Can 3G technologies benefit rural India?

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To increase telecom penetration into rural India, we would need low cost options for networks and devices that provide support not only for voice services, but also for rich media and higher data rate services. In this paper, the authors examine whether the evolution of GSM (Global System for Mobile communication) into 3G and HSDPA (High-Speed Downlink Packet Access) could enable this transformation, since this provides higher peak data rates and also significantly increases the network capacity. The problem is that 3G devices and services are typically part of the premium (high-price) services in the developed countries, while they have to be offered at very affordable prices if they have to take off in the rural areas. A paradigm shift may thus be required to resolve this paradox. In this paper, the authors examine if low cost 3G and HSDPA is really feasible.

Keywords: 3G technology, HSDPA, GSM

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1 Introduction and context

India has seen a rapid increase in wireless coverage. GSM and CDMA (Code Division Multiple Access) are the competing technologies. As of July 2005, the wireless penetration at 59.83 million is significantly higher than landline penetration, which is at 47.17 million. The overall tele-density\(^1\) is around 9.86%. The monthly cellular additions are getting closer to 3 million/month, with GSM technology base having a higher subscriber base accounting for about 80%. The bad news is that the gap between rural tele-density (1.74%) and urban tele-density (26.2%) has been widening, perhaps because per capita rural GDP of $ 352 is a fourth of urban GDP\(^2\). This is unacceptable since 72% of India is rural. However, there is a strong push to increase cellular coverage in the rural areas, and the Government of India has set targets as shown in Table 1, primarily for voice services\(^3\):

<table>
<thead>
<tr>
<th>By area</th>
<th>By population, Million</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>2006</td>
</tr>
<tr>
<td>2004</td>
<td>2006</td>
</tr>
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</table>

On the other hand, the rapid spread of television content in rural India shows us that audio-visual content can be easily absorbed by the rural masses. Delivery of such “rich media” requires bandwidth that is clearly not supported by existing 2/2.5G cellular services or even by early 3G services – it needs deployment of evolved technologies like HSDPA (High-Speed Downlink Packet Access). However, HSDPA is expensive primarily because it is viewed as a high revenue opportunity in the western world. In fact, as shall be discussed in this paper, the incremental cost of delivering bandwidth using HSDPA to specific places is not actually that high. The key problem with HSDPA is range – providing high bandwidth universal access over a large area using HSDPA could prove to be expensive.

To circumvent this, the following two points are noted:

(i) In the rural areas, only certain types of services can be delivered directly to the end user. The World Bank in an unpublished study identified radio, TV,
loud speakers, poster boards and to an extent telephony as services that can be delivered without any mediation. On the other hand, more sophisticated content like those available on the internet may have to be delivered only through an intermediary – such as a postman, a rural health worker, a teacher or a kiosk operator.

(ii) Full mobility may not really be required in rural areas. The key value of wireless is in its ability to offer “untethered” communication, so that we can dispense with costly wires. In terms of services, untethered wireless could be used to deliver services at low cost kiosks and at mobile-van stops. These kiosks and mobile vans could provide several non real-time services as well, which do not need any connectivity.

Thus there could be intermediate solutions, if the focus is on providing high bandwidth connectivity only at designated points using HSDPA.

2 The GSM advantage

It may not be readily evident that the bottleneck in rolling out services to rural areas is not the cost of electronic equipment, but is actually due to the following:

(i) The most significant cost component is the site preparation and the erection of the tower. Infrastructure like roads and electricity may have to be first set up. The towers are about 40 m tall, and require considerable amounts of expensive steel.

(ii) The second highest contributor to the cost is the power infrastructure – rf cables running to the top of the tower, the power amplifiers, rf filtering and the transceivers. Roughly 55% of the cost of the base station equipment is in these rf components.

(iii) The maintenance of cell site infrastructure requires local personnel who should be trained to deal with the problems that arise in wireless equipment.

