

Information and Communication Technology Infrastructure and Its Distributed Generation Solutions in Remote Areas

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Abstract – This paper investigates two key factors that potentially enable sustainable telephone and Internet connectivity to majority of households in remote locations. These are ‘*affordable telecommunications infrastructure*’ and ‘*its locally available distributed generation solutions*’. Several telecommunication technologies are reviewed and one that is affordable and has the lowest power consumption for remote equipment is discussed in detail. This is followed by insights into the system configurations and estimates of peak power and energy usage for each component. Next, the paper reviews the availability of renewable energy resources as well as fossil fuel resources in the target country - Bangladesh. Finally, based on the resource availability, a range of power schemes are examined which can support these systems and meet the electricity demand.

Keywords: ICT, distributed generation, corDECT WLL.

1. INTRODUCTION

Information and Communication Technology (ICT) has long been recognized as a crucial constituent in the social infrastructures to constitute a modern nation. In many developing countries, ICT plays a key role in social development. The evidence has indicated that ICT has potential to empower the quality of lives for people living in poverty. It provides the community with the power to access virtually all kinds of information, knowledge, as well as communications services. In Africa [1] for instance, ICT is being used as a tool to achieve better learning outcomes and enable access to material and resources from international, national and local sources in remote communities. It has also become common understanding that telecom and Internet infrastructure is indispensable for the development of economy. In addition, ICT benefits community businesses in numerous ways, essentially by facilitating access to global markets, and boosting both domestic and international trade. For example, in Sri Lanka farmers used newly installed telephones to find out the prices of coconut, fruit and other produce in Colombo. Instead of selling them at fifty to sixty percent of the Colombo price, farmers were able to get between eighty and ninety percent [2].

Although the benefits of ICT have long been established, and several attempts have been initiated to integrate ICT into the economy of the developed world, least developed countries are being left behind in their number of telephone and Internet subscribers. According to the recent article in “The Economist” [3], the least developed countries have a teledensity and a share of total world’s Internet users of less than 0.5%. In addition, the figures from International Telecommunication Union (ITU) in 2002 indicate the fixed teledensity in Bangladesh is only 0.51 per 100 inhabitants and the internet users is only 1.5 per 1,000 inhabitants as shown in Table 1.

Table 1: ITU Asia-Pacific Telecommunications Indicator 2002

Country	Fixed telephone density	Mobile phone density	Internet users (per 1000)
Thailand	9.87	26.4	77.5
Sri Lanka	3.98	4.92	10.6
India	2.66	1.22	15.9
Pakistan	2.48	0.56	3.5
Bhutan	2.84	0	14.4
Nepal	1.41	0.09	2.7
Bangladesh	0.51	0.81	1.5

Source: [4]

Generally, there are two main reasons behind such a low telephone and Internet connection in Bangladesh and in many developing nations. The first reason is the high access fees for ICT solution in most developing countries. For instance, according to a study by Abu Saeed Khan [5], the state telecom company in Bangladesh has been charging Tk. 18,400 (US\$335) connection fees, which is 27% higher than the per capita GDP (US\$263). The second reason comes from the fact that most of the rural villages are neither connected to electricity grid network

nor have access to local reliable power sources. Consequently, ICT connections are almost impossible in such locations since electricity is an absolute prerequisite for the use of modern ICT systems.

Thus in order to bridge the gap in low-income countries like Bangladesh, the main focus of this paper is on investigating: (i) "Affordable Telecommunications and Internet infrastructure"; and (ii) "Its locally distributed generation solutions" to support telecom and Internet connections in remote areas. Section 2 briefly reviews current backbone status and possibility to provide nationwide access in Bangladesh. Section 3 reviews several applicable last-mile telecommunications systems and suggests that wireless in local loop (WLL) is the most efficient and affordable telecommunications solution employed in remote areas. Section 4 gives an insight into the WLL architecture recently introduced by Indian Institute of Technology at Madras, India [6]. Also, it describes the possible deployment scenarios and estimates electric power requirements to support ICT subsystems and end-user appliances. Section 5 presents an assessment of renewable energy resources as well as the availability of fossil fuel resources in Bangladesh. These resources include solar energy, wind energy, biomass energy, as well as natural gas and diesel oil. Based on the resource availability, a range of potential power schemes are proposed and compared using life-cycle-cost analysis in Section 6. Finally, major conclusions of the paper are presented in section 7. By examining these key issues, it is the intention of the paper to bring them into sharp focus and offer a solution to overcome the 'digital divide' that limits the economic and social opportunities to majority of the world's population.

