An assessment of spectrum management policy in India

A final report to the GSMA

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1 Introduction

In an Order dated the 16th of June 2008, the Government of India established a Committee to recommend a method for the future assignment of cellular mobile spectrum. As part of its terms of reference, the Committee is required to:

- *"recommend the method to be followed for the allocation [sic] of spectrum for Access Telecom Services" and to*
- *"reward Access Service providers for efficient use of spectrum and Penalise them for inefficient use"*

This study, commissioned by the GSMA, is designed to provide input to the Committee. It provides an independent assessment of the current spectrum policy in India from a public interest perspective. In particular it considers the impact which the current spectrum assignment policy has on the economic and social development of India. The study is based upon:

- A review of recent relevant presentations by India's GSM and CDMA operators on the issue of spectrum management
- Benchmarks of 2G cellular mobile assignments in India to assess how assignments per operator and spectrum efficiency in India compare with international norms
- An independent assessment of the extent to which Indian operators have introduced spectrum optimisation technologies
- Analysis of how the number of mobile operators per country has changed over the past 10 years.

Chapter 2 provides a brief review of current spectrum policy while Chapter 3 assesses the direct consequences of this policy. Chapter 4 then provides an assessment of the economic impact of these consequences, before we draw conclusions and make recommendations to the Committee in Chapter 5.

2 The current spectrum management policy

Under the current spectrum policy in India:

- Initial spectrum is bundled with each licence
- Newly licensed cellular operators receive an initial assignment of spectrum to enable them to start operations. GSM licensees receive 2x4.4 MHz and CDMA licensees 2x2.5 MHz
- Operators then receive additional spectrum as the number of subscribers grow. This is available on a first come first serve basis to any entity which complies with the eligibility criteria on subscriber numbers.

In the initial years the Indian Government followed a case by case approach, which was subsequently formalized into subscriber linked criteria in 2002. The number of subscribers required to be eligible for a given spectrum assignment has increased over the years. Figure 2.1 illustrates. It specifies the number of subscribers required in order for a GSM operator to be eligible for a given assignment of spectrum. We can see that the Indian Government Order of January 2008, based on TRAI recommendations, increased the number of subscribers required for a given spectrum assignment by a factor of two to four times.

Figure 2.1: The number of subscribers (in 00,000s) required for a GSM operator to be eligible for a given spectrum assignment

Service Area	Delhi & Mumbai		Kolkata & Chennai		Circle A		Circle B		Circle C	
Assignment (in MHz)	From 3/06	From 1/08	From 3/06	From 1/08	From 3/06	From 1/08	From 3/06	From 1/08	From 3/06	From 1/08
4.4	*	*	*	*	*	*	*	*	*	*
6.2	3	5	2	5	4	8	3	8	2	6
7.2		15		15		30		30		20
8	6		4		8		6		4	
8.2		18		18		41		41		31
9.2		21		21		53		53		42
10	10		6		14		10		6	
10.2		26		26		68		68		52
11.2		32		32		82		82		62
12.2		40		40		90		90		70
12.4	16		10		20		16		9	
13.2		48		48		98		98		78
14.2		57		57		107		107		87
15	21	65	13	65	26	116	21	116	12	96

This spectrum assignment policy is unusual, if not unique. Elsewhere in the world operators typically receive the full amount of spectrum in a specified band at the time they are licensed – even though parts of the spectrum may be unusable until existing users have vacated the allocated spectrum[1].

We can find no explicit statement which sets out the reasoning which underlies India's spectrum management policy. But based upon a review of relevant documents and discussions with operators we have identified three likely reasons. Such a policy:

- Makes it easier for the Government to license new entrants and thus increase the level of competition in the cellular mobile markets
- Helps the spectrum manager deal with problems of spectrum scarcity in India. Most countries have allocated between 2x90 MHz and 2x110 MHz of 2G spectrum. India has so far allocated between 2x40 and 2x70 MHz in most circles. This reflects the fact that parts of the 2G spectrum identified by ITU is still used by the military in India and is only gradually being released. Linking spectrum assignment to subscriber numbers allows the spectrum manager, at least in theory, to match spectrum assignment to spectrum availability more easily.
- Allows the Government to follow a prescriptive approach towards spectrum utilization by operators.

We assess the degree to which the objectives which underpin the policy are being met in Chapter 4. But first we consider the direct consequences of the policy.

[1] This applies to the bulk of countries with three to five operators rather than to countries with a duopoly

3 The direct consequences of the current policy

3.1 Introduction

The current policy has a number of important consequences. It means that:

- India has more operators per circle than other countries. While most countries have assigned spectrum to three to five operators to compete in a given area, the Indian government has assigned spectrum to as many as 11 or 12 operators which use a mix of GSM and CDMA technologies and promised spectrum to an additional 3 or 4
- Because of the limited availability of spectrum, mobile operators in India must use assignments which are around one quarter of the spectrum available to mobile operators elsewhere in the world
- Because of these restricted assignments, mobile operators in India are using their spectrum far more intensively than operators elsewhere. We estimate that, when measured using the spectrum utilisation measure of busy hour traffic per square kilometre per MHz in dense urban areas, Indian operators are extracting around eight times more capacity than operators in the UK, Hong Kong, or Singapore.

We set out the evidence which has led us to these conclusions in the rest of this chapter.

3.2 The number of operators in India

Figure 3.1 compares the number of cellular operators in the Indian circles with the number in other countries. There are five categories of operators with claims on 2G spectrum:

- Operational GSM operators
- GSM operators to whom spectrum has been assigned but who are not yet operational
- GSM operators to whom spectrum has been promised
- Operational CDMA operators
- CDMA operators to whom spectrum has been assigned but who are not yet operational.

In compiling the table we have treated organisations running both a GSM and a CDMA network in the same circle as separate networks.

Figure 3.1: The number of operators with spectrum assigned or promised - India vs other countries[2]

Circle	GSM			CDMA		Total
	Assigned and operational	*Assigned but not operational*	*Spectrum promised*	*Assigned and operational*	*Assigned but not operational*	
Metro circles						
Delhi	4	3	4	3	1	15
Mumbai	5	6	0	3	1	15
Chennai	4	7	0	3	1	15
Kolkata	4	3	3	3	1	14
A circle						
Maharashta	4	4	3	3	1	15
Gujarat	4	3	4	3	1	15
Andhra Pradesh	4	6	1	3	1	15
Karnatka	4	3	4	3	1	15
Tamil Nadu	4	7	0	3	1	15
B circle						
Kerala	4	7	0	3	1	15
Punjab	4	7	0	4	1	16
Haryana	4	7	0	3	1	15
Uttar Pradesh West	4	3	4	3	1	15
Uttar Pradesh East	4	7	0	3	1	15
Rajasthan	4	2	6	4	0	16
Madya Pradesh	5	1	5	3	1	15
West Bengal	5	0	5	3	1	14
C circle						
Himachal Pradesh	5	5	1	3	1	15
Bihar	5	1	5	3	1	15
Orissa	5	5	1	3	1	15
Assam	4	1	6	2	2	15
North East	5	0	6	1	3	15
Jammu and Kashmir	3	2	6	2	2	15
Average for India	4.3	3.9	2.8	2.9	1.1	15.0

[2] Source: media reports/COAI. Operators with both CDMA and GSM networks in a circle are counted as two operators

Circle	GSM			CDMA		Total
	Assigned and operational	*Assigned but not operational*	*Spectrum promised*	*Assigned and operational*	*Assigned but not operational*	
Other countries						
HK (1)	5	0	0	0	0	5
Indonesia (2)	5	0	0	0	0	5
Korea	0	0	0	3	0	3
Malaysia	3	0	0	0	0	3
Netherlands (3)	4	0	0	0	0	4
Pakistan	5	0	0	0	0	5
Singapore	3	0	0	0	0	3
UK (4)	4	0	0	0	0	4
Average for other countries						4.0

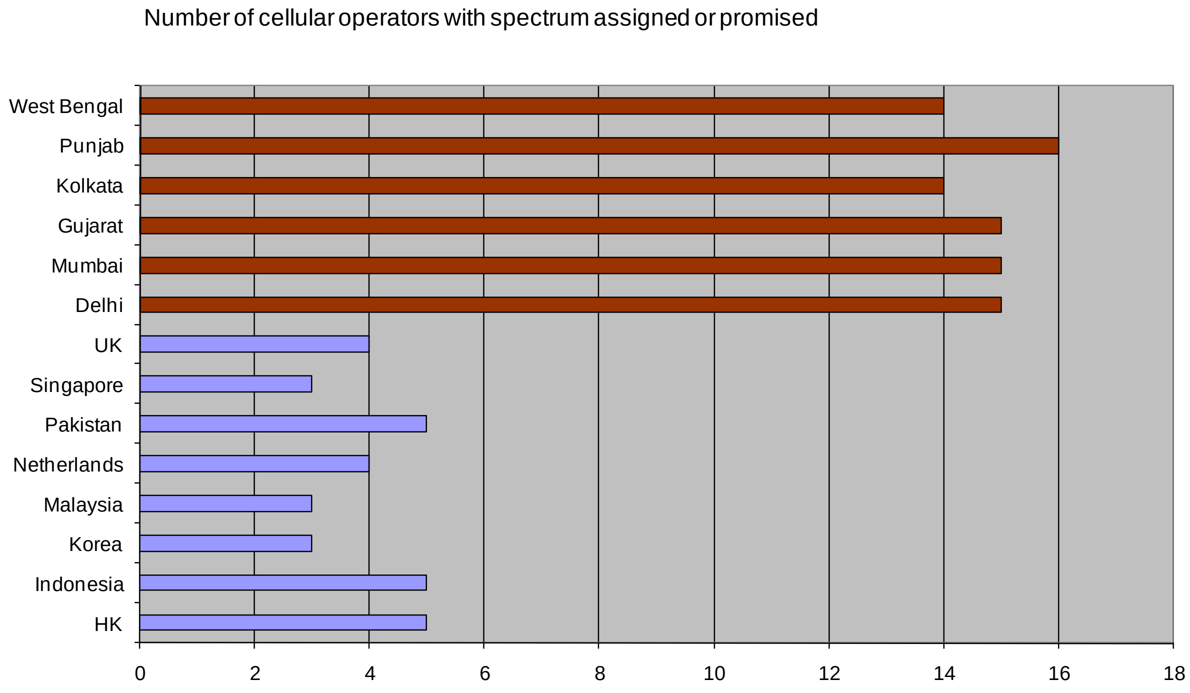
(1) Excludes one CDMA operator licensed primarily for use by roamers from mainland China
(2) Old NMT 450 licensee excluded
(3) Excludes 29 MHz available for a fourth licensee
(4) Excludes Hutchison 3 which is a 3G only operator

