Annex A : Design Drivers

1 The Indian Rural Scenario

About 70% of India's population, or 750 million, live in its 600,000 villages. More than 85% of these villages are in the plains or on the Deccan plateau. The average village has 200-250 households, and occupies an area of 5 sq. km. Most of this is farmland, and it is typical to find all the houses 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 centre serves a catchment of around 250-300 villages in a radius of about 20 km. As the population and the economy grow, several large villages are continually morphing into towns and market centres.

The telecommunication backbone network, mostly optical-fiber based, which passes through 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 rarely more than 10-15 years old. The mobile revolution of the last four years has seen base stations sprouting in all these towns, with three or more operators, including the state-owned company. These base stations are also networked using mostly 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 together ends abruptly when it reaches the towns and larger villages. Beyond that, cellular coverage extends mobile telephone connectivity up to a radius of 5 km, and then telecommunications simply peters out. Cellular telephony will expand further as it becomes affordable to the rural populace. It is a highly sought after service, and the only reason for the service not spreading as rapidly in rural areas as in urban areas is the lack of purchasing power in the the rural areas. Fixed wireless telephones have been provided in tens of thousands of villages as a service obligation; however, the wireless technologies currently being deployed can barely support dial-up speeds as far as Internet access is concerned.

The rural per capita income is distinctly lower than the national average, and rural income distribution is also more skewed. About 70% of the rural households earn less than Rs 3000 per month, and only 4% have incomes in excess of Rs 25000 per month. Only the latter can be expected to even aspire to have a personal computer and Internet connection. For the rest, the key to Internet access is a public kiosk providing a basket of services. Provision of basic telecommunications as well as broadband Internet services is imperative, since ICT is known to be an enabler for wealth creation

2 Affordability

When considering any technology for rural India, it is clear that the question of affordability must be addressed first. Given the income levels, one must work backwards to determine the cost of any economically sustainable solution. It is reasonable to expect an expenditure on telecommunication services of only around Rs 60 per month on the average (2% of household income) from about 70% of the 200-250 households in a typical village. Thus, the revenue of a public kiosk can only be of the order of Rs 4500 per month (assuming two kiosks per village on the average). Apart from this, a few wealthy households in each village can afford private connections. Taking into account the cost of the personal computer, power back-up, peripherals, etc, it is estimated that a cost of at most Rs 15000 per broadband connection is sustainable for the kiosk. This includes the User Equipment, as well the per-subscriber cost of the Network Equipment connecting the user to the optical fiber PoP.

A typical wireless system for servicing such a rural area will have a BTS at the fiber PoP. A BTS can be expected to serve about 250-300 connections initially, going upto a 1000 connections as the service becomes stable and popular and the wealthy households decide to invest in a computer. Growth to full potential will take several years. Given the cost target mentioned above, it is found that a wireless technology becomes economically viable in the rural areas only when it has reached maturity and volumes worldwide are high enough to bring the cost down. New technologies at the early induction stage are too costly, particularly since the slow growth in the subscriber base keeps the per-subscriber cost of the BTS and associated equipment high.

3 Coverage, Towers and System Cost

We have already mentioned that we need to cover a radius of 15-25 km from the PoP using wireless technology. The system gain is a measure of the link budget available for overcoming propagation and penetration losses (through foliage and buildings) while still guaranteeing system performance. Mobile cellular telephone systems have a system gain typically of around 150-160 dB, and achieve indoor penetration within a radius of about 3-5 km. They do this with Base Station towers of 40 m height, which cost about Rs 5 lakhs each. If a roof-top antenna is mounted at the subscriber end at a height of 6m from the ground, coverage can be extend upto 15-20 km with this system gain. When the system gain is lower at around 135 dB, as with many low-power systems such as those based on the WiFi standard or the DECT standard [ ], coverage is limited to around 10 km and antenna-height at the subscriber-end has to be at least 10m. This increases the cost of the installation by about Rs 1000.