2. OPPORTUNITY FOR NATIONWIDE TELECOM AND INTERNET ACCESS IN BANGLADESH

2.1 Current backbone status

The major telecommunication backbone of Bangladesh consists of microwave link and optical fiber. The microwave link of the Bangladesh Telegraph and Telephone Board (BTTB) is divided into three tiers. The major tier backbone spreads with star formation through 57 hops covering 2,188 km (56% digital). The second tier backbone is 1,749 km in length (59% digital) and the third tier covers 1,538 km inter-district spur links (40% digital). Then, BTTB's backbone migrates from the microwave link to optical fiber along the national railway network and the national highway route. Bangladesh Railway commissioned 1,800-km fiber alongside its 2,900-km track, covering a total of 46 out of the 64 district headquarters and 5 out of 6 divisional headquarters. Capacity of this backbone is STM-4 (OC-12) and STM-1 (OC-3) for 800 km and 1,000 km respectively. In addition to the public sector, private sector also plays an important role in extending the optical fiber between main cities. Acatel is rolling out a 276-km STM-16 (OC-48) link along the national highway connecting Dhaka-Chittagong route. Netas is rolling out a 370-km STM-4 (OC-12) link along the national highway between Dhaka and Bogra via Tangail. CMEC of China also connects the 54 out of the 64 district headquarters with fiber and microwave link [5].

2.2 Optical fiber and wireless technology to provide national access

Although Bangladesh has the existing broadband infrastructure, it covers only 28% of the area. By utilizing optical fiber, this backbone can be cost-effectively extended along the national railway track and the national highway route. In addition, the deployment of wireless technology as a last-mile solution from the extended backbone can provide the telecommunication and Internet access to reach 90% of the population in Bangladesh.

Note that due to the flat-terrain characteristic of Bangladesh, wireless technology with a line of sight distance of 30-40km means that the entire 144,000-km² country can be covered by a handful of towers – as few as 15 towers with 50-km radius [7], as illustrated in Figure 1.



Figure 1: Possibility for Nationwide Telecom-and-Internet Access in Bangladesh

3. THE APPLICABLE LAST-MILE TELECOMMUNICATIONS SYSTEMS

This section investigates various last-mile solutions that are applicable to provide ICT connection in rural areas. These are plain old telephone service, optical fiber system, TDMA point-to-multi-point systems and wireless local loop systems, and lastly satellite communication system.

3.1 Plain Old Telephone Service (POTS)

POTS is the most common telecommunications system that presently provides telecom and Internet access to majority of the world's population. POTS connects end users to public switched telephone network (PSTN) through copper wires. Its popularity stems from the very simple connection and its low cost of entry if copper wire is available in the area. Usually, its distance limitation is in order of 2 to 5 km from the PSTN. To connect to the Internet, a user uses a telephone line, with a moderately equipped personal computer and a modem, and dials an Internet service provider (ISP). Then, the ISP connects the user to a router, which in turn is connected to other routers on the Internet as shown in Figure 2.