Figure 3.1 shows that:

- Spectrum has been assigned to between nine and 16 operators in the various circles of India. In a typical circle there might be four GSM and three CDMA operators offering service with a further four operators with spectrum assigned but yet to start operations
- In addition spectrum has been promised to a further six operators in some circles. Keeping these promises will mean that, as new 2G spectrum becomes available, it will go to the new operators rather than being used to increase the assignment of existing operators
- In other countries spectrum is typically assigned to three to five operators only.

On average there are 11.7 operators per circle in India with spectrum assigned and 15 with spectrum either assigned or promised. This compares with 4.0 operators with spectrum assigned in the benchmark countries. This difference is shown graphically for selected Indian circles in Figure 3.2.

Figure 3.2: Number of operators - graphical format



3.3 Spectrum assignment per operator

Figure 3.3 compares the average 2G spectrum assignment per operator in a typical Indian circle[3] with the assignment per operator in eight other countries of Asia and Western Europe. In this comparison we exclude from our analysis GSM operators, enumerate in Figure 3.1, to whom spectrum has been promised but not get assigned.

We can see that:

- The average operator in India has been assigned 5.5 MHz of spectrum with which to serve customers. The calculations and assumptions underlying this estimate are set out in Figure 3.4
- In contrast the average assignment per operator in the benchmark countries is to do the only a car right just under 22 MHz per operator
- The average Indian operator has an assignment which is 25% (5.5 MHz/22 MHz) of the spectrum available to the average operator in the benchmark country.

This major difference in spectrum assignment arises for two main reasons:

- The number of operators to whom spectrum is assigned is three times greater in India than in the benchmark countries
- The total amount of spectrum allocated to 2G cellular mobile services is around 20% less in India than in the average of the benchmark countries. Figure 3.5 illustrates.

[3] Based on six circles - Mumbai, Gujarat, Delhi, Punjab, West Bengal and Kalkata

Figure 3.3 2G spectrum per operator (2xMHz)

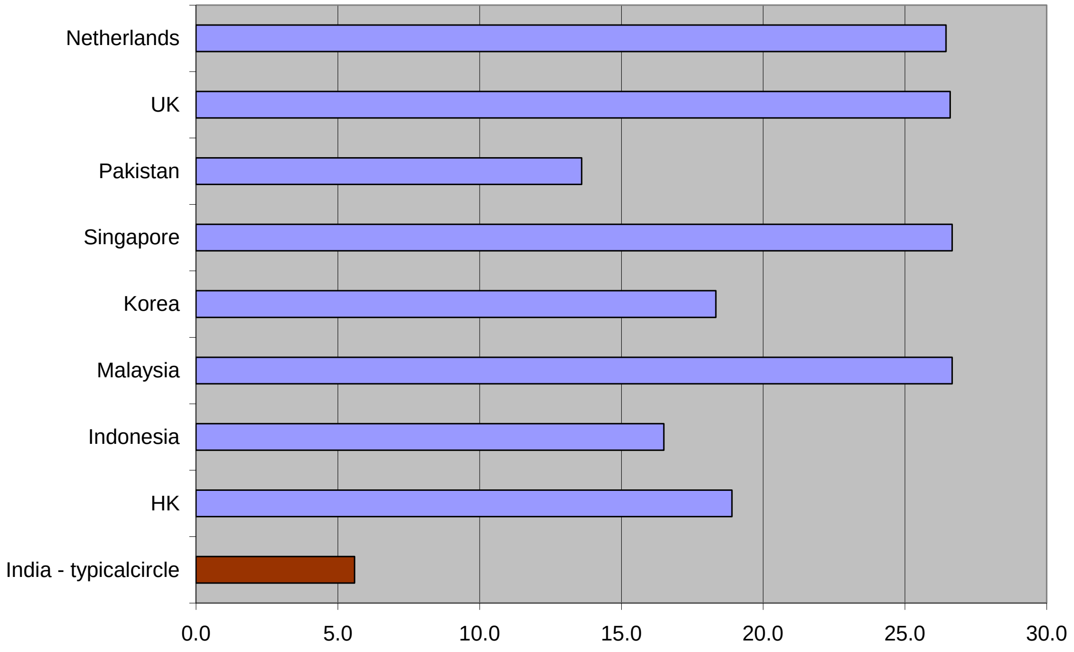
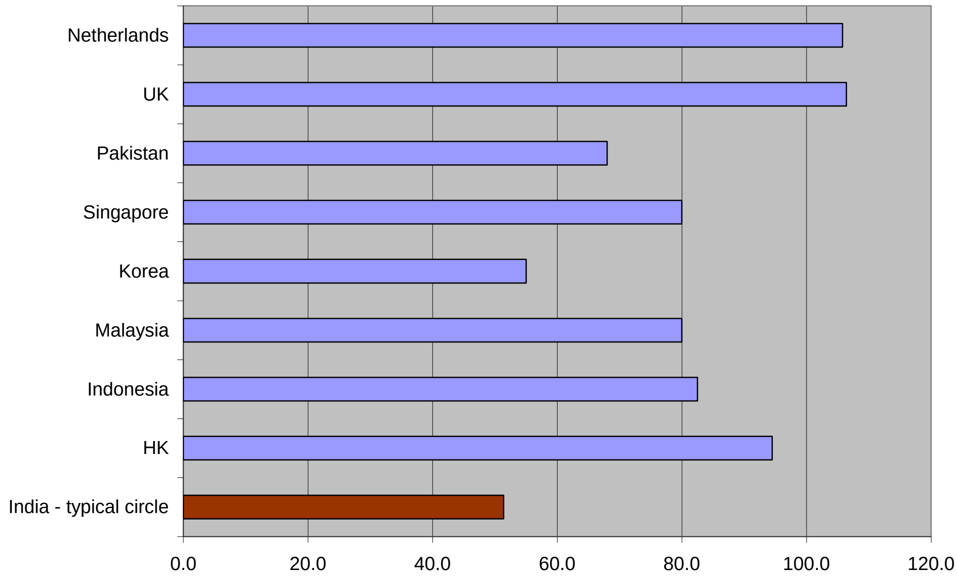


Figure 3.4: Estimating the spectrum assignments in selected circles (2x MHz)

Circle	*Assigned to GSM ops (2xMHz)*		*Assigned to CDMA ops (2xMHz)*		*total*	*total ops*	*MHz/op*
	Operational	*Non operational(2)*	*Operational (1)*	*Non operational(3)*			
Delhi (4)	40.4	13.2	15	2.5	71.1	11	6.5
Gujarat	32.2	13.2	11.25	2.5	59.15	11	5.4
Kolkata	34	13.2	11.25	2.5	60.95	11	5.5
Punjab	31.8	30.8	15	2.5	80.1	16	5.0
Mumbai	46	26.4	15	2.5	89.9	15	6.0
West Bengal	31	0	7.5	2.5	41	9	4.6
total	215.4	96.8	75	15	402.2	73	5.5

(1) Assumes all CDMA operators have same assignment as TTSL
(2) No of non operational GSM operators with spectrum assigned x 4.4 MHz
(2) No of non operational CDMA operators with spectrum assigned x 2.5 MHz
(4) See Annex D for details

Figure 3.5: Total 2G spectrum assigned by country (2x MHz)[4]



3.4 The technical spectrum efficiency of mobile operators in India

By comparison with operators in a subset of the benchmark countries, India's cellular operators function at significantly higher levels of technical spectrum efficiency. Figure 3.6 illustrates. It compares the spectrum efficiency achieved by operators in London, Singapore and Hong Kong with that achieved by GSM operators in the Mumbai and Delhi circles of India. In making the comparison we:

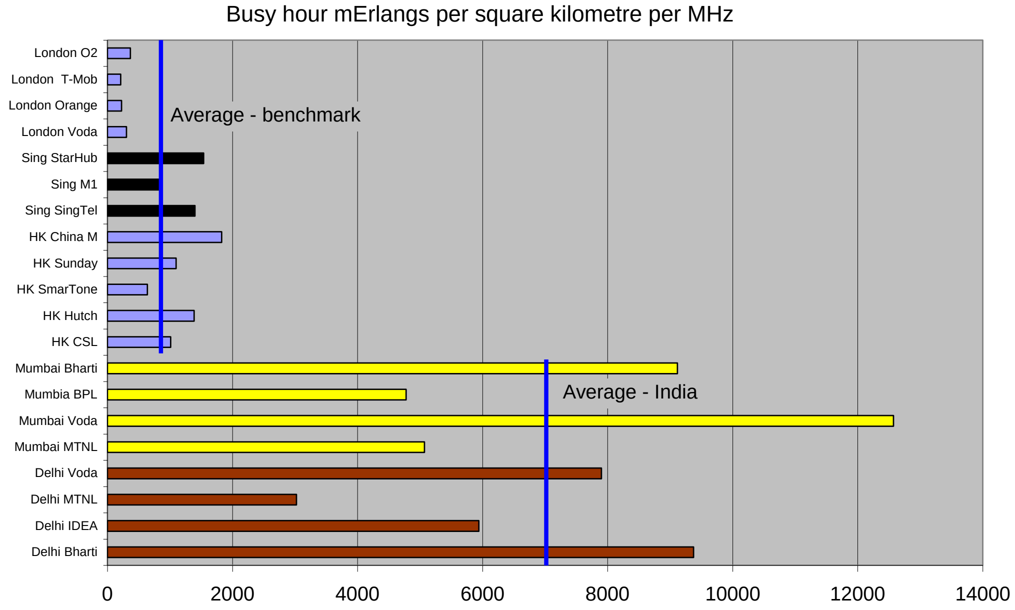
- Compare the spectrum efficiency of Indian GSM, rather than CDMA, operators with operators in the benchmark cities in order to provide a like-for-like comparison
- Use as our measure of spectrum efficiency the busy hour traffic as measured in Erlangs[5] carried per square kilometre per MHz. This is the spectrum utilisation index recommended by the ITU[6]
- Make the assumptions and calculations set out in Annex A to derive the estimates of Figure 3.6.

