December 1998

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Introduction

Internet has seen tremendous growth in terms of number of hosts and number of users in recent years. Despite this growth, Internet is not universally available. Most of the Internet activity takes place in the developed nations. Even in places where Internet connectivity is available, users are constrained to use low bandwidth connections because of the limitations of the access network that connects them to the backbone networks. This problem, known as "last mile" problem in telecommunications has attracted the attention of researchers. Bell (1996) addresses the last-mile problem for Internet connectivity as applicable to developed countries and prescribes possible wireline based access network solutions. Khasnabish (1997) addresses both wired and wireless access networks, again in the context of developed economies. Chatterjee (1997) briefly discusses this problem for providing broadband access. Developing countries have very low teledensities and have inferior telecommunication infrastructure. The technology alternatives suitable for developed nations are not suitable for developing countries. Paulraj (1995) addresses the last-mile problem in developing countries and suggests wireless solutions for basic telephony based services. In this paper we extend the model described in (Paulraj, 1995) to address additional factors to be considered for the evaluation of access network alternatives for providing Internet connectivity in developing countries. We investigate which access network technology is suitable for Internet connectivity for residential users in developing countries. Preliminary studies indicate that wireless access solutions have an edge over wireline technologies.

Access Network

Figure 1 shows the network components which connect the residential user to Internet resources. The network resources can be present in the local network of the ISP or on any host in the local, regional, or national networks. All countries, including developing countries have upgraded their regional and national networks using fiber optic transmission lines operating at T3 (45 Mbps), OC-3 (155 Mbps) or even OC-12 (622 Mbps) speeds. However, lack of quality access loop infrastructure that connects the residential user to the access network proves to be a deterrent for Internet connectivity in developing countries.

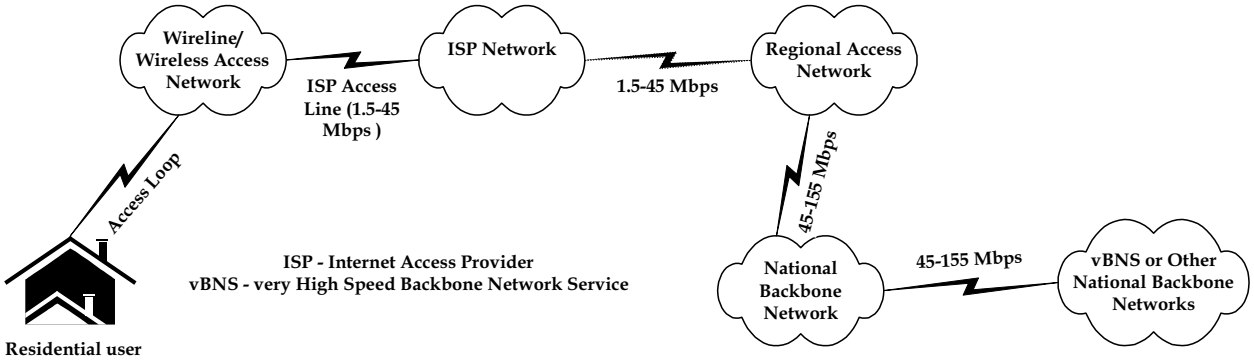

Figure 1. Telecommunications Infrastructure for Internet Access

Factors Affecting Access Network Infrastructure

Access Technology Options: Factors that affect the access network infrastructure in developing countries is illustrated in Figure:2. Teledensity in countries such as India is about 7 access lines per 1000 people as compared to a world average of 255 access lines and the U.S. level of over 550 access lines (Paulraj 1995). International Telecommunication Union (ITU) recommendation of 200 access lines per 1000 population is far beyond the capabilities of many nations. Table:1 compares the technology options for Internet access for home users in developing and developed countries. Due to inadequate wireline infrastructure, access technologies such as ADSL, VDSL and Cable Modems that are being considered by developed countries are not suitable for developing countries. On the other hand, advances in technology have been driving towards a wireless revolution in basic telephony and data services in developing countries. Developing countries can leap frog from limited phone service to full-fledged high speed Internet access using fixed WLL technology. The WLL infrastructure revenue is expected to

grow from $827,000 in 1997 to $7.8M by year 2000 in developing countries as compared to $1.3M and $10.7M in the same period in developed countries (Budde 1997). This indicates that the rate of growth in WLL in developing countries is comparable to developed countries. In India, $4.7B investment in WLL systems is expected in the coming years. Digital cellular systems are being implemented in metro areas in India to satisfy demands for basic telephony. In future, these can provide CDPD based narrowband Internet connectivity. Direct satellite systems have penetrated television broadcasting in developing countries, thus bypassing the development of wired infrastructure required for cable television. These satellite systems are expected to provide direct Internet access in developing countries. Broadband Low Earth Satellite (LEO) systems such as Teledesic and Skybridge, when operational in 2001/2002 are expected to provide broadband Internet connectivity for the developing regions of the world.