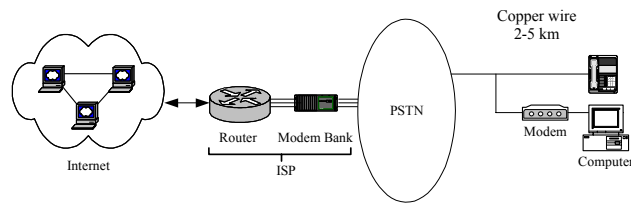


Figure 2: POTS and its Internet access

3.2 Optical Fiber System

Although POTS is the common means to provide voice and data connectivity to majority of the world's population, POTS has certain shortcomings due to its insufficient quality and short distance limitation. Optical fiber transmission system, another wireline system, has been developed and used for long-distance high-capacity trunk networks. Generally, it is used to provide high-bandwidth connections between all major cities in both urban and rural areas. A typical system for trunk circuit is shown in Figure 3.

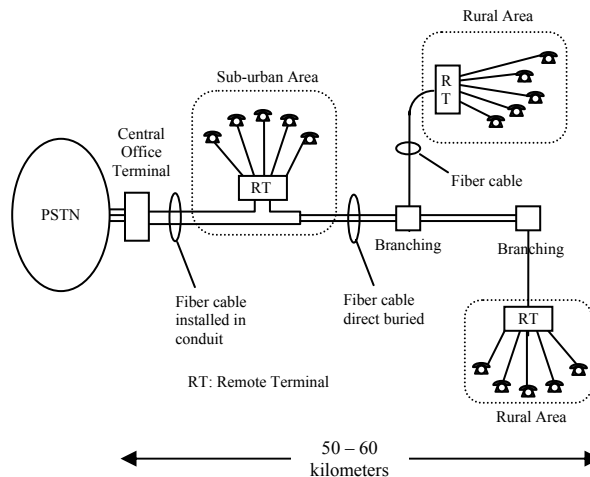


Figure 3: Optical fiber system configuration

The system is applicable for rural areas thanks to its features, such as long distance transmission without repeater (60 km), high capacity, and low price of cable. Nevertheless, due to uneconomic returns from the wireline systems in sparse remote areas, both POTS and optical fiber system are not economically viable to install in such locations. The following wireless access systems are being introduced as alternatives to wireline systems.

3.3 TDMA Point-to-Multi-Point Systems and Wireless Local Loop Systems

Currently, two wireless access systems – TDMA point-to-multi-point system and wireless local loop system – are being utilized in many developing countries, for instance Thailand, Bhutan, India, etc. These systems are intended to provide both telecommunication services and Internet access to rural households as substitutes to POTS. Due to the utilization of wireless access system, substantial reduction in the cost and time of installation can be realized. The paper presents three examples of the systems being utilized in certain developing countries.

(a) The SR500 System

The SR500 is a point-to-multipoint microwave radio system provided by SR Telecom Inc., Canada. The system is currently implemented in Thailand for pay phone and home phone connections in remote areas where wireline is not available. This system is considered as an alternative to POTS using combination of wireless access and wireline system. The system configuration is shown in Figure 4.

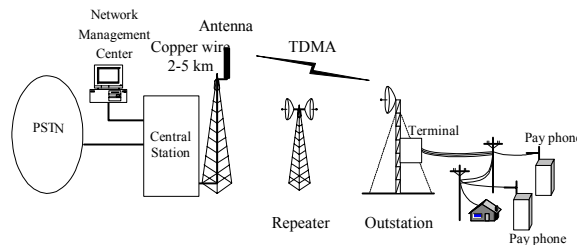


Figure 4: TDMA SR500 System

A single system is composed of one central station, a series of repeater stations (or none of them) and outstations. A central station is used to connect subscriber lines of an existing or newly installed exchange in the TDMA system. It operates in various frequency bands: 1.3 to 2.7 GHz, 3.5 GHz and 10.5 GHz. The 60 full-duplex trunks can provide services to a maximum of 1024 subscribers. The central station is also capable of centralized supervision and control of all subscriber radio stations. The repeater station receives the downlink signals transmitted from the central station. After regenerating the received signals, the repeater station transmits the regenerated signals to the outstations within its cell and to the adjacent repeater stations on different frequencies. The coverage can be extended to 700 km with 11 line-of-sight repeaters in tandem. Two types of repeater stations are possible: drop/through repeater stations. Pay phones or telephones can be connected at the repeater site using drop repeater; while through repeater is used only to regenerate the received signal. At remote sites, as low as 2 and 10 subscribers can be connected to the central station using Micro II and SLIM 10 respectively. The line capacity can be expanded using auxiliary equipment, i.e. SLIM AUX 34, AUX 50 and AUX 100. These subscribers are connected to the outstation using ordinary copper wire.