[4] Includes both operational and non operational networks. For GSM includes spectrum assigned at both 900 and 1800 MHz and for CDMA includes spectrum assigned at 850, 1700 and 1900 MHz in Korea, India and Hong Kong

[5] A voice channel occupied for 30 minutes per hour carries 0.5 (30/60 minutes) Erlangs of traffic

[6] *Definition of Spectrum Use and efficiency of a radio system*, ITU Recommendation SM-1046-2

Figure 3.6: Spectrum efficiency in the cities of India and other countries



The high level of spectrum efficiency of the Indian operators is, almost certainly, driven by the need to meet rapidly growing demand for cellular mobile services while using limited spectrum assignments. Spectrum efficiency might be generated in one of two ways:

- Through the deployment of a higher density of base stations per square kilometre
- Through the use of advanced technologies to maximise the traffic carrying capacity of the available spectrum.

Our analysis suggests that Indian operators use both approaches in order to increase spectrum efficiency.

First the operators tell us that the distance between macro cell sites in the dense urban areas, where traffic its heaviest, is now less than 100 metres in cities like Delhi and Mumbai. In contrast the distance between macro cell sites in the centres of the major cities of other countries is significantly greater[7]. See Section 4.3 for further discussion on this point.

Secondly our assessment of the deployment of advanced technologies to maximise spectrum capacity indicates that Indian operators are world leaders in the deployment of advanced technologies such as AMR and synthesised frequency hopping. Figure 3.7 illustrates.

Despite this deployment, it has been claimed that there is scope for GSM operators to substantially increase the capacity of their networks through the further deployment of advanced technologies. We have assessed the validity of this claim in Annex B and summarise our findings in Figure 3.7.

[7] For example around 200 metres in Istanbul, 300 metres in Munich and 350 metres in Berlin. See Vodafone presentation to the DoT Committee on 26/11/07

Figure 3.7: The deployment of advanced technologies in India

Technology	*Potential capacity gain*		*Costs*	*Deployment in India*[8]
	Claim	***Likely gain***		
Synthesised frequency hopping	No claim made	Substantial - provided 2x5 MHz or more spectrum is available to each operator[9]	Upgraded BTS and handsets	Widespread
Discontinuous transmission and power control	No claim made	Substantial	Upgraded BTS and handsets	Widespread
AMR codec	~150%	Up to 100% dependent on AMR handset penetration. Gains may be smaller if GSM half-rate is already used.	BTS software + AMR enabled handsets	Widespread
Micro cells and in building solutions	Substantial	Limited by the tight spectrum assignments in India which makes use of micro-cells as well as macro-cells difficult in many circles. IBS is primarily used for coverage in places like airports, high rise buildings etc.	Capex for micro cells	Limited
Six sector BTS	Up to 100%	Limited by cell characteristics. Also limited by the availability of antennas. Only 1 antenna vendor is available whose antennas are under trial.	Upgrades of antennae and masts	Trials
SAIC	50 to 60%	Uncertain but probably substantially less than claim	SAIC enabled handsets	Not yet
Synchronised networks	20%	Trials have yet to confirm	BTS upgrade and GPS cost for the sites.	Trials
DFCA	60 to 90%	Capacity gain uncertain while limited availability of DFCA handsets and network equipment	Network upgrade + DFCA enabled handsets	Trials planned to assess the gains

We find that:

[8] COAI presentation to the DoT Committee, 27 November 2007

[9] The gain from SFH is limited where the available spectrum is restricted. This is due to the need to hop over a minimum number of frequencies and because BCCH carriers cannot be hopped. An indicative 2 x 5 MHz is required to achieve a gain in practice (and this is dependent upon network configuration)

- The claims regarding the scale of the capacity increases possible with the use of various techniques are significantly overstated
- In the case of adaptive multi-rate (AMR) codecs this technique is already being deployed on a widespread basis by GSM operators in India
- The claims wrongly assume that the capacity gains from the different techniques are additive. This is simply not true in a number of cases. For example the gain achievable with DFCA is less if AMR has already been implemented.
- There are substantial costs associated with deploying advanced techniques - both for operators in terms of network upgrades and for end users in terms of new handsets
- It is important to be aware that deployment of some of the techniques, such as AMR HR, leads to lower quality of service
- The focus on spectrum optimisation techniques for 2G networks fails to take into account the fact that the efforts of the suppliers have now shifted from 2G optimisation to 3G deployment.

Those making these claims seek more intensive deployment of advanced techniques to maximise technical spectrum efficiency. But a better policy objective, as we argue in Section 4.1, is overall economic efficiency. From this perspective it only makes sense to deploy advanced technologies when this is a lower cost way of increasing capacity than adding further base stations. Indeed it is against the interests of the Indian economy to deploy them if this is not the case.

4 An economic assessment of the current spectrum assignment policy

4.1 The need to balance dynamic and allocative efficiency

In developing spectrum policy in India it is important for the Committee on Spectrum Assignment to maximise economic efficiency in the way scarce spectrum is assigned. This requires the Committee to balance:

- **Dynamic efficiency gains** which arise through increased competition between cellular operators. One obvious way to make such gains is to increase the number of operators. We look at how these gains change as the number of operators increases in Section 4.3
- **Allocative efficiency** in which the overall costs of the industry are minimised. There are two effects here:
  - First each new operator incurs fixed costs in terms of core network and IT systems, marketing, management and network coverage costs regardless of the scale of its operations. In particular in areas where cells are coverage limited[10] each operator must deploy the same radio access network, with the same number of cells as its rivals, if it is to offer competitive coverage. So total costs are lower with fewer operators. Such effects mean that there are economies of scale in the production of mobile services and, for a given level of competition and market size, each additional mobile operator raises the unit costs of the industry
  - Secondly the industry's combined radio access network costs rise in areas where the radio access network is capacity rather than coverage limited, as the number of operators increases and the amount of spectrum per operator decreases[11]. There are two main reasons:
    - The total number of cells required increases as the number of operators grows
    - Fragmentation of spectrum assignment has technical effects which reduce the traffic carrying capacity per MHz. These are discussed in Section 4.2 below.

So far policymakers have focused on maximising dynamic efficiencies by increasing competition. For example they have, over the past few years, assigned newly released spectrum to new entrants rather than to existing cellular operators so as to increase competition and make dynamic efficiency gains. At the same time they have tightened the criteria for assignment of additional spectrum to existing operators as illustrated in Figure 2.1. This means that existing operators must improve their spectrum efficiency if they are to handle new subscribers and additional traffic.

Policymakers do not so far appear to have taken any account of the need to maximise allocative efficiency as well. For example they have not yet considered the impact of restricting spectrum assignments to the existing operators on the industry's radio access network costs.

[10] i.e. the cell never reaches its busy hour capacity but is provided to serve customers wanting high levels of geographic coverage

[11] Assuming a fixed allocation of 2G spectrum in India

In effect the current spectrum assignment policy is designed to maximise the technical spectrum efficiency of the cellular industry rather than to maximise its overall economic efficiency. We believe it is important for the Committee on Spectrum Assignment to set itself the objective of maximising overall economic efficiency before developing detailed policies for assigning spectrum.

4.2 How would increased spectrum assignments per operator impact mobile prices in India?

What would happen to long run costs for cellular mobile services in India if the assignment of spectrum per operator were increased four fold, with corresponding reductions in the number of operators. Such changes reflect the difference between the benchmark average of just under 22 MHz per operator and the Indian average of 5.5 MHz per operator?

First there is an increase in the economies of scale in the deployment of cell sites:

- In areas where cells are coverage limited (i.e. the cell never reaches its busy hour capacity but is provided to serve customers wanting high levels of geographic coverage) each operator must deploy the same radio access network, with the same number of cells as its rivals, if it is to offer competitive coverage. So total costs are lower with fewer operators
- In areas where a cell is capacity limited more spectrum leads to an increase in busy hour capacity. So, although the total traffic carried by each operator rises as the number of operators falls, the number of cell sites required per operator does not increase, and the total number of cell sites required falls significantly. Given that a substantial part of the cost of deploying a cell site is not traffic sensitive, the total cost of deploying radio access networks falls as the number of operators shrinks and the unit costs of carrying traffic falls.

