Consultation Paper no. 11/2004

Telecom Regulatory Authority of India

Consultation Paper

on

Spectrum related issues:

Efficient Utilisation, Spectrum Allocation, and Spectrum Pricing

New Delhi
31st May 2004

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Preface

Efficient utilisation, spectrum pricing and allocation procedure has its genesis in the Unified License policy wherein the TRAI envisages the spectrum allocation policy to be separate from licensing of services. Also, the scarcity of this resource requires initiatives that encourage its most efficient usage. The Government has sought the TRAI's recommendations on the following

a) Efficient utilisation of spectrum
b) Spectrum allocation procedure
c) Spectrum pricing

The TRAI has undertaken a study of the best international practices in this regard and has prepared this consultation paper raising key issues for comments of the stakeholders. Data was called on from cellular mobile service providers to gauge the level of efficiency achieved by the existing operators. A comprehensive framework balancing the technical and economic aspects is the objective that the consultation process seeks to achieve and this paper provides a basis to hold discussions in this regard.

The paper first discusses the current status of spectrum award, spectrum pricing, likely demand and spectrum allocations. Thereafter the technical and pricing options that encourage efficient usage of spectrum has been detailed. Using the technical and economic aspects, there arises issues and options pertaining to spectrum allocations. Further, key issues such as spectrum Re-farming, Trading, Mergers & Acquisition and Spectrum surrender have also been brought out.

We are hopeful that this paper would succeed in meeting the objectives that it seeks to achieve towards formulation of a policy on important issues relating to spectrum. The paper has already been placed on TRAI's website (www.trai.gov.in)

Written comments on this paper may be furnished to Secretary, TRAI by 30th June, 2004. For any further clarification on the matter, Secretary TRAI or Advisor (MN), may be contacted at trai07@bol.net.in (Ph.No.26167448) and jsengg@trai.gov.in (Ph.No.26106118) respectively.

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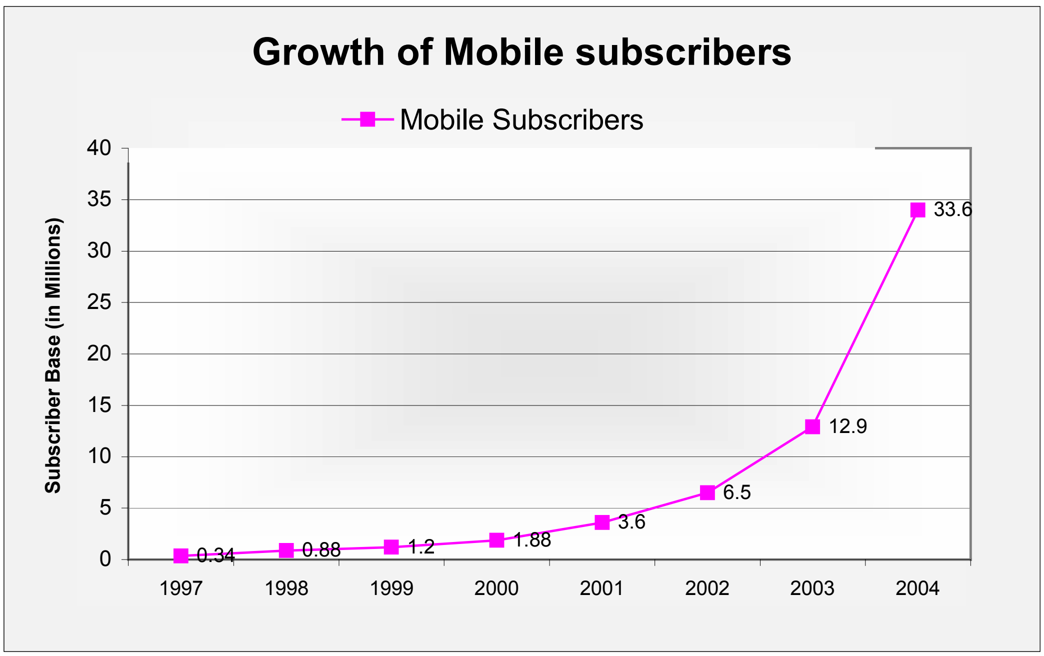
Chairman, TRAI

1.0 Background

Today, the country is witnessing tremendous growth in mobile wireless access segment, largely propelled by decreasing tariffs and increasing coverage. About 2 Million mobile wireless subscribers are being added every month, which translates in a monthly Tele-density increase of 0.2. At the present growth rate, it is expected that there would be about 100 Million wireless subscribers by the end of 2005.

Figure1: Growth of Mobile wireless subscribers



This trend of high wireless growth is a recent world-wide phenomenon. While Mobile Tele-density was 1/9th of the total Tele-density in 1995, it exceeded ½ in 2003.

Table 1: Fixed and Mobile Tele-density worldwide

Year	***1990***	***1995***	***2000***	***2003***
Fixed Tele-density	**9.90**	**12.30**	**16.38**	**18.76**
Mobile Tele-density	**0.19**	**1.56**	**12.34**	**21.91**
Total Tele-density	**10.09**	**13.86**	**28.72**	**40.67**

Source: ITU Database

While mobile has significantly accelerated the growth of Tele-density, it has also raised the requirement for spectrum significantly. This has necessitated Governments / Regulatory Authorities to examine the issues linked with the adequacy of spectrum, the procedure to distribute this scarce resource and the consequential requirement to build technical & economic frameworks that promote it's efficient utilisation.

In India, Cellular Mobile Services started with a duopoly in 1994-95. These licenses were awarded through a bidding process for Service Areas mostly co-terminous with provinces and metros. The technology at that point of time was specified as GSM and the licenses had a spectrum commitment of 4.5 + 4.5 MHz later amended in 2001 to 4.4 + 4.4 with a possibility of increase to 6.2 + 6.2. Keeping in view the development of technology, all the licenses were made technology neutral in 1999. Also, the third Cellular Mobile license was granted to the incumbent[1] in 1999. In 2001, the Government auctioned the fourth Cellular License in 1800 MHz band. In the 4th Cellular license, the committed spectrum was 4.4 + 4.4 MHz and a possibility of increasing it to 6.2.+ 6.2 MHz was mentioned . The spectrum charges were earlier based on number of mobile terminals and allocated spectrum. Since 1.8.1999 the spectrum charges have been converted to percentage of AGR. This varies from 2% to 6% based on the amount of spectrum allocated.

The large uptake of cellular mobile services required spectrum in excess of 4.4 MHz for GSM Service Providers. The Service Providers were assigned additional spectrums on meeting certain subscriber base criteria. Most of the operators today have 6.2 MHz, while some have been allocated upto 10 MHz based on criteria of subscriber base. The amount of revenue share increases with the increased allocation, i.e. 3% upto 6.2 + 6.2 MHz, 4% upto 10 + 10 MHz, 5% upto 12.5 + 12.5 MHz and 6% upto 15 + 15 MHz.

In Basic Services segment competition was introduced in 1997-98 with the introduction of duopoly in the country. These licenses were awarded through a bidding process. Licenses were successfully awarded in 6 of the 20 Circles. For these service providers also, the spectrum was allocated to offer telecom services through wireless access.

Post New Telecom Policy 1999, open competition was introduced in the Basic Services in 2001 and these licenses were available on First-come-first serve basis. In order to add value to their services, BSOs were permitted to provide '*limited mobility*' services. The frequency bands for providing their WLL (M) Services included 824-844 MHz paired with 869-889 MHz (FDD) & 1880 – 1900 MHz (Micro-cellular technology based on TDD). The Service Providers were given an initial 2.5 + 2.5 MHz to start service. The amount of spectrum could be increased to 5 + 5 MHz on meeting certain criteria (largely on subscriber base & roll out) in steps of 1.25 MHz.

At the end of this phase of licenses, the Cellular Mobile Services were being provided on GSM platform while the WLL(M) Services were being provided using CDMA technology.

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[1] As a policy of the government, the incumbent (which was a part of Government till 2000) was not allowed to operate Cellular Mobile Services.

In 2003, the TRAI recommended to the Government a migration from the service specific regime to a Unified License regime. This was to be implemented in two phases. The first phase provided the licensees with the option to migrate to a Unified Access Service License on payment of the differential between the entry fees paid and the amount paid to acquire the fourth cellular license. In places, where there was no fourth cellular licensee, the benchmark was set at the entry fees of Basic Service Providers in that service area. With the advent of Unified Access License, the country today has 5 to 8 Cellular Mobile Service Providers in most of the areas, with 3~4 on GSM & 2~ 4 on CDMA.

1.1 New Telecom Policy 1999 and need to conserve spectrum

NTP'99 states

"*5.0 Spectrum Management*

With the proliferation of new technologies and the growing demand for telecommunication services, the demand on spectrum has increased manifold. It is therefore, essential that spectrum be utilised efficiently, economically, rationally and optimally. There is a need for a transparent process of allocation of frequency spectrum for use by a service and making it available to various users under specific conditions."

Also

" *Relocation of existing Spectrum and Compensation:*

- *Considering the growing need of spectrum for communication services, there is a need to make adequate spectrum available.*
- *Appropriate frequency bands have historically been assigned to defence & others and efforts would be made towards relocating them so as to have optimal utilisation of spectrum. Compensation for relocation may be provided out of spectrum fee and revenue share levied by Government.*
- *There is a need to review the spectrum allocations in a planned manner so that required frequency bands available to the service providers.*

There is a need to have a transparent process of allocation of frequency spectrum which is effective and efficient."

The growth in cellular mobile has exerted pressure on spectrum. In cities like Delhi and Mumbai, where operators have been allocated upto 10 MHz, there is already demand for more than 10 MHz. With the 900 MHz GSM band completely occupied, the allocations beyond 8 MHz to each operator is possible only in 1800 MHz band. In 800 MHz CDMA band, some licensees have been allotted upto 3 carriers, out of a total of 4. With the growth of data, there is likely to be demand for more here too. Internationally, the next band for expansion of GSM and CDMA systems is 1800 MHz / 1900 MHz. Other Government users are presently occupying a large part of these bands and refarming of this spectrum is a continuous but long drawn process. It, thereby, increases the pressure on the existing spectrum and necessitates most efficient utilisation by all. In areas, where the amount of available spectrum at the time of demand exceeds supply, some criteria would need to be applied for allocation. These could be technical, economic or techno-economic. In parallel, efforts would have to be made by the Government to accelerate the process of refarming.

1.2 Context of Recommendations

The Government has sought the TRAI's recommendations on the following

a) Efficient utilisation of Spectrum
b) Spectrum allocation procedure
c) Spectrum Pricing

Together with these three, the TRAI is also examining a policy on spectrum surrender and 're-farming' (surrender & re-allocation).

1.3 Structure of the Consultation Paper

The paper is divided in seven chapters. The first two focus on the current status of spectrum award, spectrum pricing, likely demand and spectrum allocations. The third chapter discusses the technical issues linked with spectrum efficiency. Spectrum Pricing related issues are mentioned in Chapter Four. Using the technical and economic aspects, issues pertaining to spectrum allocations are available in Chapter Five. Chapter Six deals with Re-farming, Trading, Mergers & Acquisition and Spectrum surrender issues. The issues for consultation are summarized in Chapter Seven.

Chapter 2 Current spectrum availability and requirement

2.0 Introduction

The issue of sufficient spectrum availability for mobile services is central to the growth of these services in the country. This leads to the need to examine two aspects. Is the spectrum being utilised efficiently and even with the efficient utilisation of spectrum, is the total available spectrum adequate to meet the requirement. The aspect of efficient utilisation of spectrum is discussed in detail in chapter 3. In this chapter, we examine the available spectrum, their service specific and non-service specific aspects as also technology specific and non technology specific allocation possibilities, the likely spectrum requirement in future even with maximised spectrum utilisation for a given grade and quality of service.

2.1 Spectrum for 2G and 2.5G Services

The bands recognised for providing the 2nd / 2.5 Generation mobile services internationally and in India are given below:

Table 2.1: Spectrum allocations for 2 / 2.5 G cellular mobile services

	International allocations*	Indian allocation
800 MHz	824 – 849 MHz paired with 869 –894 MHz	824 – 844 paired with 869 – 889 MHz *(Used to provide WLL (M) & CDMA based mobile services)*
900 MHz	890 – 915 MHz paired with 935 – 960 MHz (880 – 890 MHz paired with 925 – 935 MHz E-GSM band)	890 – 915 paired with 935 – 960 MHz** *(Used by 1st, 2nd and 3rd Cellular Mobile Service Providers for GSM)*
1800 MHz	1710 – 1785 MHz paired with 1805 – 1880 MHz	1710 – 1785 paired with 1805 – 1880 MHz *(Used by 4th CMSP and for additional allocations to 1st, 2nd and 3rd CMSPs.)*
1900 MHz	1850 – 1910 MHz paired with 1930 – 1990 MHz *(North American PCS band)*	1880–1900 MHz is earmarked for Micro cellular technologies based on TDD

** SOURCE: ITU-R Recommendation M.1073-1 & NFAP 2002. The above table does not reflect allocations where these technologies co-exist. The bands of operation for Cellular Mobile Services for GSM & CDMA worldwide are placed at* ***Annexure A****.*
*** Out of 2 X 25 MHz, 2 X 1.6 MHz is with the Railways*

2.2 Possible use of 450 MHz and 1700 MHz bands

It may be noted that the present policy on spectrum use is technology neutral but equipment availability and the accruing economies of scale also govern choice of technology. Though in a market of size that India promises, there are possibilities to negotiate equipment availability in such bands. This is not unique. South Korea is one such example where CDMA is available in 1700 MHz band. Some countries such as Romania, Russia , China (Tibet area) have Cellular Mobile systems working in 450 MHz band. There is possibility of using 450 MHz band for rural applications. Pricing incentives could be considered for these bands to encourage their usage.

2.3 Spectrum for IMT-2000 Services

IMT-2000 services have been identified by ITU to cover following data speeds:

2Mbps	Stationary
384 Kbps	Pedestrian
144 Kbps	Vehicular

besides global roaming, high quality, multimedia capability, high degree of design commonality, etc. For these type of services, IMT-2000 band has been identified

ITU-R Recommendations M.1036 states

"IMT-2000 will operate in the frequency bands identified in the Radio Regulations (RR) as intended for use on a worldwide basis by administrations wishing to implement IMT-2000, as follows:
WARC-92 identified the bands:

- *1 885-2 025 MHz*
- *2 110-2 200 MHz*

and WRC-2000 identified the bands:

- *806-960 MHz***
- *1 710-1 885 MHz*
- *2 500-2 690 MHz*

** *The whole band 806-960 MHz is not identified on a global basis for IMT-2000 due to variation in the primary mobile service allocations and uses across the three ITU Regions.*

for possible use by IMT-2000 systems, noting (in accordance with RR No. 5.388) that identification of these bands does not establish priority in the RR and does not preclude use of the bands for any other services to which these bands are allocated. Also, some administrations may deploy IMT-2000 systems in bands other than those identified in the RR."

The detailed allocations are mentioned in the recommendations as under

"Frequency arrangements

6.1.1 Paired frequency arrangements in the band 806-960 MHz

The recommended frequency arrangements in these bands, taking into consideration existing public mobile systems, can be summarized as shown in Table 1 and in § 6.1.4.1.

TABLE 1

Paired frequency arrangements in the band 806-960 MHz

Frequency arrangements	***Mobile station transmitter (MHz)***	***Centre gap[(1)] (MHz)***	***Base station transmitter (MHz)***	***Duplex separation[(2)] (MHz)***
A1	*824-849*	*20*	*869-894*	*45*
A2	*880-915*	*10*	*925-960*	*45*

NOTE 1 – Due to the overlap of base station transmitter and mobile station transmitter bands and the different usage of the bands 806-824 MHz, 849-869 MHz and 902-928 MHz between Regions, there is no common solution possible in the near- and medium-terms.

(1) Centre gap – the frequency separation between the upper edge of the lower band and the lower edge of the upper band in an FDD paired frequency arrangement.

(2) Duplex band frequency separation – the frequency separation between a reference point in the lower band and the corresponding point in the upper band of an FDD arrangement.

6.1.2 Frequency arrangements in the band 1 710-2 200 MHz[2]

The recommended frequency arrangements in these bands, taking into consideration existing public mobile systems, can be summarized as shown in Table 2 and in§ 6.1.4.2

TABLE 2

Frequency arrangements in the band 1 710-2 200 MHz

Frequency arrangements	***Mobile station transmitter (MHz)***	***Centre gap (MHz)***	***Base station transmitter (MHz)***	***Duplex separation (MHz)***	***Un-paired spectrum (e.g. for TDD) (MHz)***
B1	*1 920-1 980*	*130*	*2 110-2 170*	*190*	*1 880-1 920; 2 010-2 025*
B2	*1 710-1 785*	*20*	*1 805-1 880*	*95*	*None*
B3	*1 850-1 910*	*20*	*1 930-1 990*	*80*	*1 910-1 930*
B4 (harmonized with B1 and B2)	*1 710-1 785 1 920-1 980*	*20 130*	*1 805-1 880 2 110-2 170*	*95 190*	*1 900-1 920; 2 010-2 025*
B5 (harmonized with B3 and parts of B1 and B2)	*1 850-1 910 1 710-1 755 1 755-1 805*	*20 50 305*	*1 930-1 990 1 805-1 850 2 110-2 160*	*80 95 355*	*1 910-1 930*
B6 (harmonized with B3 and parts of B1 and B2)	*1 850-1 910 1 710-1 770*	*20 340*	*1 930-1 990 2 110-2 170*	*80 400*	*1 910-1 930*

2 The 2 025-2 110 MHz band is not part of this frequency arrangement.

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NOTE 1 – Administrations can implement all or parts of these frequency arrangements.

NOTE 2 – In the band 1 710-2 025 and 2 110-2 200 MHz three basic frequency arrangements (B1, B2 and B3) are already in use by public mobile cellular systems including IMT-2000. Based on these three arrangements, different combinations of arrangements are recommended as described in B4, B5 and B6. The B1 arrangement and the B2 arrangement are fully complementary, whereas the B3 arrangement partly overlaps with the B1 and B2 arrangements.

For countries having implemented the B1 arrangement, B4 enables optimization of the use of spectrum for paired IMT-2000 operation.

For countries having implemented the B3 arrangement, the B1 arrangement can be combined with the B2 arrangement. Two different arrangements (B5 and B6) are therefore recommended to optimize the use of the spectrum:

– *B5 would implement the B2 arrangement to harmonize parts of the extension bands globally. B5 enables the use of spectrum to be maximized for paired IMT-2000 operation in countries where B3 is implemented and where the whole band 1 710-1 850 MHz is available.*
– *B6 enables the use of spectrum to be maximized for IMT-2000 in countries where B3 is implemented and where the band 1 770-1 850 MHz is not available in the initial phase of deployment of IMT-2000 in this frequency band.*

NOTE 3 – TDD may be introduced in unpaired bands and also under certain conditions in the uplink bands of paired frequency arrangements and/or in the centre gap between paired bands.

NOTE 4 – If selectable/variable duplex technology is implemented within terminals as the most efficient way to manage different frequency arrangements, the fact that neighbouring countries could select either option B5 or B6 will have no impact on the complexity of the terminal. Further studies are necessary.

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In India, the requirements of IMT-2000 applications in the frequency bands 1885 –2025 MHz and 2110 – 2200 MHz is slated to be co-ordinated with existing users initially for 1920 -1980 MHz paired with 2110 – 2170 MHz (FDD mode) and 2010 – 2025 MHz (TDD mode) depending on the market needs and availability. Thus initial availability of about 60 + 60 MHz (paired) and 15 MHz (unpaired) has been envisaged. If we look in Table 2 in this section it can be observed that IMT-2000 equipment would also be available in 1710-1785 paired with 1805-1880 MHz, (B2 & B5 arrangements).

2.4 Technology Consideration

Currently GSM, CDMA and Cor-DECT technologies are in use in the country with each one of them having some claims to the spectrum. The other evolving technology is the WAN technology, which is based on IEEE 802 series of standards and use frequency bands 2.5 GHz, and 5 GHz. These services are still evolving and their ultimate spectrum requirement will not be known for some time. This aspect especially the enhanced services called 4G, is expected to be covered in WARC-2007.

2.5 Spectrum requirement for mobile services in India

To estimate the spectrum requirement for services, we have to identify the methodology used, the growth of subscribers, the type of services likely to be in demand, the anticipated traffic, etc. To be able to carry out this exercise for the future requirement in India, this section outlines the methodology, which has been recommended by the ITU. This methodology necessarily requires certain exemptions to be made and the final estimate could vary substantially depending on the assumptions made. It should be noted that the ITU spectrum estimation method gives a conservative estimate in that it is based on a fixed frequency re-use and does not take into account methods of improving spectrum utilisation through careful planning and other system techniques. But for the purpose of spectrum planning, we can consider assessing spectrum requirements on a conservative basis. Through this Consultation Paper it is proposed to try and arrive at assumptions, which are considered reasonable so that by using either the ITU recommended methodology or any other suggested methodology, some estimate of longer-term requirement of spectrum may be arrived at.

It is, however, appreciated that potentially there is a high demand for spectrum, particularly if the mobile data usage picks up at any point in the future.

2.5.1 Methodology

The future radio spectrum requirement can be estimated using ITU methodology given in Recommendation ITU-R M.1390[2]. Whilst this method was developed to calculate the spectrum requirements for IMT-2000 systems, the ITU-R M.1390 specifically recommends and encourages the use of the methodology for other Public Land Mobile Radio systems.

The basic theme of this methodology is to determine the individual spectrum requirements of a combination of specific environments and services in a given geographical area. The spectrum requirement is obtained by summing the spectrum for the specific services and environments and applying weighting factors to take account of concurrent services ($ά_{es}$) in a given area and to accommodate the impacts of multiple operators and spectrum sharing (β). The estimation of spectrum requirements for the future is not an exact calculation and the methodology intends to capture only the first order effects.

The process flow of the method, (calculated separately for the uplink and down link) is explained in ITU-R M.1390 and is briefly as follows:

1) Defining The Environment
   - In Building High Density (CBD)
   - Urban Pedestrian

[2] Methodology for the Calculation of the IMT-2000 Terrestrial Spectrum Requirement.

- Urban Vehicular

For each environment the cell geometry (circular or hexagonal) is defined and the nominal cell dimension for each environment

2) Defining Service Type
   - Voice
   - Short Message
   - Switched data
   - Medium Multi-Media etc.

3) Defining Population Density

   For each environment type (i.e. In Building, Urban Pedestrian etc)
   - Population Density (population/sq. km.)
   - Penetration rate for each environment and each service

4) Defining Traffic Parameters

   For each environment type (i.e. In Building, Urban Pedestrian etc)
   - Busy Hour Call Attempts per user
   - Average Call Duration
   - Activity Factor

5) The method then calculates the following for each environment and service:
   - Traffic per user
   - Offered traffic per cell
   - The service channels for the required Quality of Service (e.g. blocking rate)
   - The total traffic for a cluster of cells based on the cell re-use factor
   - The number of service channels per cluster.

6) Using the system parameters and the number of service channels, the number of radio channels is calculated for:
   - Each environmental type
   - Each service type

7) The total spectrum is the summation of the spectrum requirement for the up and down link for each environment and service type. Finally, weighting factors ($\acute{\alpha}_{es}$) and (β) applied.

2.5.2 Assumptions used in forecasting

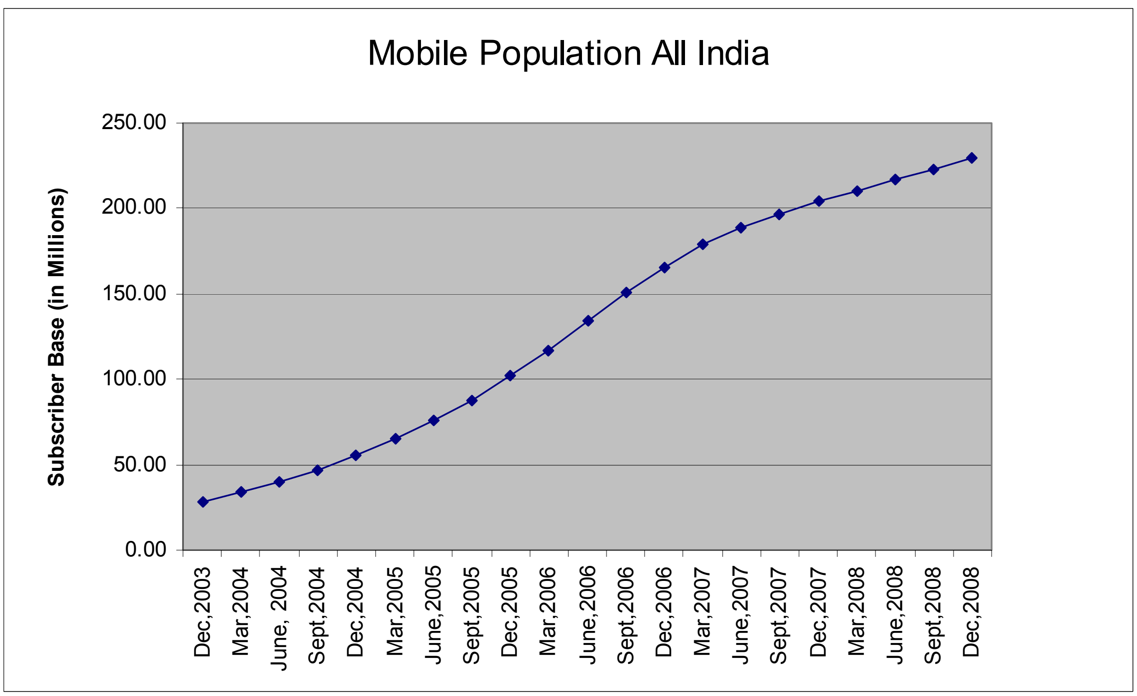
The spectrum calculation is driven by population density and penetration rates of the various services in the defined environments. These are normally obtained from demographic and economic data together with market assumptions of the take up of the individual services.

The ITU recommendations, which also contains an example and certain default assumptions is placed at Annexure-B. Certain assumptions require forecasting. For the purpose of estimation, it would be necessary that these assumptions are finalised through the consultation process. Stakeholders are requested to provide their comments on the assumptions given in sample calculations provided in ITU Recommendations reproduced in **Annexure B**. The stakeholders are requested to provide their forecast of spectrum using ITU-RM.1390 methodology either separately or as a part of their comments to this consultation paper. In addition stakeholders may provide any other methodology/spectrum estimations clearly giving the assumptions and their basis.

2.5.3 Estimates of Subscriber Growth

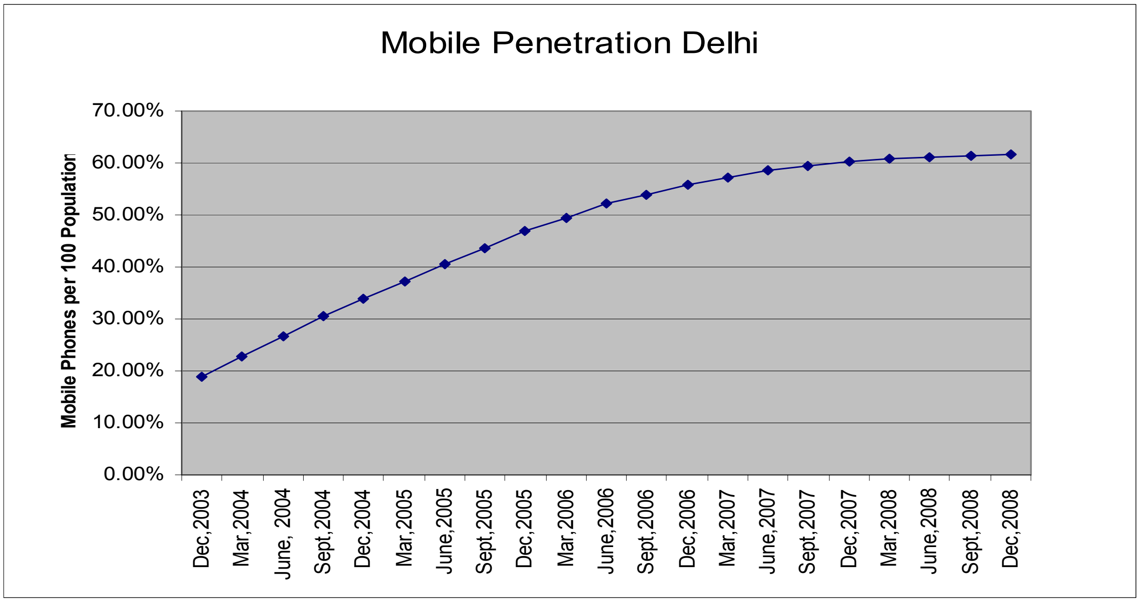
The subscriber growth curve (figure 2.1) has been constructed using current subscriber growth rates and projected growth for India with the assumption that the number of mobile subscribers will reach 230 million (penetration approximately 20%) by 2008/9.

Figure 2.1 Forecast for Mobile Subscribers nationwide



For the purpose of estimating spectrum required, the mobile population of Delhi can be taken as being representative of the most dense mobile service area. Mobile Penetration for Delhi is estimated in Fig. 2.2

Figure 2.2: Mobile penetration in Delhi



2.6 Currently available spectrum and the likely to be available spectrum vs anticipated demand

2.6.1 Currently available spectrum

Though spectrum bands for mobile services has been earmarked in NFAP 2002 in 800 MHz, 900 MHz and 1800 MHz band, the present amount of spectrum available or likely to be available in near future is 20 MHz in 800 MHz band, 23.4 MHz in 900 MHz band and 10~25 MHz[3] in 1800 MHz band.

Table 2.3 provides the amount of spectrum available and it's distribution. The details of allocation and approaches mentioned are discussed in Chapter 5. In brief,

Approach I: Freeze the allocations at existing levels of spectrum provided except to those where license conditions warrant further allocation but only upto the levels committed in the license.

Approach II: Another approach could be to allocate / reserve upto 2 X 10 MHz for all existing operators.