In practice, to connect to the Internet in Thailand, end-users use modem to dial an ISP, thus the maximum speed for data transmission is 56 kbps. Then, the ISP connects the user to a router and the Internet. Thus, Internet access still rides on the telephone network. This can result in severe congestion and network collapse since telephone network is not designed to handle such high traffic.

(b) CorDECT WLL system

Wireless local loop (WLL) services may be defined as fixed wireless services intended to provide access to the telephone network. WLL systems can be based on cellular or PCS technology, either analog or digital. Among several technologies, the widely used one is based on Digital European Cordless Telephone (DECT) standard, known as corDECT WLL. This system is being implemented in India introduced by the Indian Institute of Technology at Madras. It has also been shown that this system can potentially provide telephone and Internet connections to virtually all households in remote locations. A simplified version of the corDECT WLL system is shown in Figure 5.

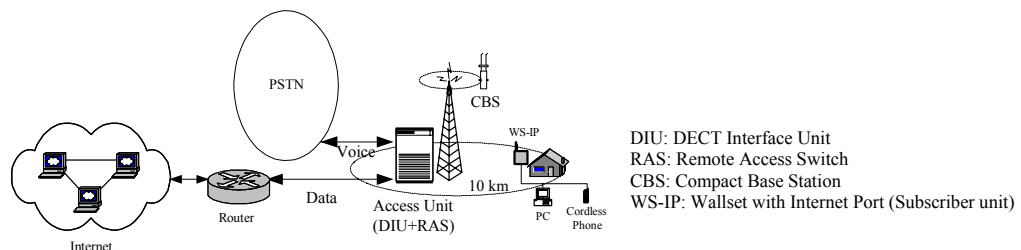


Figure 5: CorDECT Wireless Local Loop

CorDECT WLL system is composed of a base station, which includes an access unit and a compact base station, repeater stations (optional – not shown) and a subscriber unit at the receiving end. The subscriber unit is a WS-IP, which provides Internet access at 35-70 kbps as well as normal telephone service for subscribers in the corDECT system. The CBS provides the radio interface between subscribers or WS-IP and an Access Unit (AU), which consists of a DIU and RAS. The distance between CBS and WS-IP is as high as 10 km; or more with a series of repeater stations. At the base station, the DIU separates the voice traffic and directs it to the telecom network, as well as switches the Internet calls to a built-in RAS. The RAS then routes the traffic to the Internet network [8]. Note that WLL offers a number of key advantages: faster deployment, sooner realization of revenues; lower construction costs; and greater flexibility to meet uncertain levels of penetration and rates of growth.

(c) JRC SCG-5000T

It is the combination of both systems discussed earlier provided by Japan Radio Co., Ltd [9]. The entire system consists of two subsystems: one is a 2.4-GHz band TDMA point-to-multipoint subsystem and the other is a 1.9-GHz band PHS-WLL subsystem as shown in Figure 6. The 2.4-GHz TDMA system consists of a base station, repeater stations (optional) and remote stations. It has two functions of telephone services to be provided from each TDMA remote station directly to subscriber units and of PHS-WLL approach lines. The PHS consists of a wireless cell station and wireless subscriber unit to configure a WLL. Currently, the TDMA remote station and the PHS wireless cell station are installed in each of 1,777 village cluster centers and the PHS wireless subscriber unit is installed at each of 3,264 villages in Thailand [10].

