Report on the 2010 Value of Spectrum in the 1800 MHz Band

January 30, 2011

Introduction

1. This is a report on the value of spectrum in the 1800 MHz band and is the result of a study entrusted to us by the Telecom Regulatory Authority of India.

2. In its Recommendations of May 2010 on "Spectrum Management and Licensing Framework" (hereinafter referred to as 'the Recommendations'), the Telecom Regulatory Authority of India (TRAI) established that as per the UAS/CMTS license conditions, the contracted spectrum is 6.2 (respectively,5 MHz) for GSM (respectively, CDMA) technologies. It also recommended that all the service providers that have spectrum beyond the contracted spectrum should pay excess spectrum charges at the 'current price', prorated for the period of the remaining validity of their licence subject to a minimum of seven years. Keeping in view the limited amount of spectrum available for meeting the requirement of different service providers, the TRAI has indicated that it is not feasible to auction the spectrum in 800, 900 and 1800 MHz bands. Thus, it is necessary to determine the value of spectrum.

3. TRAI also noted that the price of spectrum can be last said to have been discovered through the bidding for the 4th Cellular licenses in the year 2001 Thereafter, this discovered price has been applied for pricing of all subsequent licenses. However, TRAI believes that the market conditions have since changed significantly, and the price discovered in the year 2001 needs to be modified to reflect the present value. In Para 3.73 of the Recommendations, TRAI noted that *"the issue to be deliberated is the price at which the spectrum should be given in future. This price will also form the basis for the calculation of one time levy on the operators with excess spectrum".*

4. Having considered different options, TRAI was, in Para 3.81 of the Recommendations, of the opinion that, pending further deliberations on the subject, 3G prices may be adopted as the price for 2G. It accordingly recommended, in para 3.82 of the Recommendations, that "*3G prices be adopted as the "current price" of spectrum in the 1800 MHz band. At the same time, Authority is separately initiating an exercise to further study the subject and would apprise the Government of its findings."*

5. In order to study the various issues involved in determining the price of 2G spectrum in the 1800 MHz band, the Authority requested us to undertake a study to evaluate the value of the spectrum and give our independent opinion. The issue for determination posed to us was to determine the value of 1800 MHz spectrum. We were also provided with all the responses received from industry stakeholders in this regard.

6. To understand the various issues involved, we examined the responses of various stakeholders on the subject. Since the issues involved in determining the value of spectrum are both technical and commercial in nature, we decided to study these two aspects separately. Accordingly, in Chapter I, using reasonable engineering models and parameters, we compare the traffic carrying capacity of spectrum in the 1800 MHz and 2100 MHz bands. In Chapter II, we use two different economic modelling approaches to determine the value of spectrum beyond 6.2 MHz in the 1800 MHz band which can then be used to draw comparisons with the 3G auction price of spectrum in the 2100 MHz band.

Chapter-I

A Technical Analysis of the Capacities of 2G and 3G Mobile Cellular Communication Technologies

1.1 This chapter is aimed at making a technical analysis of the spectrum in the 1800 MHz band and 2100 MHz band in respect of their traffic carrying capacities. For this analysis we make the reasonable assumption that 3G technologies will be deployed in the 2100 MHz band while 2G technologies will be used in the 1800 MHz band. Thus the analysis in this chapter presents the impact of the technological features of 2G and 3G mobile communication technologies on the voice and data traffic that they can carry.

A. Background

1.2 Mobile cellular communication technologies divide the service area into cells. Further, each cell is divided into sectors. We analyse the spectrum available per cell and the consequent voice and data traffic that can be supported in each cell. While cellular communication technologies are classified in an `evolutionary' manner, e.g., 2G, 3G, etc., there is considerable variety in the choice of technologies available in each of these generations and also the combinations in which these technologies can be deployed and used. The actual combinations are usually driven by socio-economic factors and legal obligations. Like in any reasonable analysis, we need to make some assumptions about the technologies that are deployed and the service levels provided. Here, we assume the following. In the deployment of 2GGSM technologies, the available spectrum is used for voice, data over GPRS protocol and data over EDGE protocol. For 3G, WCDMA or HSPA technologies carry the traffic. We will also be making assumptions about other operating parameters and these will be stated whenever relevant.

1.3 The traffic in a cellular communication network arises in many different ways and in different combinations. To present a reasonable analysis, we will make suitable assumptions about the traffic mix; we will consider several combinations of voice and data users. As we will see later, many technologies are available to make the bit rate to carry voice adaptive, and hence variable. Taking into account all possible combinations in which the different rates will actually be used is impossible in any modelling exercise. We will thus consider a simplified model that will help us obtain the necessary insights into the nature of the beast. An assumption that is made in obtaining a quantitative estimate is that an average rate can be specified for the voice calls and that the calls always use this average rate. It should be noted that data users exhibit significantly higher variations in their demands on instantaneous bandwidths. However, for the purposes of analysis, we assume that they too have a fixed busy hour average rate and a time average can be associated with each user, and a reasonably defined ensemble average can be associated with each of the time averages of the active users. The rates we use represents this ensemble average. We remark that in practice the time average requirement of a user can manifest in many different combinations of peak rates and idle times between consecutive accesses. In this note, we do not analyse these different combinations.

1.4 Assumptions like in the preceding paragraph will be made for most of the parameters that we will be using in all the analyses. We reiterate that the instantaneous parameters associated with the different users is going to exhibit significant variations in the same cell over time and also across cells at any time instant. What we use is an educated guess of the average value that is obtained via sources in literature and also in discussions with the network operators, wherever available.

1.5 Corresponding to each cell and also each service area, we will also analyse the dimensioning of the backhaul equipment, primarily connectivity from the base stations. A brief note on this is then provided. Finally, we provide a note on the propagation characteristics of the 2100 MHz band vis-a-vis the 1800 MHz which can impact the size of each cell and hence the number of BTS and the corresponding equipment.

B. Traffic Carrying Capacities

1.6 We will first consider networks in the 1800 MHz band using GSM technologies. The calculations below are for spectrum with 6.2 MHz, 8 MHz and of 10 MHz. Much of the calculations are approximations and are not meant to be an exact and a rigorous academic exercise. This is reasonable because many of the assumptions of the model are approximations.

1.7 In all our analysis we assume 5 cell reuse pattern, 3 sectors per cell, 2% blocking for voice traffic, 0.05 Erlang per voice user and an average rate of 10 Kbps per data user.

a. GSM in the 1800 MHz band

1.8 We begin by considering voice service with 6.2 MHz band in a service area. This corresponds to 31 carriers each with 200 KHz bandwidth. Assuming a reuse factor of 5, each cell is allocated about 6 carriers or 48 timeslots. With 3 sectors per cell, there will be approximately 16 slots per sector. Of these, 2 will be used for BCCH and other control channels. This gives us 14 timeslots per sector. For 2% blocking, this would correspond to a voice capacity of about 8.2 Erlangs per sector or 24 Erlangs per cell. Assuming a busy hour load of 0.05 Erlangs per subscriber, this would correspond to a busy hour subscriber density of about 480 subscribers per cell.

1.9 In GPRS, data is transmitted in slots that are not used by voice. Carrying 8.2 Erlangs with 14 timeslots essentially means that, on the average 8.2 out of the 14 slots are used. This means that the remaining 5.8 slots can be used for data traffic. Thus, with this voice load, an average of approximately 5.8 slots or 70 Kbps is available for data of which about 53 Kbps can be assumed to be the effective data rate. Assuming a peak user rate of 10 Kbps per user, this will support 5.3 active data users per sector along with 8.2 Erlangs of voice traffic at 2% blocking probability.

1.10 Increase the spectrum to 8 MHz and we get: a total of 40 carriers with 8 carriers per cell; 64 timeslots per cell; and 21 timeslots per sector; 18 slots available for voice traffic supporting 11.5 Erlangs per sector or about 35 Erlangs per cell. Further increase the spectrum to 10MHz and we get: 50 carriers, 10 carriers per cell; 80 timeslots per cell; and 27 timeslots per sector; 24 slots available for voice traffic supporting 16.6 Erlangs per sector or about 50 Erlangs per cell.

1.11 The above is a standard textbook analysis and assumes that carriers are statically allocated to the sectors. See [Kumar et al, 2008] for details of such analyses. In a typical implementation, a subset of the carriers are dynamically allocated to each sector. This results in Erlang capacities that will be significantly higher. Furthermore, newer developments and implementation practices allow fora significantly more efficient reuse of the spectrum and we analyse that case below.

1.12 In practice significantly higher spectral reuse is achieved by using techniques like frequency hopping of the carriers that introduce suitable frequency diversity. Interference cancellation techniques provide additional capabilities and together they provide greater flexibility in the management of overall frequency plan. See for e.g, [Halonen et al, 2003] for additional information on these techniques. These techniques allow significantly tighter reuse of the dynamic channels. This in turn implies that a larger number of frequencies become available in each sector of each cell. This is illustrated by an example implementation that demonstrates the effect of these techniques. We continue with the assumption of 5 cell reuse group. The fifteen sectors in each reuse group are statically allocated one carrier each which will carry the control channels. (A static allocation for the control channel, sometimes called the BCCH channel, is necessary to enable the mobiles to contact the network.) The remaining channels are dynamically allocated.

1.13 With 6.2 MHz spectrum, 15 of the 31 carriers need to be statically allocated to each sector of the reuse group. Of the remaining 16 carriers we can assume most of them are available for use in each cell, say about half of these dynamic carriers. This means that, on an average, each sector has about 3 carriers in addition to that used for the control channel. (Note that with sufficient resources up to 16 carriers can be made available in each cell.) This yields about 30 timeslots per sector supporting about 22 Erlangs per sector at 2% blocking probability.. In addition, each sector can support about 72 Kbps of effective cumulative data rate for data users per sector. With 8 MHz spectrum, we can assume about 5 carriers per sector are available. This will yield about 37 timeslots for voice after accounting for control channels. This can support about 28 Erlangs (560 subscribers) and 8 active data users per sector. With 10 MHz spectrum, we can assume about 7 carriers per sector are available. This will yield about 50 timeslots for voice after accounting for control channels. This can support about 40 Erlangs (800 subscribers) and 10 active data users per sector.

1.14 The effect of these dynamic carriers when all of the dynamic carriers are used in each cell can also be illustrated via calculations like above. With 6.2 MHz, each sector gets an average of 5.3 dynamic carriers. This corresponds to about 45 timeslots to carry voice traffic which in turn can carry about 35 Erlangs of voice traffic per sector. Calculating like before, this will leave room for 9 active data users per sector at 10 Kbps per user. Similarly, with 8 MHz spectrum, if all the dynamic carriers are used in each cell, then we get about 8 dynamic carriers per sector. This yields about 67 timeslots for voice after accounting for control channels. This can support about 56 Erlangs of voice traffic and about 10 active data users per sector at 10 Kbps per user. With 10 MHz spectrum, if all the dynamic carriers are used in each sector, then we get about 12 carriers per sector. This yields about 90 timeslots for voice after accounting for control channels. This can support about 76 Erlangs and about 12 active data users per sector.