[3] The amount of spectrum varies from region to region

Table No. 2.3: Amount of Spectrum available and its distribution

(This table only indicates the distribution of spectrum amongst existing operators following the two approaches mentioned earlier. This is to illustrate the shortfall / surplus of the spectrum in 800 MHz, 900 MHz, 1800 MHz band)

Metro					**[All figures in MHz]**	
Scenario		**800 MHz**	**900 MHz**	**1800 MHz**	**1800 MHz (expected)**	**Total (800, 900, 1800 MHz)**
Approach I	**Total Spectrum available**	**20**	**23.4**	**10**	**15**[4]	**20 + 48.4**
	Spectrum Allocated / reserved as per license conditions	[5,5,5,5]	[8,8,6.2]	[6.2, 2]	[2]	20 + 32.4
	Surplus / shortfall after meeting license conditions	0	1.2	1.8	13	0 + 16
Approach II	**Total Spectrum available**	**20**	**23.4**	**10**	**15**	**20 + 48.4**
	Spectrum Allocation to meet 2 X 10 MHz for every Service Provider	[40]*	[8,8,7.4]	[8,2]	[2,2,2,0.6]	[40] + 40
	Surplus / shortfall after reserving 2 X 10 MHz for every Service Provider	- [20]	0	0	8.4	- [20] + 8.4
Non Metro		**800 MHz**	**900 MHz**	**1800 MHz**	**1800 MHz (expected)**	**Total**
Approach I	**Total Spectrum available**	**20**	**23.4**	**10**	**15**	**20 + 48.4**
	Spectrum Allocated / reserved as per license conditions	[5,5,5,5]	[8,6.2,6.2]	[6.2]		20 + 26.6
	Surplus / shortfall after meeting license conditions	0	3	3.8	15	0 + 21.8
Approach II	**Total Spectrum available**	**20**	**23.4**	**10**	**15**	**20 + 48.4**
	Spectrum Allocation to meet 2 X 8 MHz (7.5 for CDMA) for every Service Provider	[30]*	[8,8,7.4]	[8,0.6]	Nil	[30] + 32
	Surplus / shortfall after reserving 2 X 8 (7.5 for CDMA) MHz for every Service Provider	- [10]	0	1.4	15	- [10] + 16.4

** Present allocation is only 20 MHz. No allocation as on date in other bands. Therefore, entire 30 MHz, 40 MHz is shown in 800 MHz*

[4] Varies from 0 ~ 15 MHz from area to area

2.6.2 Additional spectrum requirement and IMT 2000 spectrum deployment policy

From Table 2.3 it is evident that at the present juncture and particularly in metros, GSM is expected to get spectrum to the tune of total 15 MHz when additional spectrum gets released in the 1800 MHz band. So far as CDMA is concerned, there is no path available for provisioning more than the currently allocated/committed amount of 2x5 MHz to four service providers.

If we examine the bands which are available for use of cellular mobile services as approved by WARC but not necessarily available in India and also look at the picture of equipment availability, the following scenario emerges.

IMT-2000 band has already been outlined as 1885-2025 and 2110-2200 MHz at WARC-92 and a further identification of 1710-1885 MHz has been done at WARC-2000. This aspect has been discussed in Section 2.3.

One possibility is the use of the North American PCS band in India, viz. the FDD band 1850-1910 MHz paired with 1930-1990 MHz for CDMA purposes for which equipment is also available. Out of this band, the segment 1880-1900 KHz has been designated for micro cellular technologies on TDD and operators have largely deployed TDD based indigenous CorDECT technology band. This is further discussed in the following Section 2.7. There are, however, issues in using the PCS band for CDMA applications in India. Firstly, if the spectrum in this band is allocated to the cellular mobile services (FDD), it would reduce the 3G spectrum availability as upper band of CDMA (1930-1990 MHz) clashes with the lower band on IMT-2000 spectrum (1920-1980 MHz), though one could argue that CDMA 2000 1x is recognised by ITU as IMT 2000 service capable.

Another issue that arises from using both IMT 2000 and PCS 1900 band plan relates to interference. It has been brought to our notice that using both WARC – 92 bands (1920 – 1980 / 2110 –2170 MHz) and PCS 1900 band plan (1850 –1910 / 1930 –1990 MHz) may cause interference problems. Prima facie there appears to be possibility of such interference, however, this would need further examination.

The other possibility is the formulation of strategies on IMT-2000 spectrum, its potential use and availability.

The options in this regard are

a) IMT 2000 spectrum be considered an extension of 2nd Generation Mobile Services and be treated in the same manner
b) IMT 2000 spectrum be considered separately and be provided to operators for providing IMT 2000 services only

In the event that we adopt option a), the advantage is that the existing operators would have greater clarity over the availability of this spectrum and would be able to plan their network accordingly. The allocation of IMT-2000 spectrum as an extension of 2G mobile services may also give more flexibility to operators (both GSM and CDMA cellular operators) in network planning. They may also consider offering voice and low speed data services like SMS etc. on existing 2G frequency band and high speed data services on IMT 2000 band. This could be only a possibility and Authority is not expressing any viewpoint on this. As per the information available, CDMA operators who do not have equipment widely available in the 1800 MHz band would have an expansion path. However, IMT 2000 spectrum is also the band for expansion worldwide for WCDMA users, which is the normal migration path for GSM technology. One option could be to open up this band in continuum and all the CMSPs / UASLs be made eligible for allocation of spectrum from either of the bands. Since GSM operators still have possibility of additional spectrum allocation in 1800 MHz band, the IMT 2000 spectrum allocation to CDMA operators should not completely exhaust this spectrum. Some spectrum in IMT 2000 band should be reserved for allocation to GSM operators as and when complete spectrum in 1800MHz is allocated or even earlier for launching 3G services by GSM operators. To have level playing field the terms and conditions of allocation of spectrum, pricing etc. will need to be completely technology neutral.

The disadvantage in option a) is the possibility of using IMT 2000 Spectrum for offering 2G Voice and Low speed data services and therefore when high speed data services are required to be offered, there could be a scarcity of spectrum.

In option b) since IMT 2000 spectrum is completely delinked from 2G/2.5G services, therefore, its availability for high speed data services is ensured.

While considering options a) and b) it is to be kept in mind that Authority is already working on Unified Licensing recommendations. Under Unified Licensing Regime the type of service (2G or 3G) to be offered will be as per choice of licensee. If any licensee wants to offer 3G services, then he should get the required spectrum. But necessary safeguards for efficient utilisation of spectrum should always be kept in mind.

Another aspect to be considered is whether in our country we expand the IMT 2000 band in line with alternatives B2 or B5 approved by WRC 2000. The issue involved here is the conversion of whole or part of 1710 – 1785 MHz band paired with 1805 – 1880 MHz band currently assigned for cellular services and presumably planned for 2G / 2.5 G applications. It is evident that whether this band or IMT 2000 band (unexpanded) are used for creating additional spectrum for current cellular operations in GSM 2G / 2.5G or CDMA operations, there would be a requirement to reach a firm agreement with the present users of these bands on the timely surrender of this spectrum, in order that the costs and time scales associated with the migration can be identified. Also it is important to consider the method of award of this spectrum in order to provide the flexibility to introduce further data services. A view will therefore have to be taken on

(i) Whether IMT 2000 band should be expanded to cover whole or part of 1710 – 1785 MHz band paired with 1805 – 1880 MHz?
(ii) What should be the path for creating more spectrum for CDMA and GSM services viz., options (a) or (b), and
(iii) Should the 450 MHz or any other band be utilised for CDMA growth path?.

2.7 CDMA and CorDECT

Another issue over allocation that has been raised by stakeholders is the allocation of 1880 – 1900 MHz for Cellular Mobile services. As per the present allocations, this band has been designated for Micro cellular technologies. Operators have largely deployed TDD based indigenous CorDECT technology in this band. As this band is used in some countries for providing cellular mobile services, there has been demand by service providers to either allocate this band for cellular mobile services and relocate CorDECT, or permit sharing of this band with CorDECT.

A reference to this issue was also made by TRAI in its recommendations on Accelerating Growth of Internet and Broadband Penetration. Para 3.7.4.11 mentions

"Requirements of micro cellular WLL systems based on TDD access techniques, especially indigenously developed technologies, capable of coexistence with multiple operators…" should be altered to remove the reference to WLL. This should be done so that the link between fixed wireless and mobile wireless technologies, which remains because of former WLL regime, is corrected for current technologies and bands, and future ones."

2.8 Contiguous spectrum allocation and guard bands

Presently spot frequencies allocated to service providers are not necessarily contiguous and therefore require larger amounts of guard band resulting in inefficient usage of spectrum. If reorganisation of existing allocations is carried out to achieve as much of contiguous allocations as possible, then better efficiencies can be achieved. Also it would reduce the need for guard bands. However, the exercise of reorganisation is likely to be difficult and exhaustive.

2.9 Issues for Consultation

(i) Should the 450 MHz or any other band be utilised particularly to meet the spectrum requirement of service providers using CDMA technology?
(ii) The consultation paper has discussed ITU method for assessment of spectrum requirement. Based upon the methodology submit your requirement of spectrum for next 5 years. While calculating the required spectrum, please give various assumptions and its basis.

(iii) Whether IMT 2000 band should be expanded to cover whole or part of 1710 – 1785 MHz band paired with 1805 – 1880 MHz?

(iv) Should IMT 2000 spectrum be considered as extension of 2G mobile services and be treated in the same manner as 2G or should it be considered separately and provided to operators only for providing IMT 2000 services?

(v) Reorganisation of spot frequencies allotted to various service providers so as to ensure the availability of contiguous frequency band is desirable feature for efficient utilisation of spectrum. Please suggest the ways and means to achieve it.

(vi) Whether the band 1880 – 1900 MHz be made technology neutral for all BSOs / CMSPs / UASLs and be made available with the pair 1970 – 1990 MHz or should it be kept technology neutral but reserved for TDD operations only.

Chapter 3 Technical Efficiency of Spectrum Utilisation

3.1 Definition of Spectrum Utilisation Efficiency

3.1.1 ITU definition of Spectrum Utilisation Efficiency

ITU-R Recommendations SM.1046-1 on "DEFINITION OF SPECTRUM USE AND EFFICIENCY OF A RADIO SYSTEM" mentions

"Efficient use of spectrum is achieved by (among other things) the isolation obtained from antenna directivity, geographical spacing, frequency sharing, or orthogonal frequency use and time-sharing or time division and these considerations reflected in definition of spectrum utilization. Therefore, the measure of spectrum utilization – spectrum utilization factor, U, is defined to be the product of the frequency bandwidth, the geometric (geographic) space, and the time denied to other potential users:

$$U = B \cdot S \cdot T$$

where:

B : frequency bandwidth

S : geometric space (usually area) and

T : time.".

Also, the recommendation mentions

"*According to the definition of SUE (or spectrum efficiency as a shortened term) of a radiocommunication system, it can be expressed by:*

$$SUE = \frac{M}{U} = \frac{M}{B \times S \times T} \qquad (2)$$

where:

M : amount of information transferred over a distance"

For cellular mobile systems, it can be expressed as

$$SUE = \frac{\text{(Traffic in Erlangs)}}{\text{(Amount of Spectrum in MHz) X (Area in Sq. Kms)}} \Bigg|_{\text{For a specified GoS}}$$

The time factor can be taken as 1 as the system operates continuously.

This definition takes into account the traffic carrying capacity of a technology per MHz and the capability of the technology to replicate the available spectrum in the unit area for a specified Quality of Service. However, it does not take into account the cost involved in the implementation of individual technologies, and hence does not take into account any economic aspect of spectrum utilisation. Also, this definition presupposes that all the required QoS parameters are met at all times.

The approach adopted by TRAI is first to examine the technical aspects of Spectrum Efficiency and then build in the economic aspects to provide a comprehensive view to the stakeholders for discussion.

3.1.2 Other measures of Spectral Efficiency

As explained in the previous section, Erlang / MHz / Sq. Kms indicates the Erlang density supported per unit of spectrum and thus gives the geographic intensity with which the network deploys the spectrum and is the measure for the assessment of spectrum utilisation in this exercise.

Other ways of expressing spectral efficiency:

- *Effective Reuse* – describes how often the same frequency is re-used in the network. Effective re-use is equal to the total number of frequencies used divided by the average number of TRx per sector. This measure does not indicate if the radio resource is fully loaded.

- *Fractional Load* - measures the efficiency of frequency hopping networks in relation to effective frequency re-use.

- *Frequency Allocation Re-use(FAR)*– indicates how closely the frequencies are actually re-used in a network. FAR equals the total number of frequencies used divided by the average number of frequencies in the Mobile Allocation lists[5] (MA lists). This measures the ability of hopping networks to implement tight re-use. If fractional loading is not used then frequency allocation re-use is the same as effective re-use.

- *Frequency Load* – indicates how much traffic is carried by the available spectrum. Frequency Load is equal to the busy hour timeslot occupation multiplied by the Fractional Load.

- *Effective Frequency Load* – quantifies the loading of each frequency in the system.

3.2 Methodology for evaluating the technical spectrum efficiency of Service Providers

3.2.1 Spectral efficiency concept

The performance of a network in terms of load and quality is shown in Fig 3.1. Network 1 and Network 2 can be different networks or the same network with added functionality. Network 2 is more spectrally efficient than Network 1 because, for the same quality level it can carry more traffic for a given amount of spectrum. The relative value of this additional traffic load is the capacity provided by the added functionality.

[5] The frequency hopping list is given by the Mobile Allocation list.

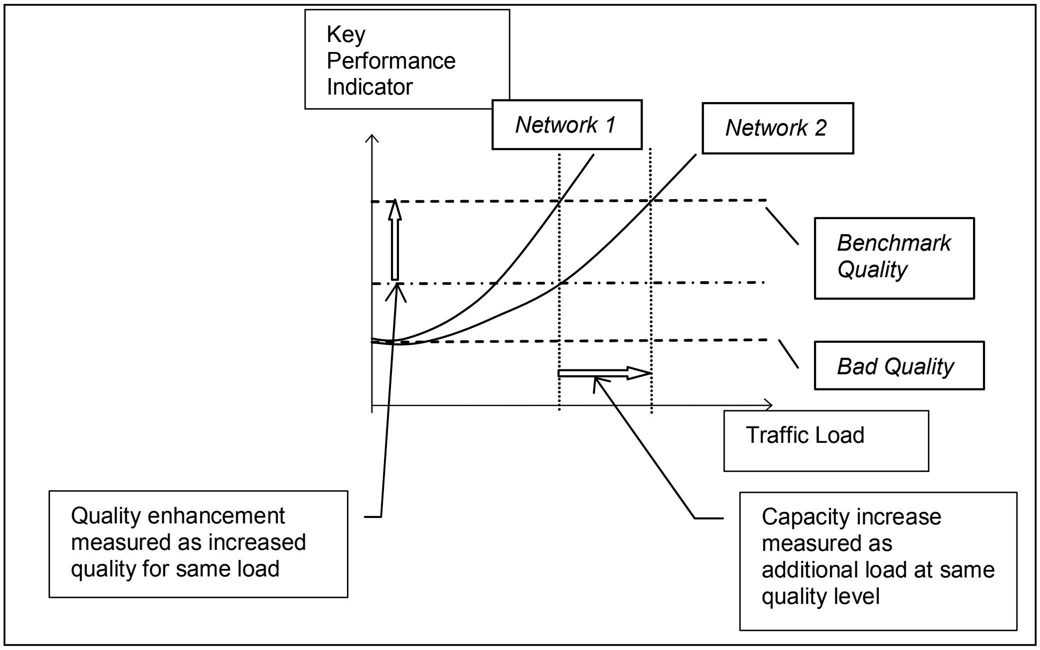


Figure 3.1: Spectral efficiency concept

Thus, when comparing the spectrum efficiency or the spectrum utilisation of different networks, or when considering improvement in spectrum utilisation of the same network through engineering enhancements, it must be done against a common measure of quality.

3.2.2 Quantifying Spectral Utilisation Efficiency

The basic principle used by TRAI was to estimate the efficiencies of networks vis-à-vis theoretical benchmarks, practical implementations and enhancements possible by the use of advanced techniques.

The first step is to have a measure of theoretical efficiency.

The following terminology is used in this paper

- *Cell/Sector* – the logical entities that have a single Broadcast Control Channel (BCCH) associated with each one of them.
- *Site* – The physical location accommodation multiple or single c*ells / sectors*
- *Packing density – The number of cells per Sq. kms*

3.2.2.1 Theoretical spectrum utilisation factor

Theoretical values of spectrum utilisation are determined using plane earth with ideal, regularly spaced equi-sized cells.

3.2.2.1.1 GSM networks

The traffic capacity that a given amount of radio spectrum can support in a cellular network is a function of the number of times the same radio channels can be re-used within a cluster of cells and the amount of traffic carried per channel. This is determined by the carrier to interference ratio the radio receiver needs for a minimum quality of baseband signal. The re-use factor determines the number of cells in a re-use cluster and the smaller the cluster size, the greater is the re-use of frequencies in a given area. Finally, the smaller the cell size, the greater is the density of traffic that can be supported.

Thus, given a frequency re-use factor, an amount of radio spectrum and definition of the cell area; a theoretical measure of spectrum utilisation can be calculated and used in benchmarking the spectral utilisation of an actual network. However, in a practical network there are variations as radio propagation is highly variable and ideal geometry may not be achievable. But, the theoretical benchmark is a useful performance bound when considering relative performance of networks.

The cellular network deployment is bound by the worst case Carrier to Interference ratio. The detailed derivation of C/I is given in **Annexure C**.

The worst-case C/I for K (cluster size) = 3, 7, 9, 12 is given below.

K	3	7	9	12
C/I (dB) 2 Interferers 120 Degree – Sectored cell	14.5	20.4	22.2	24.2
C/I (dB) 6 Interferers - Omni Antenna	2.6	11.6	14.0	16.7

The minimum C/I for GSM is 9dB, to which a margin needs to be added to allow for irregular terrain and imperfect site locations. Section 4.4 Annexure 2 of ITU-R recommendations M.1037 on "Digital Cellular Land Mobile Telecommunication Systems " states

"*Co-channel protection ratio down to C/I □ 9 dB is acceptable by the system and yields a possible reuse corresponding to a 9-cell cluster (3-cell reuse patterns with three sectors per cell).*"

The table above shows two cases:

- Sectored antenna (120° sectored cell) with two first tier co-channel interferers
- Omni Antenna cell with 6 first tier co-channel interferers

The minimum value of k for an acceptable C/I can be considered to be greater than 9 dB: k=7 for 2 interferers; k=12 for 6 interferers. In a real situation the number of interferers will be between 2 and 6, hence the minimum value k is taken for GSM to be 7, however three sectored sites are generally used to reduce the cost of radio sites (a cluster of three, three-cell sites) so a re-use factor of 9 is forced by this geometry. For omni directional cells a re-use of 7 is possible.

Although Spectrum Efficiency calculations using a reuse pattern of 9 seems appropriate, it does not take into account the efficiencies achievable by deploying

a) **Advanced techniques such as Frequency Hopping (FH).** The objective behind using these techniques is to achieve a reuse as close to 1 as possible. Using tighter reuse pattern such as 3 can simulate this factor.
b) **Multi layered architecture:** The use of multi-layered architecture helps in achieving much higher Spectral efficiency when compared with single layered macro architecture. A reuse of 3 has been used for micro layers in the methodology. The sensitivity of spectral efficiency with the percentage of area covered by micros has been carried out.

A model was constructed in Excel that calculated the Spectrum Utilisation against radio frequency available.

The model had two parts:

- Macro cell layer – input parameters nominal cell radius, frequency re-use factor.
- Micro cell layer – input parameters, micro cell radius, frequency re-use, % area of macro cell layer covered by micro cells, number of TRX per micro cell.

The macro cell layer assumed a cluster of cells being equal to the re-use factor. The model calculated the traffic capacity in Erlang at the macro cell layer for available radio spectrum, ranging from 1 MHz to 31 MHz. The model calculated the TCH time slots available for each cell (sector) making an allowance for BCCH and SDCCH channels.

The model assumed:

- Ideal plane earth
- Circular cells of equal radius
- full rate codecs.

The micro cell layer calculated the traffic capacity of the micro cells based on the % area of the macro cells as specified by the input parameter. The model carries out calculation on the assumptions that separate radio spectrum is available for the micro layer.

Table 3.1: Assumptions used in assessing spectrum utilisation

	Assumptions	Remarks
Macro cell re-use	9	Explained above
Micro cell re-use	3	Explained above
Number of TRXs used per micro cells	2	
Cell nominal radius	300 metre radius for Macro cells, 80 metres radius for micro cells	
Synthesised Frequency Hopping	Not included in theoretical bench mark	Included by taking tighter reuse
Half rate codecs	Not included in theoretical bench mark	Included by taking tighter reuse
Hierarchical Cell Structures	Two layer – Macro and micro	
Area covered by Micro cell	Assumption 1) – No micro cells Assumption 2) – 15% Assumption 3) – 25%	
Micro cell spectrum	Assumption – separate spectrum allocated to micro cell layer	

For the above case the total traffic capacity in the Macro cell area is calculated. The spectrum utilisation in Erlang/Km^2/MHz is calculated using the traffic capacity, the area covered by the macro cells and the spectrum.

A calculation of the spectrum utilisation of the area covered by the micro cells was also made to enable the peak spectrum utilisation to be gauged. The detailed model indicating a sample calculation is placed at **Annexure D.**

Some results from the model are given in Fig 3.2 and Fig 3.3. These figures indicate Erlangs / MHz / Sq. Kms for a macro cell for different reuse factor vis-à-vis spectrum and the effect of adding micro cells.

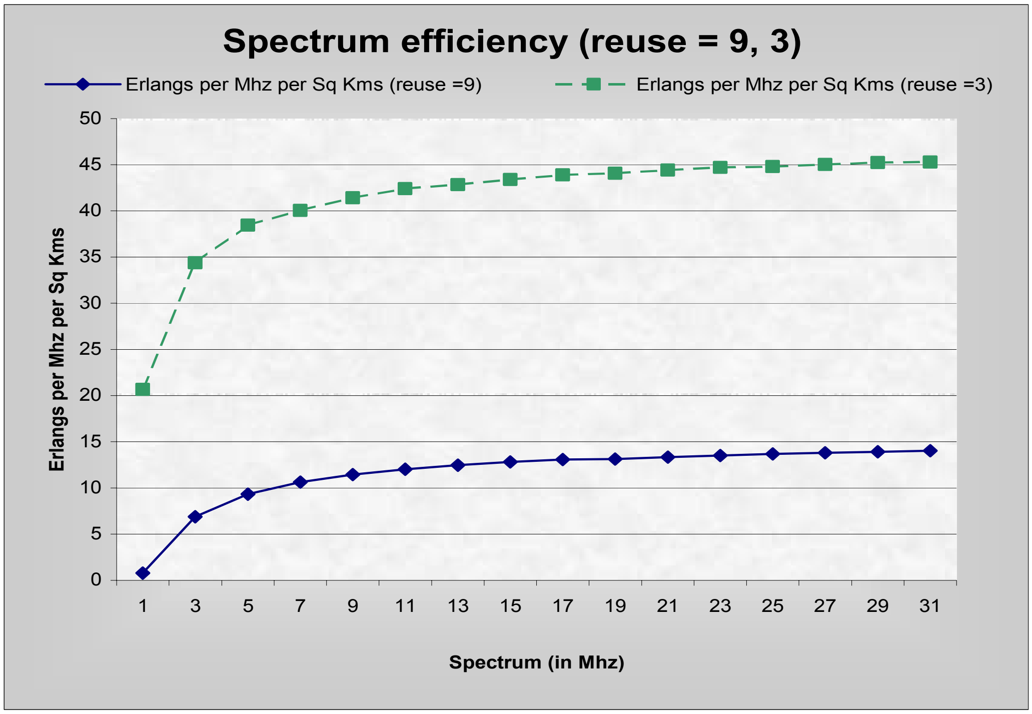


Figure 3.2: Spectrum Utilisation of Macro cells.

The graph in Figure 3.2 shows the Spectrum Utilisation verses frequency with a re-use of 9 and 3 for macro cell radius of 300 metres. The utilisation increases to a maximum of around 14 for reuse of 9 and 45 for a reuse of 3.

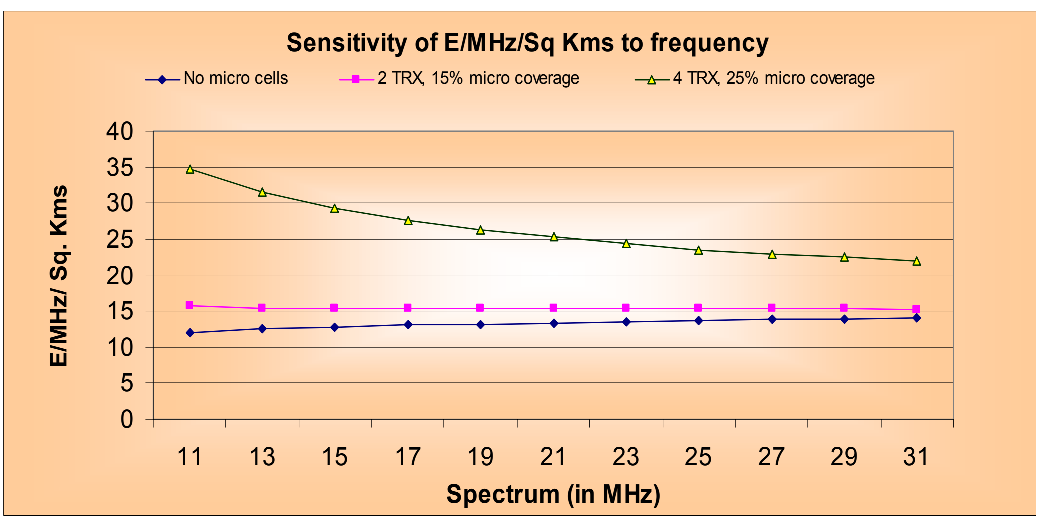


Figure 3.3 Spectrum Utilisation with the addition of micro cells,

The graph in Figure 3.3 shows the effect of the micro cells on the overall utilisation. The three scenarios assumed are:

a) No micro cell.
b) 15% of area covered by micro cells / 2 TRXs per micro cell

c) 25% of area covered / 4 TRX per cell. The graph assumes constant allocation of TRX/cell with frequency. In an actual network higher efficiencies are possible.

A re-use of 1 may or may not be achievable. But the likelihood of achieving a re-use of 3 is much higher and is a close bound on the maximum utilisation. Furthermore the use of half rate encoding will open the prospect of considerable capacity increase.

From the above analysis, it is apparent that for a particular spectrum, the Erlangs/MHz/Sq. Km is sensitive to reuse and deployment of microcells. A change in reuse from 9 to 3 increases the efficiency from 12 to 42 (for 10 MHz of spectrum), while the sensitivity of micro-cell deployment is tabulated below.

Spectrum = 10 MHz	**0% of macro are as micro**	**15% of macro are as micro**	**25% of macro are as micro**	**50% of macro are as micro**
Erlangs per MHz / Sq Kms (reuse =9)	11.6	15.8	20.6	30.3

These estimates are based on 2 TRXs per cell. But in practice, with the frequency increase more number of TRXs can be deployed in micro layer, which would further enhance erlang density. For example the Erlangs per MHz per Sq. Kms increases from 15.8 to 19.6 with 15% of macro areas covered by micros, if the no of TRX per cell in micro is increased from 2 to 3.

It is clearly seen that it is possible to attain much higher efficiencies with greater number of micro cells and deployment of advanced techniques that improves the reuse factor. There exist GSM networks that have been able to achieve efficiencies in excess of 100 Erlangs per MHz per Sq Kms with about 2 X 17.5 MHz of spectrum.

This section primarily dealt with the theoretical efficiencies achievable and their sensitivities. The practical benchmarking vis-à-vis Indian networks is discussed later.

3.2.2.1.2 CDMA 2000 1x networks

The theoretical efficiency of CDMA 2000 1x can be estimated as under:

Traffic that can be carried per Frequency Assignment has been mentioned in TEC specification as 25 Erlang. International data and discussion with experts suggest that the maximum packing density that can be arrived at in CDMA is about 5 sites per Sq. kms, while the international practices vary between 2 and 3.

If we assume 4 carriers (in a bandwidth of 6 MHz) of CDMA 2000 1x, the spectral efficiency for a 3 sector comes out to

Spectral efficiency = (25 X 4 X 3) / (6) X (No of sites / sq. kms)

= 50 X No of sites

For a packing density range of 3 ~ 5, the spectral efficiency lies between 150 to 250. If a loading factor of 0.8 is also taken into account, the effective efficiency achievable would be between 120 and 200. These levels are comparable with the best and highly loaded GSM networks practically in place. However, it is important to note that on a single layer basis CDMA provides higher efficiency.

CDMA networks are generally limited by inter-site distances. Inter-site distance of 500 metres[6] (or nominal cell radius of 250 metres) is specified as the minimum inter-site distance to be used in planning CDMA 2000 networks. The planning of CDMA networks is based on meeting a required value of E_B/N_o to provide a required bit error rate. E_B/N_o is influenced by all the interferers in the same sector and from other sectors.

3.2.2.2 Estimating efficiencies of present day GSM and CDMA networks and their comparison with theoretical efficiencies.

A questionnaire was sent to all operators requesting specific information on the network performance. Cell traffic, installed capacity and cell blocking rates supplied by the operators were used in determining the spectrum utilisation. For each network, the area of around 25 Sq. Km in the highest traffic demand location was identified. Within this area a cluster of more than 9 cells was selected for the evaluation. For some networks, an area of around 8 Sq. Km within this cluster was also identified for evaluation. The areas of 25 Kmsq and 8 Kmsq are representative average and peak traffic within the selected areas and were chosen after a sensitivity of cell traffic and cell dimensions.

The following data for each cell was used:

- The radio spectrum allocation for the network
- Cell identity
- Carried traffic in cell
- Installed capacity of cell
- Blocking rate
- Nominal cell area – obtained from data supplied by operator or estimated from scale map of most likely server.

From this data the following was calculated:

[6] This figure comes from modelling, simulation and field measurements done by equipment vendors. If smaller cells are deployed then the cost of the infrastructure increases and the gain in terms of additional capacity is small because of the need to balance transmission powers and minimise the impact of interference.

- Theoretical Spectrum Utilisation for given amount of radio spectrum.
- Actual Grade of Service (GoS) of cell – calculated from Erlang tables using installed capacity and carried traffic
- Spectrum Utilisation based on carried traffic
- Spectrum Utilisation based on installed capacity
- The percentage of cells with a GoS poorer than the acceptable level of 2%.

It should be noted that there is no measure of Quality experienced (drive test) included in the above-mentioned data and that the spectrum efficiency should ideally be measured in relation to a given quality benchmark.

The spectrum utilisation of the networks was evaluated for a number of GSM networks and CDMA 2000 1x networks.

The following methodology was devised and used to assess the spectrum utilisation of the Indian networks.