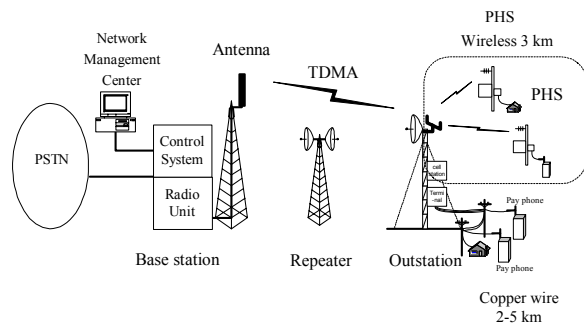


Figure 6: TDMA-WLL system

From the base station to subscribers, the system provides services using radio link (TDMA technique). The TDMA base station is centered in the circular area of 30 km radius; however, the service area can be extended to 500 km by using a series of repeater stations. The cluster centers are located within the area. A TDMA remote station and a PHS-WLL cell station are installed at each cluster center. Each subscriber unit of the cluster center is connected to the TDMA remote station via wired lines. This will limit the connecting distance from the terminal box to 2 to 5 km. In addition to TDMA system, PHS-WLL wireless subscriber units are installed within the coverage of 3 km radius from the village cluster center. The wireless subscriber unit is connected to a public home telephone or a public pay telephone via a metallic cable with maximum distance of 1 km.

Modem is used if an end-user would like to connect to the Internet. By using the modem, the maximum speed for data transmission in TDMA system is 56 kbps; on the other hand, that in WLL system is only 9.2 kbps [10]. This system is suitable for an area where a number of service areas are widely scattered and a pocket of subscribers is concentrated in each area.

3.4 Satellite Communication System (VSAT)

In the areas where there is no wireline (optical fiber or POTS) available, or the areas where the population is so dispersed that the construction of many towers and base stations makes TDMA system and WLL solutions expensive, VSAT can be considered as a viable option. The VSAT system in these situations directly connects remote users the PSTN, through the satellite in the sky.

There are three components in a VSAT network as shown in Figure 7. The first is called the Master Earth Station (MES) or a central hub, which is the network control center for the entire VSAT network. It is responsible for the configuration, monitoring and management of the VSAT network. The second component is the VSAT remote earth station. This is the hardware installed at the customer’s premises, including the outdoor unit (ODU), the indoor unit (IDU) and the interfacility link (IFL).

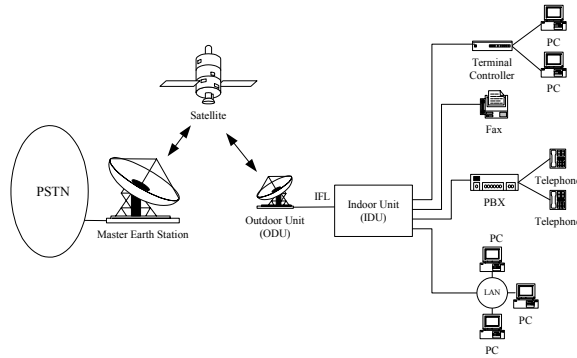


Figure 7: VSAT System Architecture

The ODU consists of an antenna and a radio frequency transceiver. The IDU functions as a modem and also interfaces with the end user equipment like stand-alone PCs, LANs, FAX, telephones or PBXs. Lastly, the IFL consists of coaxial cables that connect the ODU to the IDU. The third component of a VSAT network is the satellite itself. The VSAT system uses a geostationary satellite, perched 36,000 km above the equator, through which all signals sent between the VSAT systems are beamed.

Currently, VSAT solutions are increasingly being recognized as the most cost-effective and efficient method of providing the ICT connectivity, particularly in the areas where little or no terrestrial infrastructure is available. These regions are, for example, Asian-Pacific (India, Bangladesh, the Philippines, Indonesia), Latin America (Argentina, Brazil, Colombia, Ecuador, Mexico, and Venezuela), as well as Africa. Such situations have led to successful deployment of VSAT systems and services in more than 120 countries on every continent, providing telecommunications and broadcast services for commercial customers, governments and consumers.