(iv) Availability of ULC phones at costs below Rs 1500 (US$ 35) with financing packages.

(v) Proper distribution infrastructure for phones, SIMs, spares and accessories in the remotest areas, and availability of basic training to users so that they can use the phones properly.

(vi) Billing and collection infrastructure for pre- and post-paid subscribers.

If one accepts these as the real bottleneck, then it is immediately evident that as soon as there is sufficient GSM voice coverage across India, we are already past the key hurdles. The cell sites and towers are set up and maintenance, distribution, user training and billing/collection infrastructure put in place.

Let us first argue that it makes economic sense to deploy 3G just for voice. For this, one needs to determine the incremental cost of a 3G handset and cell site infrastructure, to deploy 3G. The latter requires a careful comparison of GSM and 3G systems from the point of view of voice capacity.

3 Comparison of GSM and 3G voice capacity

It is not easy to compare the capacity of GSM systems with that of 3G systems, as they are based on different principles. However, if one intends to replace one with the other, an estimate of the 3G equipment required to support the same number of voice calls served by an existing GSM system has to be made.

Now offered load is given by

\[
\text{Offered load (Erlangs/km}^2\) = \text{number of cells/km}^2 \times \text{available spectrum (Hz)} \times \text{voice spectral efficiency (Erlangs/Hz/cell)}
\]

From the previous section, one cannot afford to deploy any new cell sites, but only add electronic equipment at existing cell sites. One can assume that there is 5+5 MHz spectrum available for each system. To compare the voice spectral efficiency in Erlangs/5MHz/cell of the two systems, the following can be noted:

(i) 3G systems use WCDMA that requires a minimum of 5 MHz of bandwidth each for uplink and downlink that supports over 60 simultaneous voice calls, while GSM requires only 200 kHz each way to support 8 simultaneous calls.

(ii) In GSM, interference from neighbouring cells can significantly affect the performance. Consequently, frequency planning is used to ensure that a frequency band used in a cell is re-used only in cells that are spaced sufficiently far away. A re-use factor of 7 means that the frequency in a cell is different from the six cells that surrounds it. Since 3G systems are based on CDMA technology that can deal with interference, neighbouring cells can share the same frequency. The 3G also uses advanced coding and modulation methods.

(iii) However, GSM technology has been continuously improving over the years in interference management. In particular, the use of cell sectorization reduces interference significantly. Cells
with 3 sectors are typical, while a higher number of sectors (6 or higher) could also be deployed. Use of discontinuous transmission (transmission is suspended when there is no voice activity) and slow frequency hopping allows interference between cells to be reduced. Adaptive (intelligent) antenna arrays could also be used to direct the transmission power towards the active users. All the above allow the reuse factor to be reduced even to 1. By using adaptive multi-rate (AMR) codecs, the quality of voice can be improved, especially at larger distances. Finally, by using half rate AMR, the capacity of a GSM cell could be doubled.

Assuming 2% grade of service, with these advances GSM can provide a voice spectral efficiency of 13-33 Erlangs/5MHz/sector, while 3G using WCDMA can provide 52-83 Erlangs/5MHz/sector. This means that 3G offers a voice capacity increase of 2-3 times over GSM.

4 Migrating to 3G for voice

To deploy 3G at a cell site, Node B equipment has to be installed (instead of or in addition to the GSM BTS equipment). The cost of such Node B equipment has been falling by approximately 40% each year over the last 4 years. Taken together with the fact that 3G offers more capacity than GSM, the 3G Node B is just 50% more expensive today than the GSM BTS to deploy the same voice capacity. It has already been seen that 55% of the cost of base station equipment is in the rf. Since a single 3G channel of 5 MHz replaces many GSM channels of 200 kHz required for achieving the same capacity – the rf costs of 3G systems should over time be lower than that of GSM systems. Does this mean that 3G will eventually lead to cheaper equipment than GSM?