Using the data, the following was calculated for each network:

- The spectrum utilisation of the networks in a high traffic location for an area of around 25 $Km^{2.}$ ($SU_{theoretical}$)
- The theoretical spectrum utilisation for the given amount of radio spectrum used (SU_{actual}) as derived from section 3.2.2.1.
- The grade of service (GoS) of each cell in the area under consideration - using the carried traffic and the installed capacity
- The percentage of cells whose GoS was worst than 2%
- A "Figure of Merit" for the spectrum utilisation (FoM)
- A "Congested Cell Rating" (CCR)

Definition of Congested Cell Rating (CCR)

$$CCR = x.[1+\sigma] \quad \text{where } \sigma = \text{the standard deviation of the GoS of each cell}$$

$$\text{x} = \text{the number of cells with GoS} > 2\%$$

A scatter graph of the results for all the GSM networks was plotted using the following scales:

Y Axis:

$$\text{FoM} = \text{SU}_{\text{actual}} - \text{SU}_{\text{theoretical}}$$

X Axis: CCR

The ideal value of CCR is 0: all cells are better than 2% GoS. However in practice, there are possibilities of some cells will exceed 2% GoS occasionally. Therefore, a threshold value for acceptable value of CCR needs to be identified. The value used for indication purpose is1.5.

The network spectrum utilisation obtained from the performance data submitted by operators is combined with a theoretical measure of spectrum utilisation. The results are plotted on a scatter graph and the location of the various scatter points indicates the relative performance.

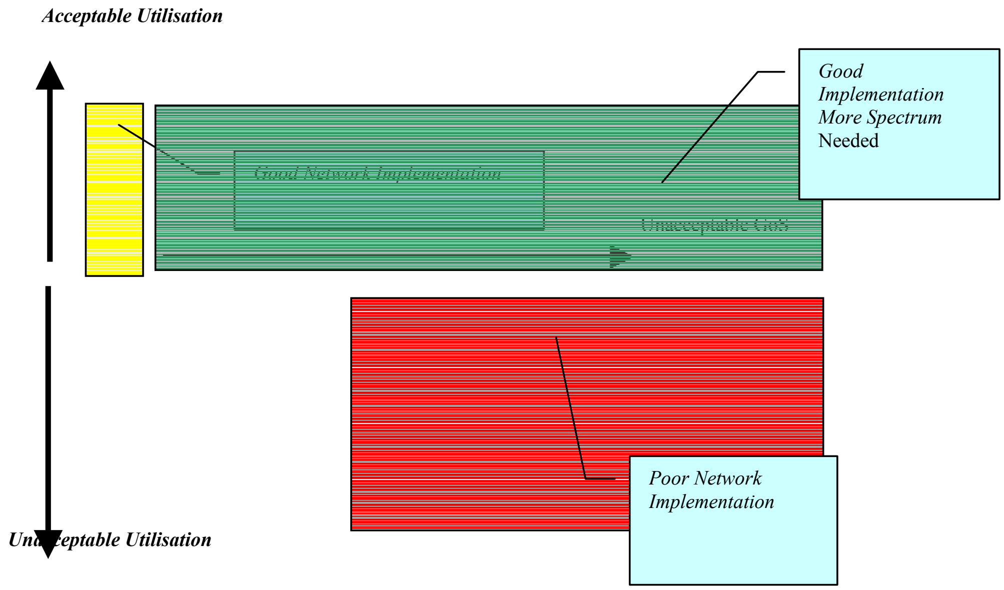


Figure 3.5 Example of Scatter Graph

The graph in Figure 3.55 shows the relative performance of each network. The position of the network rating point in the scatter graph gives a good indication of how well the network has been implemented and if it is in need of more radio spectrum. For example, the top left hand side region of the chart indicates good network implementation. The further right in the top region of the chart indicates more radio spectrum required. The bottom left hand side region indicates poor network implementation and that no additional spectrum should be allocated as better network implementation will improve the GoS with the same spectrum allocation.

Thus the chart provides an instant indication of the state of a network and will enable the change in performance to be tracked and an indication of reaching a stage when more spectrum is needed.

Some results are given here. Three benchmarks are used:

- Reuse: Macro Layer = 9; Micro Layer = 3
- Cell Radius: Macro Layer = 300m; Micro Layer = 80m
- Macro Cell Layer and No micro cells
- 15 % area covered by micro cells
- Different spectrum is used for Macro and Micro layers: this is a representative of the practical implementation of the networks.

Graphs for Spectral Utilisation are plotted for planned capacity and carried capacity for GSM networks for the selected 25 Sq Kms area.

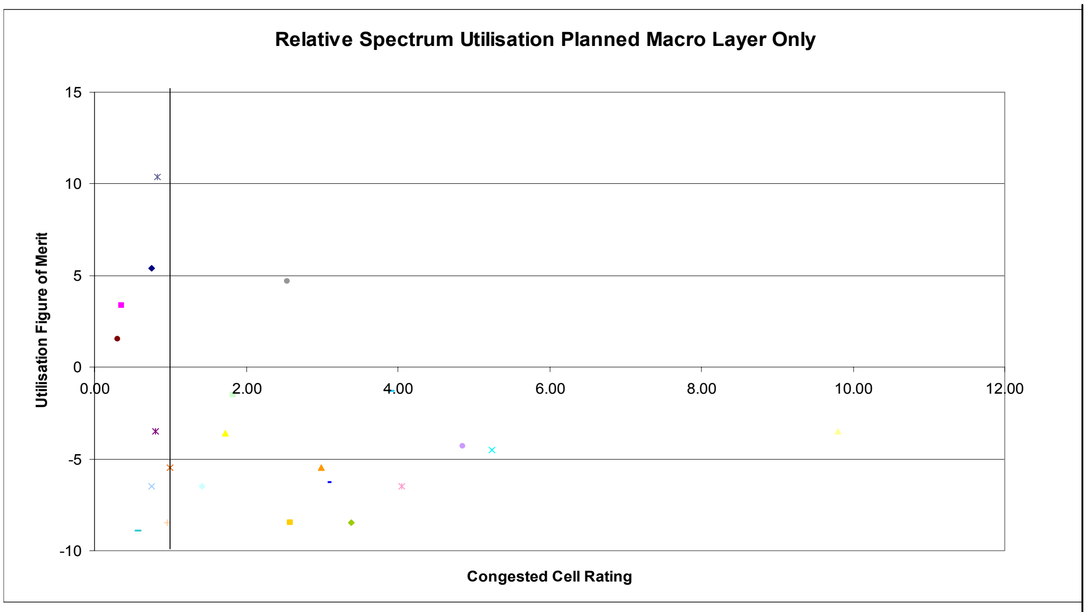


Figure 3.6: Spectrum Utilisation planned capacity Macro Layer only

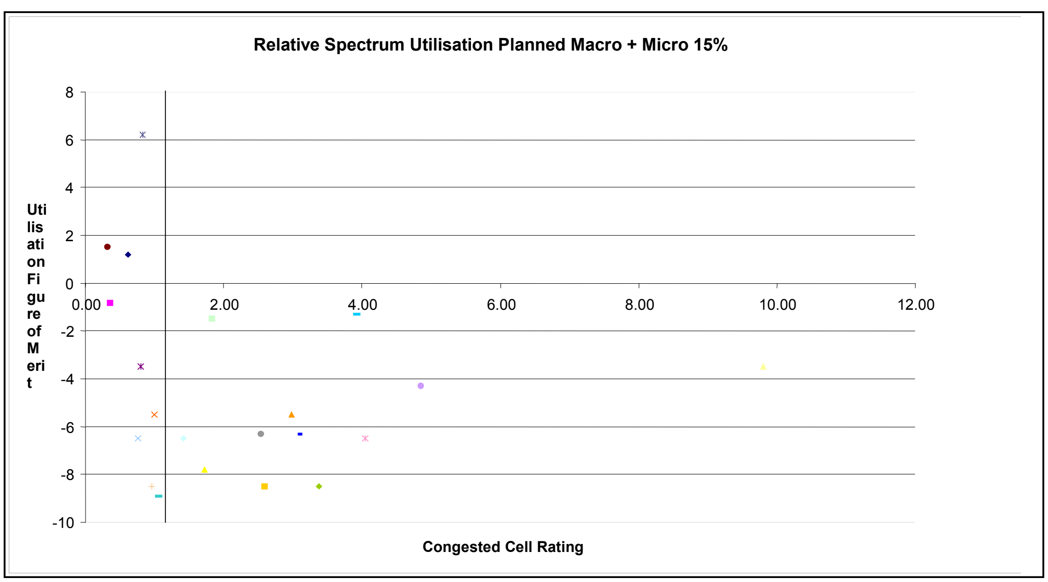


Figure 3.7: Spectrum Utilisation planned capacity with 15% micro cells

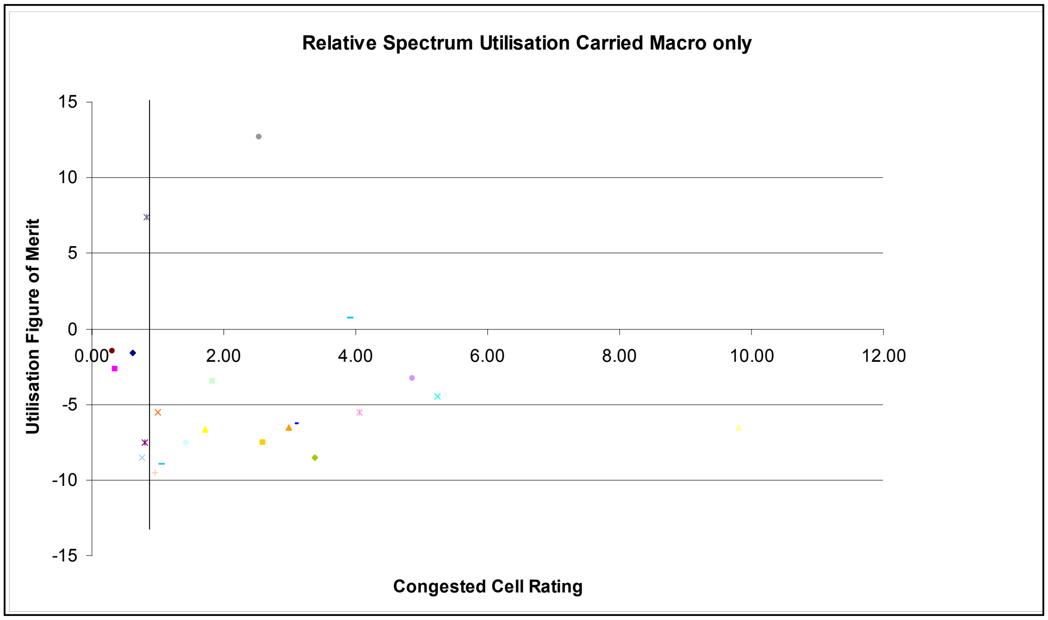


Figure 3.8: Spectrum Utilisation carried traffic macro cells only

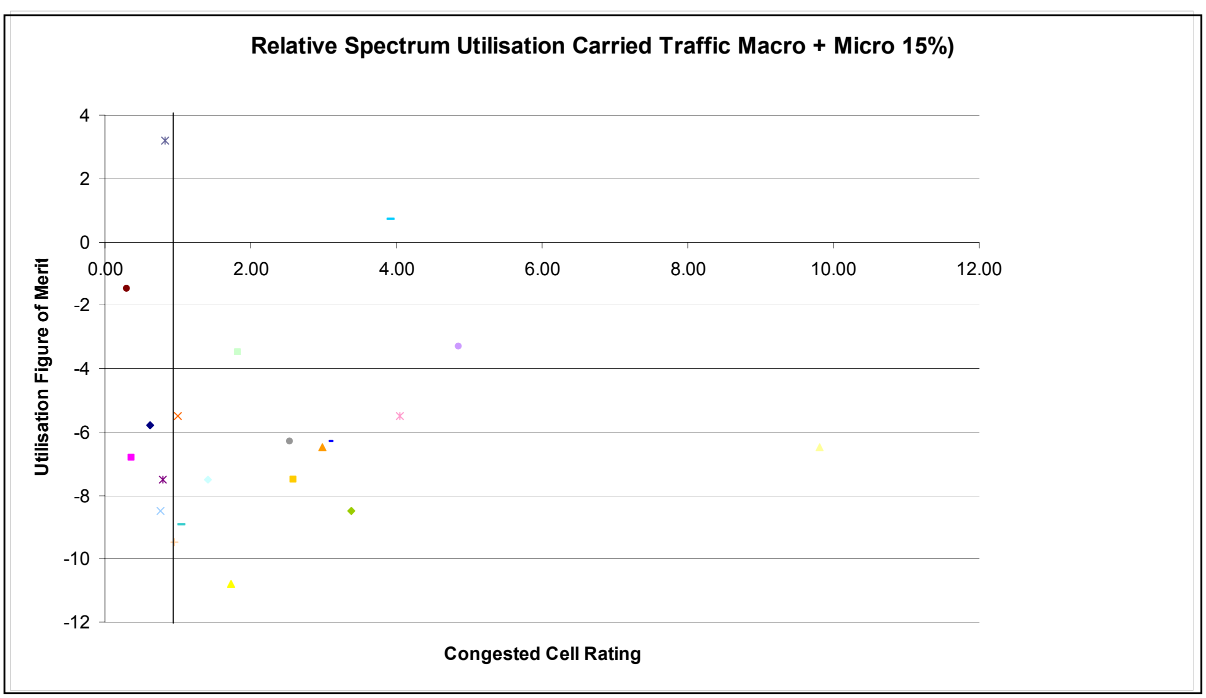


Figure 3.9: Spectrum Utilisation carried traffic 15% micro cells

Analysis of performance of GSM networks

- Some networks are achieving high spectrum utilisation, even when a combination of Macro and 15% Micro is used.
- Other networks performance rating indicates lack of investment in network capacity.
- Most of the networks do not employ hierarchical layers techniques and half rate codecs; the major networks in the country are starting to employ small cells and some micro cells but this is not being done on the basis of structured layers.
- The best Erlangs per MHz per Sq Kms achieved over an area of 25 Sq Kms is 22 while over an area of 8 Sq. kms is 38.
- The best networks are currently operating with a maximum cell packing density of about 13 per sq km in approximately 25 Sq Kms area and 23 per Sq Kms over an area of 8 Sq Kms.
- In certain networks, there are also variations in deployment on account of specific topography and municipal laws.

3.2.2.3 Impact of utilisation of advanced techniques in GSM networks

A number of techniques and system features are available that improve system quality and spectral utilisation. These are primarily concerned with speech performance, which despite the growth of data services, is likely to remain the dominant service for GSM. Additionally, a number of developments are underway that in connection with the system features are claimed to have the potential to increase system capacity within the GSM frequency bands including 1800 MHz band.

The techniques of spectrum utilisation and quality enhancement techniques are briefly discussed below:

– 1) *Baseline GSM Speech enhancement* – Frequency Hopping, Power Control, Discontinuous Transmission (DTX)

– 2) *Frequency Re-use and Partitioning Methods* – Hierarchical Structures/Layers are deployed in GSM networks to enhance capacity.

These techniques divide the radio spectrum into blocks that can be assigned to separate layers in the network each with different frequency re-use. A higher layer with a “loose” re-use factor ensures full contiguous coverage (called an overlay layer) whilst other lower layers, which need not be contiguous in coverage and have a very tight re-use and hence high capacity (underlay layer). Mobiles are directed to the appropriate layer by the network, depending on their location in the network and speed of travel. There are many different implementations of re-use partitioning that are proprietary to the equipment vendors, e.g. Concentric Cells – Motorola, Multiple Re-use Patterns – Ericsson, Intelligent Underlay-overlay – Nokia

– 3) *Trunking Gain Functionality* – Directed Retry (DR) and Traffic Reason Handover (TRHO) techniques
– 4) *Radio Link Enhancement Techniques* – Uplink and Down Link antenna diversity, Mast Head amplifiers, Interference rejection
– 5) *Half Rate and Adaptive Multirate speech coding*
– 6) *EDGE AMR enhancements*

The details of these techniques and their impact is provided in **Annexure E.**

Minimum spectrum requirement to build hierarchical networks

Some operators have raised concern that the present allocation levels are insufficient to build hierarchical networks. It is difficult to deterministically assess the minimum spectrum required for a hierarchical cell structure. It is theoretically feasible to provide coverage based on repeating clusters of four cells, each with three sectors. If there is a single frequency per sector then the total spectrum required to provide continuous service would be 12 x 200 KHz, i.e. 2.4 MHz. This network would be very limited in terms of capacity and grade of service. If instead each sector has four frequencies, the requirement of spectrum for voice services would be 2 x 9.6 MHz. If we take take three carriers this would be 2 X 7.2 MHz.

A micro layer then has to be added to provide additional capacity using repeated clusters of three cells, each with three sectors. If each sector has three frequencies then the micro layer will require 5.4 MHz. If each sector has two frequencies then the total requirement is 3.6 MHz.

Hence a reasonable spectrum requirement for hierarchical cell structure could be assessed at about 2 X 10.8 MHz ~ 2X 15 MHz.

3.2.2.4 International benchmarks

London GSM networks

Information on cellular radio cell sites is available on the UK's Ofcom website (www.sitefinder.radio.gov.uk). This web site gives the location of all the base sites of all the UK operators, together with antenna height, transmitter power and frequency band. Figure 3.10 and Figure 3.11 give an analysis of the base station heights and powers in the West End of London and Figure 3.12 and Figure 3.13 gives power and heights for base stations in the City of London.

In both cases, 80% of antennas are below 6 metres in height above ground level and 50% of transmitters are less than 9 dBW erp, indicating that most of the cells are micro cells.

In both cases the cells are located within an area of 700 metres by 700 metres (0.49 kmsq). The numbers of base stations and packing density is given in Table 3.2. Clearly this represents a densely planned network utilising mainly micro cells in the areas of high traffic density. The networks operate within the GSM GoS and quality performance recommendations indicating the ability of the GSM technology to provide very high capacity.

Table 3.2: Analysis of cell sites in two London locations

	City	**Packing Density Base stations per Kmsq/cells per Kmsq**	**West End**	**Packing Density Base stations per Kmsq/cells per Kmsq**
Vodafone	16	32.6/81.6	38	77.5/193.8
Orange	18	36.7/91.8	19	38.8/96.9
MMO2	24	48.9/122.4	34	69.3/173
T-Mobile	9	18.4/45.9	38	77.5/193.8
Hutchison 3	2	4/10.2	3	6.1/15.3
Total	69	-	132	-
Packing density Base stations per Kmsq/cells per Kmsq	140/ 352	-	269/6 73	-

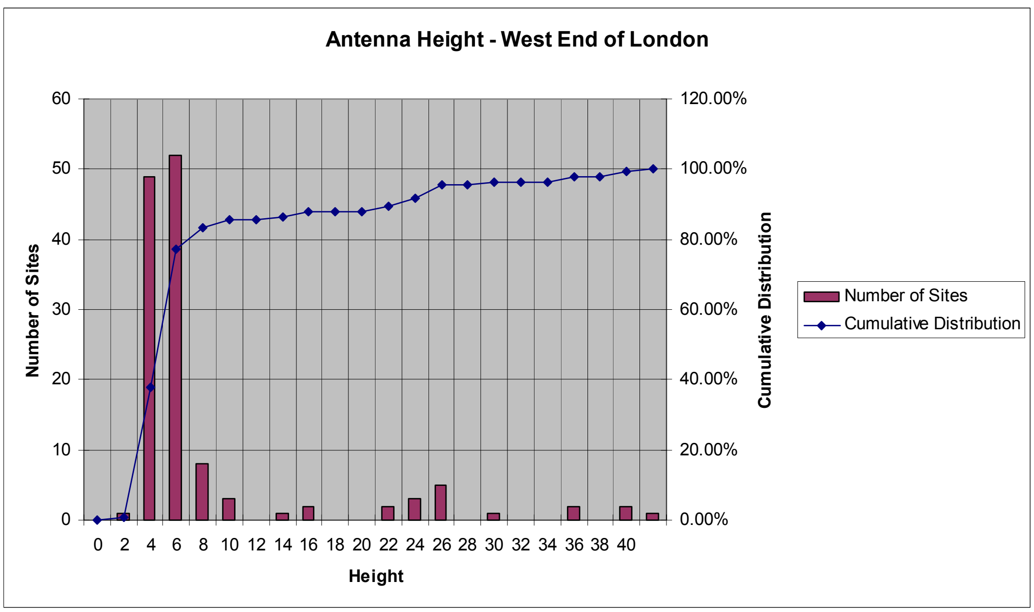


Figure 3.10: Analysis of Base Station Antenna Heights in West End London

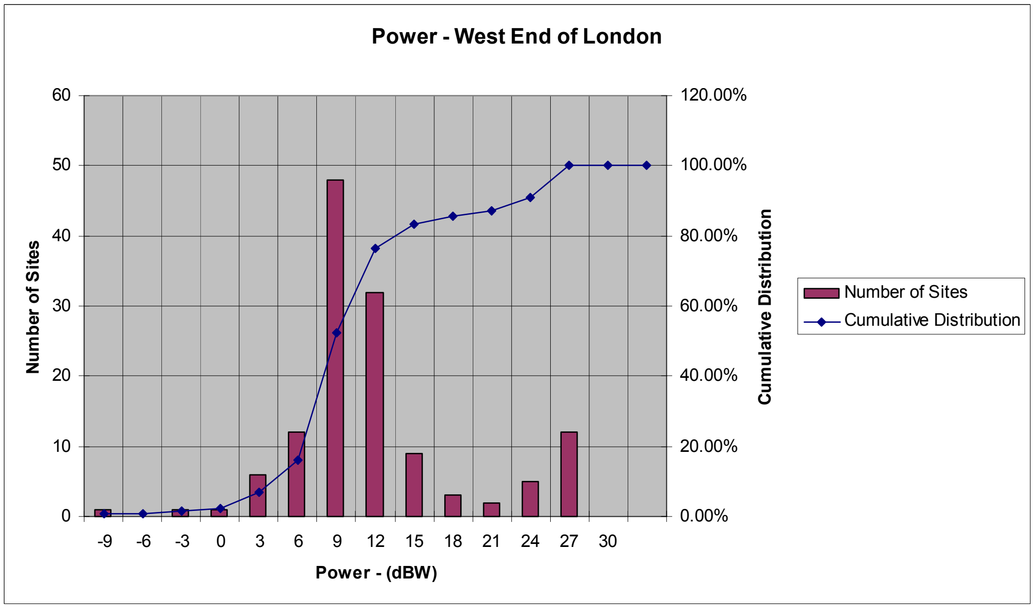


Figure 3.11: Analysis of the Base Station Transmitter Power in the West End of London

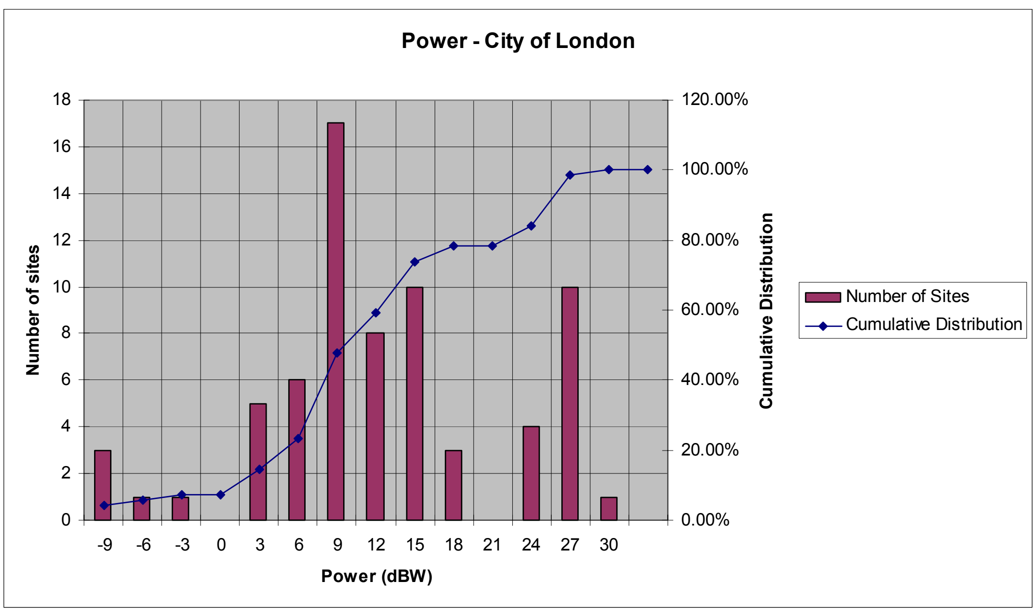


Figure 3.12: Analysis of the Base Station Transmitter Power in the City of London

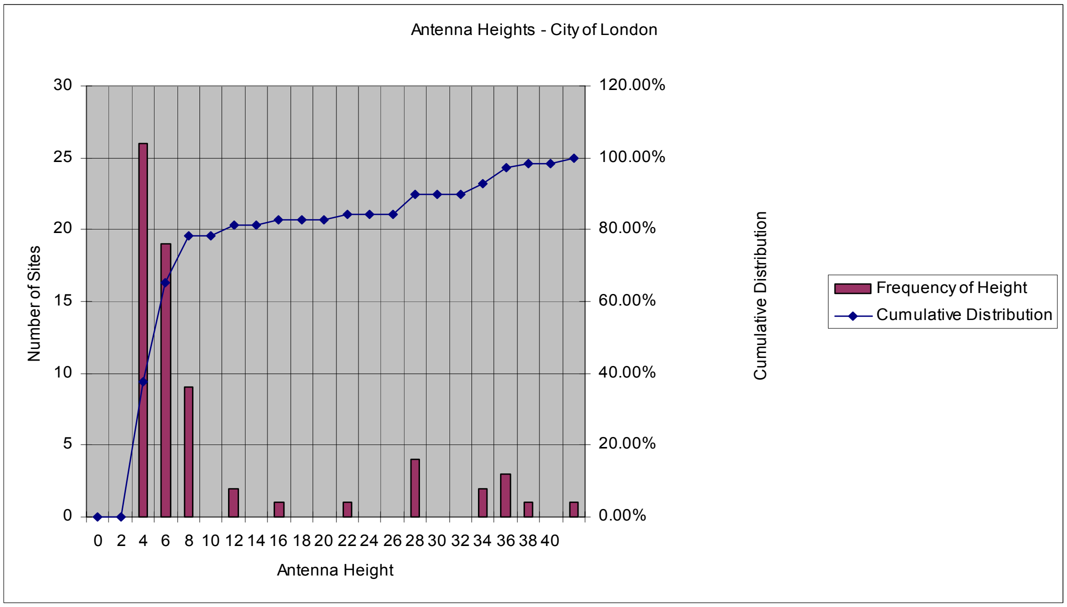


Figure 3.13: Analysis of the Base Station Antenna Heights in the City of London

3.2.2.6 Erlangs per MHz per Sq. Kms in Europe for GSM networks

GSM networks in major cities in Europe have achieved between 8.35 Erlang/km^2/MHz to in excess of 100 Erlang/ Sq. km/MHz but the actual efficiency depends on the geographic area considered, density of the population in that area and typical busy hour.

3.2.2.7 CDMA networks

The utilisation of the CDMA networks for a few networks is shown in Figure Figure 3.14. For the CDMA networks the Erlangs per MHz per Sq. Kms was calculated. Primary analysis suggests good utilisation figures. Also, the networks were not found to be congested at the current traffic levels. This is clearly seen from the table below:

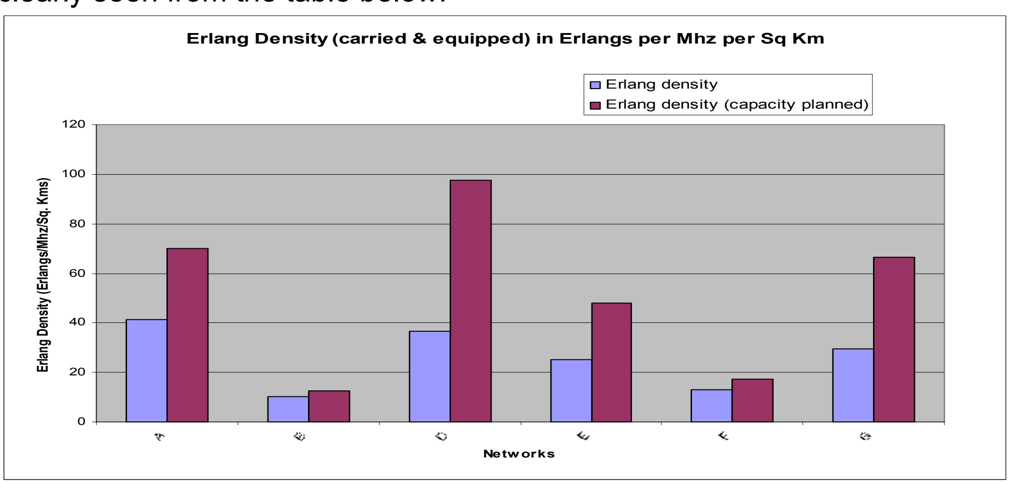


Figure 3.14: Relative spectrum utilisation of CDMA 2000 1x networks

In India, networks have achieved Erlangs per MHz per Sq. kms of 100 over an area of 25 Sq kms.

This however, does not take into account the capacity requirement arising from data services.

3.2.2.8 International Practices on CDMA 2000 1x network

International practices on the packing density of CDMA sites suggest the following benchmarks:

1) A 2.3 sites per Sq.Kms
2) B 2.2 sites per Sq.Kms
3) C 2.9-3 sites per Sq.Kms

This translates to

Networks	No. of sites per Sq.Kms	Erlang per Sq. Km per MHz with 80% loading
A	2.3	92
B	2.2	88
C	3	120
Maximum	5	200

3.2.2.9 Capacity enhancement techniques for CDMA 2000 1x

If there is a significant demand for multimedia services, increased data rates and therefore system capacity it would be possible to deploy 1xEV-DO in one of the 1.25 MHz channels. 1xEV-DO is an integral part of the family of CDMA 2000 standards and is optimised for high-speed data transmissions. Commercial deployment of these systems began in 2002.

The use of data compression and also smart antennas may also increase the spectrum utilisation.