Secondly the increase in spectrum per operator increases the traffic handling capacity of each MHz in three main ways:

- The trunking efficiency of the cell site increases, allowing higher utilisation for a given grade of service. For example utilisation of a cell with a 15 voice channel capacity can reach 60% before the probability of a blocked call in the busy hour exceeds 2%. In contrast utilisation of a cell with 50 voice channel capacity can reach 80% for the same grade of service
- The first 2.4 MHz of spectrum allocated to GSM must be transmitted at full power in order for the broadcast control channel (BCCH) to function. This means that the reuse factor[12] for the spectrum is 12 or more. Additional spectrum can be subjected to power control technologies which enables significantly lower reuse factors. This means that an operator can carry significantly more voice traffic on the second and subsequent 2.4 MHz assignments of spectrum than on the first 2.4 MHz
- As the distance between sites decreases below 1 km[13] cell capacity is reduced because of increased interference. Up to 600 metres from a base station[14] signal strength reduces in inverse proportion to the square of the distance. At greater distances it falls much more rapidly - in inverse proportion to the fourth power of the distance. This means that when inter-cell distances

[12] The reuse factor measures the number of cells which require different frequencies before the spectrum can be reused. The higher the reuse factor, the lower is the traffic handling capacity of a given assignment of spectrum.

[13] Using 900 MHz spectrum

[14] With a height of 10 m

fall below 1000 metres there is increased interference between cells using the same frequency and network capacity is reduced. So in India, where inter-cell distances in urban areas are shorter than in countries with more generous assignments of spectrum per operator, this effect leads to a loss of capacity per MHz. Conversely capacity per MHz rises as inter-cell distances grow beyond 1000 metres.

The combined effect of these three factors is to substantially increase the traffic carrying capability of each MHz of spectrum as the assignment becomes more generous. For example Vodafone[15] estimates that:

- An operator with 2x6 MHz of spectrum can carry ***six*** Erlangs of traffic per MHz per sector while
- An operator with 2x12 MHz of spectrum can carry ***nine*** Erlangs of traffic per MHz per sector.

In other words there is a 50% increase in the traffic carrying capability of each MHz for the operator with the more generous assignment.

We estimate the net effect of these changes on the cost base of the Indian operators in Annex C. We assume that:

- The cost structure of the Indian operators reflects that reported in the PWC benchmarking study of Indian operators[16]
- 35% of traffic is generated in cells which are capacity rather than coverage limited
- 65% of capital expenditure and 90% of network operating expenditure are radio access network related.

Given these assumptions we calculate that increasing spectrum assignment to international norms[17] would lower the Indian industry's current cost base by 21% or Rs 117 billion per year (as estimated in Annex C). This cost reduction provides an estimate of the scale of allocative efficiency losses which the current spectrum assignment policy generates. It is worth noting that the estimate of Annex C is conservative in that it excludes the effects of many of the fixed costs per operator[18].

Were the Indian authorities to have pursued a policy of spectrum assignment to international norms, it is highly likely that this cost reduction would have translated into lower prices rather than be taken as increased profits, given the highly competitive nature of retail mobile markets. This would, in turn, have had the following positive effects on the Indian economy:

- Lower prices would have increased the level of usage by existing users and so increased consumer welfare. This is roughly equal to the cost reduction of Rs 117 billion per year calculated in Annex C
- Lower prices would have made mobile services more affordable to lower income groups within India - so leading to faster take-up of mobile services among the urban poor and the rural population of India

[15] *Spectrum policy - International trends*, Professor Mike Walker, 19/9/08

[16] *Indian GSM cellular benchmark study 2007*, PWC, 2008

[17] With a corresponding decrease in the number of mobile operators

[18] For example IT or core network costs

- The lower prices would have stimulated GDP growth. According to studies by Waverman[19] and Indepen[20] such accelerated growth could have a very substantial impact on the rate of growth of GDP in India. Waverman, for example, found that a 10% increase in mobile penetration would lead, in a low-income country like India, to an additional 0.6% per annum growth in GDP - net of any effect of GDP stimulating demand for telecommunications. A 21% decrease in price might, if we assume a subscriber price elasticity of -0.5, produce a 10% increase in demand and a 0.6% pa addition to GDP. Currently this is worth Rs 240 billion per year to the Indian economy.

The calculation set out above estimates the likely losses to the Indian economy from pursuing its current spectrum assignment policy. But how quickly can India reduce its losses by following a policy which allows industry consolidation in the mobile services sector? Clearly the situation cannot change overnight. But the mobile market in India is very dynamic. At 27% mobile penetration is a long way from saturation and mobile broadband is still in its infancy. In these circumstances changing to a more economically efficient spectrum assignment policy should have substantial and relatively rapid positive effects.

4.3 The impact of Indian spectrum policy on mobile competition

How effective has the Indian policy, of assigning spectrum to 10 to 12 operators per circle been in increasing competition in the Indian mobile market?

In general additional operators increase the intensity of competition. But there are good reasons to believe that the increase diminishes rapidly in the mobile markets as the number of operators increases beyond three or four. The evidence is as follows:

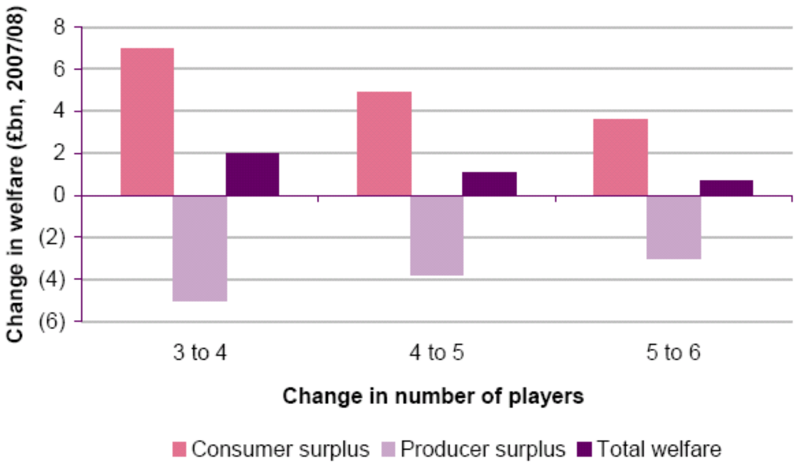
- A recent study by Ofcom in the UK[21] shows that the likely welfare gain from adding each additional mobile operator reduces rapidly as the number of operators increases beyond three. Figure 4.1 illustrates. It shows that the ***additional*** welfare gain from each **additional** operator halves as the number of operators increases. It is important to note that the calculations of Figure 4.1 ignore the cost increases, discussed in Section 4.2, which arise if additional operators lead to less spectrum per operator. We would not expect that the scale of welfare changes shown in Figure 4.1 would apply in India. But we would expect that the relative gains in welfare from increasing the number of operators would follow broadly the pattern shown in this figure.

[19] *The impact of telecommunications on economic growth in developing countries*, Waverman, Meschi and Fuss, March 2005, Vodafone Policy Paper 2

[20] *The economic impact of mobile services in Latin America*, a report for the GSMA, GSM Latin America and AHCIET by Indepen and Ovum, December 2005

[21] *Application of spectrum liberalisation and trading to the mobile sector*, Ofcom, Annex 10, September 2007. Ofcom built a model of oligopoly competition in which it calculated welfare gains and losses which resulted from reducing the number of mobile operators in the UK from the current five to three or four, and from increasing the number of operators by one. It assumed that market demand and costs were independent of the number of players. In each case a change in the number of operators generates a change in the Cournot equilibrium within the oligopoly market model. As the number of operators increases or decreases, so the profit maximising position of each player changes. This then produces changes in the total producer and consumer surpluses.

Figure 4.1: The welfare effect of increasing the number of mobile operators



- Most countries in the world have licensed three to five mobile operators as illustrated in Figure 3.1
- Most European countries attempted to expand the number of mobile operators by issuing one additional licence when assigning 3G spectrum in 2000 and 2001. But in many cases the extra licence was either not taken or handed back before operations started and the number of operators remained at three or four. For example Telia Sonera returned a 3G licence in Denmark and Tele2 did the same in Norway, while in France there were no acceptable offers for the additional 3G licence offered there. Such behaviour is evidence of limits on the efficient number of operators in mature markets rather than in expanding markets such as that of India
- In many countries we have seen consolidation in the number of mobile operators in the past few years. In the Netherlands the number of operators reduced recently from five to four; in the US the number of nationwide cellular operators reduce from six to five with the merger of Sprint and Nextel; in Korea SKT acquired the fourth mobile operator to gain access to more spectrum; and in Hong Kong the number of GSM operators recently reduced from six to five[22] when CSL and New World merged
- Now we are seeing further consolidation in the number of operational radio access networks. For example in Spain Orange and Vodafone now share 3G radio access network, as do Hutchison 3G and T-Mobile. These developments are driven by a need to roll out a higher density of base stations to provide 3G services in a cost efficient manner.

As the number of mobile operators in a circle increases it is even possible that the intensity of competition will decline. The mechanism for this to happen is as follows:

- Increasing the number of operators decreases the amount of spectrum available to each operator (for a fixed allocation of 2G spectrum)
- The operators must deal with additional traffic by increasing the density of base stations and by deploying advanced technologies to increase spectrum utilisation

[22] These number exclude the CDMA operator which was licensed recently, primarily to provide roaming services for CDMA end users from mainland China

- There are limits on the extent to which the density of base stations can be increased which is reached once inter-cell spacing falls below a certain minimum distance. There are two limiting effects:
  - As cells become smaller, the individual buildings and streets have a major impact on the shape of the cell boundary. Planning for contiguous coverage becomes more difficult
  - The precise location of base stations becomes very important. For cells with diameters of several hundred metres there is a wide range of possible sites which are near optimal. For cells with diameters of less than this minimum distance there is often only one location where deployment is effective. If this location is not accessible then there are significant losses in efficiency
- Several network operators have reached this minimum separation distance in the dense urban areas of the big cities of India
- The consequence of reaching this limit is to weaken competition. The most successful operator reaches the limit first. Its network then suffers from unavoidable congestion in the dense urban areas and its customers churn to less successful rivals.

