 FDD
Loading downlink	20%	27%	8%
Loading uplink	15%	16%	0%
Loading x 3 downlink	60%	82%	23%
Loading x 3 uplink	45%	49%	1%

Table 16: Effective cell loading for Scenario 6 (with QoS factor applied)

Service Class	Macro	Micro	Pico
	Share	Share	Share
High MM	0%	0%	100%
MMM	5%	70%	25%
HIMM	5%	70%	25%
Switched Data	10%	65%	25%
Simple messaging	10%	65%	25%
Speech	10%	65%	25%
No of Carriers	1 FDD	2 FDD	1 TDD
Loading downlink	16%	14%	8%
Loading uplink	12%	8%	4%
Loading x 3 downlink	48%	42%	25%
Loading x 3 uplink	35%	25%	11%

Table 17: Effective cell loading for Scenario 7 (with QoS factor applied)

Service Class	Macro	Micro	Pico
	Share	Share	Share
High MM	0%	0%	100%
MMM	4%	71%	25%
HIMM	4%	71%	25%
Switched Data	9%	66%	25%
Simple messaging	9%	66%	25%
Speech	9%	66%	25%
No of Carriers	1 FDD	2 FDD	1 FDD
Loading downlink	18%	19%	10%
Loading uplink	14%	11%	0%
Loading x 3 downlink	55%	57%	31%
Loading x 3 uplink	41%	34%	1%

Table 18: Effective cell loading for Scenario 8 (with QoS factor applied)

Service Class	Macro	Micro	Pico
	Share	Share	Share
High MM	0%	0%	100%
MMM	4%	71%	25%
HIMM	4%	71%	25%
Switched Data	9%	66%	25%
Simple messaging	9%	66%	25%
Speech	9%	66%	25%
No of Carriers	1 FDD	3 FDD	1 TDD
Loading downlink	18%	13%	11%
Loading uplink	14%	8%	5%
Loading x 3 downlink	55%	38%	33%
Loading x 3 uplink	41%	23%	15%

9. Summary of results

Table 19 Summary of effective cell loading for Scenario 1 - 8 (with QoS factor applied)

Scenario	Macro layer		Micro layer		Pico layer				
	Load downlink	Load uplink	Load downlink	Load uplink	Load downlink	Load uplink	No of operators	Spectrum /operator [MHz]	Totally allocated [MHz]
1			249%	31%			12	10	120
2			54%	33%	14%	6%	7	15	105
3			63%	38%	15%	1%	6	20	120
4	56%	45%	52%	30%	16%	7%	6	25	150
5	60%	45%	82%	49%	23%	1%	4	30	120
6	48%	35%	42%	25%	25%	11%	4	35	140
7	55%	41%	57%	34%	31%	1%	3	40	120
8	55%	41%	38%	23%	33%	15%	3	45	135

Even if the distribution of traffic between the cell layers has diminished the number of overloaded cell layers, it can still happen in some scenarios that one cell layer is overloaded or close to be overloaded. In reality the possibilities to redistribute traffic between layers is limited by its characteristics (such as speed and response time). Fast moving mobiles should not be handed over to the micro cell or pico cell layer. Therefore a loading close to 100% will limit the flexibility of the network. If re-distribution of traffic on to the pico cell layer is inappropriate the problem could be resolved in some areas by reducing micro cell sizes.

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