3.2.3 Options for defining technical efficiency

From the discussions above, a combination of the following parameters can be used to quantify efficiency for a particular quality of service. These include

a) Erlangs per MHz per Sq. Kms over an area. One could also consider specifying efficiencies at different reuse levels for two areas say reuse 9 for 25 Sq Kms and reuse 3 for an area of say 5 Sq. kms
b) Average antenna height / power
c) Percentage of area covered by micro cells (in case of GSM)
d) Packing density

3.3 Issues for consultation

(i) Please offer your comments on the methodology outlined in this Chapter for determining the efficient utilisation of spectrum. Also provide your comments, if any, on the assumptions made.

(ii) Please provide your perception of the likely use of data services on cellular mobile systems and its likely impact on the required spectrum including the timeframe when such requirements would develop?

4.0 Objectives of Spectrum Pricing

The principal reasons why a fee is generally applicable for the right to use radio spectrum, include

i) Promoting efficient use of scarce spectrum resources, where it serves as a means to ensure that those using the spectrum do not acquire more than they need to provide a service
ii) Recovering the costs associated with managing the spectrum.
iii) In situations, where the demand for a particular part of the radio spectrum exceeds the available supply, spectrum fees provide one means of reflecting the scarcity value of this spectrum and can be used as a selection criterion.

Other means that are used to reflect the scarcity value of spectrum is to include the application of licence obligations such as requirements to provide a minimum level of coverage, linking the award of additional spectrum to the achievement of certain milestones such as network traffic or number of subscribers, or simply restricting the maximum amount of spectrum that one Service Provider can hold. In practice, a combination of these approaches may be appropriate.

It is important to decide upon the objectives that the pricing policy should achieve. These objectives are generally a combination of following principles:

a) Promote spectrum efficiency;
b) Simplicity and transparency;
c) Cost recovery;
d) Reflecting market value of spectrum;
e) Promoting competition;
f) Increasing rural roll out;
g) Raising government revenue

If the objective is to promote availability of services in rural areas where the volume of subscribers is insufficient to justify the incremental cost of network rollout, applying a fee structure that increases these incremental costs will be counter-productive. On the other hand, if an objective is to maximise the degree of competition in areas where demand is high, it is desirable to accommodate a number of competing Service Providers within the available spectrum and to encourage each Service Provider to use as little spectrum as possible. There are also situations where one –time fees is introduced either to eliminate non-serious player or to serve as a selection methodology.

4.1 Methodologies for pricing spectrum

There are currently a number of methods that are used to charge Service Providers for their use of the radio spectrum and the main ones include

- Auctions
- Administrative Incentive Pricing (AIP)
- Recovery of operating costs of the frequency management / regulatory bodies ("cost recovery")
- Payment related to Service Provider's revenue arising from the licensed service and/or use of the radio spectrum (generally referred to as a "levy").
- Based on Market Indicators.

Each method has advantages as well as disadvantages but where the aim is to ensure efficient use of the radio spectrum then one of the first two methods are generally used. In the case of auctions the charges payable by the winning Service Providers are set directly by the market, except where there are insufficient bidders. In such cases only the reserve price be paid. Administrative Incentive Pricing (AIP) requires the charges to be set by the Regulator. This has been a common approach in many countries.

4.3 Present Pricing Policy and the need for change

The present level of spectrum allocation and the concerned bands have already been discussed in Chapter 2. The following text provides a brief history of spectrum pricing in India.

4.3.1 Spectrum Pricing Policy for Cellular Mobile Services

4.3.1.1 Entry fees for spectrum

The first mobile licences were awarded in 1994 for metros using a beauty contest (with license fees and call charges as given parameters). For Non-metro Service Areas, the Government on the basis of highest levy quoted decided the license fee. In 1999, these operators were migrated to a revenue share regime with a model having an entry fees & an annual license fees revenue share. In addition, the operators pays an annual spectrum fees as revenue share. An auction process was carried out to award the 4^{th} CMSP license in 2001.

The entry fees paid at that point of time included spectrum and thereby in effect included an one-off Spectrum Charge. The entry fees paid by CMSPs reflected the scarcity value of CMSP license, and this scarcity reflected in the oligopoly was a result of spectrum scarcity. However, it is very difficult to assess the amount that has been paid by operators at that time for spectrum alone.

Basic Service Licenses were initially allocated through tender during the first round, but 2001 onwards these licenses were granted on meeting certain pre specified criteria. The right to use spectrum was on a first-come-first-serve basis and the entry fees was pre-defined. Also, 2001 onwards Basic Service Operators were permitted to offer limited mobility.

Another mode of entry in cellular mobile has been as a result of recent migration to UASL. In this case the benchmark was set against an entry fees decided through auction i.e., the entry fees paid by the 4th Cellular Operator. Therefore, even in this case the situation is similar to the earlier CMSPs and determining the amount of entry fees causal to spectrum is difficult.

4.3.1.2 Annual spectrum charges

In respect of annual charges, there was clear distinction in the annual fees payable for spectrum, the various methodologies over the period of time are explained in subsequent sections.

4.3.1.2.1 Annual Spectrum License fees for CMTS

Prior to 27.8.97

Annual Royalty = M X C X K + 1200 W, where
M = 4800,
C = Number of RF channels each of 200 kHz,
K = constant multiplier = 8
W = 1000 for every 1000 subscriber or part thereof

27.8.97 till 31.7.99

Annual Royalty = M X C X K, where
M = 4800,
C = Number of RF channels each of 200 kHz,
K = constant multiplier = 8

(The per handset royalty charge was removed)

Post 1.8.99

2% of AGR for spectrum usage upto 4.4 + 4.4 MHz
3% of AGR for spectrum usage upto 6.2 + 6.2 MHz
4% of AGR for spectrum usage upto 10 + 10 MHz
5% of AGR for spectrum usage upto 12.5 + 12.5 MHz
6% of AGR for spectrum usage upto 15 + 15 MHz.

In addition, charges have to be paid separately in respect of frequencies used for microwave links and backbone.

Initially, GSM operators were assigned 2 x 4.4 (4.5 in the first phase of licensing for 1st and 2nd CMSPs) MHz and a further 2 x 1.8 MHz was assigned. The spectrum allocation was increased in steps to 2 x 10 MHz on meeting the prescribed subscriber thresholds. So far 3 GSM[7] licensees have been allocated upto 2 X 10 MHz. All GSM spectrum beyond 2 x 8 MHz per

[7] As per data of 31.3.2004

operator (for 1st, 2nd and 3rd Cellular operators) and the entire spectrum for 4th Cellular operator is in the GSM 1800 MHz band.

4.3.1.2.2 Annual Spectrum License fees for WLL Services (now cellular mobile)

The present spectrum/license fees for WLL services is 2% of AGR (upto 2x5 MHz) in the complete service area for Wireless Access Systems. In addition, charges have to be paid separately in respect of frequencies used for microwave links and backbone.

4.3.2 Implications of the current pricing regime on spectrum efficiency

The current pricing regime is based on revenue rather than the payment of a fixed amount per unit of spectrum licensed. This has the advantage for operators that the amount payable is small in the early days of network rollout. Also, the regime is very simple, easily understandable and accountable.

However, this mechanism poses certain difficulties in the present scenario.

a) The amount increases sharply as the network matures and revenue increases, potentially restricting the scope for infrastructure investment and/or tariff reductions.
b) The low level of fees during the early stages of network rollout does not provide any significant financial incentive to use spectrum more efficiently, hence the level of efficiency is determined by the regulatory limit placed on spectrum assignments. This is currently linked to the number of subscribers, which means that in the initial phase of network rollout Service Providers may be tempted to adopt a sub-optimal approach to network design.
c) This pricing mechanism would tend to penalise the most efficient operator (in terms of revenue). The spectrum charge per MHz paid by efficient operators would be more than inefficient ones, even in the same technology.
d) Under Unified License with service providers deploying technologies that are at large variation in efficiency and revenue realisation, it would be difficult to ascertain the service that would be provided using the spectrum, thereby, making the spectrum charges highly unpredictable and variable.

It is, therefore, advisable that in a scenario where there are likely to be a large number of licensees with similar rights to spectrum, the fee be based on the amount of spectrum assigned rather than the level of revenue and the number of subscribers. This would enable Service Providers to balance their approach to network design against the cost of a larger spectrum assignment.

4.3.3 Spectrum Pricing and need for technology and service neutrality

In a Unified License regime, the endeavour is to proceed from technology neutrality to service neutrality. Accordingly, the Government in its guidelines on Mergers & Acquisition have decided to charge the same license fees for spectrum irrespective of the technology or service. Letter No. 20/232/2004 – BS III dated 17th March 2004 on the issue of guidelines for Mergers and Acquisition in a Service Area states

“5. The spectrum charges shall be calculated for the total spectrum held by the merged entity as Govt. has already decided that spectrum charges shall be same for CDMA and GSM”.

4.4 Options for evolving a structure for pricing spectrum

In the existing framework, the spectrum charge has two components i.e., an entry fees and an annual license fees. The objective is to devise a pricing strategy taking into account both these components.

Internationally, the practices vary from country to country. Table 4.1 clearly demonstrates that while in some countries there is no one off fees there is high recurring fees and in others vice versa.

The issue to deliberate upon is whether to continue with the present scheme of determining entry fees through a competitive mechanism together with a pricing mechanism for annual charges or to have only entry fees or only annual license fees.

It may perhaps be advisable that the entry fees for spectrum be kept separate from the annual license fees. The prime reason being the fact that the basis for determining these fees are different.

Table 4.1 Spectrum Charges for GSM in Europe

	Network	Spectrum Licensed (MHz) GSM 900 Mhz	GSM 1800 Mhz	Administrative fees (€) Once-off	Recurring (p.a.)	Spectrum fees/Charges(€) Once-off	Recurring (p.a.)
Belgium	Belgacom (Proximus)	2x12	2x15[6]	12500	250000	223,101,000	3375000[5]
	mobistar	2x12	2x15[6]	12500	250000	223,101,000	3375000[5]
	KPN Orange	2x5[1]	2x22[6]	12500	250000	198,435,945	3375000[5]
Denmark	TeleDanmark Mobil	2x8.8	2x26.8	0	0	0	487,688
	Sonofon	2x8.8	2x19.8	0	0	0	397,032
	Telia Denmark	2x7.4[2]	2x14.4	0	0	0	304,764
	Mobilix	2x7.4	2x14.4	0	0	0	304,764
Germany	T-Mobil	2x12.4	2x5	Info not available (fees currently subject to legal review)	201,138	1,556,883	201,138
	Mannesman	2x12.4	2x5.4		201,138	1,556,883	201,138
	E-plus	0	2x22.4		201,138	2,004,253	201,138
	Viag Interkom	0	2x22.4		201,138	2,004,253	201,138
Greece	Panafon GSM	2x15	2x15	0	Annual levy based on turnover	211,795,949	0
	Telestet	2x10	2x15	0		123,188,297	0
	Info-Quest	0	2x10	0		20,542,930	0
	Cosmote	0	2x25	0		46,871,717	0
Spain	Telefonica Moviles	2x12	2x15	0	0.15% of turnover		65.530.120
	Airtel	2x12	2x15	0	0.15% of turnover		65,530,120
	Amena	0	2x15	0	0.15% of turnover		34,036,145
France	Itineris	2x10.8	2x13.2[3]	304,898	152449	0	7,317,432
	SFR	2x10.8	2x13.2[3]	304,898	152449	0	7,317,432
	Bouyges Telecom	2x3.2[4]	2x23.2	304,898	152449	0	8,049,175
Ireland	Eircell	2x7.2	2x14.4	12,500		22,220,416	1,523,686
	East Digifone	2x7.2	2x14.4	12,500		22,220,416	1,523,686
	Meteor	2x7.2	2x14.4	12,500		22,220,416	1,523,686
Italy	Telecom Italia Mobile	2x10.2	2x9.6	56810	61975	57,850,000	0
	Omnitel	2x7.2	2x9.6	56810	61975	413,850,000	0
	Wind	2x5	2x14.4	56810	61975	57,850,000	0
	Blu	0	2x15	56810	61975	57,850,000	0
Luxembourg	P+T	2x11.6	2x9.8	1,859,200	743,680	1,850,335	740,135
	Millicom	2x11.6	2x9.8	1,859,200	743,680	1,850,335	740,135
Netherlands	KPN Mobile	2x12.2	2x17.6	363[7]	356670	143,000,000	267,410
	Libertel	2x12.2	2x5.2	0	353949	40,800,000	156,139
	Telfort	2x5	2x17.4	0	353949	268,000,000	200,995
	Dutchtone	2x5	2x15	0	353949	272,000,000	179,460
	Ben	0	2x16.8	0	353949	122,500,000	150,746
Austria	Mobilkom Austria	2x8	2x15	5087	Annual levy on turnover of 0.1 ~ 0.2%	288000000	732,159
	Max mobil	2x8	2x8	5087		288000000	509,328
	Connect Austria	0	2x28.8	7267		165600000	916,790
	Tele.Ring	0	2x14.6	7267		98000000	464,762
Poland	TMN	2x8	2x6	4988	9976	Fee payable deends on number of base stations and subscribers	
	Telecel	2x8	2x6	4988	9976		
	Optimus	2x7.8	2x6	4988	9976		
Finland	Sonera	2x13.6	2x11	0	0	0	2,651,366
	Radiolinja	2x10	2x8.2	0	0	0	1,959,706
	Telia Finland	0	2x8.2	0	0	0	149,253
	Suomen 3G	2x8.6	2x7.2	0	0	0	339,763
	Elisa	0	2x7.2	0	0	0	655,258
Sudan	Telia Mobitel	2x7.2	2x15	10,893	5,447 plus levy of 0.15% of turnover .7	0	Fee payable depends on number of base stations
	Comviq	2x7.2	2x8.4	10,893		0	
	Europolitan	2x7.2	2x8.4	10,893		0	
UK	BT Cellnet	2x16.8	2x5.8	40,000	Annual levy of up to 0.08% of turnover	0	24,271,000
	One2one	0	2x30	40,000		0	26,826,000
	Orange	0	2x30	40,000		0	26,826,000
	Vodafone	2x16.8	2x5.8	40,000		0	24,271,000

Source: Study on administrative and frequency fees related to the licensing of networks involving the use of frequencies, Aegis, Connogue

Notes:
[1] Licensed but not currently available or charged for due to use by CT1 cordless phones
[2] 2 x 1.4 MHz not available until 2002
[3] Only in certain urban areas
[4] Only in rural areas
[5] This is a maximum figure, actual amount paid depends on amount of spectrum being used rather than amount of spectrum licensed.
[6] The spectrum indicated is the spectrum reserved for the respective operators. In practice not all that spectrum is in use for the time being. Only Mobistar currently uses the complete 2x27 MHz
[7] Applies to operators with SMP

4.4.1 Methodologies for Spectrum Pricing

The following methodologies exist for spectrum pricing

Administrative Incentive Pricing,
Auction,
Based on market indicators;
Cost recovery
Revenue Share

These are detailed below. The pros and cons of each methodology are tabulated in Annexure-F.

4.4.1.1 Administrative Incentive Pricing (AIP)

AIP is used where demand for spectrum exceeds supply. It involves setting the fee for a right to use radio spectrum in a way that supports specific objectives, such as promoting technical efficiency or the provision of services in rural areas. To be effective, AIP has to be set at such a level that it will influence the investment decisions made by the Service Provider, e.g. by making it more economic to build more base stations rather than acquire more spectrum or to extend service to areas that might otherwise be uneconomic. In areas and frequency bands where the demand for spectrum exceeds the supply, the level of AIP should reflect the amount of spectrum assigned to each user.

AIP levels may be set by considering the cost implications for a Service Provider of adding or subtracting a quantity of radio spectrum, assuming that the same network capacity and grade of service is maintained. These costs would typically include an increase or reduction in infrastructure, the use of an alternative transmission platform such as cable, or the use of an alternative, sub-optimal frequency band. This approach is sometimes referred to as the "least-cost alternative" approach to AIP. An example to demonstrate the applicability of AIP in the Indian context is given in Section 4.4.1.1.2.2. The example carries only indicative values.

4.4.1.1.1 Choice of technology to determine AIP

AIP is not intended to favour any one particular technology, hence where spectrum may be used by a choice of technologies a consistent fee should apply regardless of the actual technology chosen. This raises the question of how the fee should be determined, i.e. should it be based on the assumption that the most efficient technology is used, or on some other basis?

Fees should be set at a level that ensures Service Providers have an incentive to use the spectrum efficiently, but not so high that their ability to offer an acceptable grade of service at a competitive price is compromised. Setting fees on the basis of the most efficient available technology (in this case assumed to be CDMA) could have such adverse impact on existing GSM operators, as it would not be practical to switch their networks to another technology. A better solution is to base the value of the spectrum on the "second best" technology, since this provides users of that technology with an incentive to use it in the most efficient manner whilst avoiding penalising users of the more efficient technology. This is also in keeping with the approach to AIP recently recommended in the UK, which recommended that where there is more than one use of spectrum, the valuation should be set towards the bottom end of the range between the two highest value uses.

4.4.1.1.2 Example of applying AIP to Cellular Mobile Service Providers

4.4.1.1.2.1 Basic Principle

It is possible to define a hypothetical reference GSM network based on typical traffic levels, population density and market penetration. The basic principle is to calculate the marginal value of the GSM spectrum by taking into account the amount of additional network required if the spectrum is not provided. Alternatively, the price reflects the amount of savings in infrastructure as a result of additional spectrum allocation.

A minimum number of sites are required to provide coverage and these provide a "base" level of capacity. Adding base stations, having more spectrum and additional transceivers at the existing sites or a combination of the two, can then provide additional capacity. The additional capacity is not required throughout the network and in some areas the "base" capacity may be sufficient. As the amount of spectrum held by a Service Provider increases, the areas where he needs extra spectrum decreases as traffic demand varies across the network depending on the geographic area[8].

Since it is the marginal value of the spectrum that is calculated it should be based on traffic in the denser areas where traffic is highest. In India usage is more concentrated in urban areas and therefore any calculations based on total assumed traffic density in a region should assume that a high percentage of the demand would come from those areas where there is a need for more spectrum. An alternative approach would be to base the AIP calculations on the urban population rather than the total population.

4.4.1.1.2.2 Methodology

The Model has two parts. First, it estimates the amount of total traffic that the network generates in the busy hour. Using this it estimates the number of sectors required in (say) 10 MHz of spectrum allocation. Thereafter, the number of sectors required in (say) 12.4 MHz is calculated. The net saving in the number of sectors is estimated. Adjustments are made for the cost of TRXs, which would be required in both the cases. Finally, using the cost differential, the price per MHz is calculated.

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[8] Geographic area can be defined as rural, sub-urban, urban and dense urban.

Sl. No.	Parameter	Values that would be required in the model	Remarks
1	Population	Census data	The values used in the model are indicative only.
2	Market share	Statistical average	
3	Busy Hour Traffic per subscriber	Actual measurements	
4	Reuse	9	
5	Cost per BTS	Industry data	
6	Cost per TRX	Industry data	

The fees can be calculated on an annual basis for each service area and may be reviewed after a fixed period, say every 2 or 3 years. Over these years the market share has the potential to change significantly especially in a developing market and it is therefore proposed to assume a reasonable but equal market share. This is based on the principle that all service providers should be charged for per MHz of spectrum based on fair share and equally efficient use. The market share may also be taken as some statistical value of existing market shares, say a mean or mode.

The number of Erlangs per sector, assuming a 2% call blocking probability, is 32.5 if four frequencies per sector are available (corresponding to 2 x 10 MHz), or 42.4 if five are available (corresponding to 2 x 12.4 MHz). Hence the number of sectors required to cater for the busy hour traffic with 2 x 10 MHz is (40000 / 33) = 1229 sectors, whereas the number required with 2 x 12.4 MHz is (40000 / 42) = 943 sectors. Hence the number of additional sectors required to compensate for a 2 x 2.4 MHz reduction in spectrum would be (1229 - 943) = 286 sectors.

The number used in Table below are indicative. In event, the stakeholders agree with the methodology, please provide the comments on the assumptions issued.

A	**Service Provider**	Figures are for illustration only	
	Service Area		
	Population	in Millions	20
	Subscriber base	In Millions	5.00
	Current market penetration	in %age	25%
	Projected market share	in %age	20%
	Busy hour traffic per sub	mE	40
	Total busy hour traffic	Erlangs	**40000**
B	**Calculation of number of sectors**		
	Frequency allocated	MHz	10
	Reuse		9
	No of sectors		3
	Number of channels per sector	nos.	44.4
	Erlangs per sector	in Erlangs	32.5
	Number of sectors required	nos.	1229
	New frequency allocated (cumulative)	in MHz	12.4
	Number of channels per sector	nos.	55
	Erlangs per sector	in Erlangs	42.4
	Number of sectors required	nos.	943
	Number of sectors reduced	nos.	**286**
C	**Costing Parameters**		
I	Equipment capital cost per sector (excl TRX)	in Rs.lakhs	4.00
	Discount rate	in Rs.lakhs	10%
	Per annum cost	in Rs.lakhs	0.40
II	TRX cost	in Rs.lakhs	2
	Discount rate	in Rs.lakhs	15%
	Per annum cost	in Rs.lakhs	0.3
III	Equipment maintenance cost @ 15% of (I) & (II)	in Rs.lakhs	0.90
IV	Site rental per sector	in Rs.lakhs	0.33
D	**Calculation of Spectrum charge**		
	Cost of new sectors	in Rs lakhs	581
	Cost of additional radios at existing sites if extra spectrum used	in Rs lakhs	86
	Net cost of additional infrastructure	in Rs lakhs	495
	Net cost of additional infrastructure per MHz	in Rs lakhs	206
	Spectrum charge for 10 MHz	in Rs lakhs	2064
	Spectrum charge for 10 MHz	in Rs Crores	21
	Spectrum charge per MHz	in Rs Crores	2.1
E	**Discount for rural coverage**		
	No of BTS in rural area	nos.	20
	Total number of Base Station	nos.	500
	Total amount of Discount	in %age	4%
	Net spectrum charge per MHz	in Rs Crores	2.0

4.4.1.1.3 Using AIP to promote coverage in rural areas

On a purely commercial basis, Service Providers may find it uneconomic to extend coverage substantially into rural areas if the additional revenue that would be generated as a result is likely to be less than the costs that would be incurred. There are two ways in which the price mechanism could be used to promote coverage in rural areas.

i) A discount could be applied based on the proportion of the total network infrastructure (base stations) that is located in rural areas, as defined by the census authorities. This would involve the total fee being reduced by a factor F, where F = no. of rural base stations / total base stations. The example in section 4.4.1.1.2.2 demonstrates the methodology.

ii) Another option could be to reduce the number of sectors used in the calculation of the urban fees by an amount equivalent to the number of base stations serving areas of population density less than a specified value per sq. km. It may be reasonable to apply this reduction only to the minimum 2 x 2.4 MHz spectrum that is required to provide basic coverage, since this is all that would be required in rural areas and this would ensure that additional spectrum continued to be subject to AIP whilst also providing a worthwhile incentive to promote rural rollout.

4.4.1.1.4 Phased implementation

It is important that any regime that is planned has a smooth implementation path. A transition mechanism could be worked out for AIP. One option could be to begin with application of AIP only beyond 2 X 10 MHz. Thereafter, over a period of time AIP is made applicable to the entire spectrum.

4.4.1.2 Auctions

A well-designed auction should treat all potential bidders fairly and transparently and should achieve a realistic market price for the spectrum and encourage efficient use of the spectrum. Efficient use of the spectrum in this context means maximising the economic value of the spectrum, providing good grade of service at an economic cost but with the minimum of spectrum and ensuring that the number of Service Providers who are accommodated in the spectrum maximise competition.

4.4.1.2.1 Types of auctions

There is no single auction design that can be used in all cases of spectrum allocation because the amount of spectrum, number of potential bidders, geographic coverage (regional or national) and policy objectives are all likely to differ. The main types of auctions are:

- Ascending-price
- Sealed-bid
- Anglo-Dutch

Ascending-price

Simultaneous ascending price auctions[9] have been demonstrated to be effective where a number of licences are to be awarded and they cover, for example, different geographic areas. In this case there are a number of sequential rounds of bidding and each bidder must increase the previous bid on a "lot" by more than a pre-set amount. When there is no more bidding the auction ends and the bidders with the highest bids on each "lot" will be the winners. The fact that bidders can see how their opponents are bidding and derive information on how they value spectrum in the different geographic areas will allow them to win more efficient allocations than might happen in a sealed bid. Ascending price auctions are also ideal for conducting through electronic means.

The down side is the potential for collusion. Measures can be taken to avoid collusion such as ensuring bids can only be in "round" numbers (in some cases the final digit in the bid can be used to convey a "signal" to other bidders).

Others

Sealed-bid

Sealed-bid auctions involves each bidder only making one single offer. They are more attractive to new entrants than the ascending auction as there is always the possibility that they might outbid an incumbent who has under-estimated the value of the spectrum.

Anglo-Dutch

This is a mixture of the two auction types above. Initially there is an ascending price auction and then when the number of bidders has been reduced to one more than the number of licences available[10] there is a sealed-bid. The sealed-bid has to be the same or more than the final price reached through the ascending auction.

Reserve prices

It is important that the reserve prices are set at a level that ensures the spectrum cannot be won cheaply and successful bidders pay near the expected market price. The following options exist to set reserve price

i) Based on an estimate of what would have been the fees paid using Administrative Incentive Pricing.

ii) Based on market indicators

An alternative approach is to attempt to set levels based on market indications, such as the prices paid at auction in comparable frequency bands and geographic territories, however such prices are subject to wide fluctuation

[9] For example ascending price auctions have been used in the US, Canada, Australia, UK, Germany and Austria.

[10] The licences would need to be in the same geographic area.

as was the case in the European 3G mobile auctions, which may result in fees that are widely out of line with the least cost alternative approach and so may fail to have the desired impact on investment decisions. If the price is set too high, Service Providers will be deterred from entering the market or, if they do, may be deterred from acquiring sufficient spectrum to address a wide market, choosing instead to concentrate on high spending, non-price sensitive users. If too low, there will be no incentive to use spectrum in the most efficient manner.

iii) Basis of pre auction bid amounts. This approach was used while awarding the fourth cellular licenses.

4.4.1.3 Based on cost recovery

In the case of cost recovery the fees are generally set on a service by service basis and depend on the actual costs incurred by the regulatory authority in the licensing of the networks / services concerned and associated management of the radio spectrum. There will be additional "indirect" costs such as international activities or work on licence-exempt services that cannot be directly attributed to a service that is licensed. These costs will have to be spread across the different services according to some transparent basis. For example it could be done according to the ratio of fees payable by the different services so each one only pays a small addition in comparison with their own costs of management. Alternatively, some Regulatory Authorities recover costs by means of a levy on turnover.

Cost based pricing is appropriate where there is no excess demand for spectrum and may be applied as a minimum fee where AIP is deployed, to ensure that the regulator's costs are always covered.

4.4.1.4 Continue with revenue share

Another option is to continue with the existing revenue share model. This methodology has already been discussed earlier.

4.5 Issues in Spectrum charging

While adopting an approach towards spectrum pricing, it is important to take note of the existing legacy. The existing operators have already treaded a certain path towards spectrum charging i.e., they have been paying annual charges based on revenue for allotment of spectrum upto 10 + 10 MHz. In the event we choose to migrate to a new regime, it is important to take care of level playing field issues of new operators vis-à-vis the existing operators.

One option could be that, for those existing service providers, who have not reached 10 + 10 MHz, the present revenue share mechanism be continued till they reach 10 + 10 MHz or a certain time frame, say 3 years. After a lapse of the period or the attainment of this spectrum, whichever is earlier, the new charging mechanism will be applicable.

The options for applying any new methodology are

a) The new charging method be adopted for the entire spectrum;
b) Revenue share mechanism continues till 10 + 10 MHz, and any spectrum beyond this is charged on the new method;
c) In spectrum bands where there is no excess demand, the spectrum fee could be based on cost recovery.
d) There could also be discounts for operations in rural regions and /or usage of spectrum that is less in demand such as 450 MHz spectrum .

4.6 Use of surpluses generated by auctions or AIP

In event that the use of new methodology generates revenues in excess of the costs associated with licensing and managing the spectrum, the surplus may be wholly or partly hypothecated to support particular national objectives, such as the provision of services in rural areas or to provide compensation to existing spectrum holders in return for the early release of their spectrum.

4.7 International experience on Pricing of spectrum

Table 4.1 provides the details of spectrum pricing policy in Europe. In China, the spectrum is priced at 15 Million RMB per MHz per annum for nationwide use and 1.5 Million RMB per MHz for use in a city. Summary of pricing formulae in some other countries is provided in Table 4.2.

Table 4.2: Spectrum charge formulae for 2G & 3G Mobile Service in other countries

Country	2G Service	3G Service
Lesotho	**Cost =** 1500*K1*K2*K3 Where K1 = Spectrum Value K2 = Area Factor / Type of service K3 = Amount of spectrum in KHz	**Cost =** 1500*K1*K2*K3 Where K1 = Spectrum Value K2 = Area Factor / Type of service K3 = Amount of spectrum in KHz
Egypt	**Cost =** Cf + Ef Cf = 27.825 * D * N Ef = (A + 50 N) * Y D = 20 Km or 40 Km A = 150 If Output Power > 5 W = 250 If Output Power > 5 W N = No. of channels Y = No. of equipment	**Cost =** Cf + Ef Cf = 27.825 * 20 Ef = (250+50N) * Y
Sri Lanka	**Cost =** N * Delta.f * Cf + N * Cp Cf = frequency charge per kHz Cp = power charges Delta.f = Bandwidth N = No. of channels per base station	**NA**
Armenia*	**Cost =** K * B K = number of transmitter B = time coefficient of radio spectrum monitoring; B = 30	**Cost =** K * B K = number of transmitter B = time coefficient of radio spectrum monitoring; B = 30
Czech Rep.	**Cost =** S1 * K1 * K2 S1 = fee for 1 kHz of bandwidth K1 = coeff. of assigned bandwidth K2 = coeff. of regional assignation	**Cost =** S1 * K1 * K2 S1 = fee for 1 kHz of bandwidth K1 = coeff. of assigned bandwidth K2 = coeff. of regional assignation
Switzerland	**Cost =** Basic fee * Delta.f/25kHz * territ. * t t is duration in years territ. = factor for area covered	**Cost =** Basic fee * Delta.f/25kHz * territ * t t is duration in years territ. = factor for area covered

* 2G,3G not specifically mentioned
Source: ITU spectrum fee database

4.8 Summary of pricing options

	New entrants	Additional Spectrum to existing operators	Additional Spectrum to existing operators
		Up to 10 + 10 MHz and within the specified time frame	Beyond 10 + 10 MHz
One time entry fees	• Auctions • AIP • Cost Recovery where there is no competition • Market based benchmarks	• Administrative Pricing • Cost Recovery where there is no competition • Increased revenue share	• Auction • Administrative Pricing • Cost Recovery where there is no competition • Increased revenue share
Annual Charges	• Revenue Sharing • AIP • Cost recovery for all spectrum	• Revenue Sharing • AIP • Cost recovery for all spectrum	• Revenue Sharing • AIP • Cost recovery for all spectrum

4.9 Spectrum Charges and processing for other Terrestrial Wireless Links

Telecom operators including ISP's and IP-II operators, as well as corporate customers have raised the issue of high spectrum royalty charges, the structure of charge determination, and hurdles in the form of procedural delays for spectrum allocation, siting clearances and other formalities. Promoting efficient usage of such technologies is important to the quick and cost effective spread of internet and broadband, both for commercial and residential users. The issues pertaining to the last set of hurdles have already been addressed by the Authority in its Broadband Recommendations, while the first two will be discussed in this Consultation process.