In any case, we see that fixed terminals with roof-top antennas are a must if one is to obtain the required coverage from the fiber PoP. A broadband wireless system will need a system gain of around 140 - 150 dB at bit-rates in excess of 256 kbps, if it is to be easily deployable. This system gain may be difficult to provide for the higher bit-rates supported by the technology, and one may have to employ taller poles in order to minimize foliage loss.

There is an important relationship between coverage and the heights of the towers and poles, and indirectly their cost. The Base Station tower must usually be at least 40 m high for line-of-sight deployment, as trees have a height of 10-12m and one can expect a terrain variation of around 20-25m even in the plains 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 Rs 15000 or more, this is substantially costlier than a pole, even if the mast is a guyed one and not self-standing. The cost of 250-300 such masts is very high compared to the additional cost of a 40 m tower vis--vis a 30 m one. With the 40m towers, simple poles can be deployed at the subscriber-end, and these need be only than 12m high.

In summary, one can conclude that for a cost-effective solution the system gain should be of the order of 145 dB, (at least for the reasonable bit-rates, if not the highest ones supported), a 40 m tower should be deployed at the fiber PoP, and roof-top antennas with 6-12m poles at the subscriber-end. The system gain can be lower at around 130 dB, provided repeaters are used to cover areas beyond 10 km radial distance, and assuming antenna poles that are 10-12m high are deployed in the villages. The cost per subscriber of the tower and pole (assuming a modest 300 subscribers per tower) is Rs 2500. This leaves about Rs 12500 per subscriber for the wireless system itself.

4 Definition of Broadband

The Telecom Regulatory Authority of India has defined broadband services as those provided with a minimum downstream (towards subscriber) data rate of 256 kbps. This data-rate must be available unshared to the user when he/she needs it. 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 utilise a much higher bit-rate, and as technology evolves, this will become available too. However, it is important to note that even at 256 kbps, since kiosks can be expected to have a sustained rate not much lower, 300 kiosks will generate of the order of 75 Mbps traffic to evacuate over the air per Base Station. This is non-trivial today even with a spectrum allocation of 20 MHz.

The broadband wireless access system employed to provide Internet service to kiosks must also provide telephony using VoIP technology. Telephony earns far higher revenue per bit than any other service, and is an important service. The level of teletraffic is limited by the income levels of the populace. Assuming that most of the calls will be local, charged at around Rs 0.25 per minute, even if only one call is being made continuously from each kiosk during the busy hours (8 hours per day), this amounts to an expenditure of Rs 120 per day at each kiosk. This is a significant fraction of the earnings of the kiosk, and a significant fraction of the total communications expenditure of the village.

Thus, depending on the teledensity in the district, one can expect around 0.5-1 Erlang traffic per kiosk. This works out to a total of around 100-200 Erlangs traffic per BTS. Assuming one voice call needs about 2x16 kbps with VoIP technology, this traffic level requires 2x1.5 Mbps to 2x3.0 Mbps of capacity. If broadband services are not to be significantly affected, the system capacity must be several times this number. It is to be noted here that if the voice service either requires a higher bit-rate (say, 64 kbps) per call, or wastes system capacity due to MAC inefficiency when handling short but periodic VoIP packets, we will have significant degradation of other broadband services. Thus, an efficient VoIP capability is needed, with QoS guaranteed, that eats away from system capacity only as much as is unavoidably needed to support the voice traffic. Such a capability must be built into the wireless system by design. It is also important not to discourage use of the system for telephony since it is the major revenue earner as well as most popular service.

5 Broadband Wireless Technologies circa 2006

One of the pre-requisites for any technology for it to cost under Rs 12500 per connection 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 easily meetthe above cost target, except that they do not provide broadband access.

The third-generation evolution of cellular telephone technologies may, in due course, meet the cost target while offering higher bit-rate data services. However, they are ain the early induction stage at present, and it is also not clear whether they will right away provide the requires system capacity. However, the third-generation standards are constantly evolving, and the required system capacity is likely to be reached at some time. The only question is regarding when the required performance level will be reached and when the cost will drop to the required levels.