1.15 In most networks, there will be significant marginal gains if GSM-HR (half rate coding) or AMR (adaptive multirate coding) is employed. Of course, the actual gain depends on the availability of AMR handsets and also the location of the mobile device in relation to the cell tower. Other spectrum saving techniques are also available. There are many modes of operation in each of these techniques and it is rather difficult to quantify the effect of these without an extensive survey or by making strong modeling assumptions.

1.16 A simple mechanism that we choose to use here is to capture the overall effect of all of the techniques by estimating the additional slots available for voice with the use of these techniques. We can assume an additional 25% slots from all of these techniques and we can then redo the above calculations. We will consider the case where half the dynamic carriers are available in each cell. This will give us 37 timeslots with 6.2 MHz spectrum (supporting 28 Erlangs per sector), 46 timeslots (supporting 36 Erlangs per sector) with 8 MHz and 63 timeslots (supporting 53 Erlangs per sector) for 10 MHz spectrum.

1.17 In the above, it is assumed that data is carried through GPRS. The analysis with EDGE can become a bit more complex and further simplifications will need to be made. The two primary difficulties are that multiple data rates are possible and EDGE services will require that an entire carrier be devoted for data in each sector. Here is an example calculation. Assume 3 carriers per sector; further assume 1 or 2 carriers for data and obtain the corresponding Erlang capacity for voice. Further, since 384 Kbps is the peak rate, we can assume an average of about 150 Kbps. This is because the deterioration of the signal is faster than linear with distance from the cell center and the mobile nodes that are further from the base station will experience significantly lower data rates. The voice load that can be supported can be calculated using methods similar to the above for the remaining carriers in each sector.

1.18 If 10 MHz is available with 7 carriers per sector, we can reserve 1-3 carriers for data and the remaining can be used for voice and calculations carried out along the lines as above. For example, with 2 carriers reserved for data, a total of 300 Kbps is available for EDGE users, about 37 timeslots are available for voice traffic. This will support 28 Erlangs of voice traffic and still leave about 80 Kbps for GPRS based data users.

1.19 In the above, we have not accounted for link errors for the data traffic. At the periphery of the cell this can become substantial. We have also not accounted for possible reservation of channels for handoffs which may typically be done to reduce the call dropping probability. It is also possible to further increase the capacity significantly by using a very high reuse factor, say of 1 cell. Of course, this can lead to severe service degradation and may violate regulatory guidelines.

b. WCDMA in the 2100 MHz Band

1.20 Let us now consider 3G systems. We will first consider WCDMA based systems. We assume a reuse factor of one with the entire 5 MHz being available in each cell. It is to be noted that as the number of active transmitters in a cell increases the `self interference' and the interference from the neighbouring cell also increases and causes a `loading' in the cell. What this means is that the total data rate available to the users decreases with increasing number of active users. To put it another way, the data rate available per user decreases faster than linearly in the number of active users.

1.21 To analyse the load carrying capacity, we need to specify a loading factor that determines the SIR for the transmissions. (Typically, the interference is an order of magnitude higher than the receiver noise and we can ignore the later in simplified calculations.) Higher loading factors contribute to higher interferences from within the cell and also on the neighbouring cells. Thus increasing the loading factor reduces the coverage area of a cell because the interference level becomes high. Another issue that needs to be considered is that the uplink and the downlink calculations need to be performed separately. This is because of the asymmetry in the traffic pattern of data users: higher download rates than upload rates. We also assume perfect power control.

1.22 A simple mechanism to calculate the data rate that is possible in a cell would be as follows and is from [Glisic, 2003].

$$E_b/N_0 = \frac{W}{\alpha_j R_j}\frac{P_j}{I_{total} - P_j}$$

$$P_j = \frac{1}{1 + (W/(E_b/N_0)R_j\alpha_j)}\, I_{total}$$

$$L_j = \frac{P_j}{I_{total}} = \frac{1}{1 + W/((E_b/N_0)R_j\alpha_j)}$$

In the above *W* is the chip rate, *Rj* is the data rate of user *j*; E_b/N_0 is the ratio of the energy per bit in the modulated waveform, *Pj* is the transmission power of user *j;* I_{total} is the total received power and *Lj* is the load due to node *j;* and *αj* is the activity factor of user *j.*

1.23 Assumingthat all *N* mobile nodes have the same data transmission rate of *R* we can approximate the `loading' on a cell as

$$\begin{aligned} \eta &= \frac{E_b/N_0}{W/R} N\alpha(1+\theta) \\ N &= \eta W \frac{1}{R\alpha(1+\theta)(E_b/N_0)} \end{aligned}$$

Here θ is the ratio of the interference from the neighbouring cells to that from the local cell. Typical values for η are 0.5-0.75 and for θ it is 0.5. Other numericals will be, *W* = 3:84 Mcps; α = 0:6 and E_b/N_0 = 5.0 dB – 8.5 dB. The coding rate will determine the *R* [Holma et al, 2003].

1.24 It is important to note that with lower speech coding rates, a higher $E_b/N_0$is required to ensure that the quality of speech does not deteriorate to unacceptable levels. Thus the lower rates cannot be exploited by all the users but by only those that experience a good channel. A sample of the suggested $E_b/N_0$for different speech coding rates, obtained from [Holma et al, 2003], is shown in the table below.

Table: 1.1 $E_b/N_0$for different speech coding rates

AMR bit rate	12.25 Kbps	7.95 Kbps	4.75 Kbps
Downlink E_b/N_0	7.0 dB	7.5 dB	8.0 dB

1.25 As is to be expected, in any cell there will be a mix of different rates in use and each of them will require a different E_b/N_0 for acceptable voice quality. Following the average parameter model, we use the following values for the average of the different parameters: E_b/N_0= 7.0 dB and R = 10 Kbps. We will use α = 0.6 and η = 0.6. The value of η is based on the value used in the published literature. We have chosen a slightly higher value of α to account for the protocol overheads. With these parameters, the system can support a maximum of 51 active users with an Erlang capacity of 40 per sector.

1.26 If data users are to be accommodated like in the GSM system, i.e., provide spare capacity to the data users, simplistic calculations would yield the following. In the first system above we would be able to carry about 9 active users of data with an average rate of 6 Kbps and in the second system, we would be able to carry about 11 users using an average rate of 5 Kbps each. These rates are available at the same E_b/N_0as that used for voice. For data this is not acceptable because it would lead to higher packet errors and hence lower throughput for the data users. Thus we need to make our calculations differently by accounting for the higher E_b/N_0that the data users expect.

1.27 Another issue that we need to address in analysing the effect of the presence of data traffic is the asymmetric nature of the data traffic - typically, download volumes are significantly higher than upload volumes. We first analyse the uplink from the MS to the BTS using a method similar to the above and the following assumptions: 80% of the users will be generating voice traffic and the remaining 20% will be generating data traffic. Also, datatraffic will require $E_b/N_0$of 10 dB while voice can continue with 7.0 dB. The average voice rate would be 10 Kbps with an activity factor of 0.6 while the average data rate would be 10 Kbps after accounting for the activity factor, i.e., in our calculations we will take it to be 1.

1.28 Note that in GPRS, the data users can use the idle slots that are unused by the voice traffic, this is not the case in WCDMA. The data users will contribute to the `loading' of the cell and hence affect the overall capacities.

1.29 Of the N active users, 0.8N will generate voice traffic and 0.2N will generate data traffic. We use

$$\begin{aligned}
\eta &= \frac{(E_b/N_0)_v}{W/R_v}(0.8N)\alpha_v(1+\theta) + \frac{(E_b/N_0)_d}{W/R_d}(0.2N)\alpha_d(1+\theta) \\
&= \frac{(1+\theta)N}{W}\left(0.8\alpha_v R_v(E_b/N_0)_v + 0.2\alpha_d R_d(E_b/N_0)_d\right) \\
N &= \frac{\eta W}{(1+\theta)} \; \frac{1}{0.8\alpha_v R_v(E_b/N_0)_v + 0.2\alpha_d R_d(E_b/N_0)_d}
\end{aligned}$$

to obtain *N*: If we assume η= 0.65 and α_d = 1; we get *N* = 38; of which about 31 are active voice users and 7 are active data users.

1.30 If we consider the data users to be limited by downlink rates, then the calculations will be different. Theorthogonality factor will need to be subtracted from the total interference term (1 + θ); i.e., we need to replace (1 + θ) by (1 + θ - θ_d) where θ_d is the downlink orthogonality factor. To keep the calculations simple, we will make the approximation $\theta_d \approx \theta$. Now *N* will be determined by

$$N = \eta W \frac{1}{0.8\alpha_v R_v (E_b/N_0)_v + 0.2\alpha_d R_d (E_b/N_0)_d}$$

Using the values from the preceding calculations, we have *N*=57 of which about and 46 are active voice users and 11 are active data users at 10 Kbps average rate. With an average data rate of 20 Kbps, *N*=39 of which 32 are active voice users and 7 are active data users at 20 Kbps average rate.

1.31 Since an important aspect of 3G services is the support of data traffic, it would be reasonable to also consider the case when the user download data rates are significantly higher, say 50 Kbps. In this case, N= 20 of which about 16 are active voice users and 4 are active data users. We believe that the assumption of a higher data rate for the data users is not unreasonable because the expectation from 3G services is of a higher data rate. In fact, 50 Kbps may be a lower estimate on the expectation because the promised peak rates are in the range of a few Mbps.

1.32 We also remark here that WCDMA allows soft blocking which can provide an additional capacity. This improvement though is marginal at high Erlangs, or equivalently for large values of N in the latter calculations. Further, we are also assuming that all the available codes are being used and that the system is not “code-limited”.

c. Use of HSPA and Implications

1.33 HSPA will use a range of advanced technologies, e.g., MIMO, advanced modulation and channel coding techniques to increase the peak data rate to significantly higher values. These technologies can push the highest rate higher but do not assure that all nodes operate at this high rate. A useful peak data rate of 4.3-10.8 Mbps (or 0.86-2.16 bps/Hz) is possible. One can expect that the average rate, especially in India and during the early phases of deployment, will be significantly lower because of the following reason.

- If the cell size is large, (and many operators may have to have it large because of cost implications) the users at the edge will experience lower SINRs and hence lower data rates. Although such users do not get high data rates, they contribute significantly to the loading factor. There may be significant amount of operational engineering expertise that will be needed to make the best use of all the capabilities. This can only be acquired by an operator in due time.

Thus in the medium term, it is reasonable to believe that the traffic carrying capacity in HSPA systems is similar to that of the WCDMA systems and is as calculated previously.

C. Equipment Dimensioning

1.34 The dominant determining factor and the cost of operations for cellular service systems would be the BTS and BSC equipment, MSC and the associated equipment like TRAU, VLR, HLR, AuC, SMSC, EIR and IWF.