The current model used for pricing of this spectrum is based on the equation R=MxWxC, where R is the upfront annual payable royalty amount, M is determined by the distance the clearance is being sought for, W is determined by the amount of frequency being allocated, and C is the number of RF channels used (twice the number of duplex RF channel pairs). Both M and W are determined by range slabs, such that the multiplier increases significantly as soon as the requirements for the operator cross into the next slab. Details can be found in Annexure G. In addition to payment for spectrum, there is also an additional Rs. 1,000 per additional antenna beyond the first two within the area of granted clearance, with each new antenna requiring explicit clearance.

Frequency allocation for spectrum which is not included in the license of an operator is typically granted on the basis of non-exclusive, non-protection and non-interference, whereas others are allocated with protections. This parameter means that even though users are granted clearance for usage of specific spectrum in a particular geography, they are not guaranteed that they will be the only users, or that they will not experience any interference. Since this allocation process also allows for accommodating a number of operators within a given frequency, maximizing spectrum usage, and therefore is in the interest of spectrum efficiency, should there be a consideration for having lower price levels for such usage, as the current system does not account for that.

4.10 Issues for consultation are

(i) Is there a necessity to change from the existing revenue share method for determining the annual spectrum charge?

(ii) If yes, what methodology should be used to determine spectrum pricing for existing and new operators? (Please refer table in Section 4.8)

(iii) In the event AIP is adopted as a means to price spectrum, would it be fair to choose GSM as a reference for determining the spectrum price?

(iv) Please provide your comments on the assumptions used in A.I.P.

(v) In case Auction methodology is used for pricing the spectrum, please give suggestions to ensure that spectrum pricing does not become very high and spectrum is available to those who need it.

(vi) Should the new pricing methodology, if adopted, be applicable for the entire spectrum or should we continue with revenue share mechanism till 10 + 10 MHz, and apply the new method only for spectrum beyond this?

(vii) What incentives be introduced through pricing to encourage rural coverage and / or using alternative frequency bands like 450 MHz?

(viii) Does M X C X W formulae for fixed wireless spectrum pricing need a revision? If so, suggest the values for M, C, W?

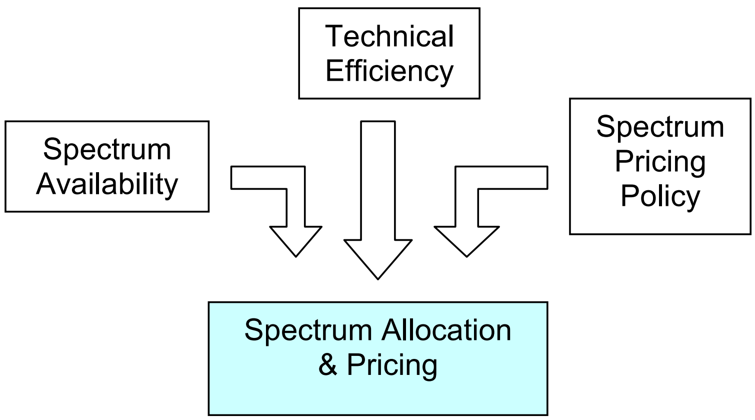
(ix) Should there be different pricing levels for shared spectrum versus spectrum that is allocated with protection? How should this be determined?

Chapter 5 Spectrum allocation

Spectrum Allocation and Pricing Policy

5.1 Introduction

In the previous two chapters, we have discussed the technical and pricing methodologies to evaluate and determine the efficiency of spectrum utilisation. Utilising the two aspects of efficiency, we now proceed to evolve a spectrum allocation and pricing policy, which takes spectrum requirement and availability into account.



5.2 Existing Procedure

The procedure for allocation of spectrum to CMSPs is given in Text Box 5.1

Text Box 5.1 Procedure for Spectrum allocation to CMSPs

- Service Providers could be considered for allocation beyond 2 X 6.2 MHz on achieving a subscriber base of 5 lakhs;
- Service Providers could be considered for allocation beyond 2 X 8 MHz on achieving a subscriber base of 10 lakhs;
- Service Providers could be considered for allocation beyond 2 X 10 MHz on achieving a subscriber base of 12 lakhs;

The procedure for spectrum allocation to BSOs is given in Text-Box 5.2

Text Box 5.2 Procedure for Spectrum allocation to BSOs upto 5 + 5 MHz

a) “On installing the Point of Presence (abbreviated as POPs) in a SHORT DISTANCE CHARGING AREA (SDCAs), a Basic Telephone Service LICENSEE shall be eligible to apply for allocation of WLL spectrum to the extent of 2.5 MHz + 2.5 MHz in the band of 824 - 844 MHz paired with 869 – 889 MHz for such SDCA.

b) After completion of first phase roll out obligations as stipulated in the guidelines for grant of license for basic services and effectively utilizing the allocated spectrum as indicated in para (a) above, a basic telephone service LICENSEE shall be eligible to apply for further allocation of WLL spectrum to the extent of 1.25 MHz+1.25 MHz in the band of 824-844 MHz paired with 869 – 889 MHz for such SDCAs in which POP has been established.

c) After completion of second phase roll out obligation as stipulated in the guidelines for grant of license for basic services and effectively utilizing the allocated spectrum, a Basic Telephone Service LICENSEE shall be eligible to apply for allocation and use of additional WLL spectrum as follows:-

(i) Additional spectrum to the extent of 1.25 MHz + 1.25 MHz in the band of 824-844 MHz paired with 869 –889 MHz for those SDCAs in which spectrum up to 3.75 MHz + 3.75 MHz has been allocated and effectively utilized.

(ii) Additional spectrum to the extent of 1.25 MHz + 1.25 MHz in the band of 824-844 MHz paired with 869 –889 MHz for those SDCAs in which spectrum up to 2.5 MHz + 2.5 MHz has been allocated and effectively utilized

Spectrum allocation procedure for Delhi

After completion of the stipulated first phase roll out obligations in terms of establishment of Points of Presence (POPs) in SHORT DISTANCE CHARGING AREA s (SDCAs), a Basic Telephone Service LICENSEE shall be eligible to apply for allocation of WLL spectrum to the extent of 2.5 MHz +2.5 MHz in the band of 824-844 MHz paired with 869 –889 MHz for those SDCAs. Any further allocation of WLL spectrum to the extent of 1.25 MHz +1.25 MHz in the band of 824-844 MHz paired with 869 –889 MHz shall be considered only after reaching the SUBSCRIBER base of 2 lakh. After reaching the SUBSCRIBER base of 3 lakh, additional allocation of WLL spectrum to the extent of 1.25 MHz +1.25 MHz in the band of 824-844 MHz paired with 869 –889 MHz shall be considered

In October 2003, TRAI provided recommendations on Unified Licensing. The first stage of migrating towards Unified Licensing i.e., Unified Access Licences which means that the Service Providers can offer both fixed and mobile services using their spectrum has been implemented by the Government and UASL licenses have been issued. This license has moved beyond technology neutral approach to service neutral approach under one license. Text Box 5.3 UASL license mentions the following criteria for spectrum allocation

Text Box 5.3 Spectrum allocation criteria in UASL license

"43.5 Subject to availability and as per Guidelines issued from time to time, the spectrum allocation and frequency bands will be as follows :

43.5.(i) For wireless operations in SUBSCRIBER access network, the frequencies shall be assigned by WPC wing of the Department of Telecom from the frequency bands earmarked in the applicable National Frequency Allocation Plan and in coordination with various users. Initially a cumulative maximum of upto 4.4 MHz + 4.4 MHz shall be allocated in the case of TDMA based systems @ 200 KHz per carrier or 30 KHz per carrier or a maximum of 2.5 MHz + 2.5 MHz shall be allocated in the case of CDMA based systems @ 1.25 MHz per carrier, on case by case basis subject to availability. While efforts would be made to make available larger chunks to the extent feasible, the frequencies assigned may not be contiguous and may not be the same in all cases or within the whole Service Area. For making available appropriate frequency spectrum for roll out of services under the licence, the type(s) of Systems to be deployed are to be indicated.

43.5(ii) Additional spectrum beyond the above stipulation may also be considered for allocation after ensuring optimal and efficient utilization of the already allocated spectrum taking into account all types of traffic and guidelines / criteria prescribed from time to time. However, spectrum not more than 5 + 5 MHz in respect of CDMA system or 6.2 + 6.2 MHz in respect of TDMA based system shall be allocated to any new Unified Access Services Licensee. The spectrum shall be allocated in 824-844 MHz paired with 869 - 889 MHz, 890 - 915 MHz paired with 935 - 960 MHz, 1710 – 1785 MHz paired with 1805 – 1880 MHz.

43.5(iii) In the event, a dedicated carrier for micro-cellular architecture based system is assigned in 1880 - 1900 MHz band, the spectrum not more than 3.75 + 3.75 MHz in respect of CDMA system or 4.4 + 4.4 MHz in respect of TDMA system shall be assigned to any new Unified Access Services Licensee.

43.5(iv) The Licensor has right to modify and / or amend the procedure of allocation of spectrum including quantum of spectrum at any point of time without assigning any reason."

5.3 Need for change

The present basis of allocating spectrum based on Subscriber base in a way reflects the Erlang density but assumes constant traffic pattern (i.e. mE / sub). In a dynamic and aggressively competitive sector like ours, substantial traffic increase occurs when tariffs fall, thereby, upsetting the basic assumption of constant traffic pattern.

On purely technical ground, it would be advisable to shift to an evaluation criterion based on Erlang density achieved over a pre-specified area for a given Quality of Service & bandwidth.

But as discussed earlier, this would ignore the economic aspects of spectrum efficiency, such as

a) Whether the cost incurred in achieving a particular efficiency is justified in the market under question? e.g. while normal business practice would justify large amount of micro-sites in Mumbai or Delhi, it may not be so for urban centres in Cat 'C' urban areas. Especially in a situation, where the pressure on spectrum is less in such cities.
b) Whether it would be more economical for service providers to take additional spectrum or to deploy additional infrastructure?

5.4 Approaches to spectrum allocation to Service Providers

Before we consider allocating spectrum to new service providers it is pertinent to ensure that the existing service providers both GSM and CDMA have adequate spectrum. For allocating spectrum to the existing service providers it is imperative to keep in mind the availability of equipment in the bands proposed to be allocated so as to take advantage of the economies of scale. It is also important to ensure that allocated spectrum is being efficiently utilised.

At the outset it is important to understand the legacy issues vis-à-vis the spectrum availability while evolving methodologies for spectrum allocation. The following considerations are noteworthy in this regard

a) Spectrum already allocated;
b) Procedure adopted in allocating that spectrum;
c) Contractual Obligation in the license conditions
d) Need to ensure level playing field

In practice, spectrum varying from 2 X 4.4 MHz to 2 X 10 MHz have been allocated to Service Providers using GSM technology, while 2X 2.5 MHz to 2 X 3.75 MHz has been allocated to Service Providers using CDMA technology. Also, the license conditions for Cellular Mobile Service Providers envisage allocation upto 2 X 6.2 MHz (commitment of 2 X 4.4 MHz), while that of Basic Service Operators / UASL (using CDMA) envisage allocations upto 2 X 5 MHz.

The present spectrum available or likely to be available in near future is 20 MHz in 800 MHz band, 23.4 MHz in 900 MHz band and upto 25 MHz (This varies from 10 MHz to 25 MHz depending upon service area) in 1800 MHz band.

Two possible approaches emerge for spectrum allocation.

These approaches are discussed with the assumption that 25 MHz is available in 1800 MHz band.

5.4.1 Approach I: Freeze the allocations at existing levels of spectrum provided except those where license conditions warrant further allocation but limit the maximum only upto the levels committed in the license. The present level of allocation to CMSPs (1^{st}, 2^{nd}, 3^{rd} & 4^{th}) / UASLs (using GSM technology) range from 2 X 4.4. MHz to 2 X 10 MHz, while to BSOs / UASLs (using CDMA) range from 2 X 2.5 MHz to 2X 3.75 MHz. The commitment in license of CMSPs / UASLs (using GSM) is of 2 X 4.4 MHz (with possibility of allocation upto 2 X 6.2 MHz) while that of UASL (using CDMA) is 2 X 5 MHz (4.4 MHz). The spectrum remaining thereafter is to be distributed and priced in a manner so as to ensure efficient utilisation and sustained growth. This approach heavily relies on market dynamics and makes spectrum available in a timely manner to those who need the most. The level playing field aspect has been taken care of in this approach by meeting the license commitments in respect of all players. In this approach the spectrum allocation beyond the commitment in license conditions is proposed to be based on the new methodology, which will encourage efficient utilisation of this scarce resource. One of the objectives of current consultation process is to evolve this new methodology. The question arises whether for new operators also the same approach i.e. allocation upto license commitment as per existing procedure and beyond this as per new methodology is followed or new methodology is followed right from the beginning. In either situation depending upon the pricing mechanism for new methodology, the new operators could be in advantageous or disadvantageous situation.

Impact of Approach I

Table 5.1 demonstrates that applying Approach 1 will leave 2x16 MHz of spectrum in Metros and 2 X 21.8 MHz in Non Metros to be allocated in 900 & 1800 MHz band and no spectrum in 800 MHz band. This spectrum allocation would be made in a technology neutral manner.

5.4.2 Approach II: Another approach could be to retain the existing methodology for allocation and pricing upto 2x10 MHz allocation or 2 to 3 years which ever is earlier and after that new methodologies would be applied.

Impact of Approach II

In Approach 2, 2 X 8.4 MHz in Metros and 2 X 16.4 MHz in Non Metros would be the balance spectrum to be allocated through a competitive mechanism for GSM while there would be shortfall of 2x20 MHz in metro and 2x10 MHz in non-metro for CDMA based operation. Comments of stakeholders is invited on the approach suggested.

5.5 Spectrum allocation issues for fourth cellular operators

While allocating spectrum upto the limits of 2 X 10 MHz there are issues relating to bands in which these allocations be made.

There has been demand from fourth cellular operators that some frequencies be made available to them from the 900 MHz band to help them in rural coverage. The License of 4^{th} CMSP stipulates that frequencies shall be assigned by WPC from the designated bands prescribed in NFAP 2000. However, it further commits allocation in 1800 MHz band. But this allocation procedure envisages allocation upto 2 X 6.2 MHz.

The issue for consultation is should we consider giving some spectrum in 900 MHz band to fourth CMSPs?

5.6 Spectrum availability

Table 5.1: Spectrum availability for existing Cellular operators

Metro						[All figures in MHz]
Scenario		**800 MHz**	**900 MHz**	**1800 MHz**	**1800 MHz (expected)**	**Total (800, 900, 1800 MHz)**
Approach I	**Total Spectrum available**	**20**	**23.4**	**10**	**15**[11]	**20 + 48.4**
	Spectrum Allocated / reserved as per license conditions	[5,5,5,5]	[8,8,6.2]	[6.2, 2]	[2]	20 + 32.4
	Surplus / shortfall after meeting license conditions	0	1.2	1.8	13	0 + 16
Approach II	**Total Spectrum available**	**20**	**23.4**	**10**	**15**	**20 + 48.4**
	Spectrum Allocation to meet 2 X 10 MHz for every Service Provider	[40]*	[8,8,7.4]	[8,2]	[2,2,2,0.6]	[40] + 40
	Surplus / shortfall after reserving 2 X 10 MHz for every Service Provider	- [20]	0	0	8.4	- [20] + 8.4
Non Metro		**800 MHz**	**900 MHz**	**1800 MHz**	**1800 MHz (expected)**	**Total**
Approach I	**Total Spectrum available**	**20**	**23.4**	**10**	**15**	**20 + 48.4**
	Spectrum Allocated / reserved as per license conditions	[5,5,5,5]	[8,6.2,6.2]	[6.2]		20 + 26.6
	Surplus / shortfall after meeting license conditions	0	3	3.8	15	0 + 21.8
Approach II	**Total Spectrum available**	**20**	**23.4**	**10**	**15**	**20 + 48.4**
	Spectrum Allocation to meet 2 X 8 MHz (7.5 for CDMA) for every Service Provider	[30]*	[8,8,7.4]	[8,0.6]	Nil	[30] + 32
	Surplus / shortfall after reserving 2 X 8 (7.5 for CDMA) MHz for every Service Provider	- [10]	0	1.4	15	- [10] + 16.4

** Present allocation is only 20 MHz. No allocation as on date in other bands. Therefore, entire 30 MHz, 40 MHz is shown in 800 MHz*

[11] Varies from 0 ~ 15 MHz from area to area

5.7 Allocation of available spectrum

The issue for discussion is the policy of additional spectrum allocation to existing players vis-à-vis new entrants. The country today has upto 8 networks / licenses capable of providing Cellular Mobile Services. The competition is aggressive and there has been a pressing demand from these operators for 800 MHz / 900 MHz / 1800 MHz spectrum. Today we have a spectrum scarce scenario, and it may take some time before additional spectrum is made available by re-farming.

To take care that scarcity of spectrum does not impede the growth of existing networks, it may be worthwhile to consider allocation / reservation of a certain amount of spectrum for existing operators and allocation to new entrants in these bands be considered only if surplus is available. This cap on fresh allocation can be maintained for a period of 2 years or a situation where a certain amount of spectrum per operator has been re-farmed. Also this cap would not be applicable for service areas where the number of networks is less than 8. However, the new entrants would be free to provide and acquire spectrum in other bands such as 450 MHz even within this time frame.

5.8 Procedure for allocation of spectrum to Service Providers

Allocation of additional spectrum / new spectrum is a function of technical efficiency achieved, One-off price payable, amount of spectrum available vis-à-vis demand.

(Allocation methodology) = F (Tech eff., Price, Scarcity (availability - demand))

5.8.1 Areas where there is no scarcity

In areas where there is no scarcity, there is no requirement for price to be a criteria for selection and the operators could be awarded spectrum provided they are utilising the existing spectrum efficiently (technical efficiency) and agree to pay the charges. Allocation of spectrum could be on the basis of the operator meeting the technical benchmarks (discussed in Chapter 3). The charges for the spectrum would be arrived at using a methodology that would have an inherent efficiency consideration (options discussed in Chapter 4). This would however, necessitate different technical evaluation benchmarks for different technologies and possibly areas.

5.8.2 Areas where there is scarcity

In areas, where demand exceeds supply there are two possible alternatives

a) Spectrum is equally distributed;
b) Spectrum is allocated through a competitive mechanism

5.8.2.1. Spectrum is equally distributed

This approach has the advantage of being fair but does not take into account any relative efficiencies of utilisation. Therefore, there would be no incentive to use the spectrum efficiently. Also, it may result in lesser allocation to operators who need it the most and in turn impede their growth. This methodology is more suited if all players grow at equal pace and have similar need for the resource. In event this approach is chosen, one way of dealing with this issue is to impose price-based mechanism that deter hoarding of spectrum together with spectrum cap. Also, the spectrum could be reserved but not allocated until technical efficiencies are met.

5.8.2.2 Spectrum is allocated through a competitive mechanism

For this purpose, the existing spectrum could be divided in usable blocks and then awarded through a competitive mechanism i.e., a beauty contest or an auction. A comparison of the two approaches is as follows:

5.8.2.2.1 Comparative selection (beauty contest)

Beauty contests. These involve evaluating each application against a number of pre-defined criteria, which may include operational commitments such as coverage, service quality or tariffs and in some cases may also include a financial element. Beauty contests were used to award the majority of GSM licences in Europe and around half of the 3rd Generation (3G) mobile licences. Key issues in the design of comparative selection procedures are the criteria used to choose the winning applicant, the precision and transparency of the criteria (i.e. publication in advance of the tender), the weighting given to different criteria and the transparency of reasons for the final decision.

The disadvantages of such an approach are the difficulties of specifying and evaluating the criteria and the potential for legal controversy, litigation and subsequent delays in the use of the radio spectrum. For example, the award of the third GSM licence in Ireland was delayed by over a year as a result of a legal challenge, even though this was ultimately rejected by the courts. If comparative selection processes are objective, transparent and non-discriminatory, then many of their disadvantages can in principle be overcome. In particular, if measurable criteria are used with an explicit weighting system then the “amounts” bid can be written into licences and the winning bidder should be the applicant that best fulfils society’s objectives (as defined by the REGULATOR or Government).

There have been some cases, where the criteria used to assess the original tenders have been relaxed by the REGULATOR at a later date without the imposition of penalties, or difficulties have arisen in measuring performance against criteria, where these cannot be measured in a quantifiable way. There are also cases where tenderers make commitments that they have no intention or possibility of realising as the markets develop. It is therefore important to ensure, prior to the submission of tenders, that all participants are aware of the penalties that will be imposed for not meeting the various criteria, and that criteria are specified in a way that facilitates objective measurement.

Typical criteria that can be measured through comparative selection include:

- Coverage (typically specified in terms of geographic or population coverage at a pre-defined field strength level)
- Number of base stations that will be deployed to provide this level of coverage
- Grade of service that will be delivered (e.g. percentage of blocked or dropped calls)
- Customer service (e.g. time taken to respond to complaints or repairs)

Also other issues can be taken into account such as:

- Financial viability of bidders
- Willingness to accept specific obligations such as:
  - Infrastructure sharing
  - Provision of national roaming to any new entrants
  - Providing network access to mobile virtual network operators (MVNOs)

Other criteria on which the regulator might be able to assess the bids:

- Viability of business plan
- Financial Commitments (e.g. a performance bond may be required to guarantee compliance with other criteria such as coverage – if the commitment is not met the amount of the performance bond must be paid to the REGULATOR)

Criteria which are difficult to predict over the timescales of the licence:

- Tariffs for the services to be provided
- Types of services that will be provided
- Revenues
- Costs
- Customer base

5.8.2.2.2 AUCTIONS

The use of auctions has become increasingly popular recently with many of the 3G mobile licences awarded through this process. Provided there is sufficient demand for access to the spectrum a well-designed auction is considered by some to be the “most likely method to allocate resources to those who can use them most valuably” and it will directly set the market value of the spectrum without it having to be estimated. It is certainly the case that properly designed auctions provide a transparent and somewhat less subjective approach to authorisation than beauty contest.

Auctions have advantages over other allocation methods in terms of transparency and objectivity and have been shown to be an effective method for the authorisation of spectrum use. There does however need to be sufficient viable bidders for a positive outcome and where there are insufficient bidders it is important that the reserve price set by the REGULATOR reflects as closely as possible the economic value of the spectrum. Auctions might also be used if the spectrum packages to be offered differ and would be valued differently by the bidders. For example, in the German 3G mobile auction the amount bid per MHz for paired spectrum was around 30 times higher than that bid for unpaired spectrum, reflecting the greater utility that paired spectrum was felt to have at the time.

Most auctions involve bidding fixed sums which may be payable either as a single lump sum on licence issue or in instalments over the duration of the licence. However, in some cases, notably Hong Kong, bids have taken the form of a “royalty” payment where the amount bid is expressed as a percentage of revenue over time.

The US Federal Communications Commission (FCC) was one of the first Regulators to use auctions.

One of the disadvantages often voiced against auctions is that the auction costs will be passed on to users through higher tariffs for their services. It is argued that this does not apply to auctions where the winning bidders will make a single up-front payment as when the services are marketed they will only charge the prices that maximise their profits and are necessary to compete with the other Service Providers. This argument is supported by the UK experience to date, where the recently launched 3G network offers lower basic call tariffs than established GSM operators, despite the very high payment made in the UK auction.

The situation may be different in the case of auctions with a royalty fee as the amount paid by the winning bidders will depend on their annual revenues and therefore will potentially have an impact on the prices that are charged to end users.

The key to the success of an auction is the design, which must address a number of concerns, and objectives, some of which are shown below:

- Avoidance of collusion between participants to avoid high prices.
- Encouraging a sufficient number of bidders, particularly new market entrants.
- Setting of appropriate reserve prices
- Packaging of spectrum licences (i.e. amount of spectrum associated with each licence that is offered)
- Potential market structure
- Default after winning the auction
- Type of auction .

Experience of both successful and unsuccessful auctions demonstrates that there is no single auction design that can be used universally and expert advice is required. However it is noted that in many countries they have used multiple round auctions with the differences including:

- whether there are national or regional spectrum packages,

- whether there is a maximum limit placed on the spectrum any one bidder can obtain or whether the spectrum package sizes are pre-defined,
- whether there are any time limitations on the duration of access to the spectrum,
- whether there is a minimum pre-qualification requirement and how this is specified, and
- the rules for the running of the auction.

Avoidance of collusion

In some auction designs it is possible for the participants, through their bids, to signal to others, when prices are still low, which blocks of spectrum or geographic regions they are interested in. This can then limit the competitiveness of the bidding and the prices paid may be significantly less than would have occurred without such collusion. Likelihood of collusion is less in a single stage format of auction.

Encouraging sufficient bidders

One of the concerns raised by auctions is the potential for anti-competitive effects because Dominant Service Providers or other large organisations can buy all the available spectrum in an area and therefore prevent the entry of new players into the market. There are a number of approaches that can be used to assist in avoiding such instances:

- Spectrum cap. This can be used to ensure that no single organisation can dominate the market by limiting the amount of spectrum that can be awarded to an individual Service Provider in a specific area. It is also possible to limit the number of areas in which an organisation could win access to spectrum.
- Restricting one or more spectrum blocks to new market entrants.
- The type of auction that is used. In ascending auctions it is likely that the dominant service providers will beat all other bids because there is considerably more commercial pressure on them to win and they are able to leverage their existing network infrastructure, reducing their rollout costs relative to a new entrant. They can outbid any new entrant in the final stages of the auction and any new entrant will seriously consider whether it is worth the cost of bidding. A different type of auction design, such as a sealed-bid may encourage the participation of new players.

Reserve prices

It is essential to set a proper reserve price to avoid winning bidders obtaining access to spectrum at well below market prices. Reserve prices can be determined, for example, by:

- Comparison with other countries which have auctioned the spectrum. Clearly the prices paid will need to be modified to take into account any differences in terms of demographics, economy and the state of the mobile market at that time both internationally and nationally.

- Developing business plans for the life time of the licences based on sensible assumptions which can be used to calculate potential revenue and profit and from this a reserve price can be derived.
- Current costs for access to spectrum based on Administrative Incentive Pricing;
- Pre auction bid as in the case of fourth CMSPs.

Generally part of the detailed auction design will involve determining the reserve price.

It is important that the auction rules should make it clear what would happen if the reserve is not met so that bidders are not encouraged to bid low in the hope that the spectrum is still there to be licensed. Low reserve prices encourage collusion because bidders see the potential of obtaining spectrum at well below the market price. An example of the impact of low reserve prices is the Swiss 3G auction where the reserve prices were set at a level which was twenty times lower than the Government's predicted value. Consequently the Swiss auction resulted in the lowest per-capita payment of any of the European 3G auctions.

Where the reserve price is not met this indicates that the value placed on the spectrum by potential operators is less than that foreseen by the regulator. An illustration of how much value is placed on proven technologies is provided by the prices paid for GSM licences in developing countries, as the following table indicates. Note that in some cases the amount paid as a percentage of national gross domestic product (GDP) for GSM licences is greater than the average amount paid (0.49) for each 3G mobile licence in the UK as a percentage of GDP.

Country	Amount paid for GSM licence (US$)	Amount per capita ($)	% of GDP
Algeria	737M	24.71	0.45
Egypt	516M	7.94	0.22
Morocco	1,100M	36.19	1.01
Turkey	2,600M	40.93	0.59
Tunisia	454M	49.11	0.75

Table 5.2: Value placed on GSM licences in developing countries

Potential market structure

One of the key considerations in choosing an auction design is the extent to which it will help to optimise the use of the available spectrum and promote competition in the market. For example, the offering of a large number of small spectrum packages can be seen as advantageous in terms of facilitating multiple new entrants. But if these can be aggregated to form much larger blocks, a small number of bidders may purchase all the available spectrum, possibly acquiring more spectrum than would be considered necessary for efficient spectrum use. Furthermore, Dominant operators may be incentivised to bid more than new entrants in order to ensure that such new entrants are kept out of the market, thus reducing competition and pressure on the dominant operators to reduce prices or improve service.

It may therefore be preferable to predetermine the number of winning bidders by pre-packaging the available spectrum or using a spectrum cap, and to encourage new entrants by either making the number of spectrum packages exceed the number of incumbents or reserving one or more licences for new entrants. This approach has to take into account the necessary spectrum for a new entrant to compete effectively with existing players, or provide other means of levelling the playing field.

If the number of spectrum packages is the same as the existing number of operators then it is unlikely that any new players will bid. In the Netherlands this was the case and the only new entrant that entered the auction withdrew early and the prices paid by the winning bidders were significantly less, per-capita, than in the UK. However this has to be considered together with the requirement to have sufficient spectrum for existing licences, which has been discussed earlier.

Default after winning

It is important that penalties are imposed to avoid winners defaulting after the end of the auction (i.e. being unable or unwilling to pay the amount bid by the specific deadline). If the penalties are small it can encourage the entry of less well-financed bidders who are taking an opportunistic approach in the hope of obtaining the necessary financial backing once they have been allocated spectrum. This can lead to spectrum not being used and additional costs to the Regulator in re-licensing the "returned" spectrum. Pre-auction qualification requirements can also address this problem by ensuring the bidders are financially viable.

5.9 Blocks in which spectrum to be allocated

One of the issues in spectrum allocation pertain to the amount in which addition spectrum be made available to 2nd generation and 3rd generation mobile operators and the amount that should be made available to new entrants for starting service.