The issue with 3G is scalability. In 3G, capacity can only be deployed in large chunks – voice call demand has to be about 60 erlangs per sector for the capacity provided by one carrier to be effectively utilised. On the other hand in GSM, capacity can be deployed in smaller chunks, since the smallest carrier is 200 kHz, supporting 8 simultaneous calls. The opportunity to migrate to 3G thus arises only when the GSM system capacity starts to fill up. The ideal system is thus a combination of GSM and 3G. One can start building up capacity using GSM – once the capacity per sector nears 60 Erlangs, that cell site can migrate to 3G.

What about handsets? If one does not consider the multimedia applications and costly peripherals typically present in 3G handsets, then the only difference between 3G and 2G is in the baseband and rf silicon. As is known very well, silicon costs diminish rapidly over a period of time. Looking at pricing trends for 3G silicon, ULC 3G handsets should be available at price points below Rs. 2200 (US$ 50) in 2-3 years, excluding royalty costs.

Thus it makes economic sense for an operator to deploy 3G just for voice, even at the low price points set by existing GSM operations in rural areas. Next, data services can be looked at.

5 The 3G for data services

Once 3G systems are deployed, they are already able to offer some rudimentary data services that require up to 100 kbps to near line of sight terminals at distances of up to 5 km. For example, a phone equipped with video telephony application based on the H.324M standard can operate a data rate of 64 kbps, and such phones could be available for price points below Rs. 3500 (US$ 80) in 2008. Thus, one can support some “rich media” services at marginally higher monthly subscription rates.

However, good quality audio-video delivery requires 512 kbps data rates, which is not possible using 3G.

6 Upgrading 3G to HSDPA

To enable availability of innovative services with rich visual content, operators must deploy evolved 3G technologies like HSDPA (High Speed Downlink Packet Access). The HSDPA has several advantages:

(i) Increased bandwidth: The HSDPA offers higher than seven times peak data rates, and up to a theoretical maximum of 14 Mbps.
(ii) Increased network capacity: Over four times existing capacity, through better spectral efficiency and advanced modulation schemes (16 QAM). It is also reuse efficient, with a reuse factor of 1.
(iii) Reduced round-trip-time: Incremental redundancy and Hybrid ARQ at the Layer 1-Layer 2 level reduces RTT, as against convention ARQ, implemented in the IP Layer.
(iv) Favourable allocation of resources: Network schedules grants based on mobiles that are active in the cell.
The net effect is to increase the average capacity of the system and to improve the service performance experienced by individual users. Using HSDPA, the expectation is that the cost to deliver a 10 Mbyte file can be brought down to one-fifteenth the amount that it would take via GPRS and one-fifth$^7$ via UMTS Release 99.

The HSDPA is realised by a downlink channel (HS-DSCH) shared between terminals by allocation of individual codes, from a common pool of codes assigned for the channel. The HS-DSCH is associated with one downlink DPCH, and one or several Shared Control Channels (HS-SCCH). The HS-DSCH is transmitted over the entire cell or over only part of the cell using beam-forming antennas. The HS-SCCH is a fixed rate (60 kbps, SF = 128) downlink physical channel used to carry downlink signaling related to HS-DSCH transmission. The High Speed Physical Downlink Shared Channel (HS-PDSCH) is used to carry the High Speed Downlink Shared Channel (HS-DSCH). A HS-PDSCH corresponds to one channelization code of fixed spreading factor SF = 16 from the set of channelization codes reserved for HS-DSCH transmission. Multi-code transmission is allowed, i.e. the terminal can be assigned multiple channelization codes in the same HS-DSCH sub-frame, depending on the terminal capability. An HS-PDSCH may use QPSK or 16QAM modulation. A comparison of QPSK with 16QAM is given in Table 2.