In theory the current rules in India, which link spectrum assignment with subscriber numbers, might deal with this problem. In practice there is an increasing number of operators sharing a (near) fixed amount of spectrum and such increases in assignments have proved very difficult to make.

So the net effect of this mechanism is to handicap the operator offering the best services and lowest prices and to reward its weaker rivals. This weakens the competitive process. The incentive for a mobile operators to strive to outperform its rivals, which is at the heart of the competitive process, is substantially weakened if a mobile operator knows that its success will lead to an unavoidable reduction in network performance.

4.4 Implications for the development of mobile broadband

Our analysis so far has focussed on the impact of current spectrum policy on mobile ***voice*** services. But this policy also impacts the likely development of mobile ***data*** and broadband services in India.

Effective deployment of mobile broadband and associated data services is likely to be of central importance to the economic development of India over the next 10 years:

- A new generation of mobile phones, like the Apple i-phone, has led to a massive jump in the use of the Internet from mobile terminals. Some studies[23] indicate 50-fold greater use of such phones for Internet searches than of traditional mobile terminals
- Analysts now project massive growth in the use of mobile broadband services worldwide - initially through use of high-speed packet access (HSPA) over W-CDMA and subsequently through the deployment of long term evolution (LTE) technologies using more advanced modulation techniques. Cisco's projections for worldwide and Asia Pacific growth in mobile data traffic are shown in Figure 4.3. They suggest that mobile data traffic will more than double in each of the next five years

[23] See for example http://www.macworld.co.uk/ipod-itunes/news/index.cfm?rss&newsid=20446

- Mobile data applications are of central importance to economic development. For example in a study for the CTIA[24], Indepen and Ovum estimated that productivity gains from mobile data services would generate increases in consumer welfare for the US of $63 billion per year by 2010 - compared with $106 billion per year for voice. When combined with the economic gains which mobile access to the Internet might generate, this suggests that mobile data services will more than double the economic benefits now generated by mobile voice services
- Use of mobile broadband for Internet access and data services will be especially important in India where the roll-out of fixed networks is limited, especially outside the main cities. At the moment for example there are nearly 300 million mobile subscribers in India but fewer than 40 million wireline subscribers and fewer than 4 million broadband[25]users[26]. We might expect the benefits from mobile data and mobile broadband in India will also double the economic benefits from mobile services, if somewhat further into the future than the USA. These benefits are likely to be very large. In a study for the GSMA and the regulators of South America, Ovum and Indepen[27] established that the consumer surplus from voice mobile services is typically 1.4 times revenues. This suggests the current consumer surplus from mobile voice services in India is:

Rs1067 billion pa = Rs762 billion pa[28] x 1.4

Figure 4.3: Projection of mobile data traffic to 2012

Year	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*
Global Traffic in petabytes per month	7	26	65	153	345	744	1,496
Asia Pacific in petabytes per month	1	4	10	25	56	118	241

Source: Cisco Visual Networking Index, 2008

The current Indian policy of assigning cellular mobile spectrum to (say) 12 operators per circle would, if applied to spectrum used for mobile data services, make the effective deployment of mobile broadband in India very difficult. There are three main points to consider.

First the ITU has identified 2x60 MHz of spectrum at 2.1 GHz to 3G services using W-CDMA. So it would be possible, assuming the allocated spectrum is free, to assign 2x5 MHz to each of the 2G operators in most of the Indian circles. But most analysts believe that a 2x10 MHz or 2x15 MHz assignment per operator is required for effective deployment of 3G services - with one set of 5 MHz carriers used for macro-cells, another for micro-cells and a third for in-building coverage[29]. Only with this increased assignment is it possible to deal effectively with the traffic hotspots of the kind which airports and shopping malls generate. Thus while 2x5MHz may be a starting point, it is important to identify and reserve additional spectrum for 3G to ensure effective deployment of 3G in India..

[2424] *The impact of the US wireless telecommunications industry on the US economy*, Lewin and Entner, CTIA , September 2005

[25] Over 256 kbit/s

[26] *The Indian Telecom Services Performance Indicators*, TRAI, June 2008

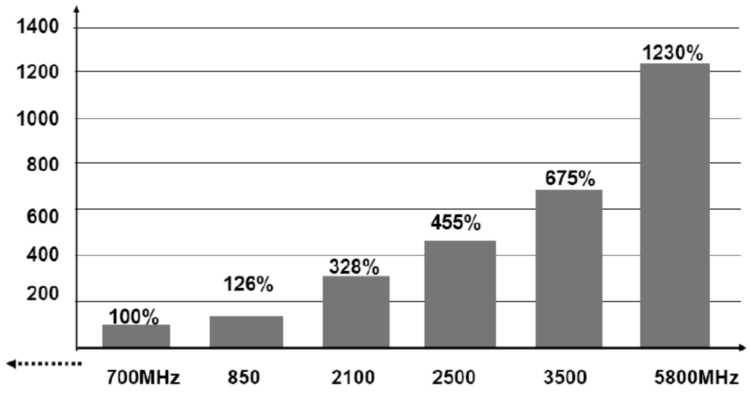
[27] The economic impact of mobile services in Latin America, A report for the GSMA, GSM Latin America and AHCIET ,David Lewin and Susan Sweet, December 2005

[28] From TRAI data. See Annex C for the estimate

[29] In dense urban areas like London for example UK operators are already deploying their second 3G carrier.

Secondly the 900 MHz spectrum is important for the deployment of mobile broadband services in India - both to allow the cost-effective rollout of 3G services outside the main cities and for improving in-building coverage within them. As Figure 4.4 shows deployment at 850 or 900 MHz rather than at 2.1 GHz cuts the investment required for 3G infrastructure by 60% or more. Making additional 2x5 MHz assignments of 900 MHz spectrum for 3G is not possible as nearly all the spectrum in this band has already been assigned for 2G services. Even for the existing operators, these allocations are limited, making it difficult to refarm their allocation for 3G use.

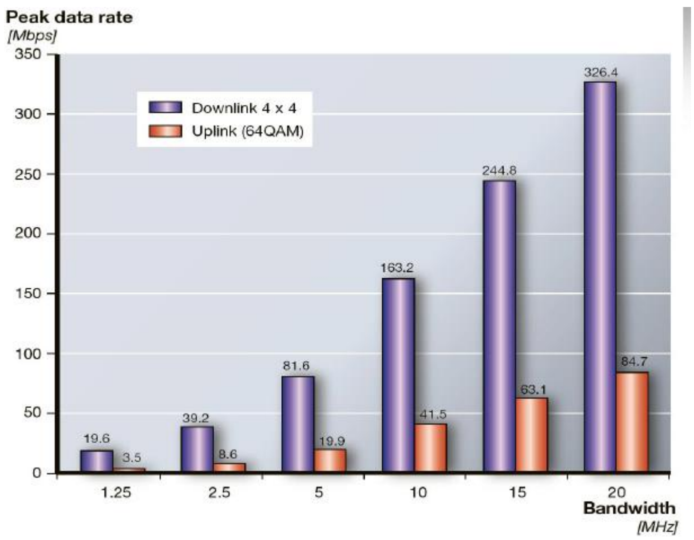
Figure 4.4: Relative capital expenditure for 3G infrastructure for given assigned spectrum



Source: Emerging Technologies and Their Implications on Regulatory Policy, Ericsson, ITS Biennial Plenary, June 2008

Finally, looking further ahead, the ITU has identified 2x70 MHz at 2.6 GHz for mobile technologies such as LTE. This band could be important to the development of 3G in India. However we understand that the Government is planning to auction this band for TDD use. If this were to be done, it could have a serious adverse impact on the growth of 3G, since there would then be no roadmap prescribed beyond 2.1GHz.

Figure 4.5: Peak data rate as a function of available bandwidth



Source: Emerging Technologies and Their Implications on Regulatory Policy, Ericsson, ITS Biennial Plenary, June 2008

5 Conclusions and recommendations

5.1 Conclusions

We can summarise the findings of the previous chapters as follows:

1. To date spectrum assignment policy in India has been focused on ensuring that there is sufficient spectrum available for new entrant mobile operators and on ensuring that the existing operators maximise technical spectrum efficiency.

2. As a result:

- There are ***three times*** more mobile operators with spectrum assigned in a typical circle in India than in other countries
- The average Indian operator can use only about ***one quarter*** of the spectrum available to mobile operators elsewhere in the world
- When measured in terms of busy hour traffic per square kilometre per MHz in the dense urban areas, mobile operators in India are generating typically ***eight times*** more capacity in their use of spectrum than operators elsewhere in the world.

3. Policymakers in India have so far ignored the need to balance conflicting requirements for:

- Strong competition in the mobile market. This is served, up to a point, by increasing the number of mobile operators in each circle ***and***
- Maximising allocative efficiency by minimising the sum of the fixed costs of the mobile operators plus the radio access network costs of the industry as a whole. This is served by restricting the number of operators.

4. Increasing the spectrum per operator four fold to reach international norms, together with a corresponding consolidation of the industry would reduce industry costs by at least 21%. This would, almost certainly, lead to lower prices, with consumer welfare benefits in excess of Rs 117 billion per year under 2008 market conditions[30]. Such price cuts would also make mobile services more affordable to India's rural population and accelerate take-up by new subscribers. This in turn would generate further economic benefits by stimulating GDP growth.