1.35 In addition to the above we should also include the trunking costs from the BTS to the BSC and from the BSC to the MSC. In areas of high subscriber density (and hence high BTS density), these costs can become substantial, especially for 3G because they need to have the capacity to carry higher data rates. For example, each carrier in GSM will generate about 100 Kbps of voice and a possible overhead of 20 Kbps. With a 6.2 MHz spectrum, in the worst case, each cell has about 19 carriers which can generate about 2.3 Mbps. With 8 MHz, there will be at most 28 carriers in a cell which will require about 3 Mbps uplink from the cell site. With 10 MHz, when all the dynamic carriers are used in a cell, there will be about 38 carriers giving us at most 4.5 Mbps per cell. These correspond to 1-2 E1 circuits from each cell site. For 3G services, this number will be substantially higher because each cell can generate at least 10 Mbps. This corresponds to at least 5 E1 circuits. With higher bit rates of HSPA, this requirement will be even higher.

1.36 The nature of the equipment is similar in both technologies. Of course, there will be substantial difference in the costs in terms of both capital and operational expenditure for both these technologies. While there are some GSM BTSs that can be `upgraded' to provide WCDMA some others will need to replaced.

1.37 We now comment on the equipment for additional spectrum allocation in the 1800 MHz band. Additional spectrum provides additional carriers and existing equipment can be used to use the additional spectrum. Only additional transceivers may need to be added. In deploying 3G services, at least at the BTS, new equipment has to be deployed or the old equipment will need to be upgraded.

1.38 Thus, we believe that for a cell servicing similar customer densities, there will be a significant cost advantage to 2G systems in the 1800 MHz band than for the 3G Systems in the 2100 MHz band.

d. Propagation characteristics

1.39 Cell sizes, or equivalently inter BTS distances, are determined by the following two factors.

- The need to cover a large area.
- The need to support a subscriber density with a specified blocking probability.

Propagation characteristics determine the size of the cell in areas of low caller density and low traffic. These areas will be called `coverage limited areas.' Such areas are more likely to be present in the rural areas than in the urban and semi urban areas.

1.40 There are many propagation models for rural, urban and semi urban environments. As we mentioned earlier, it is rather hard to select the combinations of those that will effectively capture the relative advantages of one over the other. As before, we consider simple models and we find that propagation models suggest that the 2100 MHz band will have an additional attenuation of about 1.8 dB compared to the 1800 MHz for attenuation exponent of 2.5. See, for example, [Ferreira et al, 2006]. For the same transmission power and also the same SINR, this corresponds to a reduction in the coverage area by about 15% for the 2100 MHz spectrum when the cell size dimensioning is dominated by the propagation characteristics and not by the load carrying capacity.

1.41 While the average attenuation differences are like above, a large number of measurement studies indicate that the variance is substantial and can be up to twice the average attenuation. It is not clear if this is systematic, i.e., if there is any correlation between the attenuation in the two bands. Some of the measurement studies suggest that the propagation and attenuation characteristics of the 1800 MHz and 2100 MHz are nearly the same. Thus we can provide a small advantage to systems in the 1800 MHz band.

e. Technical Comparison: Summary

1.42 We now summarise the preceding discussions. From our calculations, and under our modelling assumptions, we can say that with 6.2 MHz, GSM networks can carry more than half the voice load that WCDMA with 5MHz bandwidth can carry. However, with 10 MHz bandwidth, GSM can carry quite a bit more load than WCDMA with 5 MHz bandwidth. The actual capacity that can be realised depends on the ability of the network to deploy the many new techniques, e.g., interference cancellation techniques, dynamic channel allocation and low rate voice coding. Under our modelling assumptions, we can remark as follows.

- The average voice traffic carrying capacity of the GSM network with 10 MHz can be twice that of the WCDMA network with 5 MHz if the available enhancements are fully utilised.

- The gains can be substantial even if only a subset of the available enhancements are used. For example, we saw that using only half the frequencies available for dynamic allocation in each cell (which is a reasonable assumption), the Erlang capacity can increase from 28 Erlangs for 6.2 MHz to 53 Erlangs for 10 MHz, i.e., an increase of 25 Erlangs per sector. This can be compared with the 40 Erlangs for 5 MHz WCDMA.

- The incremental load carrying capacity per MHz as the spectrum is increased from 6.2 MHz to 10 MHz for GSM is about 6.6 Erlangs per MHz. Our analysis can be used to make similar comparisons for other increments.

- That the GSM network can support more simultaneous users is more true if we take into account the different expectations of the users from the two technologies and hence the load that they offer to the network.

- An additional point to note is that data users in GSM via GPRS use the capacity not used by voice. However, in WCDMA networks, they contribute to the `loading' of cell and hence support a lower number of users.

1.43 An important reason for a significant increase in the Erlang capacity of the GSM when an additional bandwidth is available is that the protocol overheads get amortised over a larger number of channels. Thus a significantly larger fraction of the spectrum is available to carry payload or traffic.

1.44 It is to be noted that the preceding calculations indicate significant sensitivity of the Erlang capacity to the system parameters which themselves may show wide variations in any system. Different assumptions on the parameters can of course lead to different values for the number of simultaneous active calls. It is also important to realise that the WCDMA system is a rather complex system with many parameters that determine its capacity. There is significant dimensional crowding that is possible in any analysis. The average numbers that can be obtained from such an analysiscan thus show variations in the indicated performance.

1.45 We emphasise that all the calculations above are approximate and are intended to obtain a comparative understanding of the inherent technical capabilities at a coarse level. Also, the choice of parameters, especially in the analysis of the WCDMA system, is based on what is available in peer-reviewed, published literature and also on our understanding of the values that these parameters are expected to take in the field. We believe that the parameters chosen are reasonable. Of course, many techniques to improve spectral efficiencies are becoming available and we have not considered many of them in the above analysis. For example, Femtocell technology is being increasingly deployed in many networks and can help achieve better fixed-mobile convergence. We have not considered that in our analysis above.This is ecause we do not know how to account for their effect on system performance.

1.46 The above is an exercise in a characterisation of the load carrying capabilities in the 1800 MHz and 2100 MHz bands. The two bands necessarily use different technologies and hence have different capabilities. Further, the customer expectations from the two technologies are also different and hence the offered traffic and the expected service levels will be different. In the preceding analysis, we have compared the effectiveness of the two technologies using a suitably defined `base'. Admittedly, this is a hazardous exercise fraught with assumptions and models. Nevertheless, we believe the exercise that we have carried out is reasonably fair.

1.47 The above `technical' analysis is just one aspect of the analyses to assess the value. Thus it is expected that this study will be used in conjunction with other analyses to arrive at a suitable pricing scheme for spectrum in the 1800 MHz band. We also remark that determining the marginal value of spectrum has the additional complexity of the accounting for increased efficiencies and lower usage costs. It should also be noted that with practice, enhancements will ofcourse be brought to bear on the WCDMA system. It will thus evolve into a more efficient system. Our discussion is based on our understanding of the system to the extent that it can be analysed and modelled as we have done.

1.48 Determining the value of the spectrum is more complex than just calculating the load carrying capacity. Various socio-economic and customer expectations need to be necessarily used to make any assessment. In Chapter II, an attempt has been made to assess the commercial value of the spectrum in the 1800 MHz band using economic models.

Remarks on the Technical Aspects in the Submissions by Service Providers

1.49 The following is a summary, of what we believe are the technical issues, of the submissions made by various service providers to TRAI in response to its invitation. Some issues and points seem repetitive. This only indicates that these have been made in different submissions.

- The services, applications and data speeds that can be offered in the 5 MHz carrier that has been auctioned in the 2.1 GHz band simply cannot be offered in the 200 KHz carriers that are used by the service providers in 900 MHz and 1800 MHz. Therefore, trying to equate the two would be like comparing apples and oranges.

- Capacity efficiencies of 3G system are manifold over 2G system. Thus the spectrum allocated for use of 3G is more efficient than that allocated to 2G.

- The price of 2G spectrum cannot be correlated with any other spectrum like, for example, that of 3G and BWA.

- 3G Technologies provide higher spectral efficiency and data speeds compared to 2G/2.5G networks. The 2G/2.5G market is saturating and after launch of 3G service in India, there is a likelihood of migration of data subscribers of today's 2G/2.5G networks to 3G networks in search of higher data rates. There is a significant difference in the traffic capacity of 3G and 2G and also a significant difference in the range of services and applications that can be offered in the two spectrums.

- 2G is usually for voice which is a lower value commodity while 3G can support a gamut of data based applications. The Ministry has also taken a view that the services offered under 2G and 3G are significantly different.

- The price of 1800 MHz band should be between 1.5 to 2.67 times of that of price of 2100 MHz band. Further, the price of 900 MHz band should be between 2.5 to 2.67 times of that of 1800 MHz spectrum price. The main reasons for suggesting the above include the following:

- The relative number of base stations required for pan-India coverage to provide a similar QoS experience to end customer in 1800 MHz band is 2.8 times than that in 900 MHz band.

- The site densities of 900, 1800 and 2100 MHz bands are 0.010, 0.022 and 0.028 as per OFCOM. The signal propagation characteristics in the 900 MHz band results in less than half the number of sites required for 1800 MHz and almost a third of the number of sites required for the 2100 MHz band. The CAPEX and OPEX saving can potentially be in same proportion.

- The 2G eco-system is mature, stable and well developed giving it a far better business worth as compared to 3G systems that are yet to reach global scale and acceptance levels. Moreover, operators will continue to utilize the 2100 MHz band for offloading voice and providing SMS based services in circles where they are spectrum crunched. Further, data constitutes a much smaller proportion of total revenues.

- In terms of voice capacity of GSM on a 5 MHz channel against that of WCDMA, more Erlangs of voice traffic from GSM can be served vis-a-vis that of WCDMA. WCDMA network provides good data throughput but when it comes to mix of voice and data traffic in the same 5 MHz, with addition of data traffic voice capacity exponentially reduces and vice-versa.

- The current 3G spectrum auction price for 2100 MHz only reflects the value of that band with regard to voice services only. The actual value of 2100 MHz spectrum can not be claimed to be higher because of expected data revenues and thus is a proper benchmark for pricing 1800 MHz spectrum. Moreover, there is no difference between 2G and 3G spectrum since both have been earmarked as IMT band by ITU. 2G is still growing at much faster rate than 3G spectrum systems. Therefore, 900 MHz and 1800 MHz are more valuable.

- Claims of vendors/service providers that 3G is 3 times more efficient than 2G in 1800 MHz, can be right only if the technological innovations that are available for 2G networks are nor adopted. These innovations have resulted into delivery of not only similar capacity for 2G networks as of 3G networks but even higher.

- 2G has matching voice capacity as the 3G networks and therefore no bonus can be added to the 3G spectrum for any capacity advantage over 2G networks.

- With the 1800 MHz band with 5 MHz carrier more voice capacity and more traffic can be catered using spectral efficiency techniques like SAIC, DFCA, AMR, HR, synchronized network, antenna hopping etc. than with the same carrier size in 2100 MHz band.

- Pricing 1800 MHz spectrum same as 2100 MHz by TRAI is a big concession to these incumbent GSM operators and it requires a re-look. The stakeholder further mentioned that even the BWA spectrum which is mainly for data services, which are only infancy in our country, has been priced 40% higher as compared to the 3G spectrum. Thus the 2G spectrum in 1800~MHz band needs to be benchmarked much higher than the 3G price which has much more revenue generating capabilities than BWA spectrum.