If we turn our attention next to some proprietary broadband technologies such as iBurst [], and Flash-OFDM [], or a standard technology such as WiMAX-d (IEEE 802.16d) [], we find that volumes are low and costs high. Of these, WiMAX-d has a lower system gain. 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 with a 20 MHz allocation. High cost is the inhibitory factor.

It is likely that one or more OFDMA-based broadband technologies will become widely accepted standards in the near future. WiMAX-e (IEEE 802.16e) [] is one such that is emerging rapidly. The standards emerging as the Long-Term Evolution (LTE) of the 3G standards are other candidates. These will certainly have a higher spectral efficiency, and more importantly, when they become popular and successful, they will become mass-market technologies, and the cost will be low. Going by the time-to-maturity of mass-market wireless technologies till date, none of these technologies are likely to provide an economically viable solution for India's rural requirements for several years yet.

6 Alternative Broadband Wireless Technologies in the Near Term

While wide-area broadband wireless technologies will be unavailable at the desired price-performance point for some time, local-area broadband technologies have become very inexpensive. A well-known example is WiFi (IEEE 8021.11) 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 50m 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.

One of the earliest and most widely deployed examples of such re-engineering is the corDECT Wireless Access System [ ] developed in India. A next–generation broadband corDECT system has also been launched recently, capable of evacuating upto 70 Mbps per cell in 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. Proprietary extensions to the DECT standard have been added in a manner that the low-cost mass-market ICs can continue to be used. These increase the bit-rate by three times, while being backward compatible to the DECT standard.

The system gain in Broadband corDECT for 256 kbps service is 125-130 dB, depending on the antenna gain at the subscriber-end. 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 for extending the coverage to 25 km. The system meets the price-performance requirement, but with the additional encumbrance of taller poles and one level of repeaters.

The WiFiRe standard proposed by CEWiT is an alternative near-term solution, with many similarities. It, too, is a re-engineered system based on low-cost low-power mass-market technology. Cost structures are similar, and deployment issues too are alike. There is one key aspect in which WiFiRe differs from Broadband corDECT. The spectrum used for WiFiRe is unlicensed without fees, whereas the spectrum used by Broadband corDECT is licensed with a fee. The spectral efficiency of the WiFiRe system is poorer, and the cell capacity per MHz of bandwidth is lower. However, this is offset by the fact that the spectrum used by it is in the unlicensed WiFi band of 2.4-2.485 MHz. This unlicensed use is subject to certain conditions, and some modifications to these conditions will be needed to support WiFiRe in rural areas (see section on Conditional Licensing below). WiFiRe technology is best suited for local niche operators who can manage well the conditionalities associated with unlicensed use. It does not afford the blanket protection from interference that a system operating with licensed spectrum enjoys.

7 Motivation for WiFiRe

In recent years, there have been some sustained efforts to build a rural broadband technology using the low-cost, mass-marketWiFi chipset. WiFi bit rates go all the way up to 54 Mbps Various experiments with off-the-shelf equipment have demonstrated the feasibility of using WiFi for long-distance rural point-to-point links []. One can calculate that the link margin for this standard is quite adequate for line-of-sight outdoor communication in flat terrain for about 15 kms of range. 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. The issues related to spectrum de-licensing for WiFiRe are discussed separately in the next section. Before that, we turn our attention to the suitability of the WiFi standard as it exists for use over a wide rural area. We have already seen that the limitations of the Physical Layer of WiFi can be demonstrably overcome. We turn our focus noe to the MAC in WIFi.

The basic principle in the design of MAC in Wi-Fi is fairness and equal allocation to all sources of demand for transmission. This leads to the DCF mode which operates as a CSMA/CA with random backoff upon sensing competing source of tx. On the other hand there is also a PCF mode, which assumes mediation by access points. This gives rise to the possibility of enterprise-owned and managed networks with potential for enhanced features like security and quality of service guarantees.