5. Increasing the number of mobile operators per circle should, in theory, increase competition in the mobile markets. But the available evidence suggests that, in most countries, the benefits of additional competition diminish rapidly once the number of operators exceeds four. In addition there are reasons to believe that the intensity of market competition might even diminish, if and when spectrum shortages lead to unavoidable congestion in dense urban areas for the most successful operators.

6. Effective deployment of mobile broadband and associated data services is likely to be of central importance to the economic development of India over the next 10 years. However the current Indian policy of assigning small quantities of spectrum to multiple operators per circle would, if applied to spectrum used for mobile data services, make the effective deployment of mobile broadband in India very difficult. If current spectrum policies and industry structures persist, Indian operators will not be

[30] We assume a competitive market here so that the economic surplus generated by the cost reduction flows though to Indian consumers in the long term

able to deliver the same high-speed mobile broadband at the same low unit costs as operators in the countries which are India's main economic rivals. This could generate very substantial economic losses for India, running into many hundreds of billions of Rupees pa.

7. The current limited assignments per operator at 900 MHz would cause specific problems for the roll-out of mobile broadband services in rural India. There is now growing recognition in other parts of the world that it is important to refarm 900 MHz spectrum for deployment of HSPA and LTE technologies if mobile broadband is to be deployed in rural areas in a cost-effective way. The fragmentation of assignment in India presents a significant barrier to such re-farming.

Overall the analysis set out above leads us to one simple conclusion – ***the spectrum available per operator is too little and the number of cellular operators too many for an economically efficient industry in India.***

5.2 Recommendations

For the Committee on Spectrum Assignment, and the Government which appointed it, to deal with the problems listed in Section 5.1 we make the following recommendations. They are based on the principle that it is for the market to decide on the optimal number of operators rather than for that number to be decided by government.

Recommendation 1: spectrum assignment rules should be designed with the objective of maximising the overall economic efficiency of the Indian cellular mobile industry. This requires the Committee to consider issues of allocative efficiency in the assignment of spectrum as well as the technical spectrum efficiency of the operators.

Recommendation 2: in developing spectrum assignment rules which meet this new objective, the Committee should consider the long-term development of the industry. It should develop rules which, when implemented, will allow the industry to develop economically efficient 3G services as well as 2G services.

Recommendation 3: no further mobile operators should be licensed. The analysis of Section 5.1 provides strong evidence that the number of operators with spectrum is already too high for economic efficiency. This recommendation is designed simply to prevent the situation getting worse.

Recommendation 4: as further spectrum becomes available it should be assigned to existing operators using a market mechanism such as spectrum auctions.

Recommendation 5: the relevant authorities should enable consolidation between cellular operators using market mechanisms. They might for example allow non-operational operators with assigned spectrum to sell themselves to existing operational players and to transfer the full spectrum assigned to them to the buyer without penalty. This would, almost certainly, create politically unpopular windfall gains for the shareholders of these operators[31]. But the economic gains to India from allowing such trades are likely to be substantially greater.

Recommendation 6: the relevant authorities should remove any barriers to consolidation within the industry between existing operational players. To ensure an acceptable level of competition in the markets the authorities might establish a trigger for an enquiry by the Competition Authority if any acquisition leads to one player holding a market share within a circle of more than (say) 40%.

[31] These might be offset through windfall taxes or some kind of claw-back mechanism.

Recommendation 7: the relevant authorities should allow and encourage mobile operators to share radio access network - whether at the level of site sharing, mast sharing or sharing of the entire radio access network back to the base station controller (or radio network controller in the case of a 3G network)

Annex A Comparison of spectrum efficiency

This annex sets out our assumptions and calculations of spectrum efficiency for operators in Delhi and Mumbai and compares them with the same measure for operators in Hong Kong, Singapore and central London. We first estimate subscribers per square kilometre per MHz as set out in the table below. Subscriber numbers are as at July 2008.

Delhi

Geographic area = 1, 483sq kms[32] of which 783 sq kms is rural and 700 sq kms is urban.

Operator	*% market share*	*Number of subscribers ('000)*	*Total amount of 2G spectrum*	*Number of subscribers per km2*	*Subs / km2/ MHz*
Bharti Airtel	-	4101.439	2 x 10 MHz	2766	138
IDEA Cellular	-	2078.498	2 x 8 MHz	1402	87.60
MTNL	-	1641.338	2 x 12.4 MHz	1107	44.63
Vodafone Essar	-	3456.827	2 x 10 MHz	2331	116.55

In Delhi we assume that 80% of the subscribers are in the urban areas. Then the revised figures are:

Operator	*% market share*	*Number of subscribers ('000)*	*Total amount of 2G spectrum*	*Number of subscribers per km2*	*Subs / km2/ MHz*
Bharti Airtel	-	3281.151	2 x 10 MHz	4687	234.37
IDEA Cellular	-	1662.798	2 x 8 MHz	2375	148.46
MTNL	-	1313.070	2 x 12.4 MHz	1876	75.64
Vodafone Essar	-	2765.462	2 x 10 MHz	3951	197.53

[32] Wikipedia http://en.wikipedia.org/wiki/Delhi

Mumbai

Geographic area = 603 sq kms[33]

Operator	*% market share*	*Number of subscribers ('000)*	*Total amount of 2G spectrum*	*Number of subscribers per km2*	*Subs / km2/ MHz*
MTNL	-	1895.91	2 x 12.4 MHz	3144	126.78
Vodafone Essar	-	3789.888	2 x 10 MHz	6285	314.25
BPL Mobile	-	1439.956	2 x 10 MHz	2388	119.40
Bharti Airtel	-	2528.790	2 x 9.2 MHz	4194	227.92

Hong Kong

Geographic area = 1,054 sq kms.

In December 2007 a Hong Kong Government[34] report stated there were 10.6 million subscribers and 152% market penetration. Of these 2 million were 3G service customers. We therefore assume that there are 8.6 million subscribers on the 2G networks. We then use market share data to estimate subscriber numbers.

Operator	*% market share*	*Number of subscribers ('000)*	*Total amount of 2G spectrum*	*Number of subscribers per km2*	*Subs / km2/ MHz*
CSL / New World	30	2580	2 x 31.5 MHz	2448	38.85
Hutchison	26	2236	2 x 19.9 MHz	2121	53.30
SmarTone	12	1032	2 x 19.9 MHz	979	24.60
Sunday (PCCW)	12	1032	2 x 11.6 MHz	979	42.20
China Mobile	20	1720	2 x 11.6 MHz	1632	70.34

Singapore

Geographic area = 577 sq kms.

[33] Wikipedia http://en.wikipedia.org/wiki/Mumbai

[34] http://www.gov.hk/en/about/abouthk/factsheets/docs/telecommunications.pdf

We assume 116% market penetration[35], 5.6 million subscribers[36], and the market shares in the table below to make the estimates shown in the table below.

Operator	% market share	Number of subscribers ('000)	Total amount of 2G spectrum	Number of subscribers per km2	Subs / km2/ MHz
SingTel	42	2352	2 x 29.1 MHz	4076	70.04
MobileOne (M1)	26	1456	2 x 30.8 MHz	2523	40.96
StarHub	32	1792	2 x 20.2 MHz	3106	76.87

London

The Greater London Urban Area had an estimated population of 8,505,000 in 2005 and covered a geographic area of 1,623.3 square kms[37]. The market penetration is 116.5%[38]. Note the figures are optimistic as a percentage of the subscribers traffic will now be carried over the 3G networks and '3' is not included as it does not have a 2G network.

Operator	% market share[39]	Number of subscribers ('000)	Total amount of 2G spectrum	Number of subscribers per km2	Subs / km2/ MHz
Vodafone	23.6	2338.365	2 x 23.6 MHz	1441	30.52
Orange	22.1	2189.740	2 x 30 MHz	1349	22.48
T-Mobile[40]	20.8	2060.932	2 x 30 MHz	1270	21.16
O2	28.4	2813.964	2 x 23.6 MHz	1733	36.73

Busy hour Erlangs

To convert from subscribers to busy hour Erlangs we assume that:

35 Research and Markets

36 This figure may be on the high side as does not differentiate between 2G and 3G

37 Wikipedia http://en.wikipedia.org/wiki/Greater_London_Urban_Area

38 http://www.cellular-news.com/story/30548.php

39 http://www.cellular-news.com/story/30548.php

40 Includes the market share for Virgin as Virgin's traffic carried by T-Mobile

- busy hour Erlangs per subscriber are the same in Mumbai and Delhi as in India as a whole
- busy hour Erlangs per subscriber are the same in central London as in the UK as a whole.

We then use the following estimates of busy hour Erlangs per subscriber.

Country	*BH milli-Erlangs per subscriber*	*Source*
India	40	COAI
UK	10	COAI
Singapore	20	Merrill Lynch mobile matrix 2005 (1)
Hong Kong	26	Merrill Lynch mobile matrix 2005 (2)

(1) 290 minutes per sub per month in Singapore vs 145 in UK. So 20 = 10 x 290/145

(2) 380 minutes per sub per month in HK vs 145 in UK. So 26 = 10 x 380/145

Annex B Deployment of advanced technologies for spectral efficiency in India

Introduction

Since the first GSM networks were deployed more than 15 years ago the technology has been continuously enriched and enhanced. Throughout this period several capacity expanding technologies have been developed including frequency hopping (both base band and synthesised), discontinuous transmission, and the adoption of micro- and pico-cells. These have provided very significant increases in network capacity, and the standard continues to be developed with further capacity enhancing features.

The GSM operators in India have been at the forefront in adopting advanced capacity enhancing techniques. Not only are they among a limited number of operators world wide to adopt synthesised frequency hopping and the tight frequency reuse that this makes possible but they also operate with some of the smallest outdoor sites and the highest traffic densities per MHz of spectrum anywhere in the world. Figure B1 summarises the key capacity maximising technologies adopted by Indian GSM operators, and shows how they continue to trial new techniques.