- A fair comparison is possible only between technologies (i.e., 2G, 3G and 4G) or between bands inter se (i.e., 700/900/1800/2100 MHz). As far as correlating the price of 1800/900 MHz with 2100 MHz is concerned, since both are potential candidates for deploying WCDMA, it is plausible to link their price with the relative `Spectral Efficiency' of the bands.

1.50 We now comment on the above technical issues raised in the responses by various service providers. Rather than remark for each item, we remark in a summary manner. We will not remark on the operating and/or capital costs for the equipment. Further, we also do not remark on the suggestions for the price.

- It is indeed generally true that as technology matures, many innovations will be made to use the resources efficiently. Cellular communication telephony is no exception and it indeed has a mature eco-system. Thus the so called 2G technologies have been considerably enhanced using a variety of techniques such as adaptive speech coding, interference cancellations etc. Some of these, can be carried over in the 3G networks but some are specific to 2G networks. To be sure, 3G networks will also develop similar techniques to make them more efficient. But that can be expected only after operational experience is gained on these networks.
- We have remarked on the relative voice capacities of the GSM and the WCDMA networks. In case of GSM, we have taken spectrum of 6.2 MHz, 8 MHz and 10 MHz, while WCDMA is given 5 Mhz.
- The HSPA network is going to be very messy to model and we have not attempted that in this note. This is because HSPA offers a wide variety of data rates via adaptive coding and modulation schemes. Further, the mix of data and voice users will definitely affect the throughput. A formal comparison would be hard.
- It is indeed true that 2G and 3G technologies differ significantly, especially in the adaptive nature of 3G physical layer protocols and the range of services that it can offer. We attempt a `first cut' analysis on the relative capacities for a few load mixes. We believe that this is a legitimate exercise. This is more true if we can use this with some `socio economic' analysis of the value of the spectrum, especially the marginal value.
- The relative average performance of the two technologies have been carried out with some assumptions on the parameters. We reiterate that the actual performance or capacity is usually a factor of many other variables and will also experience significant variations in `time and space.'
- It is indeed true that the actual capacity of the 3G network cannot be determined easily and variations in the claims on the system performance is possible by making different assumptions on the parameters. We have obtained the parameter values from well known sources

Chapter-II

Economic Value of Spectrum in 1800MHz band

2.1. In the previous chapter, we have compared the traffic carrying capacity of spectrum in the 1800 MHz and 2100MHz bands using, respectively, 2G and 3G technologies. In this chapter we blend the technical aspects of the spectrum (as described in Chapter-I) with commercial realities in the market, to arrive at a value of the 2G spectrum in the 1800 MHz band. As per Para 3.99 of the Recommendations, operators are to be charged for spectrum beyond the contracted amount of 6.2 MHz. Given the paucity of spectrum established in Para 2.50 and Para 3.44, it is not possible to benchmark the price of spectrum directly to the market mechanism. There was an auction held for spectrum in the 2100 MHz band to be used with 3G technology. The Authority in Para 3.80 of the Recommendations pointed out similarities in spectrum bands in 1800 MHz to be used with 2G technology, and spectrum bands in 2100 MHz to be used with 3G technology. On this basis it provisionally recommended that the price discovered in the 3G auction be used to charge for spectrum beyond the contracted amount.

2.2. From the responses of stakeholders, it is seen that there is a diversity of opinion on the value of the spectrum in the 1800 MHz band. Some of the stakeholders have stated that there is no link between 2G and 3G spectrum and hence that there is no possibility of benchmarking; some hold the view that the price of 3G spectrum should be higher by a factor of 3 and some others have argued that the price of 2G spectrum should be higher than that of 3G spectrum by a multiplicative factor varying from 1.25 to 1.67.

2.3. Taking the position that 2G and 3G spectrums, while not identical, are comparable, one way to arrive at a shadow price for 2G spectrum is to take the price revealed in the 3G auction and apply a correction factor to the winning bid based on technical and market realities. The 3G auctions assigned 5 MHz of spectrum in 2100 MHz band to 4 service providers including BSNL/MTNL in each service area. Based on assumptions about the relative efficiency (cost) of the 1800 MHz and the 2100 MHz band and their relative business potential, a shadow price of 2G can thus be determined. To be accurate, the correction factors must be based on an understanding of both the technology and the market, specifically in the Indian context.

2.4. The following points should give some insight into the complexity of this exercise. In some of the responses of the stakeholders, it is claimed that fewer base stations are required for 1800 MHz band vis-à-vis the 2100 MHz band to produce similar quality of service, implying that at the margin 2G (1800) is more cost effective. On the business side, since 2G has a developed ecosystem, its value is claimed to be higher. In addition, if the Indian market continues to be dominated by voice, the hypothesis that 2G is more valuable in the near term gains weight.

2.5. All operators who have won 3G spectrum also have varying amounts of 2G spectrum. It is therefore reasonable to believe that the two bands together will provide operators the opportunity to optimally service the customer with a more efficient use of the spectrum. For example, high data users could be shifted to 3G, while 2G continues to be used for offloading voice.

2.6. If data remains a small share of the total traffic then the business case for 2G and 3G in India may even converge in the medium term. Where voice services are expected to dominate, operators would find their 2G network to be quite attractive. Such markets are also coverage-constrained rather than capacity constrained; hence the 2G spectrum that is already held by the operators may be sufficient to meet the needs of the business. The 3G spectrum coming on top of the 2G spectrum would therefore have lower perceived value. If however data services take off, the value of the 3G spectrum could be higher in those service areas where data dominates. This implies that correction factors could be different across circles because the trajectory of data services will not be uniform across circles.

2.7. In addition, because spectrum charges vary according to the amount of spectrum held, the correction factors could even be different for different operators within the same circle. Given the difficulty of separating 2G and 3G revenues, operators will either pay 3% or the percentage they are liable to pay for their 2G spectrum, whichever is higher. Licensees of 3G spectrum in the same circle thus may pay different spectrum charges. Therefore the upfront fee revealed in the 3G auction for such circles does not reveal the value of spectrum with a common spectrum charge.

2.8. Given the complexity of starting with the price discovered in the 3G auction and factoring in all the considerations mentioned by the various stakeholders, we decided to directly estimate the price of 2G spectrum through economic models. This report presents two different economic models to directly estimate the value of 1800 MHz spectrum for the year 2010 in Metros, Category A and Category B circles. The values for Category C circles are derived by using a combination of the 2G and 3G values in Category B circles.

2.9. We start by presenting the models and calculations, discuss the stakeholder comments in the light of our findings, outline limitations of our approach, and then conclude.

A. Method 1: Cash Flow from Spectrum

2.10.In this method we compute the value of a block of spectrum by determining the Net Present Value (NPV) over the license period of 20 years of the cash flow that a mature operator in March 2010 would command by virtue of holding the corresponding block of spectrum.

2.11.We divide the problem of computing the value of spectrum in two parts: computing the value of contracted spectrum (up to 6.2 MHz), and computing the value of the incremental spectrum (beyond 6.2 MHz). Operators with start-up spectrum face many challenges related to rolling out their networks, building a brand, and acquiring market presence. While economic analysis shows the presence of economies of scale even at the level of contracted spectrum, these economies of scale are counterbalanced by start-up costs. Hence our method factors economies of scale only in the case of *incremental spectrum*. As operators progress from start-up to incremental spectrum, they would be charged for the presence of economies of scale over the lifecycle of the spectrum.

2.12.In the case of contracted spectrum, the cash flow accruing from the possession of 6.2 MHz is equal to the revenue earned from subscribers less the costs: the sum of the license fees, the spectrum charges, administrative, marketing and personnel costs, and the cost of the physical network[1], i.e.

Cash Flow = Revenue – (License Fees + Spectrum Charge + Network Cost + Administration, Marketing, & Personnel Cost)

2.13.We now present details of the method using Maharashtra as an illustration.

---

[1] At a first glance it would seem natural to start directly with the average profits earned by firms holding 6.2MHz or even 4.4 MHz. However these profits are not available at a circle level. We therefore have to calculate these profits using data available, or through estimation.

Sample Set of Operators: In our analysis we take data from GSM operators who have acquired spectrum in a circle on or before 2006. In Maharashtra we take Airtel, Vodafone and Idea into consideration for our calculation. In the exposition all totals at a circle level should be taken to mean totals with respect to the sample set of operators unless otherwise mentioned.

2.14. For revenue, it is not possible to use actual data to arrive at the revenue figure for a representative firm because the Adjusted Gross Revenue (AGR) data at a circle level aggregates wireless and wireline access services. In our model, revenue is equal to the product of the number of wireless subscribers and the Average Revenue per User (ARPU) per annum. As in the derivation of the production function (see Method 2 below), we consistently use VLR numbers as our estimate for the size of the subscriber base, and adjusted ARPUs, i.e., the reported ARPU per annum as per TRAI data multiplied by the VLR-HLR ratio[2].

2.15. Assuming that operators at 6.2 MHz can command a subscriber base proportional to the amount of spectrum they hold[3], the fair share of subscribers is equal to the proportion of spectrum held (6.2 MHz divided by the total spectrum assigned to the sample operators in that circle) multiplied by the total number of subscribers of the sample operators in that circle[4]. We take the number of subscribers and the spectrum allocated in the year 2010 as the base for calculation of the fair share.

2.16 In Maharashtra the total subscriber base is 21.2 million, and the total spectrum held is 26 MHz. Thus the fair share of subscribers of a representative operator with 6.2 MHz is 5.06 million. The VLR adjusted ARPU is Rs. 161. Hence the annual revenue is Rs. 976.7 crores.

2.17 Physical Network: The cost of the physical network is equal to the cost of the BTSs and associated towers and the cost of the core network, which includes transmission and switching. The cost of the BTSs is equal to the number of BTSs multiplied by the cost per BTS, including the rental and electricity costs associated with the physical infrastructure, while factoring the incidence of tower sharing observed in the market.

---

[2] Note that the revenue we arrive at in this way is exactly equal to the revenue we would have arrived at had we taken HLR subscribers and the reported ARPU. The basis for doing this is explained further in method 2 below

[3] To factor economies of scale we will later assume that at 8 MHz an operator can command a proportion of subscribers greater than the proportion of their spectrum holding.

4We remove the PSUs from the total spectrum held, as well as from the total subscribers serviced since their operations may not always reflect pure commercial considerations.

2.18 Our aim is to estimate the average number of BTSs held by an operator with 6.2 MHz. If we do not have at least two operators in a circle with 6.2 MHz or below, we take the BTS-spectrum ratio in the sample operators as a whole and fix the BTSs for our representative operator in a proportional fashion. If we do have two or more operators with 6.2 MHz or below we take their BTS-spectrum ratio alone in our calculations.. From the data at an all India level there appears to be no correlation between the BTS-spectrum ratio and the quantity of spectrum held so a simple pro-ration where necessary appears to be justifiable. In Maharashtra the average number of BTSs obtained from such a calculation is 5256.

