Broadband Wireless Technology for Rural India

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1. RURAL INDIA: A BRIEF BACKGROUNDER

About 70% of India's population, or 750 million, live in its 600,000 villages, and around 85% of these villages are in the plains. The average village has 250-300 households, and occupies an area of 5 sq. km. Most of this is farmland, and typically the houses are in one or two clusters. Villages are thus spaced 2-3 km apart, and spread out in all directions from the market towns. The market centers are typically spaced 30-40 km apart. Each such center serves a catchment of around 250-300 villages in a radius of about 20 km. As the population and the economy grow, large villages morph continually into towns and market centers.

The rural per capita income is distinctly lower than the national average, and rural income distribution is also more skewed. A typical village may have only 100 households with disposable income, the rest struggling to earn just enough to meet essential needs. Two-thirds of the households are dependent on agriculture for income, and even this is often seasonal and dependent on rainfall.

The towns are connected by highways of varying motorability, and in many parts, by rail. Rural roads connecting the villages to towns are little more than dirt tracks in several parts of the country, and are often eroded by floods. In contrast, the telecommunication backbone network, passing through all these towns and market centers, is new and of high quality. The state-owned telecom company has networked exchanges in all these towns and several large villages with optical fiber that is mostly less than 15 years old. The mobile revolution of the last four years has seen base stations sprouting in most towns, owned by three or more operators, including the state-owned company. The base stations of the new operations are also networked using optical fiber laid in the last 5 years. There is a lot of dark fiber, and seemingly unlimited scope for bandwidth expansion.

The solid telecom backbone that knits the country ends abruptly at the towns and larger villages. Beyond that, cellular coverage extends mobile telephone connectivity only up to a radius of 5 km, and then telecommunications services simply peter out. Fixed wireless telephones have been provided in tens of thousands of villages, but it would be safe to conclude that the telecommunications challenge in rural India remains the "last ten miles". This is particularly true if one were to include broadband Internet access in one's scope, since the wireless technologies currently being deployed can barely support dial-up speeds.

This then is the rural India in search of appropriate broadband wireless technology: characterized by fat optical-fiber POPs within 15-20 km of most villages, fairly homogenous distribution of villages in the plains, poor rural cellular coverage, and low incomes. The last aspect makes the provision of basic telecommunications as well as broadband Internet services all the more urgent, since ICT is an enabler for wealth creation.

2. COST OF ACCESS TECHNOLOGY

When considering any technology for rural India, the question of affordability must be addressed first. Given the income levels, one must work backwards to determine the cost of an economically sustainable solution. The 100 odd households in a typical village having disposable incomes can spend on an average US $1-2 per month for telephony and data services. Assuming an average of two public kiosks per village, the revenue of a public kiosk can be of the order of US$ 100 per month. Apart from this, a few wealthy households in each village can afford private connections. After providing for the cost of the terminals, it is estimated that a cost of at most US$ 300 is sustainable for the connection. This includes the User Equipment, as well the per-subscriber cost of the Network Equipment linking the user upto the optical fiber PoP.

3. COVERAGE, SYSTEM GAIN, AND COST OF TOWERS

We have mentioned that we need to cover a radius of 15-20 km from the PoP using wireless technology. The *system gain* is a measure of the link budget available for overcoming propagation and penetration (through foliage and buildings) losses while still guaranteeing system performance. Mobile cellular telephone systems have a system gain typically of 150-160 dB, and achieve indoor penetration within a radius of about 5 km. They do this with Base Station towers of 40 m height, which cost about $10000 each. If a roof-top antenna is mounted at the subscriber-end at a height of 6 m from the ground, coverage can be extended up to 15-20 km. When the system gain is lower at around 135 dB, as in the corDECT system [1], coverage is limited to around 10 km and antenna-height at the subscriber-end has to be 10 m in order to clear the tree tops. This increases the cost of the installation by about $20 per connection.

Thus, roof-top antennas in the villages are a must if one is to obtain the required coverage from the fiber PoP. A broadband wireless system will also need a system gain of around 150 dB if it is to be deployed with 6m poles. This system gain may be difficult to obtain at the higher bit-rates supported by emerging technology, and one may have to employ taller poles in order to support higher bit-rates at distant villages.

There is an important relationship between coverage and the heights of the towers and poles, and, thus indirectly, their cost. The Base Station tower must usually be at least 40 m high even for line-of-sight deployment, as trees have a height of 10-12m and even in the plains one can expect a terrain variation of at least 20-25 m over a 15-20 km radius. Taller Base Station towers will help, but the cost goes up exponentially with height. A shorter tower will mean that the subscriber-end will need a 20 m mast. At around US$ 400, this is substantially costlier than a pole, even if the mast is guyed and not self-standing. The cost of 250-300 such masts is very high compared to the incremental cost of a 40 m tower over a 30 m one. With 40 m towers, poles are sufficient at the subscriber-end, and need rarely be more than 12 m height.

In summary, for a cost-effective solution the system gain should be of the order of 150 dB (at least for the lower bit rates), a 40 m tower should be deployed at the fiber PoP, and roof-top antennas with 6-12m poles at the subscriber-end. The cost per subscriber of the tower and pole (assuming a modest 300 subscribers per tower) is US$ 50. This leaves about US$ 250 per subscriber for the wireless system itself.

4. WHAT CONSTITUTES BROADBAND?

The Telecom Regulatory Authority of India has defined broadband services as those provided with a minimum data rate of 256 kbps [2]. At this bit-rate, browsing is fast, video-conferencing can be supported, and applications such as telemedicine and distance education using multi-media are feasible. There is no doubt that a village kiosk could easily utilize a much higher bit-rate, and as technology evolves, this too will become available. However, it is important to note that even at 256 kbps, since kiosks can be expected to generate a sustained flow of traffic, 300 kiosks will generate of the order of 75 Mbps. This is a non-trivial level of traffic to evacuate over the air per Base Station, even with a spectrum allocation of 20 MHz.