One option is that spectrum upto the level decided in preceding section be reserved for existing operators and future allocations be done in chunks of 2 X 5 or 2 X 10 MHz so as to enable IMT 2000 services in 1800 MHz as well as IMT 2000 bands.

The existing Service Providers be given an opportunity to increase their spectrum availability wherever available in chunks of say 2 X 2.5 MHz provided they meet the minimum technical requirements.

Alternatively, allocation of spectrum can be in blocks of 2 X 5 or 2 X 10 MHz after the minimum reserved for existing operators is achieved so as to enable IMT 2000 services. This would be reserved only for a period of say 2 years.

Thereafter, the government shall be free to allocate it to other users. The users who have not reached the levels at a) above can also acquire IMT 2000 spectrum but in that case they would not be permitted to acquire the amounts reserved if the levels decided earlier exceeded after IMT 2000 spectrum acquisition.

5.10 Spectrum Cap

In order to prevent one Service Provider from hoarding spectrum, it would be necessary to impose a spectrum cap for allocation. Imposition of a spectrum cap will:

- ensure that no single organisation can dominate the market by limiting the amount of spectrum that can be awarded to an individual Service Provider in a specific area.
- ensure that no Service Provider can obtain an unfair advantage from having entered the market first, and
- provide clarity to the Service Providers so they can plan the roll-out of their networks.

The main issue for consideration is what should be this limit if such an approach is followed, keeping in mind the existing and new services.

However, the allocation policy to reach this cap could be competitive or non competitive based on the allocation method discussed earlier. This cap could be relevant only to allocations in the 800 MHz, 900 MHz-1800 MHz or IMT-2000 band. The issues pertaining to spectrum cap in case of Mergers & Acquisition is discussed in the next chapter.

5.11 Issues for spectrum allocation

(i) How much minimum spectrum (refer approach (I) and (II)) in section 5.4) should each existing operator be provided? Give the basis for your comments.

(ii) At what stage the amount of spectrum allocation to new entrants be considered in the 800 MHz / 900 MHz / 1800 MHz frequency bands?

(iii) Should spectrum be allocated in a service and technology neutral manner?

(iv) What should be the amount of cap on the spectrum assigned to each operator?

(v) What procedure for spectrum allocation be adopted for areas where there is no scarcity and in areas where there is scarcity?

(vi) Which competitive spectrum allocation procedure (Auction / Beauty Contest) be adopted in cases where there are scarcity?

(vii) Should we consider giving some spectrum in 900 MHz band to fourth CMSPs?

(viii) Comments of stakeholders are invited on the minimum blocks such as 2 X 2.5 MHz / 2 X 5 MHz of additional spectrum to be allocated to existing service providers in situations where IMT 2000 band is opened as well as in situation where it is not opened. Additionally, comments are also invited on the minimum allocation to new entrants.

(ix) In the event that IMT 2000 spectrum is treated as continuum to 2G, should existing operators using spectrum below the specified benchmark be treated as those eligible for IMT 2000 spectrum?

Chapter 6 Re-farming, Spectrum trading, M&A and Surrender

6.1 Re-farming of spectrum

Spectrum redeployment or refarming of frequency bands is a process that will need to be employed more and more often as existing and new applications require more bandwidth (spectrum) and the subscriber number grows. The growing demand for spectrum refarming has led to the development within the ITU of a comprehensive Recommendation, ITU-R SM.1603, “Spectrum redeployment as a method of national spectrum management”.

ITU-R SM.1603 states “*Spectrum redeployment (spectrum refarming) is a combination of administrative, financial and technical measures aimed at removing users or equipment of the existing frequency assignments either completely or partially from a particular frequency band. The frequency band may then be allocated to the same or different service(s). These measures may be implemented in short, medium or long time-scale*s.”

In this Recommendation a number of scenarios for redeployment of frequency spectrum are proposed including migration:

- At the expiry of the current licence
- At the end of the equipment’s lifetime
- To other frequency bands within the tuning range of the equipment currently using the spectrum (e.g. equipment used by the military) before either of the above
- Into other frequency bands by:
  - Immediate licence cancellation
  - Prior notice that the licence will not be renewed beyond some future date
  - Increasing the spectrum fees applied to the current spectrum relative to alternative bands
- To new technologies that are more spectrally efficient (e.g. replacement of analogue technology with digital, or 2G technology with 3G)

Apart from the first two examples all the other options may require regulatory intervention to implement the change successfully.

The table below identifies some of the advantages and disadvantages of the different options:

Table 6.1: Advantages and Disadvantages of different redeployment (re-farming) options

Method	Advantages	Disadvantages
Migration by expiry of current licence and end of lifetime of equipment	No requirement for regulatory intervention	Problem as existing licences are awarded for 20 years.
Forced migration to frequency bands within tuning range of equipment used	Enables existing equipment to remain in use, minimising cost and disruption to existing user. This has been a feasible solution for military services due to the wide tuning ranges.	It may not be possible to migrate all the services to spare spectrum within the tuning range. Spectrum within the tuning range may not be the ideal long term choice as it may subsequently be required to support ongoing growth in demand for new services.
Forced migration into other frequency bands	May provide a more satisfactory long term solution than migration within tuning ranges	This can be technically and economically difficult to implement. In some cases there will be no suitable alternative spectrum and in others it will require new costly infrastructure. It may also require a longer transition period that does not fit with the need to allow early release of spectrum.
Forced use of more spectrally efficient equipment	This could release limited spectrum by using equipment that is more spectrally efficient in part of the available band.	Insufficient spectrum may be released. May lead to a temporary increase in the spectrum required by existing operators if a transition period is required (i.e. both technologies need to operate simultaneously)

There is another issue that needs to be considered, which is the cost of redeployment. The main options are:

- The incumbent operator or user pays for the redeployment of his own system
- The new entrant pays
- Payment from a centrally managed redeployment fund
- A combination of the above

Table 6.3 Advantages and Disadvantages of various methods of redeployment (re-farming)

Method of paying for redeployment	Advantages	Disadvantages
Existing operator or user pays for redeployment of his own system	No additional costs for new entrants. Administratively straightforward.	Unless there are advantages for the existing user associated with the migration it is likely that it would take a long time and be subject to extra delays. Some kind of compensation, direct or indirect would be needed to induce the operator to move. An exception is where migration is driven by external market or technology developments, e.g. the migration from analogue to 2G digital cellular[12].
New entrant pays for migration	Spectrum is freed when needed for the new service. Only spectrum needed for new entrant is freed. Cost of spectrum is not directly linked to the market value of the spectrum but is agreed between the users on a cost recovery basis. Has proved successful in several countries where a quick migration was necessary.	Costs may be prohibitive making it difficult for the new player to compete equally with other Service Providers. May require regulatory intervention to ensure that payments are on a genuine cost recovery basis.
Redeployment fund established	Provides a means of funding redeployment from a central source	Risk that the fund is not sufficiently large to pay for redeployment. Issues about who will manage the fund, who should contribute, what the contributions should be and how to establish which migrations should be supported from the fund.

[12] For example, in the UK the Government determined that analogue cellular services should cease by no later than 2005; in practice the capacity and cost advantages associated with GSM led to both analogue networks being closed five years before this date.

The timescales for refarming will depend on:

- the type of the existing allocations (e.g. civil or military),
- the economic benefits of refarming the spectrum (these can be to the existing user, any potential new entrant and to the national economy),
- the user density within the band (i.e. volume and value of equipment that needs to be replaced and/or retuned) , and
- the financial implications for the existing user and any potential new entrant.

6.1.1 Surrender of spectrum

Another issue that has arisen relates to surrender of existing spectrum by Service Providers. As spectrum is a scarce resource, the policy issue under consideration is whether there should be an incentive in the form of refunds for voluntary surrender of spectrum.

There are two aspects

a) One time entry fees paid
b) Annual spectrum charges

It is easier to deal with the second issue, as the annual spectrum charges could be made applicable based on the amount of spectrum held by the operator in that year. However, whether any refund is due in respect of the one-time entry fees is a matter of discussion. The pros and cons are as follows:

Point in favour of refund

It would provide the operator with an incentive to return the spectrum, thereby, reducing the pressure on spectrum;

Points against refund

a) Refund of spectrum is an operator's internal decision and so no compensation is due;
b) While the operator was given the spectrum, his competitors were denied the same and accordingly a refund would mean a revenue loss to the Government and denial of services to users.
c) It is very difficult to bifurcate the amount of entry fees paid at that time between spectrum and service.
d) Also, the operator has already used the spectrum for a number of years;

6.1.1.1 Options for determining the amount of refund

If a surrender policy were built then it would be necessary to decide on the methodology to be used for estimating the amount to be refunded. In case it is decided on surrender a refund will be given then the following options exist

a) Refund the portion of amount on pro-rata basis based on the remaining license period.
b) Estimate the amount of license fees lost by not providing it to the best user during the years, when the spectrum remained unutilised using ARPU & approx. subscribers. To this an interest payment can be added and the amount emerging can be subtracted from the entry fees paid.

However, the difficulty with applying option b) to existing users is to estimate the amount of entry fees out of the total paid that was causal to spectrum.

An important point arises in connection with the refund arising as a result of Government Policy on Unified License.

In October 2003, the government provided the Service Providers with an option to move to Unified Access License, which would make the Service Providers capable of providing Basic as well as Cellular services. If a company has both these licenses in a service area (both have spectrum), and if it choses to move one licensee to UASL, the other license becomes redundant. It can be argued that this case has resulted in premature redundancy of one's license as a result of Government's policy.

6.2 Secondary trading

Another option to take care of frequency availability is to permit secondary trading. It is a mechanism where existing Service Providers can:

- **Trade part or all of their allocation to others.** This might be a simple change of ownership with no change of use or could involve part or all of the spectrum being used for a different service. The advantage of this approach is it provides an incentive to Service Providers to release un-used spectrum as it has a financial value, which can be realised. Trading can potentially provide a means of allowing new services access to spectrum more quickly.

- **Lease spectrum to others on a temporary or longer term basis**. This allows other users the benefits of access to spectrum, which would not automatically occur in a more rigid regime. Spectrum holders as well as new entrants are benefited with this approach. The new entrants could negotiate for leasing of the spectrum without spectrum holder relinquishing the spectrum.

The introduction of secondary trading needs to be under-pinned by an effective framework that can:

- Prevent interference
- Maintain competition / deal with anti-competitive behaviour by Service Providers
- Ensure access to spectrum for essential services such as public safety, for non-continuous use such as for programme making and

special events and can allow the development of new technologies through access to test and development spectrum.

It is particularly important to define clearly the nature of the rights and responsibilities associated with use of the spectrum being traded, to avoid potential disputes where spectrum is used outside the terms of the original right of use. Opening of secondary trading requires a lot of technical and legal preparedness and in any case is not linked with this exercise. Perhaps it may not be advisable to consider secondary trading at this stage.

6.3 Mergers and Acquisitions

The future development of cellular markets is likely to witness consolidation between the Service Providers. In the past 2~3 years, we have witnessed a number of consolidations in the industry.

It is important to ensure that if two Service Providers merge they do not gain access to more spectrum than they require and that the spectrum be used efficiently. The use of an appropriate pricing mechanism and a cap on the maximum amount of spectrum that can be retained would prevent this happening.

The present guideline of M&A limit the maximum spectrum that the merged entity could hold to 2 x 15 MHz per Service Provider per service area for Metros and Category 'A' Circles and 2 x 12.4 MHz per Service Provider per service area in Category 'B' and Category 'C' Circles. This cap on spectrum is independent of the cap envisaged in the spectrum allocation procedure.

Once the spectrum cap is decided, there would need to be a fixed time period during which the new combined Service Provider is required to reduce their total spectrum to this amount.

6.4 Issues for consultation are

Re-farming of spectrum

(i) What approach should be adopted to expedite the re-farming of 1800 MHz and IMT-2000 spectrum from existing users?
(ii) What approach should be adopted for re-farming of spectrum after expiry of license?

Surrender of spectrum

(iii) Should there be any refund for spectrum surrender in principle?
(iv) Should there be refund for spectrum surrender consequent to Unified Access license policy? If yes, what should be the basis?
(v) How should the amount of refund be estimated?

Spectrum trading

(vi) Should we open up the spectrum market for spectrum trading? If yes, what should be the time frame for doing so?

(vii) What are the pre-requisites to adopting spectrum trading?

Mergers & Acquisitions

(viii) Whether we should specify a cap higher than 2 X 15 MHz for Metros and Category “A” service area and 2 X 12.4 MHz for Category ”B” and “C” service area in case of M&As or should it be retained?

(ix) In case, IMT 2000 is considered as a continuum of 2G Services, is there a need to have a cap higher than that without IMT 2000 services? Should there be individual caps on 2G and 3G spectrum or a combined cap?

(x) In case of M&As where the merged entity gets spectrum exceeding the spectrum cap, what should be the time frame in which the service provider be required to surrender the additional spectrum?

Chapter 7 Issues for consultation

Chapter 2: Current spectrum availability and requirement

(i) Should the 450 MHz or any other band be utilised particularly to meet the spectrum requirement of service providers using CDMA technology?

(ii) The consultation paper has discussed ITU method for assessment of spectrum requirement. Based upon the methodology submit your requirement of spectrum for next 5 years. While calculating the required spectrum, please give various assumptions and its basis.

(iii) Whether IMT 2000 band should be expanded to cover whole or part of 1710 – 1785 MHz band paired with 1805 – 1880 MHz?

(iv) Should IMT 2000 spectrum be considered as extension of 2G mobile services and be treated in the same manner as 2G or should it be considered separately and provided to operators only for providing IMT 2000 services?

(v) Reorganisation of spot frequencies allotted to various service providers so as to ensure the availability of contiguous frequency band is desirable feature for efficient utilisation of spectrum. Please suggest the ways and means to achieve it.

(vi) Whether the band 1880 – 1900 MHz be made technology neutral for all BSOs / CMSPs / UASLs and be made available with the pair 1970 – 1990 MHz or should it be kept technology neutral but reserved for TDD operations only.

Chapter 3 Technical efficiency of spectrum utilisation

(vii) Please offer your comments on the methodology outlined in this Chapter for determining the efficient utilisation of spectrum. Also provide your comments, if any, on the assumptions made.

(viii) Please provide your perception of the likely use of data services on cellular mobile systems and its likely impact on the required spectrum including the timeframe when such requirements would develop?

Chapter 4: Spectrum Pricing

(ix) Is there a necessity to change from the existing revenue share method for determining the annual spectrum charge?

(x) If yes, what methodology should be used to determine spectrum pricing for existing and new operators? (Please refer table in Section 4.8)

(xi) In the event AIP is adopted as a means to price spectrum, would it be fair to choose GSM as a reference for determining the spectrum price?

(xii) Please provide your comments on the assumptions used in A.I.P.

(xiii) In case Auction methodology is used for pricing the spectrum, please give suggestions to ensure that spectrum pricing does not become very high and spectrum is available to those who need it.

(xiv) Should the new pricing methodology, if adopted, be applicable for the entire spectrum or should we continue with revenue share mechanism till 10 + 10 MHz, and apply the new method only for spectrum beyond this?

(xv) What incentives be introduced through pricing to encourage rural coverage and / or using alternative frequency bands like 450 MHz?

(xvi) Does M X C X W formulae for fixed wireless spectrum pricing need a revision? If so, suggest the values for M, C, W?

(xvii) Should there be different pricing levels for shared spectrum versus spectrum that is allocated with protection? How should this be determined?

Chapter 5 Spectrum allocation

(xviii) How much minimum spectrum (refer approach (I) and (II)) in section 5.4) should each existing operator be provided? Give the basis for your comments.

(xix) At what stage the amount of spectrum allocation to new entrants be considered in the 800 MHz / 900 MHz / 1800 MHz frequency bands?

(xx) Should spectrum be allocated in a service and technology neutral manner?

(xxi) What should be the amount of cap on the spectrum assigned to each operator?

(xxii) What procedure for spectrum allocation be adopted for areas where there is no scarcity and in areas where there is scarcity?

(xxiii) Which competitive spectrum allocation procedure (Auction / Beauty Contest) be adopted in cases where there are scarcity?

(xxiv) Should we consider giving some spectrum in 900 MHz band to fourth CMSPs?

(xxv) Comments of stakeholders are invited on the minimum blocks such as 2 X 2.5 MHz / 2 X 5 MHz of additional spectrum to be allocated to existing service providers in situations where IMT 2000 band is opened as well as in situation where it is not opened. Additionally, comments are also invited on the minimum allocation to new entrants.

(xxvi) In the event that IMT 2000 spectrum is treated as continuum to 2G, should existing operators using spectrum below the specified benchmark be treated as those eligible for IMT 2000 spectrum?

Chapter 6 Re-farming, Spectrum trading, M&A and Surrender

Re-farming of spectrum

(xxvii) What approach should be adopted to expedite the re-farming of 1800 MHz and IMT-2000 spectrum from existing users?

(xxviii) What approach should be adopted for re-farming of spectrum after expiry of license?

Surrender of spectrum

(xxix) Should there be any refund for spectrum surrender in principle?

(xxx) Should there be refund for spectrum surrender consequent to Unified Access license policy? If yes, what should be the basis?

(xxxi) How should the amount of refund be estimated?

Spectrum trading

(xxxii) Should we open up the spectrum market for spectrum trading? If yes, what should be the time frame for doing so?

(xxxiii) What are the pre-requisites to adopting spectrum trading?

Mergers & Acquisitions

(xxxiv) Whether we should specify a cap higher than 2 X 15 MHz for Metros and Category “A” service area and 2 X 12.4 MHz for Category ”B” and “C” service area in case of M&As or should it be retained?

(xxxv) In case, IMT 2000 is considered as a continuum of 2G Services, is there a need to have a cap higher than that without IMT 2000 services? Should there be individual caps on 2G and 3G spectrum or a combined cap?

(xxxvi) In case of M&As where the merged entity gets spectrum exceeding the spectrum cap, what should be the time frame in which the service provider be required to surrender the additional spectrum?

Annexure A

Bands of operation for CDMA and GSM based cellular mobile services

A.1 Spectrum allocation to CDMA networks

Country	Operator	Amount of Spectrum	Band of operation
Brazil	TeleSP celular	12.5 + 12.5 MHz	800 MHz
China	China Unicom	10 + 10 MHz	800 MHz
Japan	KDDI	15 + 15 MHz	800 MHz
Korea	KTF	20 + 20 MHz	1700 MHz
Korea	S K Telecom	25 + 25 MHz	1700 MHz
Mexico	LUSAcell	15 + 15 MHz	800 / 1900 MHz
Mexico	Unifone	15 + 15 MHz	800 / 1900 MHz
USA	Sprint PCS	15 + 15 MHz	1900 MHz
USA	Verizon wireless	17.5 + 17.5 MHz	800 / 1900 MHz

A.2 Spectrum allocation to GSM networks

Allocation of Spectrum in Asia Pacific Countries

Sl. No.	Name of the Country	No. of GSM Operators	Total Frequency made available for GSM Service**	Average GSM Frequency per Operator
1	China	2	2x45.0 MHz	2x22.5 MHz
2	Australia	4	2x30.0 MHz	2x7.5 MHz
3	Hong Kong	6	2x84.1 MHz	2x14.0 MHz
4	Indonesia	3	2x25.0 MHz	2x8.3 MHz
5	Malaysia	5	2x90.0 MHz	2x18 MHz
6	Philippines	3	2x25.0 MHz	2x8.3 MHz
7	Singapore	3	2x37.8 MHz	2x12.6 MHz
8	Taiwan	6	2x75.2 MHz	2x12.5 MHz
9	Thailand	3	2x57.1 MHz	2x19.0 MHz

Average per country : 2 x 52.13 MHz

Average per GSM Operator : 2 x 13.4 MHz

Allocation of Spectrum in EU Countries

Sl. No.	Name of the Country	No. of GSM Operators	Total Frequency made available for GSM Service**	Average GSM Frequency per Operator
1	Austria	4	2x59.6 MHz	2x14.9MHz
2	Belgium	3	2x81.0MHz	2x27.0MHz
3	Czech Republic	3	2x49.8MHz	2x16.6MHz
4	Denmark	4	2x109.6MHz	2x27.4MHz
5	Estonia	3	2x51.6MHz	2x17.2MHz
6	Finland	6	2x70.8MHz	2x11.8MHz
7	France	3	2x74.4MHz	2x24.8MHz
8	Germany	4	2x80.0MHz	2x20.0MHz
9	Greece	3	2x45.0MHz	2x15.0MHz
10	Hungry	3	2x68.6MHz	2x22.9MHz
11	Iceland	6	2x69.6MHz	2x11.6MHz
12	Ireland	3	2x62.4MHz	2x20.8MHz
13	Italy	4	2x71.6MHz	2x17.9MHz
14	Lithuania	3	2x43.4MHz	2x14.5MHz
15	Netherlands	5	2x105.8MHz	2x21.2MHz
16	Poland	3	2x48.8MHz	2x16.3MHz
17	Portugal	3	2x41.8MHz	2x13.9MHz
18	Romania	3	2x32.0MHz	2x10.7MHz
19	Spain	3	2x64.2MHz	2x21.4MHz
20	Sweden	3	2.75.0MHz	2x25.0MHz
21	Switzerland	3	2x79.6MHz	2x26.5MHz
22	United Kingdom	4	2x105MHz	2x26.3MHz

Average per Country 2x67.71

Average per GSM Operator 2x18.8 MHz

Annexure B

RECOMMENDATION ITU-R M.1390

METHODOLOGY FOR THE CALCULATION OF IMT-2000 TERRESTRIAL SPECTRUM REQUIREMENTS

(1999)

Introduction

I
MT-2000 are third generation mobile systems which are scheduled to start service around the year 2000 subject to market considerations. They will provide access, by means of one or more radio links, to a wide range of telecommunication services supported by the fixed telecommunication networks (e.g. public-switched telephone network (PSTN)/integrated services digital network (ISDN)), and to other services which are specific to mobile users.

A range of mobile terminal types is encompassed, linking to terrestrial and/or satellite-based networks, and the terminals may be designed for mobile or fixed use.

Key features of IMT-2000 are:

– high degree of commonality of design worldwide;
– compatibility of services within IMT-2000 and with the fixed networks;
– high quality;
– use of a small pocket-terminal with worldwide roaming capability;
– capability for multimedia applications and a wide range of services.

IMT-2000 are defined by a set of interdependent ITU Recommendations of which this one is a member.

Spectrum requirements for the terrestrial component of IMT-2000 were estimated in Report ITU-R M.1153 prior to WARC-92. Speech services were considered to be the major source of traffic at the time. As technological advancements provide additional capabilities in telecommunications users will demand more from wireless services. Future wireless services must support, not only speech but also a rich range of new services that will serve a wide range of applications. Services such as multimedia, Internet access, imaging and video conferencing will be needed in third generation wireless systems. In response to these new applications, IMT-2000 will support high rate data services. The provision of new services described in Recommendation ITU-R M.816 (Framework for services supported by IMT-2000) has an impact on the spectrum requirements for IMT-2000 systems.

There is a need to develop a new methodology for determination of spectrum requirements that can accommodate not only the new services of IMT-2000 but also the new radio transmission technologies being developed.

Scope

This Recommendation contains a methodology for the calculation of terrestrial spectrum requirement estimates for IMT-2000. This methodology could also be used for other public land mobile radio systems. It provides a systematic approach that incorporates geographic influences, market and traffic impacts, technical and system aspects and consolidation of spectrum requirement results. The methodology is applicable to both circuit switched and packet switch-based radio transmission technologies and can accommodate services that are characterized by asymmetrical traffic flows[1)].

The ITU Radiocommunication Assembly,

Considering

a) that the Radio Regulations (RR) identify the bands 1 885-2 025 MHz and 2 110-2 200 MHz as intended for use on a worldwide basis by administrations wishing to implement IMT-2000, as indicated in RR S5.388, and Resolution 212 (Rev.WRC-97);

b) that the initial implementations of IMT-2000 are expected to commence around the year 2000 subject to market considerations;

c) that the bands identified in *considering* a) are used differently in various countries;

d) that the traffic and service mix carried by IMT-2000 systems may vary from country to country, and also within countries. In some parts of the world additional spectrum may be required, whilst in other parts of the world frequency bands identified by *considering* a) could be adequate to meet IMT-2000 services present and future demands;

e) the need to support the operation of IMT-2000 terminals in different regulatory environments;

f) that the various radio access technologies that may be appropriate for IMT-2000 may have different channel bandwidth requirements, and hence varying impact on the basic frequency usage possibilities;

g) that traffic handled by mobile systems as well as the number and diversity of services will continue to grow;

h) that future systems may include the use of a range of cell types from indoor cells to satellite cells, which must be able to co-exist in a given location;

j) that IMT-2000 will offer higher data rate services than earlier systems in order to meet increasing customer demands, and this could create a demand for additional spectrum beyond that earlier estimated;

k) that efficiency of spectrum use requires consideration of the balances between IMT-2000 system costs and bandwidth needed;

1) An example of the application of the methodology is provided in Apendix 1

l) that the methodology in Annex 1 is considered flexible enough to accommodate either a global view or the unique requirements of regional markets relative to terrestrial spectrum needs,

recommends

1 that the methodology for the calculation of terrestrial IMT-2000 spectrum requirement estimates as specified in Annex 1 should be used by administrations as the basis for performing calculations involving estimates of future IMT-2000 terrestrial spectrum needs;

2 that the methodology in Annex 1 could also be considered for the calculation of terrestrial spectrum estimates for other public land mobile radio systems, and its use is highly encouraged.

ANNEX 1

IMT-2000 terrestrial spectrum requirement methodology

Terrestrial methodology overview

A methodology for development of a terrestrial spectrum requirement is presented below. This methodology enables the calculation of spectrum estimates to support mobile communication services of today and the future. The equation for this estimate is provided in equation 1.

This methodology is consistent with the global IMT-2000 vision and is also consistent with the services as presented in Recommendation ITU-R M.816: “Framework for services supported by IMT-2000”. The methodology is flexible enough to accommodate either a global view of spectrum needed or the unique requirements of regional markets.

The basic theme of this methodology is to determine the individual spectrum requirements for all representative combinations of specific environments and services (F_{es}) in a given geographical area, and to combine the set of individual spectrum requirements F_{es} together into a total terrestrial component spectrum requirement estimate, $F_{Terrestrial}$ by employing appropriate weighting factors (α_{es}) to the summation. The factor (α_{es}) takes into account the impact of concurrent services in a given geographical area. An additional adjustment factor (□) is available to apply to the composite summation to accommodate impacts such as multiple operators, spectrum sharing, and the like.

The estimation of a spectrum requirement for many years into the future is not an exact calculation. In particular, the methodology provided in this document is not intended to include the second or third order effects, but rather the calculations capture the significant first order influences which are the primary factors for terrestrial spectrum needed.

The spectrum required ($F_{Terrestrial}$) in MHz is:

$$F_{Terrestrial} = \beta \sum \alpha_{es} F_{es} = \beta \sum \alpha_{es} T_{es}/S_{es} \qquad (1)$$

where “e” and “s” are subscripts denoting dependency on environments and services respectively.

Therefore, $F_{Terrestrial}$ is the total required spectrum as a weighted summation of co-existing individual F_{es} in the same geographical area for all environments “e” and services “s” considered relevant, adjusted for influences such as spectrum sharing, multiple operators,

where:

$F_{Terrestrial}$ = Terrestrial Component Spectrum Requirement Units: MHz

T_{es} = Traffic/$Cell_{es}$ Units: Mbit/s/cell

S_{es} = System capability Units: Mbit/s/MHz/cell

α_{es} = Weighting factor Units: dimensionless

β = Adjustment factor Units: dimensionless

Equation 1 addresses both circuit and packet-switched services and includes consideration for traffic asymmetry in the uplink and downlink directions. Each of the factors of equation 1 will be defined further in the following subsections.

The calculations, parameters, and definition of inputs within the methodology are divided into four categories and serve to group similar aspects of the methodology into sub-units:

A geographic considerations,

B market and traffic considerations,

C technical and system consideration,

D spectrum results considerations.

An example is included in Appendix 1 that shows how the methodology is applied. This example is based on a representative subset of environments and services. The example is calculated with parameter values estimated from market research on public land mobile communications services, including IMT-2000, and with technical parameter values estimated from IMT-2000 radio transmission technologies, for the year 2010.

The results shown in this example should not be considered as providing an answer to the question of future spectrum requirements for public land mobile communications services, including IMT-2000, as all environments and services that must be considered for completeness have not been included in the example. Nonetheless, the example includes all environments and services required to sufficiently exercise all aspects of the methodology.

Methodology flowchart

The following material presents the methodology in "flowchart" format with a sequential listing of the steps divided among the four sub-categories. Subsequent sections of this document provide detailed information and description of the terms, parameters, calculations performed[2)].

A Geographic considerations

A1 Select "e"

"e" - environment type: selects density and mobility.

These environments are defined by a combination of a density attribute and a mobility attribute considered jointly, and are shown in the following matrix:

Mobility	In-building	Pedestrian	Vehicular
Density			
Dense Urban (CBD)			
Urban			
Suburban			
Rural			

For example, "dense urban, in-building" could be a value of "e".

A2 Select direction of calculation

Uplink (from the mobile station to the base station) or downlink (from the base station to the mobile station).

A3 Establish representative cell area and geometry Units: metres

Diameter if circular omnidirectional cell geometry; radius of vertex if sectored hexagonal cell geometry.

A4 Calculate Cell_Area A_e Units: km^2

Cell_Area$_e$.

B Market and traffic considerations

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2) The mathematical convention of describing a complex function as a function name and a list of input parameters is used in several places in this document. It is demonstrated as follows:
Function {parameter1, parameter2, …, parameterN}.

B1 Select "s"

s – service type: selects service type and hence $Net\_User\_Bit\_Rate_s$ (kbit/s)

B2 Establish $Population\_Density_e$ Units: potential users/km^2

B3 Establish $penetration\_rate_{es}$ Units: %

B4 Calculate $users/cell_{es}$ Units: users

$Users/Cell_{e\ s}$ □ $Population\_Density_e Penetration\_Rate_{es} Cell\_Area_e$.

B5 Establish traffic parameters

$Busy\_Hour\_Call\_Attempts_{es}$	**Units: calls in busy hour**
$Effective\_Call\_Duration_{es}$	**Units: seconds**
$Activity\_Factor_{es}$	**Units: dimensionless**

B6 Calculate $Traffic/User_{es}$ Units: call-seconds

$Traffic/User_{es}$ □ $Busy\_Hour\_Call\_Attempts_{es} Call\_Duration_{es}\ Activity\_Factor_{es}$.