Table1. Access Technology Options and Transmission Speeds for Internet Access

In Developed Countries	In Developing Countries
Wireline: Analog telephone network (33-53 Kbps), Integrated Services Digital Network - ISDN (128 Kbps), Asymmetric Digital Subscriber Line-ADSL (1.5-6 Mbps), Very High-Speed Digital Subscriber Line-VDSL(13-55 Mbps), Cable Modem(30 Mbps) *Wireless*: Direct Satellite Links (400 Kbps), Fixed Broadband Wireless Local Loop – WLL (30-55 Mbps), Broadband Low Earth Orbit (LEO) satellites (1-2Mbps)	*Wireline*: Analog telephone network (19-53 Kbps), ISDN (128 Kbps) *Wireless*: Cellular Digital Packet Data - CDPD (19-48 Kbps), Direct Satellite links (400 Kbps), Narrowband WLL (19-53 Kbps), Broadband WLL (30-55 Mbps), Broadband LEO satellites (1-2 Mbps)

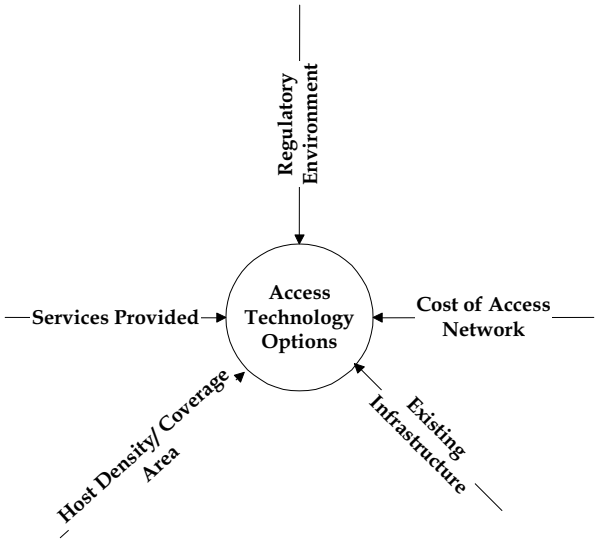

Figure 2. Factors Affecting Access Network Infrastructure

Services Provided: We define two classes of service to be provided through the access network to the home user: (1) *Class-1 service* that includes narrow-band data service at the rate of 28 Kbps to 400 Kbps. Applications such as E-mail, graphical web page access, streaming audio, IP telephony, TCP/IP based video conferencing belong to this class. Demand for this service can normally be found in metro areas. (2) *Class-2 service* that includes broadband service at the rate of 1.5 Mbps-55 Mbps. Applications that require high bandwidth such as remote LAN connectivity through Virtual Private Networks, Multimedia web page access, and Video On Demand belong to this class. The users of Class-2 service are normally small business users and sophisticated residential users in large metro areas in countries like India. In developing countries, it is expected that there will be more demand for the Class-1 service than Class-2 service.

Host Density/Coverage Area: We model a three segment approach for Internet access based on coverage area (measured in Sq. Km) and host density (measured in number of Internet hosts/Sq. Km). (i) Large metro areas (1000 Sq. km) and high host density (100 – 1000 per Sq. km) (ii) Medium sized towns and suburban metro areas with moderate coverage areas and moderate host density and (iii) Information Centers (ICs) where Internet access is provided by service operators for public to use for a fee (very small coverage area and high host density). The information centers are similar to public telephone booths operated by independent operators in many medium and large metro areas. A similar approach is described for basic telephony in Paulraj (1995).

Existing Infrastructure: In most of the developing countries, inadequate maintenance of the access loop, low quality of cables and high rate of accidental damage to cables lead to transmission impairments. In India, for example, the frequency of trouble reports is as high as 20 per year (Paulraj, 1995). For Internet access, it is crucial to have less impairments to achieve high throughput. Realizing this, in India $200M Public Switched Telephone Network (PSTN) upgrade is planned to handle long call holding times and higher bandwidth requirements for Internet access (Chaki, 1998). Fixed WLL, can provide Class-1 and Class-2 services in areas with low quality wired infrastructure. In countries like India, demand for access loop is much higher than the rate of deployment. In 1997 alone, number of new connections requested were 2.8M and number of waiting applicants carried forward from 1996 were 3.3M in India (Chowdary, 1998). In situations, like this where wired infrastructure is woefully inadequate to meet the demand, WLL should definitely be considered as a viable alternative. Areas with adequate wired infrastructure in large and medium metro areas are suitable for implementing 56K modem technology and ISDN.

Cost of Access Network: Per-line capital cost for wired loop is about $1500 - $1800 as compared to about $250 plus the cost of the handset in wireless systems (McGarty 1997). The main component in wireless systems is the cost of the handset or Customer Premise Equipment and these have been falling steadily. Per-line cost of wireless loops are not as sensitive to host

density and coverage area (Paulraj, 1995). Broadband WLL systems are viable alternatives for large metro areas and ICs for providing Class-2 service. Direct satellite and CDPD based narrowband wireless systems can supplement wireline based Class-1 services in large and medium metro areas.

Regulatory Environment: In almost all of the developing countries, the low teledensities are a consequence of deliberate political decision supporting government owned monopoly telecommunication agencies such as PTTs. There have been instances of opening up the telecommunications market to competition and foreign investment recently. However, in India, the decisions to charge exorbitant licence fees for new entrants and limiting the number of telecom operators to protect the government owned PTTs have curbed deployment of basic telephony and Internet connectivity. Furthermore, wireless systems require close co-operation between government regulatory agencies and service providers regarding spectrum allocation, license agreements and interconnectivity arrangements. Few regulators in the developing countries demonstrate a clear understanding of wireless systems management (Zita, 1997). In India, independent regulatory agencies such as the Telecom Regulatory Authority of India have been constituted only in 1997. Changes in regulatory environment and market conditions will have pronounced impact on the implementation of telecommunications infrastructure for Internet access in developing countries.

Conclusions

In this paper, we have addressed the factors that affect Internet connectivity for residential users in developing countries. Relationship between types of services, coverage area, Internet host density, cost of access network, conditions of the existing infrastructure, status of the regulatory environment and access technology are analyzed. The analysis indicates that wireless access networks can be suitable alternatives to improve Internet connectivity in developing countries. Further research is needed to build analytical models to optimally select an access network technology, given the various factors outlined in this paper.

References

References are available upon request from the author (vsridhar1@ohiou.edu).