5. SUITABILITY OF BROADBAND WIRELESS TECHNOLOGIES

One of the pre-requisites for any wireless technology for it to cost under US$250 is that it must be a mass-market solution. This will ensure that the cost of the electronics is driven down by volumes and competition to the lowest possible levels. As an example, both GSM and CDMA mobile telephone technologies can today meet the above cost target, (however, an even lower cost is needed for a non-broadband technology since the services provided are limited).

The third-generation evolution of cellular telephone technologies will probably continue to meet this cost target while offering higher bit-rate data services. However, they will not be able to provide broadband services as defined above.

If we turn our attention to some proprietary broadband technologies such as iBurst [3], and Flash-OFDM [4], or even a standards-based technology such as WiMAX-d (IEEE 802.16d) [5], we find that volumes are low and costs high. Of these, WiMAX-d has a lower system gain than the others (which are around the required 150 dB). All of them will give a spectral efficiency of around 4 bps/Hz/cell (after taking spectrum re-use into account), and thus can potentially evacuate 80 Mbps at each Base Station with a 20 MHz allocation. However, high cost due to low volumes is the inhibitory factor with these technologies.

It is likely that one or more OFDMA-based broadband technologies will become widely accepted standards within 2-3 years. WiMAX-e (IEEE 802.16e) [6] is one such that is emerging rapidly. These will certainly have a higher spectral efficiency, and more importantly, if they become popular and successful, the cost will be low. The obvious question is whether there are alternatives in the interim that meet our performance and cost objectives.

6. BROADBAND WIRELESS TECHNOLOGIES FOR THE NEAR-TERM

While wide-area broadband wireless technologies will be unavailable at the desired price-performance point for a few years, local-area broadband technologies have become very inexpensive. A well-known example is WiFi (IEEE 802l.11) technology. These technologies can provide 256 kbps or more to tens of subscribers simultaneously, but can normally do so only over a short distance–less than 50 m in a built-up environment. Several groups have worked with the low-cost electronics of these technologies in new system designs that provide workable solutions for rural broadband connectivity.

7. BROADBAND CORDECT TECHNOLOGY

One of the earliest and most widely deployed examples of such re-engineering is the corDECT Wireless Access System developed in India [1]. The next-generation broadband corDECT system has also been launched recently [7], capable of evacuating 70 Mbps per cell with a 5 MHz bandwidth (supporting 144 full-duplex 256 kbps connections simultaneously). These systems are built around the electronics of the European DECT standard, which was designed for local area telephony and data services. Broadband incorporates corDECT added proprietary extensions to the DECT physical layer that increase the bit-rate by three times, while being backward compatible to the DECT standard. More importantly, this has been done while retaining the use of the low-cost DECT chipsets.

The system gain in Broadband corDECT for 256 kbps service is 125 dB. This can be increased by a few dB, where required, by increasing the antenna gain at the subscriber-end (which is 11 dBi now). This is sufficient for 10 km coverage under line-sight conditions (40 m tower for BS and 10-12 m pole at subscriber side). A repeater is used, as in the corDECT system, for extending the coverage to 25 km. The corDECT system, and now the broadband corDECT system, meet the rural price-performance requirement, but with the additional encumbrance of 10-12 m poles and one level of repeaters.

8 RURAL WIFI TECHNOLOGY

In recent years, there have been some sustained efforts to build a rural broadband technology using WiFi chipsets. WiFi bit rates go all the way up to 54 Mbps. The system gain is about 132 dB for 11 Mbps service, and as in corDECT, one requires a 40 m tower at the fiber PoP and 10-12 m poles at the subscriber-end. The attraction of WiFi technology is the de-licensing of spectrum for it in many countries, including India. In rural areas, where the spectrum is hardly used, WiFi is an attractive option, provided its limitations when used over a wide-area are overcome.

Various experiments with off-the-shelf equipment have demonstrated the feasibility of using WiFi for long-distance rural point-to-point links. The more serious issue with regard to the 802.11 standard is that the commonly–supported MAC protocol is a Carrier Sense Multiple Access (CSMA) protocol [8] suited only for a LAN deployment. When standard WiFi equipment is used to set up a wide-area network, medium access efficiency becomes very poor, and spectrum cannot be re-used efficiently even in opposite sectors, of a base station.

A solution for this problem is to replace the MAC protocol of 802.11 with a MAC protocol more suited to wide-area deployment. One will have to craft it carefully such that a low-cost WiFi chipset can still be used, and the in-built WiFi MAC in it can be by-passed. The new MAC can be implemented on a separate general-purpose processor with only a modest increase in cost. This approach has been taken in a recent research study [9] aimed at defining an efficient rural WiFi MAC that can also be implemented at low cost. With the new MAC, it is estimated that using a single WiFi carrier, one can support about 25 Mbps (uplink + downlink) per cell. This would be sufficient for about 100 villages in a 10-15 km radius. Repeaters, possibly operating on a different frequency, will be needed for covering more villages over a greater distance.

9 CONCLUSION

Wireless broadband technologies with performance and cost suitable for rural India are expected to become available in a few years. Till then, solutions based on innovative extensions of broadband local-area technologies can provide cost-effective answers. These technologies need more care and planning during deployment, since they lack sufficient system gain, and a judicious choice of Base Station tower height and subscriber-end pole height is required to control cost while ensuring coverage. With these technologies, it is possible to provide a sustained bit rate of 256 kbps (at least on the downlink) to each village kiosk in a cost-effective manner.

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