(NOTE – May be expressed as Erlangs, where an Erlang □ call-seconds/3 600.)

B7 Calculate $Offered\_Traffic/Cell_{es}$ Units: call-seconds/cell

$Offered\_Traffic/Cell_{es}$ □ $Traffic/User_{es} Users/Cell_{es}$.

(NOTE – May be expressed as Erlangs, where an Erlang □ call-seconds/3 600.)

B8 Establish $Quality\_of\_Service\_Function_{es}$ Parameters Units: varied

$Group\_Size_{es}$;

Blocking $Criteria_s$ {Formula and Grade of Service for circuit switched; Formula and Delay fo switched}.

C Technical and system considerations

C1 Calculate number of $Service\_Channels/Cell_{es}$ required to carry $Offered\_Traffic/Cell_{es}$ Units: none

$Service\_Channels/Cell_{es}$ □

(Quality_of_Service_Function$_{s}$
{Offered_Traffic/Cell$_{es}$*Group_Size$_{es}$;
Blocking Criteria$_{s}$})/Group_Size$_{es}$

C2 Determine Service_Channel_Bit_Rate$_{es}$ needed to carry Net_User_Bit_Rate$_{s}$ **Units: kbit/s**

C3 Calculate Traffic$_{es}$ **Units: Mbit/s/cell**

T_{es} □ Service_Channels/Cell$_{es}$Service_Channel_Bit_Rate$_{es}$.

(Note conversion to Mbit/s from kbit/s.)

C4 Determine Net_System_Capability$_{es}$ Parameters **Units: varied**

System Spectral Efficiency; Coding Factor; Overhead Factor; Deployment Model; and other factors.

C5 Calculate Net_System_Capability$_{es}$ **Units: Mbit/s/MHz/cell**

S_{es} □ Function of {Spectral Efficiency; Coding Factor; Overhead Factor; Deployment Model, and other factors}.

D Spectrum results considerations

D1 Calculate individual F_{es} Component

(Answer will be for direction of calculation chosen either uplink or downlink.)

F_{es} □ T_{es}/S_{es} (either uplink or downlink) **Units: MHz**

D2 Repeat process for calculation of other direction (either downlink or uplink as appropriate)

Repeat steps A2 through D1.

D3 Calculate F_{es} for the Service "s" Combining uplink and downlink components

F_{es} □ (F_{es} uplink̦ F_{es} downlink) **Units: MHz**

D4 Repeat process (steps A1 through D3) for All Desired "e", "s"

D5 Determine weighting factor applicable to each individual F_{es}: □$_{es}$ **Units: None**

D6 Determine Adjustment Factor(s): □ Units: None

D7 Calculate Final Total $F_{Terrestrial}$ Spectrum Value Units: MHz

$F_{Terrestrial}$ □ □ □□$_{es}$ F_{es}.

Detailed description of the methodology

A Geographic considerations

A1 Environment

The initial point for consideration of terrestrial spectrum requirements is to determine the characteristics of the cells which the system will use. The system will operate in a variety of scenarios, encompassing various combinations of density and mobility. A table of possible environments is given below, although no indication has been given of which specific environments should be considered. It is thought that the matrix below is flexible enough to cover most situations encountered in deployment of a public land mobile radio system.

The variable subscript "e" represents the environment for which the calculation is performed, and the environment is defined by a combination of a density attribute and a mobility attribute considered jointly, and are show in the following matrix:

Mobility Density	In-building	Pedestrian	Vehicular
Dense Urban (CBD)			
Urban			
Suburban			
Rural			

For example, "dense urban, in-building" could be a value of "e".

Clearly some of these environments may be (geographically) overlapping, whilst others may be separate. For the calculation of the total spectrum required for IMT-2000, it will be necessary to determine the maximum spectrum which might realistically be needed in any one area. It is anticipated that not all combinations (values of "e") will be needed and in most cases only a few combinations will need to be considered. For example, "dense-urban, vehicular" as a value of "e" may not be required in practice in some calculations. Therefore the first stage of the methodology is to determine the environments which could co-exist, and which would give rise to the greatest total spectrum demand.

In practice this will be a combination of overlapping dense urban and urban environments. The method to determine the total spectrum required is then applied to each of the members of this set of overlapping environments.

A2 Select direction of calculation

Uplink (from the mobile station to the base station) or downlink (from the base station to the mobile station).

The traffic and spectrum figures in steps A2 through D1 are calculated separately for uplink and downlink directions because of the traffic asymmetry in some services. The spectrum required for any F_{es} is the sum of the requirement for both directions.

A3 Establish representative Cell_Area and geometry

For each of the “e” environments identified in A1, the cell area and geometry has to be established. Typical examples could be a circle or hexagon, either of which could be considered as a whole or could be sectored. It is possible that, for operational reasons, different environments will use cells with differing geometry, and certainly there may be a range of cell sizes.

A4 Calculate $Cell\_Area_e$ Units: km^2

Having identified the cell geometry and dimensions for each environment, it is necessary to calculate the area of the cell.

For example:

For a circular cell, $Cell\_Area_e = \pi R^2 = \pi D^2/4$

where: R = radius of the circle

D = diameter of the circle

For a hexagonal cell, $Cell\_Area_e = (3/2) . (\sqrt{3}) . R^2$

where: R = radius (to vertex) of the hexagon.

For a cell which is a sector of a circle/hexagon, the area that should be used ($Cell\_Area_e$) is the area of the sector, and it may be sufficient to divide the area of the full circle/hexagon to obtain the sector area.

Other cell geometries and corresponding formula for calculating area may be used.

B Market and traffic considerations

B1 Select "s"

"s" – service type: selects service type and hence $Net\_User\_Bit\_Rate_s$ (kbit/s).

For a given public land mobile radio service there is a set of services that are offered. Selecting a service type "s" chooses a particular service from that set for the purpose of calculation.

As an example, in IMT-2000, a reasonable set of services (the range of "s") might be:

– Speech	(circuit switched)
– Simple message	(packet switched)
– Switched data	(circuit switched)
– Medium multimedia	(packet switched)
– High multimedia	(packet switched)
– High interactive multimedia	(packet switched)

B2 Establish $Population\_Density_e$ Units: potential users/km^2

For each environment considered, it is also necessary to determine a density of population. This will be a basic figure for the number of persons per unit area within the environment under consideration.

Similar geographic locations can have differing population densities as a function of the mobility component. For example, urban-pedestrian may have a population density of 100 000 users/km^2, yet the same area would not be physically able to have an urban-vehicular density of more than 3 000 users/km^2.

B3 Establish $Penetration\_Rate_{es}$ Units: %

This parameter is the ratio of the number of people subscribing to the service "s" over the total population, in environment "e".

It should be noted that the use of each service is not exclusive. Each $Penetration\_Rate_e$ refers to the penetration of that service as a proportion of the total potential user base. Since users can use more than one service it is possible for the *total* penetration in an environment (across all services) to exceed one (100%) if a high proportion of users are using more than one service.

B4 Calculate Users/Cell$_{es}$

This parameter is dependent upon the population density and the cell area for each environment "e", and on the penetration rate for the service "s" and the environment "e".

It represents the number of people actually subscribing to the service "s" in a cell of environment "e".

$$\text{Users/Cell}_{es} = \text{Population\_Density}_{es} \cdot \text{Penetration\_Rate}_{es} \cdot \text{Cell\_Area}_{e}.$$

B5 Establish traffic parameters

For each service, in each environment, the following parameters must be established:

Busy_Hour_Call_Attempts$_{es}$ **Units: number of calls in busy hour**

Defined as the average number of calls attempted for the average user during the busy hour. It should be noted that these calls may originate either from the user or from the network. No distinction is made here between these two sources, the result in terms of resource needed being the same. This parameter is self explanatory for circuit-switched services, and for packet-switched services a call is understood as a session.

Call_Duration$_{es}$ **Units: seconds**

This parameter is defined as the mean actual duration of the call or of the session during the busy hour.

Activity_Factor$_{es}$ **Units: dimensionless**

Defined as the percentage of time during which the resource is actually used during the call. For example, if voice is transmitted only if the user speaks, or if a packet transmission is bursty, the transmission is only active during a relatively small amount of time.

B6 Calculate Traffic/User$_{es}$ **Units: call-seconds**

This parameter is defined as the probability that the user is "offhook" and active in the busy hour for a circuit-switched call or a packet-switched session. It is clearly defined in Erlangs (call-seconds/ 3 600) for circuit-switched services and for packet-switched services has the equivalent unit of average relative activity in a period of reference of the busy hour.

$$\text{Traffic/User}_{es} = \text{Busy\_Hour\_Call\_Attempts}_{es} \cdot \text{Call\_Duration}_{es} \cdot \text{Activity\_Factor}_{es}.$$

B7 Calculate Offered_Traffic/Cell$_{es}$ Units: call-seconds

This is the total traffic issued in a given cell of environment “e” for service “s” during the busy hour.

Offered_Traffic/Cell$_{es}$ = Traffic/User$_{es}$. Users/Cell$_{es}$.

It is clearly defined in Erlangs (call-seconds/3 600) for circuit-switched services and for packet-switched services has the equivalent unit of average relative activity in a period of reference of the busy hour.

B8 Establish Quality_of_Service_Function$_{es}$ (QOS$_{es}$) Parameters Units: varied

Parameters required:

Group_Size$_{es}$

Blocking Criteria$_{s}$ (Formula and Blocking for circuit switched)

Or

Blocking Criteria$_{s}$ (Formula and Delay for packet switched)

Discussion of Quality Of Service Aspects:

Bearer channel capabilities are characterized in terms of parameters having Quality of Service and Grade of Service significance. Establishing Quality_of_Service_Function$_{es}$ parameter values (herein Quality_of_Service_Function$_{s}$ is used generically to apply to both Quality of Service specifically and also to Grade of Service) directly impacts on the number of service channel resources that are required to transport the User_Net_Bit_Rate$_{s}$ streams.

These parameters are necessary to determine the actual amount of resource which is needed to carry the traffic issued from the cell. For circuit-switched services, the necessary parameter is acceptable blocking, the maximum percentage of calls which cannot be treated by the network.

For packet-switched services, the quality of service is defined in terms of maximum packet delay and packet loss probability. The acceptable values of these parameters must be established for a given Service_Type “s”.

The throughput of a packet-switched system is dependent on the choice of a suitable multiple access protocol (e.g. Aloha, PMRA, etc.). Given a particular protocol, the total throughput may be determined for a particular Service_Type “s” by application of a suitable traffic model and an appropriate packet Quality_of_Service_Function$_{es}$.

Traffic models for packet switched are dependent on many parameters, some of which might be included in the Net_System_Capability$_{es}$ variable. Some example packet-switched traffic parameters are:

– statistical arrival times of various sessions;

– numbers of packet bursts per session;

– arrival times of packet bursts within a session;

– packet size statistics.

The values of the above are also Service_Type “s” dependent. When a session consists of multiple services an aggregate traffic model should be used.

The requisite function that is used for the calculation of Quality_of_Service_Function$_{es}$ relative to the number of service channels is a matter of choice of the appropriate function to match the Service_Type “s” selected. For example, Erlang B with a blocking value of some percentage (say 2% blocking) has traditionally been used for speech (circuit switched) and may be an appropriate choice to apply in the determination of spectrum associated with the speech service type. Other functions as discussed previously, which describe Quality_of_Service_Function$_{es}$ appropriate to packet switched would be used in calculations of packet-based service types.

In consideration that radio transmission technologies and system deployments may provide some measure of traffic “sharing” or “redirection” among adjacent cells (perhaps in hierarchical or other arrangements) it is appropriate to consider traffic and Quality_of_Service_Function$_{es}$ within a grouping of cells.

The term Group_Size$_{es}$ is used to describe the number of cells considered to be grouped for the purpose of application of traffic and Quality_Of_Service_Function$_{es}$. The Group_Size$_{es}$ does not imply any particular geometry, although an example could be a regular hexagonal cell grid which results in a Group_Size$_{es}$ of seven, the value arising from the cell in question and the surrounding six first tier cells.

Essentially, the Traffic/Cell$_{es}$ is multiplied by the Group_Size$_{es}$ and the Blocking_Criteria$_{s}$ function applied over this grouping. Then to obtain the Service_Channels/Cell$_{es}$ the Group_Size$_{es}$ is divided out to restore the valuation to a per cell basis.

This calculation step has the impact of some reduction in the number of Service_Channels/Cell$_{es}$ by considering some improvement in efficiency in the traffic spread in a geographic grouping. To the extent that grouping and/or traffic sharing across geographically grouped cells is included in the System_Capability$_{es}$ parameter, then the Group_Size$_{es}$ should be set to the value of one and the Blocking_Criteria$_{s}$ function calculation performed on the traffic in a single cell.

Similarly, if the effects of a Quality_of_Service_Function$_{es}$ are included in the System_Capability$_{es}$ parameter, then the Blocking$_{s}$ function should be set to a value of one, which should in principle, also require that the Group_Size$_{es}$ value be set to unity.

C Technical and system considerations

C1 Calculate number of Service_Channels/Cell$_{es}$ required to carry Offered_Traffic/Cell$_{es}$ Units: none

The calculation of the number of Service_Channels/Cell$_{es}$ is a complex function that involves use of the parameters discussed previously:

Service_Channels/Cell$_{es}$ □ (QOS$_{es}$ {Offered_Traffic/Cell$_{es}$*Group_Size$_{es}$; Blocking Criteria$_{s}$})/Group_Size$_{es}$

Service_Channels/Cell$_{es}$ is the actual number of “channels” that must be provisioned to carry the intended traffic. A service channel is a channel which supports a service needing to have transported the corresponding Net_User_Bit_Rate$_{s}$ for the selected service “s”.

In general terms, a physical transmission facility offers a corresponding physical bit rate, which may be sub-divided into several sub-rate transmission pipes, each of which can support a number of service channels.

C2 Determine Service_Channel_Bit_Rate$_{es}$ needed to carry Net_User_Bit_Rate$_{s}$ Units: kbit/second

Due to modularity of the bit rate of the service channel, it is possible that the Service_Channel_Bit_Rate$_{es}$ might be equal to or greater than the corresponding Net_User_Bit_Rate$_{es}$. An example of this would be a Service_Channel_Bit Rate$_{es}$ of 16 kbit/s to carry a 14 kbit/s Net_User_Bit_Rate$_{s}$, or an 80 kbit/s Service_Channel_Bit_Rate$_{es}$ to carry a 64 kbit/s Net_User_Bit_Rate$_{s}$.

Service_Channel_Bit_Rate$_{es}$ can also include impacts related to coding factors and channel overhead. To the extent that the actual bit rate of the service channel, coding factors and channel overhead impacts are not included in the Net_System_Capability$_{es.}$ they should be included here. Ignoring any factors related to Service_Channel_Bit_Rate$_{es}$ that cause it to be greater than the Net_User_Bit_Rate$_{s}$, the Service_Channel_Bit_Rate$_{es}$ is merely equal to the Net_User_Bit_Rate$_{s}$.

C3 Calculate Traffic$_{es}$ Units: Mbit/s/cell

(Note conversion to Mbit/s from kbit/s.)

T_{es} □ Service_Channels/Cell$_{es}$Service_Channel_Bit_Rate$_{es}$.

At this stage the traffic has been totalled for all the factors represented by the environment, service type, selected direction of transmission, cell geometry, quality of service aspects, traffic efficiencies across a group of cells, and service channel bit rate requirements.

C4 Net_System_Capability$_{es}$ (S_{es}) Units: Mbit/s/MHz/cell

(An equivalent expression for bits/s/Hz/cell.)

Determine Net_System_Capability Parameters **Units: varied**

S_{es} is a measure of the system capacity of a specific technology. It is related to the spectral efficiency of mobile communication systems but contains many other factors. S_{es} has the unit dimension of Mbit/s/MHz/cell. which is a direct equivalent to bits/s/Hz/cell. Net_System_ Capability$_{es}$ is not the same as spectral efficiency of the radio transmission technology. It is comprised of a number of effects that are combined in a complex manner appropriate to the radio transmission technology and the service type "s" and environment "e". Often the values required to determine the Net_System_Capability$_{es}$ are obtained from the results of complex system simulations.

The major components of the Net_System_Capability$_{es}$ may include the following:

1) Radio transmission technology design or engineering impacts including but not limited to:

– physical spectral efficiency of access technology used;

– requirements of a specific E_b/N_0;

– requirements of a specific C/I;

– requirements for a specific frequency reuse plan;

– coding factors used by the radio transmission technology;

– overhead factors used by the radio transmission technology;

– environment – indoor, outdoor, stationary, pedestrian, vehicular.

2) Deployment models and/or deployment technique including microcells, macrocells, hierarchical cells, or overlay cells, etc.

It therefore follows that there is a tradeoff between $Net\_System\_Capability_{es}$ and the quality or grade of service.

C5 Calculate $Net\_System\_Capability_{es}$

S_{es} □ Function of {Spectral Efficiency, Coding Factor, Overhead Factor, Deployment Model, and other factors}.

This calculation proceeds using the values and parameters discussed previously as a function of appropriate combining functions.

D Spectrum results considerations

D1 Calculate individual F_{es} Component for a given direction

– uplink (from the mobile station to the base station); or

– downlink (from the base station to the mobile station).

The amount of spectrum required for a given service and environment, in a given direction, is determined by dividing the $Traffic_{es}$ (as determined in § C3) by the $Net\_System\_Capability_{es}$ (as determined in § C4).

$F_{es} = T_{es}/S_{es}$ (either uplink or downlink) **Units: MHz**

D2 Repeat process for calculation of other direction (either downlink or uplink as appropriate)

Repeat steps A2 through D1 for the other direction (if not previously calculated).

D3 Calculate F_{es} for the Service "s", combining uplink and downlink components

The total amount of spectrum required for a given service and environment is determined by directly adding the spectrum required for the uplink and downlink components.

F_{es} = (F_{es} uplink, F_{es} downlink) **Units: MHz**

D4 Repeat process (steps A1 through D3) for all desired “e”, “s”

Repeat steps A1 through D3 for each combination of “e” and “s” that is being considered.

D5 Determine weighting factor (α_{es}) applicable to each individual F_{es} Units: None

The weighting factor (α_{es}) provides appropriate weighting in the spectrum requirements calculations and includes the following:

– weighting to adjust for geographical offsets in overlapping environments;

– weighting to correct for non-simultaneous busy hour traffic requirements.

The value for α_{es} may range from zero up to unity, and the default value is 1.

D6 Determine adjustment factor (β) Units: None

The adjustment factor (β) provides for impacts such as:

– multiple operators (reduced trunking/spectral efficiency);

– sharing with other IMT-2000 services/systems;

– sharing with non-IMT-2000 services/systems;

– guard bands;

– technology modularity. For example, if a technology uses 10 MHz frequency division duplex (FDD) channels, then the requirements will necessarily be an integer factor of 20 MHz;

– other adjustments to be justified.

This adjustment factor is an approximation across impacts of environments “e”, services “s” and other influences. The default value for β is 1, and other values should be technically justified.

D7 Calculate the final total $F_{Terrestrial}$ Spectrum Value Units: MHz

For each environment and service, each F_{es} is multiplied by α_{es}, and then the individual products are added together. The result of the summation is multiplied by the adjustment factor (β) to derive the total terrestrial spectrum required $F_{Terrestrial}$.

$$F_{Terrestrial} = \beta \times \sum \alpha_{es} F_{es} \quad \text{MHz}$$

APPENDIX 1

Example calculations

This example provides guidance on the application of the methodology detailed in §§ 2 and 3 of Annex 1.

The example is calculated with parameter values estimated from market research on public land mobile communications services, including IMT-2000, and with technical parameter values estimated from IMT-2000 radio transmission technologies, for the year 2010 view. The results shown in this example should not be considered as providing an answer to the question of future spectrum requirements for public land mobile communications services, including IMT-2000, as all environments and services that must be considered for completeness may have not been included in the example.

Examination of environments and services reveals that there are potentially twelve values of the subscript "e" and six values for the subscript "s" that are representative major contributors to a spectrum requirement. Hence, a complete calculation of the terrestrial spectrum requirement estimate for public land mobile communications services, including IMT-2000, would require the use of 72 terms in the summation of individual F_{es} terms.

This example is based on a representative subset of environments and services as presented in the matrix below and these are sufficient to exercise all aspects of the methodology.

Representative environments "e" and services "s" (values for F_{es})

Environments "e"	High density-in Building (CBD)	Urban pedestrian	Urban vehicular
Services "s"			
Speech (S)	F_{es}	F_{es}	F_{es}
Simple Message (SM)	F_{es}	F_{es}	F_{es}
Switched Data (SD)	F_{es}	F_{es}	F_{es}
Medium Multimedia (MMM)	F_{es}	F_{es}	F_{es}
High Multimedia (HMM)	F_{es}	F_{es}	F_{es}
High Interactive Multimedia (HIMM)	F_{es}	F_{es}	F_{es}

The figures presented in the tables below are often rounded figures, but the calculation is performed with more digits to provide more accurate example results.

A Example for the year 2010

A1 Environment

A subset of all environments is considered for the purpose of this example: only high density-in building also generally known as Central Business District (CBD); urban pedestrian, and urban vehicular. This subset of three environments is extracted from all possibilities because they correspond to superimposed layers in city centres.

It should be noted that no user should occupy two operational environments at a time.

A2 Direction of calculation

– uplink (from the mobile station to the base station); or

– downlink (from the base station to the mobile station).

The following calculations are detailed for each of the direction.

A3 Establish representative cell_area and geometry

The environments are defined to have the following geometry:

TABLE 1

Environment description

Environment "e"	High density-in Building (CBD)	Urban pedestrian	Urban vehicular
$Geometry_e$	Circular	Hexagonal with three sectors	Hexagonal with three sectors
Cell $dimension_e$	Diameter □ 100 m	Radius □ 600 m	Radius □ 600 m

A4 Calculate Cell_Area

Based on the cell description, the cell areas are calculated as follows:

TABLE 2

$Cell\_Area_e$

Environment "e"	High density-in Building (CBD)	Urban pedestrian	Urban vehicular
$cell\_area_e$ (km^2)	7.85 □ 10^{-3}	3.12 □ 10^{-1}	3.12 □ 10^{-1}

B1 Select service "s"

The services are as follows:

TABLE 3

Description of Service_Type "s" and corresponding $Net\_User\_Bit\_Rate_s$

$Net\_User\_Bit\_Rate_e$	Downlink (DL) net bit rate (kbit/s)	Uplink (UL) net bit rate (kbit/s)
Service Type "s"		
Speech (S)	16	16
Simple Message (SM)	14	14
Switched Data (SD)	64	64
Medium Multimedia (MMM)	384	64
High Multimedia (HMM)	2 000	128
High Interactive Multimedia (HIMM)	128	128

B2 Establish Population_Density

For the three environments considered, population densities can be chosen as follows:

TABLE 4

$Population\_Density_e$

Environment "e"	High density-in Building (CBD)	Urban pedestrian	Urban vehicular
$Population\_Density_e$	250 000	100 000	3 000

B3 Establish $Penetration\_Rate_{es}$

The following table describes the penetration rates used in this example calculation:

TABLE 5

Penetration_Rate$_{es}$ in Percent

Environments "e" / Services "s"	High density -in building (CBD)	Urban pedestrian	Urban vehicular
Speech (S)	73%	73%	73%
Simple Message (SM)	40%	40%	40%
Switched Data (SD)	13%	13%	13%
Medium Multimedia (MMM)	15%	15%	15%
High Multimedia (HMM)	15%	15%	15%
High Interactive Multimedia (HIMM)	25%	25%	25%

B4 Calculate Users/Cell$_{es}$

The table below gives the Users/Cell$_{es}$ calculated with the above assumptions:

TABLE 6

Users/Cell$_{es}$

Environments "e"	High density-in Building (CBD) number of users	Urban pedestrian number of users	Urban vehicular number of users
Services "s"			
Speech (S)	1 433	22 756	683
Simple Message (SM)	785	12 469	374
Switched Data (SD)	255	4 052	122
Medium Multimedia (MMM)	295	4 676	140
High Multimedia (HMM)	295	4 676	140
High Interactive Multimedia (HIMM)	491	7 793	234

B5 Establish traffic parameters

The following traffic parameters are considered representative of the average user in each of the environment for each of the services:

TABLE 7

Busy_Hour_Call_Attempt$_{es}$ expressed as calls in busy hour

Environments "e"	High density-in building (CBD) calls in busy hour		Urban pedestrian calls in busy hour		Urban calls in busy hour	
Services "s"						
Speech (S)	0.9		0.8		0.4	
Simple Message (SM)	0.06		0.03		0.02	
Switched Data (SD)	0.2		0.2		0.02	
Medium Multimedia (MMM)	0.5		0.4		0.008	
High Multimedia (HMM)	0.15		0.06		0.008	
High Interactive Multimedia (HIMM)	0.1		0.05		0.008	

TABLE 8

Call_Duration$_{es}$ in seconds

Environments "e"	High density-in building (CBD) seconds		Urban pedestrian seconds		Urban vehicular seconds	
Services "s"						
Speech (S)	120		120		120	
Simple Message (SM)	30		30		30	
Switched Data (SD)	156		156		156	
Medium Multimedia (MMM)	13.9		13.9		13.9	
High Multimedia (HMM)	53.3		53.3		53.3	
High Interactive Multimedia (HIMM)	180		180		180	

TABLE 9

Activity_Factor$_{es}$

Environments "e"	High density-in Building (CBD) dimensionless		Urban pedestrian dimensionless		Urban vehicular dimensionless	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	0.5	0.5	0.5	0.5	0.5	0.5
Simple Message (SM)	1	1	1	1	1	1
Switched Data (SD)	1	1	1	1	1	1
Medium Multimedia (MMM)	1	1	1	1	1	1
High Multimedia (HMM)	1	1	1	1	1	1
High Interactive Multimedia (HIMM)	0.8	0.8	0.8	0.8	0.8	0.8

B6 Calculate Traffic/User$_{es}$

TABLE 10
Traffic/User$_{es}$ in call-seconds

Environments "e"	High density-in building (CBD) call-seconds		Urban pedestrian call-seconds		Urban vehicular call-seconds	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	54	54	48	48	24	24
Simple Message (SM)	1.8	1.8	0.9	0.9	0.6	0.6
Switched Data (SD)	31.2	31.2	31.2	31.2	3.12	3.12
Medium Multimedia (MMM)	6.95	6.95	5.56	5.56	0.111	0.111
High Multimedia (HMM)	8	8	3.2	3.2	0.427	0.427
High Interactive Multimedia (HIMM)	14.4	14.4	7.2	7.2	1.15	1.15

B7 Calculate Offerered-Traffic/Cell$_{es}$

Table 11 a
Offered_Traffic/Cell$_{es}$ in call-seconds

Environments "e"	High density-in building (CBD) call-seconds		Urban pedestrian call-seconds		Urban vehicular call-seconds	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	7.74 x 10^4	7.74 x 10^4	1.09 x 10^6	1.09 x10^6	1.64 x 10^4	1.64 x10^4
Simple Message (SM)	1.41 x 10^3	1.41 x 10^3	1.12 x 10^4	1.12 x 10^4	2.24 x10^2	2.24 x 10^2
Switched Data (SD)	7.96 x 10^3	7.96 x 10^3	1.26 x 10^5	1.26 x 10^5	3.79 x 10^2	3.79 x 10^2
Medium Multimedia (MMM)	2.05 x 10^3	2.05 x 10^3	2.60 x 10^4	2.60 x 10^4	1.56 x 10^1	1.56 x 10^1
High Multimedia (HMM)	2.36 x 10^3	2.36 x 10^3	1.50 x 10^4	1.50 x 10^4	5.98 x10^1	5.98 x 10^1
High Interactive Multimedia (HIMM)	7.07 x 10^3	7.07 x 10^3	5.61 x10^4	5.61 x 10^4	2.69 x 10^2	2.69 x 10^2

The group size is selected to be equal to 7. The Offered Traffic/Cell shown below is the traffic across all 7 cells expressed in Erlangs.

TABLE 11b

$Offered\_Traffic/Cell_{es}$ *$Group\_Size_{es}$ in Erlangs

Environments "e"	High density-in building (CBD) call-seconds		Urban pedestrian call-seconds		Urban vehicular call-seconds	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	150.5	150.5	2123.88	2123.88	31.86	31.86
Simple Message (SM)	2.75	2.75	21.82	21.82	0.44	0.44
Switched Data (SD)	15.49	15.49	245.85	245.85	0.74	0.74
Medium Multimedia (MMM)	3.98	3.98	50.51	50.51	0.03	0.03
High Multimedia (HMM)	4.58	4.58	29.09	29.09	0.12	0.12
High Interactive Multimedia (HIMM)	13.74	13.74	109.1	109.1	0.52	0.52

B8 Establish $Quality\_of\_Service\_Function_{es}$ (QOS_{es}) parameters

The quality of service function for circuit switched is selected to be Erlang B with a blocking of 2%. For packet-switched services the Quality of service function is a rounding up to the next integer number.

C1 Calculate number of $Service\_Channels/Cell_{es}$ required to carry $Offered\_Traffic/Cell_{es}$

The number of traffic channels required in the group is presented below:

TABLE 12a

Service_Channels per Group

Environments "e"	High density-in building (CBD)		Urban pedestrian		Urban vehicular	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	164	164	2 137	2 137	41	41
Simple Message (SM)	3	3	22	22	1	1
Switched Data (SD)	23	23	259	259	4	4
Medium Multimedia (MMM)	4	4	51	51	1	1
High Multimedia (HMM)	5	5	30	30	1	1
High Interactive Multimedia (HIMM)	21	21	122	122	3	3

The number of traffic channels required in the cell is service channels in the group divided by the group size of 7 and then rounded up. It is presented below:

TABLE 12b

$Service\_Channels/Cell_{es}$

Environments "e"	High density-in building (CBD)		Urban pedestrian		Urban vehicular	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	23.43	23.43	305.3	305.3	5.86	5.86
Simple Message (SM)	0.43	0.43	3.14	3.14	0.14	0.14
Switched Data (SD)	3.29	3.29	37.0	37.0	0.57	0.57
Medium Multimedia (MMM)	0.57	0.57	7.29	7.29	0.14	0.14
High Multimedia (HMM)	0.71	0.71	4.29	4.29	0.14	0.14
High Interactive Multimedia (HIMM)	3.0	3.0	17.43	17.43	0.43	0.43

C2 Determine $Service\_Channel\_Bit\_Rate_{es}$ needed to carry $Net\_User\_Bit\_Rate_{s}$

In this example, it is assumed that the $Service\_Channel\_Bit\_Rate_{es}$ is equal to the $Net\_User\_Bit\ Rate_{s}$.