Table 3 captures the key parameters of HSDPA, compared with GSM/GPRS:

### 7 HSDPA: Range is the challenge

As can be seen in Table 2, the range of HSDPA is severely limited to around 2 km cells, as compared the current GSM/GPRS systems that have range one order of magnitude higher. This could mean that the current GSM/GPRS infrastructure is largely insufficient for HSDPA coverage, and significant additional capex may be required to deploy HSDPA into rural areas. The entire cost benefit gains of HSDPA due to its higher capacity could thus be offset due to the cost increase due to lower range.

Table 2 — Comparison of QPSK with 16QAM

<table>
<thead>
<tr>
<th>Modulation format</th>
<th>Channel Bit Rate, kbps</th>
<th>Channel Symbol Rate, kbps</th>
<th>SF</th>
<th>Bits/HS-DSCH subframe</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK</td>
<td>480</td>
<td>240</td>
<td>16</td>
<td>960</td>
</tr>
<tr>
<td>16QAM</td>
<td>960</td>
<td>240</td>
<td>16</td>
<td>1920</td>
</tr>
</tbody>
</table>

Range is dependent on some key factors as discussed below:

(i) **Frequency** - Lower frequencies reach further. But it is highly unlikely that bandwidth in the 400 MHz bands will be made available for HSDPA in India.

(ii) **Data rate** - Lower rate transmissions can span a higher range. A 100 Mbps transmission can be coherently received over 200 m, while for distances in kilometres, only 100 kbps transmission per subscriber may be realisable. This may limit the kind of services.

(iii) **Position of the terminal antenna** - Rooftop antennas can provide a range$^8$ of around 30 km. Table 4 summarises this result. Such antennas are already in use, for example in the CorDect systems in India$^9$. This could lead to innovative solutions of accessing HSDPA only at designated “sockets” (at Kiosks or at designated mobile van stops). This also avoids the terrain planning problem. Voice coverage continues without any change.

### Table 4 — Increasing range using external antennas

<table>
<thead>
<tr>
<th></th>
<th>Gain, dBi</th>
<th>Height, Building loss, dB</th>
<th>Range, km</th>
<th>Relative site count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rooftop – LOS</td>
<td>10</td>
<td>8</td>
<td>0</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Rooftop NLOS</td>
<td>10</td>
<td>8</td>
<td>0</td>
<td>6.2</td>
</tr>
<tr>
<td>Terminal - upstairs window</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>1.8</td>
</tr>
<tr>
<td>Outdoor PCcard</td>
<td>0</td>
<td>1.5</td>
<td>0</td>
<td>0.780</td>
</tr>
<tr>
<td>Indoor PCcard - Suburban</td>
<td>0</td>
<td>1.5</td>
<td>10</td>
<td>0.410</td>
</tr>
<tr>
<td>Indoor PCcard - Urban</td>
<td>0</td>
<td>1.5</td>
<td>10</td>
<td>0.210</td>
</tr>
</tbody>
</table>

All figures except LOS based on COST231-Hata model with 10 dB shadow margin and no cable losses. System operates at 2 GHz with 1 Mb/s from 24 dBm EIRP terminal TX, 3 dB Eb/No, 5 dB NF RX. BS antenna = 18 dBi Source: [Ref. 5]
Using repeaters especially in rural areas, the range can be increased without substantially increasing the cost. This is an active part of Release 6 recommendations 10.

Increasing the range of HSDPA is a key research problem that determines its success for rural India.

8 Incremental cost of HSDPA

The following assumptions are made:
(i) Subscribers are dispersed. GSM coverage enables quick and easy 3G and HSDPA access.
(ii) Peak and average bandwidth requirements are the same - there are no “busy hour” traffic profiles.
(iii) Bandwidth usage per session is high due to rich media services. However, number of sessions per subscriber per day is low. Many more subscribers thus share the higher network capacity.
(iv) Since the data services delivered to rural users needs to be mediated, it may be sufficient to provide high bandwidth connectivity only at designated access points. Intermediation also leads to more effective sharing of available network capacity.