2.19 The cost of the BTS provided by TRAI is as follows (see Table 2.1):

Table 2.1: Cost of BTS in Rs.

Amortization period in years	20.00
Capex per BTS	6,00,000.00
Rate of interest	0.10
Amortized capex	64,068.89
Electricity and rental per year	6,00,000.00
Total cost per year	6,64,068.89

The cost of the core network, as provided informally by industry sources, is around Rs. 500 per subscriber[5]. Amortizing this over 20 years at 11%, we get an annual cost of Rs. 53 per subscriber. Multiplying this by the number of subscribers we get the annual cost of the core network.

The total cost of the physical network in Maharashtra is thus Rs. 376.03crores.

2.20 License Fees, Spectrum Charges: The Recommendations have specified license fees and spectrum charges for operators. We compute license fees and spectrum charges accordingly:

---

[5] Our results are not very sensitive to changes in this rate.

Table 2.2: Recommended spectrum charges as % of Adjusted Gross Revenue (AGR)

Spectrum charges for 6.2 MHz	3.1
Spectrum charges for 8 MHz	4.9
Spectrum charges for 10 MHz	6.9

Table 2.3: Recommended annual license fees as % of Adjusted Gross Revenue (AGR)

Annual License Fees	**2010-11**	**2011-12**	**2012-13**	**2013-14**
Metro	10	9	8	6
Category A	9	8	7	6
Category B	7	6	6	6

2.21 The license fee is computed from the license fee percentage and the corresponding revenues; the spectrum charge is calculated from the spectrum charge percentage and the corresponding revenues; and these are deducted from the total revenue. The total levy, i.e., license fees and spectrum charges, in Maharashtra in Year 1 comes to 12.1%, i.e., 9% for license fees and 3.1% for spectrum charges. Applied on revenue of Rs. 976.7 crores, the absolute levy equals Rs. 118.18 crores in the first year. The reduced license fees of Years 2, 3, and 4 are applied to get the corresponding levies for those years.

2.22 Administration, marketing and operating costs: The total administration, marketing and operating costs of operators as a percentage of AGR as presented in the accounting separation statement submitted to TRAI vary from 22% to 30%. The percentage is lower for operators with higher number of subscribers reflecting economies of scale. We take the percentage as 28% for small operators, those with 6.2 MHz, and 22% for larger operators. As an operator holding 6.2 MHz, our representative firm in Maharashtra incurs a cost of 28% of AGR amounting to Rs. 273.47 crores. Deducting the cost of the network, the license fees, spectrum charges, and general, marketing, and personnel costs from the AGR gives us the cash flow accruing from holding a 6.2 MHz block of spectrum in Year 1.In Maharashtra this comes to Rs. 209.06 crores. The cash flows in Years 2, 3, and 4 are computed with the corresponding license fees. The cash flow stabilizes in Year 4 at Rs.

238.31 crores for the remaining period of the license. The NPV over 20 years at 11%, the weighted average cost of capital suggested by TRAI in its May 2010 recommendation gives the value of 6.2 MHz. This is Rs. 1848.33 crores.

2.23 The price charged to the operator must allow a reasonable rate of return on their investment. We fix this at 20%[6]. The value of spectrum less the NPV of the annual return, i.e. 20% of the price, over 20 years gives the price for 6.2 MHz for 20 years.

In simpler terms

Value= Price + NPV over 20 years of (Price*20%)

2.24 The above equation allows us to compute the shadow price of the spectrum. In Maharashtra this comes to Rs. 936.37crores for 6.2 MHz for 20 years. The price per MHz for 20 years is thus Rs. 151.03 crores. This price represents the weighted average of the price of 900 MHz and 1800 MHz spectrums where the weights are the proportions of 900 MHz and 1800 MHz spectrums being used in the circle in question, and where the price of 900 MHz spectrum is 1.5 times the price of 1800 MHz spectrum as per the TRAI recommendation (para 3.91), i.e.

% of 900 MHz*(price of 1800MHz*1.5) + (% of 1800 MHz)*price of 1800 MHz = Weighted average of price of 900 MHz and 1800 MHz

From this equation, knowing the % of 900 MHz and 1800 MHz, and the weighted average of the price of 900 MHz and 1800 MHz (derived above), we extract the price of contracted spectrum in the 1800 MHz range. This comes to Rs. 117.14 crores. The price for durations smaller than 20 years can be computed by simple pro-ration. See Table 2.5 for the sample calculation for contracted spectrum for Maharashtra.

2.25 Replicating this method across all service areas results in the following prices for contracted spectrum at an all India level (see Table 2.4 below).

---

[6] Given the long period over which profit is discounted changing the rate of return makes little difference to the results.

Table 2.4 Price of contracted spectrum 1800 MHz
Rs. Crore per MHz 2010

Service Area	Price of contracted spectrum
Metro	
Delhi	149.78
Mumbai	101.11
Kolkata	49.48
Category A	
Maharashtra	117.14
Gujarat	149.87
Andhra Pradesh	153.77
Karnataka	136.16
Tamil Nadu	187.38
Category B	
Kerala	73.98
Punjab	72.86
Haryana	14.50
Uttar Pradesh (West)	60.11
Uttar Pradesh (East)	151.76
Rajasthan	106.03
Madhya Pradesh	87.71
West Bengal, Andaman & Nicobar	44.79

B. Incremental Spectrum

2.26 In order to directly estimate the price of incremental 2G spectrum beyond 6.2 MHz, the additional cash flow from moving to 8 MHz is estimated. Acquiring additional spectrum means additional capacity and additional subscribers. Typically operators also add more BTSs to take advantage of the additional spectrum, so just from the raw data it is not possible to find the effect of increasing spectrum while keeping the complementary infrastructure fixed.

2.27 Our approach in this method, consists of the following steps:

a. Increase capacity while including a trunking efficiency factor in the form of the 'beta' (β) coefficient of the production function (elaborated upon in Method 2). If the number of subscribers at 6.2 MHz is 100, the capacity at 8 MHz is taken to be $(8/6.2)^{\beta}*100$, where β is the output elasticity of spectrum computed in Method 2. We find that the β coefficient is greater than 1 everywhere except in Kolkata[7].

---

[7] See Table 2.7 for the estimated values of the elasticities from the production function across service areas.

b. Stagger the corresponding increase in subscribers over three years in equal steps and then stabilize at the capacity for the remaining 17 years.

c. Fix the steady state BTS level by increasing BTSs from the 6.2 MHz level either based on the average number of BTSs held by operators at 8MHz or above, or in the absence of at least two such data points: in proportion to the increase in spectrum.

d. Stagger the actual increase in BTSs over three years in equal steps and then stabilize at the level of point 'c' for the remaining 17 years.

e. Calculate annual cash flows for each of the 20 years as in the calculation for the price of contracted spectrum.

f. Calculate incremental cash flow for each of the twenty years: cash flow for that year calculated in step 'e' minus the cash flows with 6.2 MHz in the corresponding year, (already calculated when calculating the price of contracted spectrum).

g. Calculate the NPV at 11% to get the value of spectrum.

h. Factor a 20% rate of return to get the price of blended 900 and 1800 MHz spectrums.

i. Extract the price of 1800 MHz spectrum as in the calculation of the price of contracted spectrum.

2.28 For example, in Maharashtra, the increase in spectrum from 6.2 MHz to 8 MHz increases capacity from 5.06 million to 6.79 million. This increase translates into 5.92 million subscribers in Year 1, 6.36 million subscribers in Year 2, and 6.79 million subscribers from Year 3 onwards. The BTSs increase from 5256 to 5784 in Year 1, to 6047 in Year 2, and stabilize at 6311 from Year 3.

2.29 The incremental cash flow is Rs. 109.04 crores in Year 1, Rs. 145.57 crores in Year 2, Rs. 183.78 crores in Year 3, and Rs. 187.14 crores from Year 4 onwards. The value of the additional 1.8 MHz of spectrum for 20 years is Rs. 1383.76 crores. The price of 1.8 MHz after leaving 20% return is Rs. 701.02 crores, which translates into Rs. 389.46 crores per MHz. The percentage of 900 Mhz spectrum is 57.9%. The price per MHz of 1800 MHz of spectrum as per the methodology explained above is therefore Rs. 302.08

crores per MHz.The sample calculation of the price of contracted spectrum and incremental spectrum for the first year of their 20 year license period in Maharashtra is presented in Table 2.5.

Table 2.5: Sample Calculation for Contracted and Incremental Spectrum for Maharashtra in Rs. Crore

	Year 1 with 6.2 MHz	Year 1 with 8 MHz
Revenue	976.70	1144.71
License fees	87.90	91.58
Spectrum charge	30.28	138.51
Core network	26.99	31.63
BTS cost	349.05	384.07
Operating cost	273.48	251.84
Annual cash flow	209.01	318.05
NPV(cash flow)	1848.32	
Price of 6.2 MHz	936.37	
Price per MHz(contracted, blended 900 and 1800 MHz)	151.02	
Price per MHz contracted 1800 MHz	117.14	
Incremental cash flow		109.04
NPV(cash flow)		1383.76
Price of 1.8 MHz		701.02
Price per MHz (incremental, blended 900 and 1800 MHz))		389.46
Price per MHz incremental , 1800 MHz		302.08

2.30 To be more rigorous one would have kept the BTSs constant at the level that was determined for 6.2 MHz in the calculation of the price of contracted spectrum, and just increased subscribers as in Step ‘a’ above. This would be acceptable if we could have estimated the number of BTSs required for servicing the fair share of subscribers at 6.2 MHz with some degree of accuracy, which in turn requires us to be sure about the relevance of the production function in the range from 0 to 6.2 MHz. However this is not possible since our data points are all at 6.2 MHz or above. Empirically we do observe that BTS’ have increased and therefore we also factor increase in the number of BTS’ in a staggered manner over 3 years in proportion to the increase in spectrum.

2.31 In Delhi and Mumbai, our data is entirely in the 8-10 MHz range. Hence we disregard β and merely increase subscribers in proportion to the increase in spectrum. Given the high β of 1.59 calculated in the 8-10 MHz range for these circles and the report of the technical experts on the absence of increased trunking efficiency in the 6.2 to 8 MHz range, this approach is most likely to faithfully replicate real world productivities.

2.32 The value of incremental spectrum in the 1800 MHz band (after adjusting for the percentage of 900 spectrum actually held) is shown in Table 2.6.

Table2.6:Price of incremental spectrum Rs. Crore per MHz 2010(1800 MHz)

Service Area	Amount of 900 MHz spectrum (in %)	Price of incremental spectrum
Metro		
Delhi	57.1	229.63
Mumbai	54.8	139.83
Kolkata	49.3	43.48
Category A		
Maharashtra	57.9	302.08
Gujarat	63.1	287.84
Andhra Pradesh	57.9	391.98
Karnataka	57.9	252.20
Tamil Nadu	56.6	361.61
Category B		
Kerala	60.8	199.89
Punjab	71.6	154.24
Haryana	66.7	59.12
Uttar Pradesh (West)	60.8	168.27
Uttar Pradesh (East)	57.4	299.58
Rajasthan	60.2	231.22
Madhya Pradesh	55.9	203.72
West Bengal, Andaman & Nicobar	57.4	161.26

C. Method 2: The Substitution Approach

2.33 In this method we adopt the opportunity cost principle to derive the value of spectrum which is treated as an *essential* input for the supply of mobile services. The other input is Base Transceiver Stations, popularly known as BTS. These two factor inputs are the independent variables in the estimation of a production function to 'produce' mobile traffic or minutes of use (MoU). Subscriber numbers are used as a proxy for MoU.