Figure B1: Deployment of advanced capacity maximising technologies by Indian GSM operators

	Op. 1	Op. 2	Op. 3	Op. 4	Op. 5	Op. 6
Synthesised frequency hopping	✓	✓	✓	✓	✓	✓
Tighter frequency reuse	✓	✓	✓	✓	✓	✓
Discontinuous transmission & power control	✓	✓	✓	✓	✓	✓
AMR codec	✓	✓	✓	✓	✓	✓
Micro-cells & in-building solutions	✓	✓	✓	✓	✓	✓
Antenna hopping	Trial	×	×	Trial	×	×
Synchronised network	Trial	Trial	×	Trial	×	×

Source: TRAI recommendations, dated 29 August 2007

It should be noted that the gain from synthesised frequency hopping is limited where the available spectrum is restricted[41]. This is due to the need to hop over a minimum of three frequencies and

[41] Further, the gain from discontinuous transmission and power control relies on the use of frequency hopping.

because the BCCH carriers cannot be hopped. An indicative 2 x 5 MHz is required to achieve a gain in practice (and this is dependent upon network configuration).

Despite the deployment of capacity enhancing technologies identified above, it has been suggested that further techniques could be introduced which would lead to a substantial increase in network capacity without the need for additional spectrum. The specific claims made are summarised in Figure B2 and reviewed below.

Figure B2: Summary of capacity enhancing technologies and claimed capacity gains.

Technology	Claimed capacity enhancement
Six sector BTS	Up to 100%
Adaptive multi-rate codec	~150%
Single antenna interference cancellation	50% to 60%
Synchronised network	20%
Dynamic frequency and channel allocation	60% to 90%

Six sector BTS

Six sector BTSs are claimed to provide twice the capacity of 3 sector BTSs and this would appear logical as the same area is covered by twice as many transceivers. However, there are practical issues which reduce the capacity gain that can be achieved.

The existing GSM networks use a variety of antenna masts which have been deployed as the networks have grown and matured. Some of these masts are not suitable as 6 sector sites because of limitations of space, weight or wind loading and this clearly reduces the overall capacity gain that can be obtained in this way. In addition, there will necessarily be overlaps between the adjacent BTS sectors. This will cause some increase in the intra-cell carrier to interference (C/I) level and will increase the number of intra-cell handovers, both of which will reduce the overall cell capacity. We also understand that there are a limited number of vendors offering this solution.

Upgrading 3 sector BTSs to 6 sectors can increase network capacity but clearly the overall gain will be significantly less than 100%, and will depend upon the specific details of each site within the network. There are also associated costs to be balanced against the gain.

Adaptive multi-rate codec (AMR)

The adaptive multi-rate codec dynamically adjusts its voice encoding rate to match the radio propagation conditions giving an improved voice quality for a given C/I (in comparison with the enhanced full rate codec). This in turn can be translated into an improved voice quality for subscribers or used to provide additional capacity by operating the network at a worse C/I level (which allows tighter frequency reuse).

If used solely to provide additional capacity AMR can provide significant improvements provided the penetration of AMR enabled handsets is high. Nokia Siemens give the gain as 100%[42]. Several GSM operators have deployed AMR and we understand that the current penetration of AMR enabled handsets in India is around 50%. The maximum capacity gain achievable today will therefore be less than 50% . This will rise as the penetration increases with time, though commercial realities may demand that the operators use some of the gain to improve call quality across their networks.

AMR requires both BTSs and handsets to be AMR enabled, and there is therefore an associated deployment cost particularly for legacy networks.

AMR also supports half rate coding. In principle this could provide a doubling of capacity since each time slot can support two rather than one voice call. However, AMR half rate coding has to operate at a higher C/I than does AMR full rate coding and this effectively negates the capacity gained. It should also be noted that the half rate codec is more susceptible to acoustic impairments such as background noise and this has limited its take up by operators. A recently developed option is to use advanced network based voice quality enhancement solutions[43] to enable both AMR full rate and half rate codecs to operate satisfactorily at lower C/I levels and thus provide additional capacity. We are not aware of any deployments at present but this approach may be used to provide increased capacity in the future.

Single antenna interference cancellation

Single antenna interference cancellation (SAIC) is a technique in which handsets use training sequences within transmission bursts to map instantaneous RF channel characteristics. The handset then uses this information to subtract or reduce the interfering signals[44]. It can be used either to give call quality improvements or to allow operation with higher levels of interference which in turn means tighter frequency reuse and increased capacity. SAIC can be used with synchronised or non-synchronised networks although the improvements are higher with a synchronised network.

Simulations performed during the standardisation of SAIC showed capacity gains of 50% to 60% based on a synchronised network and 100% penetration of SAIC enabled handsets. However, trials conducted by Philips and Cingular[45] measured a capacity gain of around 20% and Nortel[46] has suggested that the total gain from SAIC in a synchronised network would be around 25%. We understand that Ericsson have indicated theoretical gains of 8% to 10% with a 50% penetration of SAIC handsets and that Nokia have stated that the “benefits are still being ascertained”.

It should also be noted that SAIC only provides capacity gains on the down link. Increasing capacity on the down link beyond that on the up link does not of course increase the overall network capacity for voice calls.

[42] “WCDMA frequency refarming. A leap forward towards ubiquitous mobile broadband coverage”, Nokia Siemens Networks brochure, 2008.

[43] See http://www.ditechnetworks.com/.

[44] Various algorithms can be used, and are proprietary to different vendors.

[45] “GSM Gets A Lift From Single-Antenna Interference Cancellation Software”, Electronic Design Online, 19 July 2004. Note that the measurements were made in pre-commercial network.

[46] “GSM spectral efficiency”, Nortel case study, 23 May 2006.

The capacity gain possible with SAIC terminals is uncertain with more recent estimates indicating significantly smaller gains than those claimed by Reliance. In addition, we understand that rather few GSM handsets are SAIC enabled. We therefore conclude that:

- SAIC cannot as yet be relied on as a capacity enhancing technique
- Gains that may eventually be achieved cannot today be reliably estimated.

The increase in processing power required in a SAIC handset will also lead to some price penalty, and may have a negative impact on battery life.

Synchronised network

This technique synchronises the base station transceivers across a network to accurately align the transmission of time slots. This allows the synthesised frequency hopping process to further reduce the level of inter-cell interference and enables a tighter reuse of frequencies. Simulations show capacity gains of 10% to 20%. Vendors, however, have reported that trials have "not been positive" and it is therefore premature to assume that these gains will be realisable in the real operating environment.

It is also important to note that synchronisation equipment is required at all base stations and that a significant cost would therefore be involved in any upgrade. Furthermore, synchronisation typically relies on GPS signals making synchronised networks vulnerable to US Government decisions.

Dynamic frequency and channel allocation (DFCA)

The concept behind dynamic frequency and channel allocation is that information on path loss and signal quality is continuously collected across the network. This information is then used to allocate calls to the frequency and time slot which optimises the C/I both for that call and for the network overall. This technique will require a fully synchronised network and substantial further changes to the network as well as upgraded handsets. As with AMR and SAIC a high penetration of appropriately enabled handsets will be needed to realise the full capacity gains.

The literature on DFCA is limited with capacity gains estimated at between 25% and 50% and no published results from trials. To the best of our knowledge it is offered by very few suppliers, and in few handsets. This means that at present DFCA is commercially a high risk option and, with low handset penetration, one that may take a significant period to realise useful capacity improvements.

Summary

Figure B3 brings together the results of the above review. It shows that:

- Practical issues involved in the proving and deployment of new technologies have not been taken into account in making claims for capacity enhancements.
- In all cases the claimed capacity enhancements are either overstated or cannot be fully realised today. The SAIC and DFAC technologies will take some time to come to maturity.

- There are costs associated with all the technologies. In most cases a hardware upgrade is required and in the case of AMR a hardware upgrade is necessary with legacy BTSs.

Figure B3: Summary of the practical issues related to the deployment of some GSM capacity enhancing technologies and the gains that can reasonably be assumed by a commercial operator today.

Technology	Claimed capacity enhancement	Comment
Six sector BTS	100%	Overall capacity gain achieved will be significantly less than 100% since it cannot be deployed in all cells and is dependent on the specific details of each BTS site. Costs: Antennas and mast upgrade.
Adaptive multi-rate codec	~150%	Capacity gain dependent on network upgrade and handset penetration, estimated at <50% today. Costs: BTS software upgrade & AMR enabled handsets.
Single antenna interference cancellation	50% to 60%	Cannot yet be relied on as a capacity enhancing technology and the potential gain has yet to be fully clarified. Requires commensurate capacity enhancement on the uplink to maximise capacity gain for voice. Costs: SAIC enabled handsets.
Synchronised network	20%	Trials have not yet confirmed the capacity gain. It is premature to conclude on the capacity advantage that will be achieved in practice. Dependent on continuous GPS availability. Costs: BTS upgrade.
Dynamic frequency and channel allocation	60% to 90%	Uncertainty over capacity gain and limited availability presently make this a high risk option for any operator. Costs: Network upgrade and DFAC enabled handsets.

It is important to note that several of the technologies discussed above are only effective in a frequency hopping network. Thus the capacity gains considered above will only be available where the operator has an adequate amount of spectrum to usefully deploy frequency hopping.

It should also be noted that the interaction between the different capacity enhancing technologies can be complex and gains measured for individual technologies cannot necessarily be simply summed. For example, the gain achievable with DFCA is less if AMR has already been implemented. Furthermore, as shown in Figure B1, the Indian GSM operators have adopted the key capacity maximising technologies. They also continue to trial the latest advances but it should be noted that the industry focus has now moved on to 3G and 4G (WCDMA and LTE) technologies and further development of the GSM standard and equipment may be limited.