Since India has not yet made any moves on 3G, it makes sense for India to directly leapfrog to HSDPA. The difference between HSDPA and 3G is only in the baseband subsystem, which contributes to only 15% of the cost of the base station 9. Thus, the incremental cost of deploying HSDPA is not likely to be more than 10%.

9 Rich media services on a fat pipe – via the cellular network

HSDPA enables rich media services. Some developments in this direction are as follows:
(i) The MBMS (Multimedia Broadcast Multicast Service) is a unidirectional point to multipoint bearer service 11. Services like streaming video and audio can be supported on MBMS. The MBMS has been standardized as part of UMTS (Universal Mobile Telecommunications System) release 6, and should see deployments in 2008. Rich media services like MMS can use the MBMS bearer. The new MPEG-4 AVC Baseline (H.264/AVC, Advanced Video Coding) is currently being favoured in the standards for Release 6.
(ii) Another innovative media delivery system taking shape is IMG (Internet Media Guides), which provides details of content like Television clips, etc. The entire IMG infrastructure can be deployed over HSDPA. An IMG browser application provides a window into the available media content. The user selects the content he desires to view. This is then viewed using another application (codec/media player, etc.).
(iii) For digital TV content, the DVB standards are more suited to mobile terminals. Integration of DVB into UMTS is being studied. The key features are time-slicing, 4K-FFT and FEC. The DVB-H employs a mechanism, where bursts of data are received at a time so that the receiver can save power. Using the 4K mode with some 3409 active carriers, DVB-H benefits from the compromise between the high-speed small-area SFN capability of 2K DVB-T and the lower speed but larger area SFN of 8K DVB-T.

10 Pricing HSDPA services

The key to enabling the proliferation of 3G and HSDPA based services in the rural areas is to get the pricing right. Currently, streaming, downloads, video clips, etc. are high-bandwidth and high-revenue opportunity for 3G operators in the western markets, as shown in Fig. 1. The introduction of higher capacity through HSDPA at marginal costs provides an opportunity to offer rich media services at much more affordable prices. High reliability and lower RTT increases the effective bandwidth available and should in turn have a cascading effect on the cost. Following new services should become available once the costs start falling:
- Mobile Crop Auctions
- Commodity Futures
- Game Score updates
- Weather forecasts
- News
- Advertisements
- e-Coupons
- Micro-credit
- Tele-medicine
11 Comparison with other options for rural India

Since there is no copper laid out in rural India, DSL is not an option to deliver high bandwidth services. Given the existing and potential coverage realised by GSM/GPRS cellular systems, the incremental cost of implementing HSDPA should be much lower than that of setting up any other green field wireless network. In particular, it can be argued that for the same coverage, HSDPA with advanced network planning can replace around 1000 Access Points of W-LAN. The WiMax could be a challenger, but its maturity is currently much lower than HSDPA, and WiMax could have similar challenges for higher range transmissions.

12 Conclusion

While the tele-density in India is increasing rapidly, the growth is primarily in the urban areas. Expanding the telecom penetration into rural India requires both voice and rich media services to be delivered at affordable costs. The authors explain how 3G deployments are already cost effective for voice services, as they can directly leverage the significant infrastructure that has been laid out for GSM. Since India has not yet made any concrete decisions on 3G licensing, it makes sense to leapfrog directly to HSDPA, which allows delivery of rich media services. The problem with HSDPA is its limited range when compared to GSM. This can be circumvented by delivering HSDPA based services at designated points like kiosks and mobile van stops, which can afford to use external antennas to get extra range. This also fits very well with the delivery method that may have to be used in the rural areas, where services are delivered through trained personnel like postmen, health workers, teachers or kiosk operators.

References

2 TRAI recommendations on spectrum related issues, 13 May 2005, Table 1.5 (pp 27) and Fig 1.3 (pp 29).
5 Rao Yallapragada, GSM AMR vocoders: Facts about increased voice capacity, QUALCOMM internal paper.
11 Multimedia Broadcast/Multicast Service, Stage 1, Release 6, 3GPP TS 22.146.