2.34 The production function approach relies on specification of a functional form. The Cobb-Douglas function is the most widely used functional form used in the economics literature to estimate the statistical relationship between inputs and output.[8] In

---

[8] The Cobb-Douglas production function is flexible and widely used in the economics literature.

telecommunications research the Cobb-Douglas function has been previously employed by Roller &Waverman (2001), Kathuria, Uppal and Mamta (2009) and Prasad & Sridhar (2009) in supply side estimation of telecom services growth and efficiency[9].

2.35 The production function is specified as follows:

$$X = Ay^{\beta}z^{\gamma} \qquad (1)$$

2.36 In the above equation, the dependent variable X refers to mobile subscriber base, which is a proxy for MoU. The two factor inputs considered as the independent variables are: (i) allocated amount of spectrum that provides the required channel capacity for traffic (y) and (ii) deployed mobile infrastructure such as BTS' (z) which provide connectivity to mobile handsets. The beta (β) and gamma (γ) values reflect the percentage change in subscriber base for a unit percentage increase in spectrum and BTS respectively and are the parameters to be estimated, besides A, which captures the magnitude of technical change. The major strengths of theCobb-Douglas production function are its ease of use and its seemingly good empirical fit across many data sets.[10]

2.37 Our specification assumes that the two inputs i.e., spectrum and BTS can be substituted for each other over a certain range of output to service subscribers. Economic theory informs us that service providers will use an optimal mix of BTS and spectrum and that this optimal mix is determined by input prices. This also seems technologically reasonable. A higher charge for spectrum will induce service providers to substitute the less expensive BTS for spectrum over the relevant range to service the same subscriber base. Naturally, the converse is also true.

2.38 A standard procedure to estimate the production function is to linearise it by taking log on both sides. Thus (1) can be expressed as:

$$\ln X = \ln A + \beta \ln y + \gamma \ln z \qquad (2)$$

2.39 β and γ measure the responsiveness of output to changes in levelsof spectrum and BTS' respectively keeping the other input constant and are estimated using data for

---

[9] The Cobb Douglas production function is equally applicable to production processes with increasing, decreasing and constant returns to scale. Its versatility combined with its algebraic tractability makes it a popular functional form in economic literature.

[10] Eric Miller, An Assessment of CES and Cobb-Douglas ProductionFunctions, Congressional Budget OfficeJune 2008

subscribers, BTS' and amount of spectrum held by mature operators across the different categories of circles. The data that we use is described ahead. For example, if β = 1.15, a 1% increase in spectrum would lead to approximately a 1.15% increase in the number of subscribers while maintaining the same number of BTS'. The estimated parameters of the production function are eventually used to derive value of the 2G spectrum relying on the substitutability between BTS and Spectrum. For example, if the service provider were to give up 1 unit of spectrum, he would need additional BTS' to be able to serve the same subscriber base. Since the price of BTS is known, the value of the 2G spectrum can be derived as an opportunity cost i.e. the savings in cost in terms of BTS' conserved by deploying an additional unit of spectrum.

2.40 The math for the calculation makes use of the principlethat at the optimum a service provider will allocate expenditure between the two inputs in such a manner that they yield the same marginal productivity per rupee spent[11]. The optimum condition, accordingly is given by

$$\frac{MP_y}{P_Y} = \frac{MP_z}{P_Z} \quad (3)$$

where MP_y is the marginal productivity of spectrum and MP_z is the marginal productivity of BTS'. Making use of Equations 4 and 5 below,

$$MP_y = \frac{\beta A y^{B} z^{r}}{y} \qquad (4)$$

$$MP_z = \frac{\gamma A y^{\beta} z^{r}}{z}, \qquad (5)$$

the value of spectrum, denoted by P_y, is derived as follows:

$$P_y = \frac{\beta z}{\gamma y} P_z \qquad (6)$$

In Equation 6, P_z is the known price of a BTS, z are the number of BTS' deployed by the service provider and therefore known , y is the amount of spectrum held and β and γ are estimated coefficients of the production function. The only unknown therefore is the price of spectrum which is calculated based on a combination of actual data and estimated coefficients of the production function.

---

[11] This is, in fact, the solution to the firms' maximization problem in the face of a budget constraint. See for example Hal Varian, Microeconomic Analysis.

2.41 The estimated parameters of the production function are as follows (See Table 2.7):

Table: 2.7: Estimated parameters of the production function

Category	Beta (β)	Gamma (γ)
Delhi & Mumbai	1.59	1.01
Kolkata	0.84	1.65
Category A	1.16	0.84
Category B	1.18	1.11

The goodness of fit of estimation is given by the ‘R-squared’ which is the variation in the subscribers that is explained by the variation in the two inputs. The R-squared in our estimations is very good, above 90% in each of the metros and above 75% in category A and B circles (ideal fit being 100%). The high R-squared gives us confidence in the estimates. In addition, both the parameters are statistically significant across all categories. It is important to note that the estimated coefficients are a product of both technology and market factors. For example the high value of β in Delhi and Mumbai reflects the greater density of subscribers in these metros compared to other licensed service areas (LSAs). This in turn implies a higher output elasticity of the spectrum.

2.42 As Table 2.7 shows, we have clubbed Delhi and Mumbai among the metros and treated categories A and B independently as we have Kolkata for the purpose of estimation. It is fairly well established that each category of circles is different. For example, metros have a predominance of dense urban areas, while Category B and C circles have a larger proportion of sparsely populated rural areas. This leads to different production possibilities across LSAs. Further, even within metros, there are wide differences in the characteristics of Delhi and Mumbai, which have pockets of densely packed traffic and housing, and Kolkata where usage is relatively uniform. We therefore separate Delhi and Mumbai from Kolkata, and also separate Category A and Category B circles.

2.43 A panel data set consisting of 16 circles for different GSM operators over the period 2007-10 has been used in the model. We omit Category C circles as their growth has principally been concentrated in cities, and historical data will misrepresent their future which will be in habitations with lower density. The calculation for Category C Circles is elaborated upon in Section E, Para 2.50. Besides Category C circles, we also do not use the public sector operators in our calculations because of their high spectrum allocation and unique operating constraints. We believe that this increases the reliability of the ourestimations in every circle. Finally, only mature operators i.e., those who have been in the market for at least 5 years have been considered. Newer entrants are likely to focus on customer acquisition and network coverage making their BTS-spectrum trade off very different from that of established operators.

2.44 The explosion in the number of subscribers n, especially after 2007, complicates the choice of the appropriate subscriber base to use in the estimation of the production function. This is illustrated in the graph in chart 1.This graph shows the divergence in the number of subscribers as measured by HLR and VLR, and we see that this divergence increases significantly after 2007, which is our estimation period. HLR numbers are higher by as much as 40% in March 2010 in metros and by 30% in Circle C. The corresponding quantities for Circle A and B are 24% and 26% respectively. Accordingly, we are of the opinion that using figures based on HLR would bias the estimates of the production function and hence we use VLR numbers in the analysis. For method 1 (as explained earlier) we made adjustments to ARPU figures since these are reported on an HLR basis by TRAI. We prefer using VLR numbers for also estimating the production function because, as stated above, it improves the estimates and provides a reliable basis for incremental revenue and profit calculations.

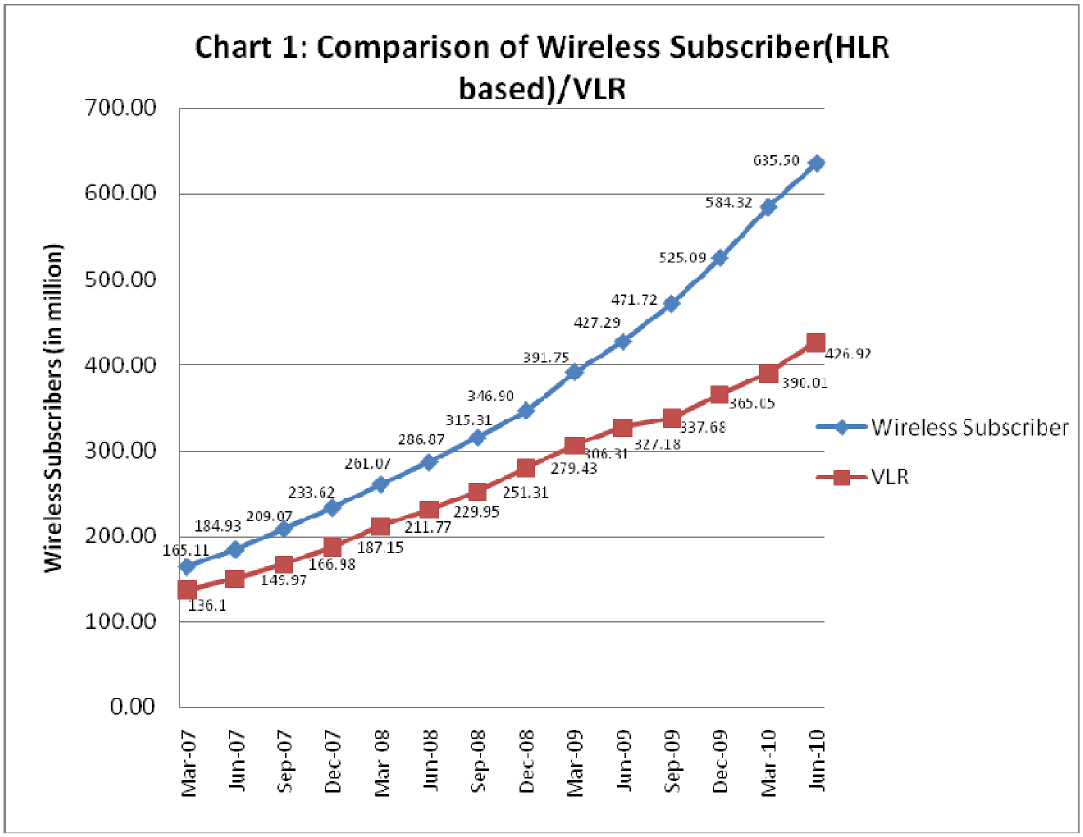


Chart 1: Comparison of Wireless Subscriber(HLR based)/VLR

In addition to the estimates of the production function parameters, β and γ, Equation 6 uses actual data for BTSs and the amount of spectrum held as of Q1 2010 to estimate the value of the spectrum. We estimate the value of incremental spectrum beyond 6.2 MHz and upto 8 MHz[12]. Wherever there are many operators with 10 MHz of spectrum in a specific area in Q1 2010, the average number of BTSs deployed is prorated for 8 MHz for use in our calculations.. In case there are no service providers with 8 MHz in a specific service area, the corresponding number of BTSs at 6.2 MHz have been used and similarly prorated to 8 MHz.