Annex C Allocative efficiency gains from additional spectrum

This annex estimates the reduction in radio access network costs which would result if:

- The spectrum assignment to Indian operators were increased four fold to reflect the difference between the current average assignment in India of 5.5 MHz per operator and the international benchmark of 22 MHz per operator and
- The number of operators with spectrum assigned were reduced from 12 to 3

There are two main effects (assuming GSM technology). ***First*** there is an increase in the economies of scale in the deployment of cell sites:

- In areas where cells are coverage limited (i.e. the cell never reaches its busy hour capacity but is provided to serve customers wanting high levels of geographic coverage) each operator must deploy the same radio access network, with the same number of cells as its rivals, if it is to offer competitive coverage. So total costs are lower with fewer operators
- In areas where a cell is capacity limited more spectrum leads to an increase in busy hour capacity. So, although the total traffic carried by each operator rises as the number of operators shrinks, the number of cell sites required per operator does not rise, and the total number of cell sites falls significantly. Given that a substantial part of the cost of deploying a cell site is not traffic sensitive, the total cost of deploying radio access networks falls as the number of operators grows and the unit costs of carrying traffic reduces.

Secondly there are gains in the traffic which each MHz of spectrum can carry. These effects are discussed in Section 4.2. Vodafone has modelled these effects and estimates that halving the spectrum per operator[47] reduces the traffic handling capacity per MHz by 33%. Using extrapolation from this result we assume in our model that a four-fold reduction in spectrum produces a 40% reduction in traffic capacity per MHz. This is clearly a conservative assumption when modelling the likely scale of the changes involved[48].

The results of the modelling a set out in Figure C1. The key assumptions are as follows:

- 35% of traffic is generated in capacity rather than coverage limited cells. This estimate was provided by GSM operators in India
- There is a 50% utilisation of the cells in coverage limited areas in the busy hour
- The percentage of the cost of a cell which is traffic sensitive varies with its traffic handling capacity according to Figure C2. These estimates are based on cost modelling of European networks. We have no reason to believe that the percentages would differ significantly in India.

[47] From 2x12 MHz to 2x6 MHz

[48] Vodafone have estimated such a change might lead to a 43.5% reduction in traffic capacity per MHz

Figure C1: The impact on RAN costs of quadrupling spectrum per operator

Scenario	1	2	
Assumptions			
No. of operators	12	3	
Spectrum assigned (MHz)	60	60	
Spectrum per operator (MHz)	5	20	Calculated
BH traffic per circle	1000	1000	Arbitrary units
% in capacity limited cells	35%	35%	COAI estimate
RAN costs for coverage limited cells			
Capacity per cell in coverage limited areas	c	4c	Proportionate to spectrum per operator
Utilisation of cells in coverage limited cells	50%	50%	Reasonable assumption
% cell costs which are traffic sensitive	27%	60%	50% of value when cell at capacity. See Fgiure C2
Total cost per cell/fixed cost per cell	1.38	2.50	With cell at 50% utilisation
Traffic in coverage limited areas	650	650	Calculated
Traffic per operator	54	217	Calculated
No of cells per operator	V	V	For competitive coverage by each operator
Total no of cells	12V	3V	
Total cost of coverage limited cells	12Vx1.38f	3Vx2.5f	
Total cost of coverage limited cells	**16.6Vf**	**7.5Vf**	
RAN costs for capacity limited cells			
Capacity per cell in capacity limited areas	c	4c	Proportionate to spectrum per operator
Adjusted capacity per cell	0.6c	4c	After adjusting for lower traffic per MHz with 5MHz assignment
Fixed cost per cell pa	f	f	
% cell costs which are traffic sensitive	31%	75%	With cell at capacity. See Figure C2
Total cost per cell/fixed cost per cell	1.45	4.00	With cell at capacity
Traffic in capacity limited areas	350	350	
Traffic per operator	29	117	
No of cells per operator	29/0.6c	117/4c	Traffic per operator/Adjusted capacity per cell
No of cells per operator	48/c	29/c	
Total no of cells	12x48/c	3x29/c	
Total no of cells	576/c	87/c	
Total cost of capacity limited cells	576x1.45f/c	87x4.0f/c	
Total cost of capacity limited cells	**835f/c**	**348f/c**	
Total RAN costs			
Total cost of coverage limited cells (A)	**16.6Vf**	**7.5Vf**	
Total cost of capacity limited cells (B)	**835f/c**	**348f/c**	
Ratio (A/B)	16.6Vf/[835f/c]		Calculated
Ratio (A/B)	0.020Vc		Calculated
Ratio (A/B)	1.86		COAI estimate - 35% of RAN costs are in capacity limited areas
So value for Vc	1.86/0.020		
So value for Vc	93	93	
Total cost - all cells	[16.6Vc+835]f/c	[7.5Vc+348]f/c	A+B
Total cost - all cells	[1544+835]f/c	[697+348]f/c	A+B
Total cost - all cells	**2379f/c**	**1045f/c**	A+B
Ratio of RAN costs - Scenario1/Scenario 2	**2.28**		

Figure C2: The % of cell site costs which are traffic sensitive

Traffic per cell (1)	0	0.5	0.6	1	2	4
Fixed cost per cell	50	50	50	50	50	50
Traffic sensitive cost	0	18.75	22.5	37.5	75	150
Total cost per cell	50	68.75	72.5	87.5	125	200
% costs traffic sensitive	0%	27%	31%	43%	60%	75%

(1) With one unit of traffic represeting a 15 channel cell

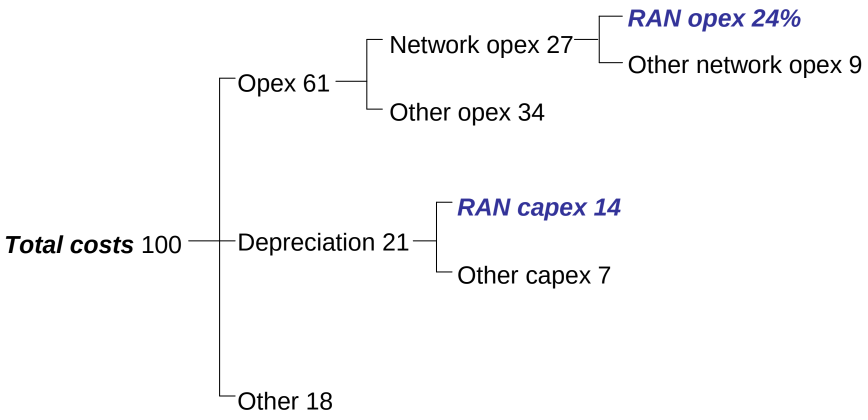
Using Figure C1 we estimate that reducing the number of operators from 12 to three (and increasing the spectrum assignment per operator from 5MHz to 20 MHz) leads to a 56% reduction in the total cost of radio access network deployment.

What proportion of the total costs of the cellular operators is represented by the provision of radio access networks? Using the PWC report on the costs of the Indian GSM operators[49] gives us the cost

[49] *Indian GSM cellular benchmark study 2007*, PWC, 2008

split of Figures C3, if we assume that radio access networks represent 65% of both network opex and capex. Figure C3 indicates that 38% (24% + 14%) of the total costs of the mobile operators are radio access network related.

Figure C3: The cost breakdown of the cellular mobile operators in India



Source: *Indian GSM cellular benchmark study 2007*, PWC, 2008

Other cost of 18 units covers licence fees, debt financing, and bad debt

Using this figure the cost savings from increasing spectrum assignment to international norms is:

21% = 56% (the RAN cost saving) x 38% (the percentage of radio access network costs)

The TRAI[50] provide estimates of the revenues generated by GSM and CDMA operators for Q1 2008 as follows:

- Rs 143 billion for the GSM operators
- Rs 24 billion for the CDMA operators

Assuming 40% per annum growth in revenues during 2008 gives us total cellular operator revenues of Rs 762 billion and costs of Rs 549 billion[51].

We can now estimate the cost reduction which moving from 12 to three operators and from 5 MHz per operator to 20 MHz per operator gives, assuming the 2008 cellular mobile cost base in India, as:

Rs 117 billion pa = Rs 549 billion x 21%

This estimate provides an indicator of the scale of the loss of allocative efficiency which results from the current spectrum assignment policy.

In summary:

- Increasing the spectrum per operator four fold and reducing the number of operators four fold leads, in capacity limited areas, to a 56% reduction in RAN costs
- This cost reduction in radio access network costs translates into an 21% reduction in total operating expenditure for mobile operators in India

[50] *Indian telecom service performance indicators*, TRAI, June 2008

[51] Assuming 28% earnings before tax as reported in the PWC benchmark study

- This 21% cost reduction is currently worth Rs 117 billion pa.

Annex D Current spectrum assignments in Delhi

Category of operator	*Operator*	*Assignment (MHz)*
Operational GSM operators at 900 MHz	Bharti IDEA MTNL Vodafone	2 x 8 2 x 6.2 2 x 6.2 2 x 8
Operational GSM operators at 1800 MHz	Bharti IDEA MTNL Vodafone	2 x 2 2 x 1.8 2 x 6.2 2 x 2
Operational CDMA operators at 850 MHz	RCOM TTSL MTNL	2 x 5[52] 2 x 5 2 x 5
GSM operators with spectrum assigned but not operational	Aircel RCOM Swan	2 x 4.4 2 x 4.4 2 x 4.4
CDMA operators with spectrum assigned but not operational	Swan	2 x 2.5
Total assigned spectrum		**2 x 71.1**
Number of operators with spectrum assigned		**11**

52 Assumed same as TTSL