TABLE 13

Service_Channel_Bit_Rate$_{es}$

Environments "e"	High density-in building(CBD) kbit/s)		Urban pedestrian (kbit/s)		Urban vehicular (kbit/s)	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	16	16	16	16	16	16
Simple Message (SM)	14	14	14	14	14	14
Switched Data (SD)	64	64	64	64	64	64
Medium Multimedia (MMM)	64	384	64	384	64	384
High Multimedia (HMM)	128	2 000	128	2 000	128	2 000
High Interactive Multimedia (HIMM)	128	128	128	128	128	128

C3 Calculate Traffic$_{es}$

Based on the number of channels needed and on the service channel bit rate, the traffic in each cell can be derived.

TABLE 14

$Traffic_{es}$

Environments "e"	High density-in building (CBD) (Mbit/s/cell)		Urban pedestrian (Mbit/s/cell)		Urban vehicular (Mbit/s/cell)	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	0.37	0.37	4.88	4.88	0.09	0.09
Simple Message (SM)	0.01	0.01	0.04	0.04	0.002	0.002
Switched Data (SD)	0.21	0.21	2.37	2.37	0.04	0.04
Medium Multimedia (MMM)	0.04	0.22	0.47	2.80	0.01	0.05
High Multimedia (HMM)	0.09	1.43	0.55	8.57	0.02	0.29
High Interactive Multimedia (HIMM)	0.38	0.38	2.23	2.23	0.05	0.05

C4 Net_System_Capabiliy_ $Parameters_{es}$ (S_{es})

A number of parameters must considered in determining key elements that influence the value of $Net\_System\_Capability_{es}$.

C5 Calculate $Net\_System\_Capability_{es}$

For the purpose of this example, an improvement factor that is the expected improvement of system capabilities in the year 2010 relative to current systems is applied to current generation capabilities to obtain $Net\_System\_Capability_{es}$.

In this example, the following net system capabilities have been used:

TABLE 15

Net_System_Capability$_{es}$ (S_{es})

Environments "e"	High density-in building (CBD) (kbit/s/MHz/cell)		Urban pedestrian (kbit/s/MHz/cell)		Urban vehicular (kbit/s/MHz/cell)	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	67	67	67	67	67	67
Simple Message (SM)	73	73	73	73	73	73
Switched Data (SD)	73	73	73	73	73	73
Medium Multimedia (MMM)	73	73	73	73	73	73
High Multimedia (HMM)	73	73	73	73	73	73
High Interactive Multimedia (HIMM)	73	73	73	73	73	73

D1 Calculate individual F_{es} component for a given direction (either uplink or downlink)

D2 Repeat process for calculation of other direction (either downlink or uplink as appropriate)

Using the traffic calculated above and the example net system capability, the F_{es} components for each direction, each environment and each direction can be derived as follows:

TABLE 16

Individual spectrum requirements (F_{es})

Environments "e"	High density-in building (CBD) (MHz)		Urban pedestrian (MHz)		Urban vehicular (MHz)	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	5.6	5.6	72.9	72.9	1.4	1.4
Simple Message (SM)	0.08	0.08	0.6	0.6	0.03	0.03
Switched Data (SD)	2.9	2.9	32.4	32.4	0.5	0.5
Medium Multimedia (MMM)	0.5	3.0	6.4	38.3	0.1	0.8
High Multimedia (HMM)	1.3	19.6	7.5	117.4	0.3	3.9
High Interactive Multimedia (HIMM)	5.3	5.3	30.6	30.6	0.8	0.8

D3 Calculate F_{es} for the service "s", combining uplink and downlink components

The summation gives the following results:

TABLE 17
F_{es} combining the uplink and downlink components

Environments "e"	High density-in building (CBD) (MHz)	Urban pedestrian (MHz)	Urban vehicular (MHz)
Services "s"			
Speech (S)	11.2	145.8	2.8
Simple Message (SM)	0.2	1.2	0.05
Switched Data (SD)	5.8	64.9	1.0
Medium Multimedia (MMM)	3.5	44.7	0.9
High Multimedia (HMM)	20.8	124.9	4.2
High Interactive Multimedia (HIMM)	10.5	61.1	1.5

D4 Repeat process (steps A1 through D3) for all desired F_{es}

The results have been presented in tables that show the values for all services “s” and all environments “e”.

D5 Determine weighting factor (α_{es}) applicable to each individual F_{es}

If all services are assumed to have coincident busy hours, and the three environments are collocated in the same geographical area, the weighting factors are assumed to be one:

$$\alpha_{es} = 1 \text{ for all “e” and “s”}$$

D6 Determine adjustment factor (ß)

To take account of the trunking inefficiency and the guard bands, an adjustment factor of 5% can be taken.

$$ß = 1.05$$

D7 Calculate the final total $F_{Terrestrial}$ spectrum value

For this example, the summation of the components with the adjustment factor gives:

$$F_{Terrestrial} = 530.3 \text{ MHz}$$

In this example, the result shown for $F_{Terrestrial}$ is the spectrum requirement estimate for public land mobile radio service, including IMT-2000, in the year 2010 because of assumptions made in the traffic and market forecasts, (namely, that the forecasts included first and second generation public land mobile radio services, and future expected IMT-2000 services).

In must be restated that, the results shown in this example should not be considered as providing an answer to the question of future spectrum requirements for public land mobile communications services, including IMT-2000, as all figures given in this example are still under study and all environments and services that must be considered for completeness may have not been included in the example.

Annexure C

Theoretical spectrum utilisation for GSM networks

C.1 A methodology for assessing spectrum utilisation

The spectrum utilisation of cellular networks is a measure of the density of traffic carried by the network for the given amount of radio spectrum. This measure is expressed as follows as Erlang/Kilometre^2/MHz of radio spectrum.

Theoretical values of spectrum utilisation are determined using plane earth with ideal, regularly spaced equi-sized cells. The traffic capacity that a given amount of radio spectrum can support in a cellular network is a function of the number of times the same radio channels can be re-used within a cluster of cells. This is determined by the carrier to interference ratio the radio receiver needs for a minimum quality of baseband signal. The re-use factor determines the number of cells in a re-use cluster and the smaller the cluster size, the greater is the re-use of frequencies in a given area. Finally, the smaller the cell size, the greater is the density of traffic that can be supported.

Thus, given a frequency re-use factor, an amount of radio spectrum and definition of the cell area; a theoretical measure of spectrum utilisation can be calculated and used in benchmarking the spectral utilisation of an actual network. However, in a practical network cell geometry is far from ideal and plane earth conditions are rare. Radio propagation is highly variable and the network performance must be stated using statistical measures. But, the theoretical benchmark is a useful performance bound when considering relative performance of networks.

C.1.1 Theoretical Spectrum Utilisation

In Figure 1 Cell Re-use cluster for K = 12 the relationship between the distance *D* and the nominal cell radius *R* is given by

$$D = \sqrt{3K}\,R \qquad \text{(eq 1)}$$

where *K* is the re-use pattern determined by tessellation of planar regions with small cell coverage for regular hexagons.

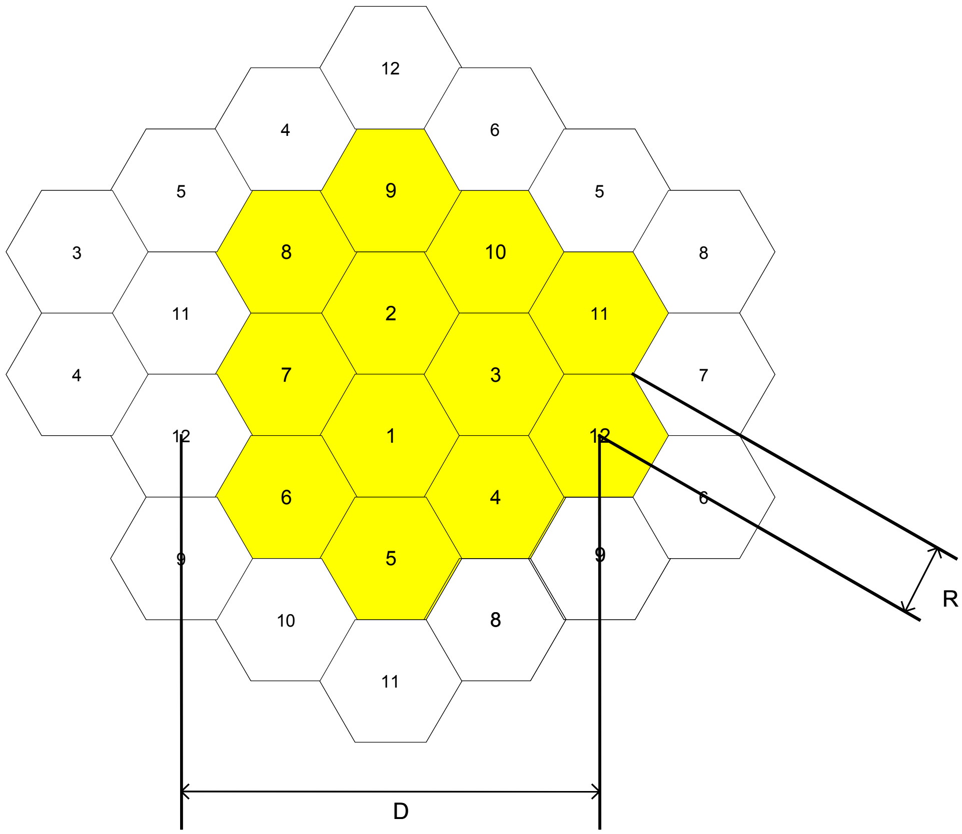

Figure 1 Cell Re-use cluster for K = 12

The values of K can take only the selected values

$$K = 1,3,4,7,9,12,13......$$

determined from[13]

$$K = (k + l)^2 - kl \qquad \text{(eq 2)}$$

where *k* and *l* are positive integers.

The *Co channel Interference Reduction Factor q is defined as:*

$$q = \frac{D}{R} \qquad \text{(eq 3)}$$

When the ratio *q* increases the co channel interference decreases. The separation distance *D* is a function of *Ki* and the *C/I*.

$$D = f(Ki, C/I) \qquad \text{(eq 4)}$$

where *Ki* is the number of co channel interfering cells at the first tier and the received Co channel to Interference ratio *C/I* at the mobile receiver is

$$\frac{C}{I} = \frac{C}{\sum_{k=1}^{K_i} I_k} \qquad \text{(eq5)}$$

In a fully equipped hexagonal-shaped cellular system, there will be six interfering cells in the first tier and K_i =6, and this can be shown to be the

[13] Microwave Mobile Communications ed W C Jakes

maximum for the first tier. Assuming local noise is less than the interference and can be neglected,

$$\frac{C}{I} = \frac{R^{-\lambda}}{\sum_{k=1}^{k_i} D_k^{-\lambda}} \qquad \text{(eq 6)}$$

where γ is the propagation path-loss slope determined by the actual terrain environment, and assumed to be 3.5. Assuming co channel interference from the second tier is negligible, substituting (eq 3) into (eq 6) gives:

$$\frac{C}{I} = \frac{1}{\sum_{k=1}^{k_i} \left(\frac{D_k}{R}\right)^{-\lambda}} = \frac{1}{\sum_{k=1}^{k_1} (q_k)^{-\lambda}} \qquad \text{(eq 7)}$$

where

$$q_k = \frac{D_k}{R} \qquad \text{(eq 8)}$$

In the case of directional antennae and sectored hexagonal cells, the number of first tier interfering sources is two and it can be shown[14] that at the worst case position, the distance from the two interferers are:

$$(D + 0.7R) \quad \text{and} \quad \text{D}$$

The worst case C/I becomes:

$$\frac{C}{I}(\text{worst case}) = \frac{R^{-3.5}}{(D + 0.7R)^{-3.5} + D^{-3.5}} \qquad \text{(eq 9)}$$

From (eq 7) and (eq 8), the worst case C/I for this two interferer case becomes:

$$\frac{C}{I}(\text{worst case}) = \frac{1}{(q + 0.7)^{-3.5} + q^{-3.5}} \qquad \text{(eq 10)}$$

For six interferers, the C/I becomes:

$$\frac{C}{I}(worstcase) = \frac{1}{6(q-1)^{-3.5}} \qquad \text{(eq 11)}$$

The worst case C/I for K =1, 3, 7, 9, 12 is given below.

K	3	7	9	12
C/I (dB) 2 Interferers 120 Degree - Sectored cell	14.5	20.4	22.2	24.2
C/I (dB) 6 Interferers - Omni Antenna	2.6	11.6	14.0	16.7

The minimum C/I for GSM is 9dB, to which a margin needs to be added to allow for irregular terrain and imperfect site locations. The table shows two cases:

[14] Mobile Cellular Telecommunications Systems, W C Lee – McGraw Hill

- Sectored antenna (120° sectored cell) with two first tier co-channel interferers
- Omni Antenna cell with 6 first tier co-channel interferers

The minimum value of k for an acceptable C/I should be greater than 9 dB: k=7 for 2 interferers; k=12 for 6 interferers. In a real situation the number of interferers will be between 2 and 6, hence the minimum value k is taken for GSM to be 7, however three sectored sites are generally used to reduce the cost of radio sites (a cluster of three, three-cell sites) so a re-use factor of 9 is forces by this geometry. For omni directional cells a re-use of 7 is possible.

CDMA 2000 technology operates with a negative C/I and achieves a re-use factor of k = 1.

Annexure D

Theoretical Benchmark for GSM Networks

Telecom Regulatory Authority of India

	Parameters	Units	Amount
1	Amount of spectrum	MHz	10.00
			15.80
2	**Macro layer characteristics**		
	Macro layer Reuse		9.00
	Radius of macro cell	kms	0.30
	Area of macro cluster	Sq kms	2.54
	Amount of spectrum per macro cluster	MHz	8.80
	Amount of spectrum per cell	MHz	0.98
	Number of voice circuits per cell		37.00
	Traffic per cell	Erlangs	28.26
	Total traffic carried	Erlangs	254.30
3	**Micro layer characteristics**		
	Reuse		3.00
	No of TRX per cell		2.00
	Amount of spectrum per micro Cell	MHz	0.40
	Amount of spectrum per micro cluster	MHz	1.20
	Radius of micro cell	kms	0.08
	Area covered by each micro cluster	sq kms	0.06
	Percentage of macro area occupied by micro	%	15%
	Area covered by micro cluster	sq kms	0.38
	Number of micro cell clusters		6.00
	Number of circuits per micro cell		14.00
	Traffic carried by each micro cell	Erlangs	8.20
	Traffic carried by micros	Erlangs	147.59
4	**Macro + Micro layer characteristics**		
	Total traffic	Erlangs	401.90
	Spectrum	MHz	
	Erlangs per MHZ per sq kms	**E/MHz/Sq Kms**	**15.80**

Annexure E

Technical Features and Developments for Improving Spectrum Utilisation and Quality of GSM systems

E.1 Basic techniques to enhance capacity

A number of techniques and system features are available that improve system quality and spectral utilisation. These are primarily concerned with speech performance, which despite the growth of data services, is likely to remain the dominant service for GSM. Additionally, a number of developments are underway that in connection with the system features are claimed to have the potential to increase system capacity within the GSM frequency bands.

The categories of spectrum utilisation and quality enhancement techniques are briefly:

- *1) Baseline GSM Speech enhancement* – Frequency Hopping, Power Control, Discontinuous Transmission (DTX)
- *2) Frequency Re-use and Partitioning Methods* – Hierarchical Structures/Layers
- *3) Trunking Gain Functionality* – Directed Retry (DR) and Traffic Reason Handover (TRHO) techniques
- *4) Radio Link Enhancement Techniques* – Uplink and Down Link antenna diversity, Mast Head amplifiers, Interference rejection
- *5) Half Rate and Adaptive Multirate speech coding*
- *6) EDGE AMR enhancements*

Items 1) to 4) are commonly adopted in GSM networks design and planning and are proven, cost effective methods of obtaining very large capacity gains and quality enhancement. They are the prime weapons in the network operator’s armoury to combat capacity congestion.

The improvement in capacity through Item 2) above can be readily quantified in a theoretical sense; however the improvements through the addition of Items 1), 3), 4) or combinations of these can only be quantified through simulation or measurement of actual network performance. The improvements are however real and beneficial.

Item 5), half rate and AMR coding can potentially provide further capacity increases depending on the population of half rate or AMR capable mobile terminals on the network. Half rate coding is associated with a reduction in quality and therefore is not used by some operators, but it is a feature that can be readily switched on and off and is often used at time of unusual peak traffic in parts of the network or as a means of “buying time” while network capacity is rolled out.

Item 6), EDGE AMR are enhancements for higher data rates which with AMR can increase speech capacity.
Adoption of these techniques by network operators depends on business decisions balancing investment costs against the returns from improvement in network capacity and/or quality. Network usually become radio spectrum constrained as the subscriber base grows and the point in time when these techniques are adopted depends on the take up of service and the network operators' investment plans and the availability of radio spectrum.

Some of these features and developments are briefly described below and their applicability to the theoretical benchmark is discussed.

E.1.1 Antenna Array Diversity and Adaptive Antennae

Receive antenna diversity is commonly used with Base Station receivers. Horizontal diversity, where two receive antenna are spaced in the horizontal plane, is preferred to vertical diversity, where the two antenna are mounted vertically in line. This is because greater de-correlation between the signals of the two antenna is achievable with a smaller spacing than for vertical separation. Receive diversity provides gain in the up-link (mobile to base direction) and an improved signal to noise ratio, which assists in the up-link down-link balance. Note the mobile transmitter operates with a much lower power than the base transmitter.

Uplink Interference Rejection is a method of reducing interference from co-channel and adjacent channel transmitters using, for example *Interference Rejection Combining* (IRC) algorithm that de-correlates the interfering signals from the antenna branches so that their total power in the combined signal is minimised.

Single Antenna Interference Cancellation (SAIC) is a generic term covering several single antenna receiver techniques that attempt to cancel interference through the use of signal processing. The technique is aimed at the mobile terminal where size and cost preclude multiple antenna. An SAIC feasibility study is underway in the 3GPP standards group with the aim to have SAIC standardisation for 3GPP Release 6. As a result of requests from some operators, to have SAIC earlier than Release 6, it is likely that commercial SAIC may become available some time in 2004.

Diversity can be applied to the base transmitter in the down link. Transmit diversity techniques include *Delay Diversity* (DD), Phase *Hopping Diversity*, (PH), *Antenna Hopping,* (PH). As with uplink diversity, in order to achieve high diversity gains, antenna signals must be de-correlated by spatial separation or cross-polarisation.

E.1.2 Half Rate Codecs and Adaptive Multi-rate Codecs

Half rate voice codecs are specified in the GSM standards and half-rate operation is a standard system feature supplied by most of the equipment vendors that can be readily switched on. With half rate operation each TCH (traffic channel) simultaneously supports two voice conversations. There is a quality penalty to be paid with half-rate, but this must be weighed against improved grade of service. Half rate operation can be switched on in parts of the network, for example the very high traffic areas, and simultaneously switched off in other parts. The gains for half rate operation depend on the percentage of the mobile terminals that are half rate capable and could assist in supporting perhaps 20% more users in the high traffic areas. Half rate operation does not increase the capacity of the network to carry data (SMS or GPRS).

Adaptive Multi-rate Codec (AMR) technology is proven and has been specified for GSM third generation standards group 3GPP. AMR is a system and mobile feature so its adoption depends on the vendor support for the technique and its impact on capacity is determined by the pool of AMR mobiles using the network.

E.1.3 Cell Splitting and Hierarchical Cell Structures

Cell splitting, hierarchical cell structures, re-use partitioning together with synthesised frequency hopping are the primary tools at the disposal of operators to increase GSM network capacity.

These techniques divide the radio spectrum into blocks that can be assigned to separate layers in the network each with different frequency re-use. A higher layer with a “loose” re-use factor ensures full contiguous coverage (called an overlay layer) whilst other lower layers, which need not be contiguous in coverage and have a very tight re-use hence high capacity (underlay layer). Mobiles are directed to the appropriate layer by the network, depending on their location in the network and speed of travel. There are many different implementations of re-use partitioning that are proprietary to the equipment vendors, e.g. Concentric Cells – Motorola, Multiple Re-use Patterns – Ericsson, Intelligent Underlay-overlay – Nokia.

E.1.4 Synthesised and Synchronous Frequency Hopping

Synthesised Frequency Hoping (SFH) is universally used in GSM networks. Here the base transmitter can operate on any frequency (as compared to Base Band frequency hopping where the transmitter is on a fixed frequency and the base band channels are switched “hopped” between transmitters). Synthesised frequency hopping provides frequency diversity and gives an improvement in carrier to interference of between 6dB and 8db. These permits the radio frequencies to be used with an effective re-use factor of 3.

The benefit of SFH increases as the number of frequencies available for hopping increases. The ratio of hopping transmitters to hopping frequencies, the fractional load, gives the mean usage of a frequency. The limiting case for fractional re-use is that all cells in the network use all available TCH spectrum and interference is controlled solely by the number of transceivers that are simultaneously active.

The improvements with SFH are higher for mobiles that move slowly and diminishes as the mobile velocity reaches 50 Km per hour. SFH is therefore very beneficial in high traffic areas of cities where there is a large population of handheld pedestrian use of the network.

Network synchronisation, where all BTS elements in the whole network are synchronised, give a potential further improvement in synthesised frequency hopping performance. This is a network feature and its adoption depends on vendor support of this feature.

E.1.5 Discontinuous Transmission (DTX)

This feature has a great influence on spectral efficiency. It is a system option controlled by the operator and can be used independently in the mobile to base and base to mobile directions. DTX reduces the transmission when the user's communications activity reduces. For speech this is typically 40% of the time during a conversation in each direction. DTX reduces the interference conditions.

E.1.6 EDGE

EDGE (Enhanced Data rate for GSM Evolution) is a modulation method used with GSM to enable higher data rates (usable rates up to 3 times GPRS rates). Interest in EDGE is primarily to provide the means to support new multi-media services on GSM systems; however, used with AMR codecs it is expected that EDGE could increase voice capacity. But this must be set against the need for a better C/I and C/N than GSM GMSK. EDGE requires new BTS elements and compatible multi technology mobiles. Some vendors claim that all its new mobiles will be EDGE compatible, but as with AMR and half rate coding, a critical mass of users is necessary before real benefits in capacity can be levered out.

Annexure F

Advantages and disadvantages of various pricing options			
Approach	**Advantages**	**Disadvantages**	**Comments**
Additional spectrum awarded based on number of users on the network. Criteria are pre-defined.	Ensures spectrum efficiency as additional spectrum only provided when specific milestones are met. Encourages Service Providers to increase user numbers to obtain additional spectrum. Approach can be carried forward to the award of IMT 2000 spectrum.	Criteria on which decided milestones will need to be modified, as data services become more readily available. Different criteria for GSM and CDMA – not technology neutral. Does not match with market approach of Unified Licensing Difficult to determine the milestones that ensure efficient spectrum use but are not perceived by the Service Providers to be too prescriptive and so limit their options. Can lead to sub-optimal design[15]. Does not allow the Service Provider to minimise costs during initial rollout and can lead to poor GoS / QoS as costs of deploying additional base stations are considerably more expensive than adding extra transceivers. Encourages Service Providers to concentrate on dense urban areas where they can quickly add subscribers and so obtain additional spectrum earlier. No clear indications to Service Providers on the maximum of spectrum they can obtain and therefore how they should plan their network roll-out / business planning. The criteria makes spectrum allocation independent of an traffic / sub, while the actual spectrum regime is linked with traffic / sub.	In summary the approach does have merit in promoting technical spectrum efficiency but could require continuous resources (need to amend criteria as data services develop / respond to Service Providers requests), provides limited certainty, detrimental to economic spectrum efficiency. Could provide first mover advantage and distort competition if surrender of spectrum does not match increased demand from the Service Providers.

[15] Work carried out by the European Conference of Posts and Telecommunications Administrations (CEPT) in 1997 suggested that a minimum spectrum assignment for a mature GSM network to provide national coverage would be 2 x 9.6 MHz. Any reduction below this would be likely to lead to serious degradation in coverage or service quality

Advantages and disadvantages of various pricing options			
Approach	**Advantages**	**Disadvantages**	**Comments**
		Could provide advantage to the first entrants, especially in the case of GSM, as they have a lead on acquiring subscribers and could potentially obtain more spectrum than their competitors if there is no limit placed on the maximum spectrum made available to any one Service Provider in a region.	
Spectrum fees based on percentage of revenue	Amount payable is small at the beginning of rollout allowing the service providers to invest in network rollout.	Does not provide any significant financial incentive to use spectrum efficiently without other regulatory measures, which in this case is the number of subscribers. High spectrum fees, unless a maximum limit is placed on the fees. Will potentially limit: • the scope for investment in additional base stations to provide capacity, • price reductions (except those necessary due to competition), and • limit investment in new services especially if there is no guarantee of large market take-up. The fees only provide an incentive for the Service Providers to consider whether they should invest further in the network at that time when they can request further spectrum. Then they have to decide whether access to the additional spectrum is viable considering the increase in fees. *Does not encourage rollout in rural areas.*	Will need to place a cap on the fees charged if continue with fees based on revenues to encourage further investment.
Administrative Incentive Pricing (AIP) – spectrum fees charged on a per unit of spectrum basis	AIP can be used to support specific objectives such as promoting technical efficiency or rollout in rural areas. The same AIP can be applied to other users of the spectrum until they	Higher initial fees.	It is important to set the level of fees such that they are not too high or too low. Too high fees will deter Service Providers from acquiring sufficient spectrum to address the wider market and so concentrate on high spending, non price sensitive users. Too

Advantages and disadvantages of various pricing options			
Approach	**Advantages**	**Disadvantages**	**Comments**
	migrate to alternative technologies or frequency bands. Provides the Service Providers with the necessary certainty to develop their business plans / network rollout provided that it is reviewed periodically.		low prices will not provide an incentive to use spectrum efficiently.
Spectrum award through auctions	Less likely to be subject to legal challenge as transparent and objective. Can still include specific obligations to which Service Providers have to agree as part of process for being allowed to bid in the auction. Could possibly make the Service Provider responsible for removing the incumbents from the band by auctioning an overlay licence.	Need to be able to provide sufficient information on future spectrum availability and potential for further competition so that the risk for the Service Providers is minimised. The higher the risk the less that will be bid. Badly designed auctions and inadequate information in the auction Information Memorandum can lead to non ideal outcomes including collusion, default after winning, low prices non ideal market structure. Also some auction designs can lead to high prices. Need to set a reserve price that ensures the spectrum is not awarded for a price below the market value in the case of limited competition. Avoids opportunity of windfall gains if at a later date secondary trading is introduced.	A disadvantage that is often voiced against auctions is that costs will be passed on to users through higher tariffs. Economists argue that this is not the case with single up-front payments as they are a sunk cost. When services are marketed Service Providers will only charge the prices that maximise their profits and are necessary to compete with other Service Providers. We would recommend that the auction should specifically be for access to the spectrum and not for market entry only.
Spectrum awarded through "beauty contest"	By careful selection of criteria, spectrum award can place obligations on	May be difficult to differentiate between the Tender responses. Greater potential for political and legal controversy,	Risk of litigation can be substantially decreased by clearly defining the criteria and

Advantages and disadvantages of various pricing options			
Approach	**Advantages**	**Disadvantages**	**Comments**
	the Service Providers that meet measurable objectives (e.g. rollout / coverage). Same pricing structure can be used for spectrum awarded through the contest and any additional spectrum that is made available later.	litigation and subsequent delays in the use of the radio spectrum. Will need to define pricing policies as value of spectrum not set by the auction. It will be necessary to monitor the Service Providers against all the criteria they undertook to meet in their bids. This is expected to cover significantly more requirements than those that must be met to qualify to compete in an auction.	the weighting given to the different criteria in advance of the Tender and providing transparency of the reasons for the final decision.

Annexure G

Spectrum pricing for fixed wireless links

The system for calculation of point-to-point and point-to-multi-point wireless links is governed by R=MxWxC, where R is the payable royalty amount, M is determined by the distance the clearance is being sought for, W is determined by the amount of frequency being allocated, and C is the number of RF channels used (twice the number of duplex RF channel pairs). Both M and W are determined by range slabs, such that the multiplier increases significantly as soon as the requirements for the operator cross into the next slab.

The most recent definition of the applicable parameters was released by the DOT in Letter No.R-11014/26/2002-LR on April 1, 2003. This letter outlines the parameters as follows:

"5.1 Constant Multiplier M where:
M = 1200 for point to point Microwave Link(s) with end-to-end distance less than or equal to 05 Kms
M = 2400 for point to point Microwave Link(s) with end-to-end distance greater than 05 Kms but less than or equal to 25 Kms.
M = 4800 for point to point Microwave Link(s) with end-to-end distance greater than 25 Kms but less than or equal to 60 Kms.
M = 9000 for point to point Microwave Link(s) with end-to-end distance greater than 60 Kms but less than or equal to 120 Kms.
M = 15000 for point to point Microwave Link(s) with end-to-end distance greater than 120 Kms but less than or equal to 500 Kms.
M = 20000 for point to point Microwave Link(s) with end-to-end distance greater than 500 Kms.

5.2 Weighting Fact 'W' which is decided by the adjacent channel separation of the R.F. channeling plan deployed where
W = 30 for adjacent channel separation upto 2 MHz
W = 60 for adjacent channel separation greater than 2 MHz, but less than or equal to 7 MHz
W = 120 for adjacent channel separation greater than 7 MHz, but less than or equal to 28 MHz
W = (120) + (30 for each additional 7 MHz Bandwidth or part thereof) for adjacent channel separation greater than 28 MHz"

There are a few implications of this overall arrangement. One of these is that the same multiplier would apply to allocations requiring either 8 MHz or 27 MHz. Furthermore, TDD, which uses one channel, is inherently priced lower than FDD, which has one channel each for transmit and receive. For example, an application for TDD spectrum of 20 MHz for a range of 5 km would attract half the royalty payment of an application for FDD spectrum of 2 channels of 10 MHz each for a range of 5 km.

For M, the distance factor, implications of the selected slabs effects how operators plan their networks and operations. Today, operators are forcefully limiting their deployments to 5 km radius usage if their technology does not have the ability to reach close to the 25 km mark, as there are no intermediate slabs. Therefore, for a 6 km radius, he would have to pay fees that are the same as that for a 25 km radius.