2.46 The value thus derived is a blend of 900 and 1800 MHz bands, and therefore we use the actual distribution of spectrum in each band per circle to estimate the value of spectrum in the 1800 band given that spectrum in 900 MHz is 1.5 times more valuable. (Recall that the latter was established in the Recommendations para 3.91). Finally, since we use Q1 data for BTS' and spectrum held in 2010, the value should be seen as pertaining to April 2010, which is the first month of the 20 years of our estimation period.

2.47 The following table shows the result of the above approach. In this approach the

---

[12] Given paucity of data, the value estimated at 8 MHz is also assumed to apply to spectrum m at 10 MHz.

value of 2G spectrum is derived based on the principle of 'opportunity cost' and thus reflects the saving in costs as a result of relieving the spectrum constraint. Unlike model 1, it is not based on revenue realization and thus ignores the amount paid by operators as spectrum fee, among other costs. The estimates show that 2G value at the aggregate level is about one and a half times the 3G bid (in Metros and Circles A and B), although there are inter-circle variations. 2G spectrum is slightly more valuable in the case of most of the category A service areas. In case of metros, its value is less than that of 3G. In category B circles where the data service uptake is expected to be low and which are expected to be coverage constrained, the value of the lower 2G bandwidths with their correspondingly higher propagation capacity is much higher.

Table 2.8: Price of Incremental Spectrum in 1800 MHz Rs. Crores per MHz (Method 2)

State/ metro	Price in crore 20 years	% of 900 spectrum	Estimated price of 1800 Mhz
Delhi	346.91	57.14	269.83
Mumbai	222.75	54.79	174.85
Kolkata	64.46	49.30	51.71
Andhra Pradesh	608.44	57.85	471.93
Gujarat	556.26	63.06	422.91
Karnataka	566.82	57.85	439.65
Maharashtra	576.11	57.85	446.85
Tamil Nadu including Chennai	692.46	82.35	490.49
Haryana	208.91	66.67	156.68
Kerala	344.80	60.78	264.43
MP	390.42	55.86	305.18
Punjab	280.90	71.56	206.88
West Bengal & A&N	350.89	57.39	272.65
Rajasthan	424.71	60.19	326.46
UP W	439.21	60.78	336.84
UP E	434.95	57.41	337.95

Methodology:

1) *We have regressed subscriber base in millions over BTS and spectrum for each category A and B and Kolkata separately and Mumbai and Delhi together to arrive at coefficients for spectrum and BTS for half yearly data from 2007-10*
2) *We ran the regressions without MTNL for metros and for each circle without BSNL.*
3) *We have used the solution to the firms optimization problem to arrive at the value of 2G spectrum. As shown in the text this is Marginal Rate of Technical Substitution(MRTS) * Price of BTS = Price of spectrum, where price of BTS -6,64,068.89 per year and MRTS = (co-efficient of spectrum/ co-efficient of BTS) *(BTS/ spectrum)*
4) *We have used the BTS estimate to be the average of BTSs per service provider in 2010 Q1 with 8 MHz of spectrum. In case 8 MHz is not available we have used the number of BTS corresponding to the next lower level of spectrum. In case many operators hold 10Mhz in a service area we prorate the number of BTS's to 8 Mhz.*
5) *We have calculated the spectrum price by applying the corresponding regression coefficients to the specific circle.*
6) *The 20 year price has been computed using NPV using a discount rate of 11%, the same as used by TRAI in the Recommendations*

D. Price for Spectrum upto 6.2 MHz

2.48 Given the paucity of spectrum data in the 0-6.2 MHz range for operators during our reference period (2007-10), method 2 best lends itself to estimating the valueof incremental spectrum, rather than for a block of spectrum. As emphasised, the substitution approach estimates the opportunity cost of additional spectrum. In principle this could be done for every small increase of spectrum from 0-6.2 MHz and aggregated to determine the value of the entire block. However, given the constraints on the kind of data that is available to perform our calculations, this is not possible. Accordingly, for spectrum of upto 6.2 MHz, the estimates obtained by method 1 are meaningful and accurate. For spectrum beyond 6.2 MHz the substitution method, *inter alia*, is an approach that can be suitably used for valuation since data is available. However, method 2 treats incremental spectrum from 6.2 MHz onwards in a uniform manner, again due to data constraints.

E. Discussion

2.49 The value of the contracted spectrum is lower than that of incremental spectrum. Our estimate for the price of contracted spectrum does not factor trunking efficiency of spectrum through the use of the β coefficient from the production function. Further, the proportion of revenue going to administration, marketing and salary costs is high in line with the accounting separation data. However, the impact of trunking efficiency and reduced operational costs are considered in the methods used to calculate the price of incremental spectrum. This leads to a higher value of incremental spectrum as compared to the value of contracted spectrum. As mentioned earlier, given the extra costs of starting up, it is proper to charge for increased efficiencies only at later stages of the operator's lifecycle.

2.50 Any economic modelling exercise yields estimates of relative magnitudes rather than of exact values. To assess the reliability of our estimates, we plot the prices of the spectrum from our estimates against economic indicators at the circle level. These are plotted in the following four charts. They show a very good relationship between the estimated values of contracted and incremental spectrum (separately) with economic indicators at the circle level thereby increasing the confidence in the methodology as well as the results.

Chart 2: Scatter Plot for Value of Contracted Spectrum and Adjusted ARPU

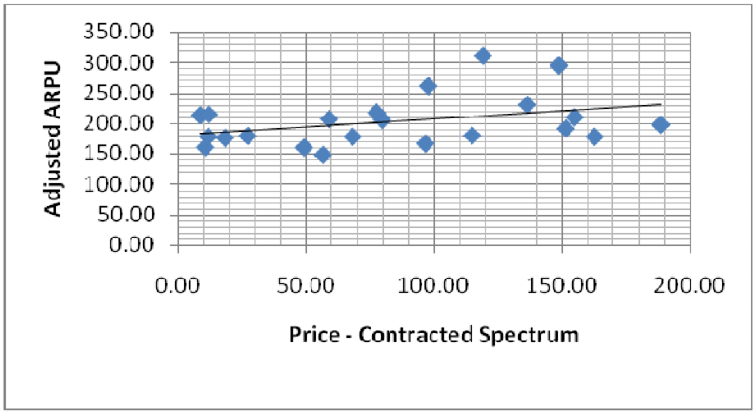


Chart 3: Scatter Plot for Value of Contracted Spectrum and VLR Subscribers

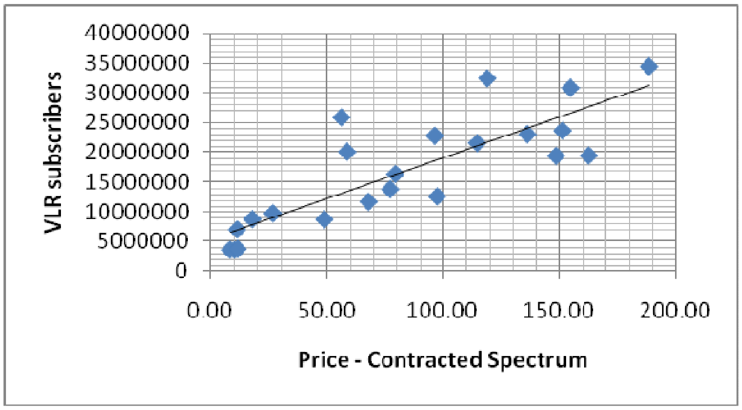


Chart 4: Scatter Plot for Value of Incremental Spectrum and Adjusted ARPU

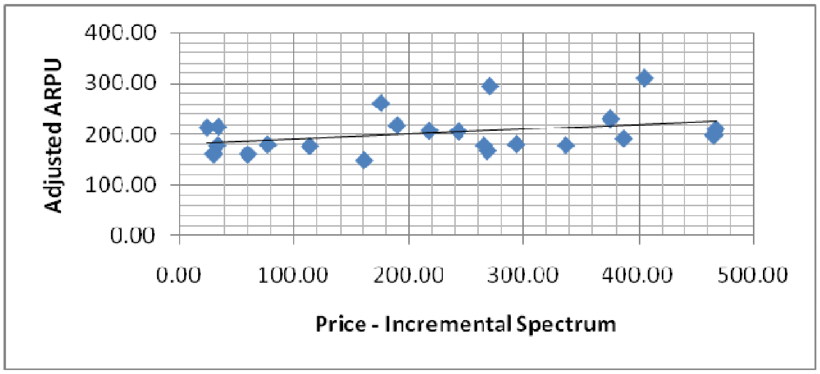
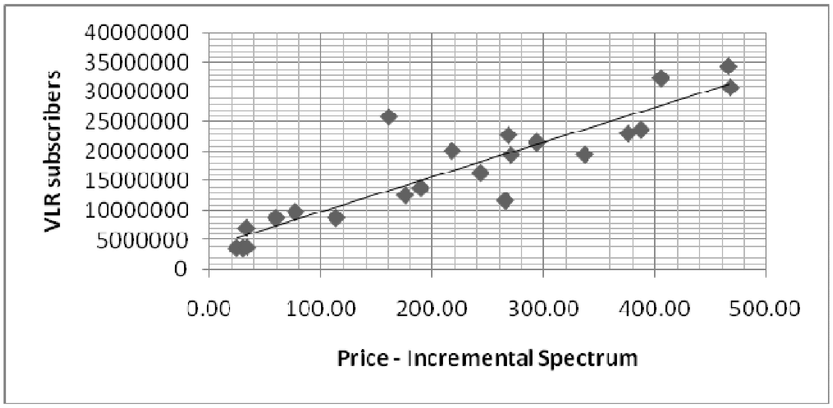


Chart 5: Scatter Plot for Value of Incremental Spectrum and VLR Subscribers



2.51 While the high R-squared gives irreproachable support to the validity of the function between 2007 and 2010, the validity could be reduced over time due to technology and market shocks. Given the maturity of the technology of 2G at the juncture, and of markets in Metros, Category A and Category B circles, we are reasonably confident about the stability of our estimates in the absence of unforeseen events. However for Category C circles, we adopt a different approach on account of this apprehension.

2.52 We start with the observation that Category C circles share some similarities in terms of terrain and ability to pay with Category B circle. We next find that taken as a whole, incremental 2G spectrum in Category B circles is priced at 3.78times 3G spectrum in Category B circles. Finally we find the price of incremental 2G spectrum in a Category C circle by multiplying the 3G price in that circle with the multiplicative factor for incremental 2G spectrum with respect to 3G spectrum in Category B circles as a whole. To calculate the price of contracted spectrum in Category C circles, we take the multiplicative factor for incremental and contracted spectrum in Category B Circle as a whole (0.33) and apply to the price of incremental spectrum in Category C circles. We recognise HP, North East and J&K have special features compared to other Category C circles; however any correction to the estimates for these circles will have insignificant impact on the overall result.

2.53 While we have suggested pro-ration to estimate the price of spectrum for lower durations, another approach is to compute the NPV of the additional cash flows over the relevant duration directly. This would also mitigate the concern that our estimates, while projecting far into the future, are based on data from the past.