The CSMA/CA DCF MAC has been analysed and turns out to be inefficient for a distribution service that needs to maximize capacity for subscribers and maintain quality of service []. The delays across a link are not bounded and packet drops shoot up rapidly in such a system while approaching throughputs of the order of 60% of rated link bandwidth. The PCF MAC will perform better than the DCF MAC. However, both the MACs in the WiFi standard become very inefficient when the spectrum is re-used in multiple sectors of a BTS site.

Fundamentally, in a TDD system, wherein uplink and downlink transmissions take place in the same band in a time-multiplexed manner, the down-link (and similarly uplink) transmissions of all the sectors at a BTS site must be synchronized. Otherwise the receivers in one sector will be saturated by the emissions in another. This can be avoided only by physical isolation of the antennas, which is very expensive if all the antennas must also be at a minimum height of 40 m. Further, this synchronization must be achieved with minimal wastage of system capacity due to the turnaround from uplink to downlink and vice versa, as well as due to varying traffic characteristics (packet sizes, packet arrival rates) in different sectors at different times.

It is thus clear that a new MAC is needed which is designed to maximize the efficiency in a wide-area rural deployment supporting both voice and data services with modest use of spectrum (see next section for the need for limiting the use of spectrum). Fortunately, most Wi-Fi chipsets are designed so that the Physical and MAC layers are separate. Thus one can change the MAC in ways that enable high- efficiency outdoor systems that can be used for rural internet service provisioning or voice applications, while retaining the same PHY. Thus without significantly changing radio costs, one can arrive at entirely different network level properties by changing the MAC, sectorization and antenna design choices and tower/site planning. Taking a cue for this approach, we design a new wireless system, WiFiRe, which shares the same PHY as WiFi, but with a new MAC. The principle of Access Points, or special nodes which control the channel and allocate bandwidth to individual nodes, and tight synchronization based on the time-slotting principle used in cellular voice systems such as GSM or upcoming data systems like WiMax, can be combined to guarantee efficiency and quality of service.

8 Conditional Licensing of Spectrum

The spectrum allotted for WiFi, in the 2.4-2.485 MHz band, can be employed by anyone for indoor or outdoor emissions, without a prior license provided certain emission limits are met [www.dotindia.com/wpc]. The 5 GHz band, also universally allotted to WIFi, can be used in India only for indoor emissions. In the 2.4 Ghz band, the maximum emiited power can be 1W in a 10 MHz (or higher) bandwidth, and the maximum EIRP can be 4W. The outdoor antenna can be no higher than 5 m above the rooftop. For antenna height higher than the permissible level, special permission has to be obtained. Further, if the emissions interfere with any licensed user of spectrum in the vicinity, the unlicensed user may have to discontinue operations.

It is clear that some modifications of the rules are needed for WiFiRe. A higher EIRP will need to be permitted in rural areas, and further, antenna deployment at 40 m must be permitted at the PoP, and possibly for repeaters (in due course). Antenna deployments at 10-15 m will have to be permitted at the villages.

The relaxations may be restricted to WiFiRe- compliant technology. It may be given only for one specified carrier per operator, and a maximum of two operators may be permitted in an area. The BTS and repeaters of the second operator (in chronological order of deployment) may be restricted to be at least one kilometer from those of the first operator in an area. This will prevent mutual adjacent-channel interference, as well as permit maximum use of the two conditionally licensed carriers by others in the vicinity of the BTSs. If an unlicensed WiFi user in the vicinity of the BTS or village kiosk/private subscriber interferes with the WiFiRe system, the unlicensed user will have to switch over to a non-interfering carrier in the same band or in the 5 GHz band. This last condition is not very restrictive, as only around 15 MHz of the available 85 MHz in the 2.4 GHz band is blocked in the vicinity of any one BTS or village kiosk/subscriber. Further, if the unlicensed user is an indoor user, the area where there is noticeable interference to/from the WifiRe system is likely to be fairly small.