F. Comparison of the Two Methods

2.54 Method 1 is used to calculate the price of both contracted and incremental spectrums. For reasons of data scarcity related to the estimation of the production function, Method 2 is only used to calculate the price of incremental spectrum.

2.55 Method 2 is the classically oriented approach to valuing spectrum while Method 1 is more anchored in the data of revenues and costs of the mobile communication industry.

2.56 Method 1 applies the economies of scale sparingly: a capacity enhancing variable β is applied but BTSs are allowed to rise without an impact on capacity. As explained this procedure is adopted on account of the instability of the production function in the 0-6.2 MHz range. Method 2 calculates the price of spectrum at 8 MHz, where our estimates are robust and hence is able to factor the economies of scale in a classical manner. This leads to higher estimates.

2.57 In the light of the complementary strengths of the two methods, a simple average of their derived values is taken to calculate the price of incremental spectrum. Following this approach, the price of spectrum beyond 6.2 MHz in the 1800 MHz band is 136% of the price of 3G spectrum on a pan India basis. The price of the contracted 6.2MHz of spectrum in the 1800 MHz band is 53% of the price of 3G spectrum on a pan India basis. The price of contracted 2G spectrum is lower in Metros and Category A circles, and higher in Category ‘B’ circles. The general pattern for both contracted and incremental spectrum appears to conform to an intuitively acceptable truth. The ratio of the value of 2G spectrum to the value of 3G spectrum increases as we move from metros to lower category circles. The ratio is the lowest in metros, i.e., 3G spectrum is most valuable relative to 2G spectrum in metros, since data services are expected to pickup. On the other hand, the ratio is the highest in Category B circles, i.e. 3G spectrum is least valuable relative to 2G spectrum in Category B circles, since these circles are voice oriented and coverage rather than capacity-constrained. Further in these circles, the current 2G spectrum holding is considered enough to meet the expected needs. The variation of 3G prices across circles is far higher than the variation of 2G prices, indicating that while circles may vary in attractiveness as 3G markets, they are beginning to converge in terms of 2G service viability.

2.58 Based on the preceding analysis we arrive at the following conclusions.

1. For all circles except Category C circles:
    a) The price of contracted spectrum should be as per Method 1.
    b) The price of incremental spectrum should be a simple average of the price discovered through Method 1 and Method 2.

2. The price of incremental spectrum in Category C circles can be linked to the 3G price in these circles using the same relative multiplicative factor that exists for 2G and 3G incremental spectrums in Category B circles as a whole (3.78).

3. The price of contracted spectrum in a Category C circle is equal to the price of incremental spectrum in that circle multiplied by the relative multiplicative factor that exists for contracted 2G and incremental 2G spectrum in Category B circles as a whole (0.33).

Table 2.9: Final value of 1800 MHz spectrum

Service Area	Price of contracted spectrum 1800 MHz Rs. Crore per MHz 2010	Price of incremental spectrum 1800 MHz Rs. Crore per MHz 2010
Metro		
Delhi	149.78	249.73
Mumbai	101.11	157.34
Kolkata	49.48	47.60
Category A	0.00	
Maharashtra	117.14	374.47
Gujarat	149.87	355.37
Andhra Pradesh	153.77	431.95
Karnataka	136.16	345.92
Tamil Nadu	187.38	426.05
Category B		0.00
Kerala	73.98	232.16
Punjab	72.86	180.56
Haryana	14.50	107.90
Uttar Pradesh (West)	60.11	252.55
Uttar Pradesh (East)	151.76	318.76
Rajasthan	106.03	278.84
Madhya Pradesh	87.71	254.45
West Bengal, Andaman & Nicobar	44.79	216.96
Category C		
Himachal Pradesh	9.34	28.12
Bihar	51.04	153.69
Orissa	24.33	73.26
Assam	10.40	31.33
North East	10.61	31.95
Jammu & Kashmir	7.60	22.89
Total	1,769.75	4,571.87

G. Our Results and Stakeholders' Comments

2.59 The stakeholders' comments related to the pricing of 2G and 3G spectrum broadly fall into two categories: one category of stakeholders holds the view that 3G spectrum is more valuable than 2G as there is a larger traffic capacity and service and application offerings possible with 3G spectrum. The other category of stakeholders holds the view that 2G spectrum is more valuable on account of the better developed eco-system, dominance of voice demand in the years ahead, and higher propagation characteristics. This stream of opinion puts forward a multiplicative factor of the value of 1800 MHz spectrum relative to 2100 MHz spectrum ranging from 1.25 times to 1.67 times. Some operators believe that the price of 2G and 3G cannot be correlated and 2G spectrum should be auctioned as and when available.

2.60 Our findings arrived upon through an independent assessment of the value of 1800 MHz spectrum seems to bear out the views of both camps. Incremental 2G spectrum beyond 6.2MHz is cheaper than 3G spectrum in Metros and more valuable in Category A, and most valuable in Category B. According to our results incremental 2G spectrum on a pan-India basis is more valuable than 3G spectrum by 136%. On the other hand, in case of 2G spectrum up to 6.2MHz in the 1800 MHz band, the pan-India price is 53% of the value of 3G spectrum.

2.61 The variation of 3G prices across circles is far higher than the variation of 2G prices, indicating that while circles may vary in attractiveness as 3G markets, they are beginning to converge in terms of viability of 2G service.

Conclusion

Technically, the value of 1800MHz spectrum using 2G technology can be seen in comparative terms. From our study, we believe that the traffic carrying capacity of spectrum in 1800MHz band upto 6.2MHz, using the 2G technology, is around two-thirds that of the traffic carrying capacity of 5MHz using 3G technologies. Further, the incremental traffic carrying capacity in 1800 MHz band beyond 6.2MHz can be comparable, with that of 5MHz of spectrum in 2100MHz bandusing 3G technologies, or even better.

Based on technical and commercial considerations which are brought to bear on two economic models, our exercise arrives at the price of 1800 MHz spectrum for both the contracted (6.2 MHz) and incremental (beyond 6.2 MHz) blocks. We find significant variation in valuation across circles and with respect to the 3G winning bids. On a per MHz basis, contracted spectrum at a pan-India level is just over half of the aggregate winning bids for 3G spectrum. On the other hand, the corresponding fraction for incremental spectrum is just over four-thirds.

(Prof. D. Manjunath)
Professor, IIT Bombay

(Prof. R.V. Raja Kumar)
Professor, IIT, Kharagpur
Vice Chancellor, Rajiv Gandhi University of Knowledge Technology, Hyderabad

(Prof. Rajat Kathuria)
Professor, IMI and Consultant ICRIER
New Delhi

(Prof. Rohit Prasad)
Associate Professor
MDI, Gurgaon

Bibliography

1. A. Kumar, D. Manjunath and J. Kuri, *Wireless Networking,* Morgan Kaufmann, 2008.
2. S. G. Glisic, *Adaptive WCDMA: Theory and Practice,* Wiley, 2003.
3. T. Halonen, J. Romero and J. Melero, G*SM, GPRS and EDGE Performance: Evolution Towards 3G/UMTS,* Wiley 2003.
4. H. Holma, J. Melero, J. Vainio, T. Halonen and J. Makinen, ``Performance of Adaptive Multirate (AMR) Voice in GSM and WCDMA," in *Proc. Of IEEE VTC,* Spring 2003.
5. L. Ferreira, M. Kuipers, C. Rodrigues and L. M. Correia, ``Characterisation of Signal Penetration into Buildings for GSM and UMTS," in *Proc of IEEE ISWCS*, 2006.
6. A. M. Viterbi and A. Viterbi, ``Erlang Capacity of a Power Controlled CDMA System," *IEEE JSAC,* vol 11, no 6, Aug 1993.
7. V. V. Veeravalli and A. Sendonaris, ``The Coverage-Capacity Tradeoff in Cellular CDMA Systems," *IEEE Trans. on Vehicular Technology,* September 1999.
8. S. Vembu and A. J. Viterbi, ``Two Different Philosophies in CDMA - A Comparison," *Proc of IEEE Globecom,* 1996.
9. O. Corbun, M. Almgren, K. Svanbrot, ``Capacity and Speech Quality aspects using Adaptive Multi-Rate (AMR)" in *Proc. Of IEEE PIMRC,* 1998.
10. Prasad, R., and Sridhar, V. (2009). Allocative Efficiency of the Mobile Industry in India and its implications for Spectrum Policy. *Telecommunications Policy*, volume 33, issue 9, October 2009.
11. Roller, R.L., &Waverman. (2001). Telecommunications infrastructure and economic development: A simultaneous approach. *American Economic Review*, 91(4), 909-923.
12. Hal R. Varian, Microeconomic Analysis Softcover, Norton & Company, ISBN 0393957373 (0-393-95737-3)
13. Kathuria, R, Mahesh Uppal and Mamta "The Econometric Impact of Mobile across Indian States, (with Mahesh Uppal and Mamta) in Socio-Economic Impact of Mobile Telephony in India, January 2009, Public Policy Series number 9 available at www.icrier.org

Annex

INPUTS

SUBSCRIBER BASE AND ARPU (GSM)

LSA	Subscriber Base (Millions) March 10	ARPU
Metros		
Delhi	11.85	251
Mumbai	7.69	261
Chennai	0	
Kolkata	6.3	161
Category A		
Maharashtra	21.2	161
Gujarat	18.6	166
Andhra Pradesh	21.5	174
Karnataka	17.07	185
Tamil Nadu	26.15	174
Category B		
Kerala	10.7	176
Punjab	9.6	181
Haryana	5.6	137
Uttar Pradesh (West)	13.8	147
Uttar Pradesh (East)	20.16	149
Rajasthan	15.7	154
Madhya Pradesh	16.2	142
West Bengal, Andaman & Nicobar	14.45	129

TOTAL SPECTRUM ALLOCATED MHz ACROSS LSAs

Delhi	28.00
Mumbai	29.20
Chennai	26.60
Kolkata	24.00
Category A	
Maharashtra	26.00
Gujarat	22.20
Andhra Pradesh	24.20
Karnataka	24.20
Tamil Nadu	26.60
Category B	
Kerala	20.40
Punjab	21.80
Haryana	18.60
Uttar Pradesh (West)	20.40
Uttar Pradesh (East)	21.60
Rajasthan	20.60
Madhya Pradesh	22.20
West Bengal, Andaman & Nicobar	23.00

BTS

	BTSs at 6.2 MHz	BTSs at 8 MHz
Delhi	2584	3334
Mumbai	1659	2141
Chennai		
Kolkata	1376	1915
Category A		
Maharashtra	5256	6311
Gujarat	4723	6094
Andhra Pradesh	5753	6665
Karnataka	4689	6209
Tamil Nadu	5879	7586
Category B		
Kerala	3803	4907
Punjab	3098	3997
Haryana	2304	2973
Uttar Pradesh (West)	4844	6250
Uttar Pradesh (East)	4797	6190
Rajasthan	4684	6044
Madhya Pradesh	4329	5556
West Bengal, Andaman & Nicobar	3870	4993