3.5 The Chosen System

This section reviews certain applicable telecommunication systems. It suggests that wireline solutions are not suitable in most remote locations due to uneconomic returns in sparse remote areas. On the other hand, VSAT systems have the highest initial costs among wireless systems. Thus, without burying tons of copper wires, the affordable wireless solutions that are recommended to provide ICT connections to remote areas include TDMA systems and WLL systems. In contrast to POTS where individual copper lines must be routed and wired from each subscriber, WLL and TDMA connects end users wirelessly to the PSTN. These systems are currently being implemented in many developing countries as substitutes to POTS where wireline is not available.

However, the paper hereafter will explore corDECT WLL system in detail for ICT connections in sparse remote areas due to two main reasons. Firstly, while connecting to the Internet in TDMA systems requires dial up, corDECT WLL systems can provide simultaneous telephone and Internet services. In other words, no modem is required to connect end-users to the Internet in corDECT systems. Additionally, the systems separate voice traffic from Internet traffic, preventing corruption of telephone network and improving reliability of Internet connection. Secondly, since the service needs to be provided to the remote areas where electricity is unavailable or unreliable, the power consumption of the remote equipment, i.e. repeater stations and subscriber units should be the lowest. By analyzing the power consumption of each component in three wireless systems, corDECT WLL equipment is found to have the lowest power consumption.

4. CorDECT WIRELESS LOCAL LOOP SYSTEM

As a result of becoming progressively less expensive and less power hungry than other alternatives, corDECT WLL technologies offer advantages of rapid and flexible deployment in remote areas. It is being used in India and Argentina, Brazil, Kenya, Nigeria, Fiji and Iran. This section provides an insight into the corDECT WLL possible deployment scenarios in Bangladesh. Peak power and energy requirements to support ICT subsystems as well as remote appliances are also estimated.

4.1 corDECT WLL Deployment Scenarios

Typically, a conduit for communication cables that provides connections with PSTN is installed along railway lines to bring telephones and Internet cheaply and quickly to remote population. Consequently, ICT connections from end-users to PSTN employing basic telephone systems are confined only to the villages at or near the railway stations. In Bangladesh, basic telephone service (POTS) can be provided to only 28% of area by utilizing the fiber available along the railway lines [11]. If corDECT WLL is used, by contrast, the provision of ICT connections to

majority of households in very remote areas can be realized. Three corDECT deployment scenarios in remote areas are the followings [12].

a) *The deployment scenario at the railway station*

The corDECT system gives a good deployment opportunity for a small town located at the railway station, as indicated in Figure 5. A DIU, which can serve as many as 1,000 subscribers, can be collocated with the PSTN through the fiber network at any railway station. There, the DIU, RAS and CBS are located at the tower, wirelessly connecting to subscriber units. The system coverage range is 10 km from the CBS by using line-of-sight connection. At the subscriber unit is WS-IP, which has a standard interface (RJ-11) and a serial port interface (RS-232). It supports standard telephone, modem, and fax through port RJ-11 and provides a direct connection to a PC through port RS-232. Thus, the WS-IP can provide simultaneous Internet access and normal telephone service to a subscriber. Note that the subscriber density served could be as low as 3 subscribers per square kilometer – subscriber density is 1,000 subscribers per 100π square kilometer. Using more DIUs at the railway station will, however, substantially increase the subscriber density.

b) *The deployment scenario with relay base station*

To serve sparse rural area, a relay base station (RBS) could be installed between the CBS and the WS-IP as shown in Figure 8. In this case, a two-hop DECT wireless link is used to provide telecom and Internet connection to the household. One link is from the CBS to the RBS. The other link is from the RBS to the WS-IP. The RBS could extend the range of the corDECT system from the CBS by 25 km or more with several RBSs. In turn, the RBS serves subscribers in a 10-km radius. This provides a subscriber density as low as 0.5 subscriber/ km^2 – subscriber density is 1,000 subscribers per 625π square kilometer.

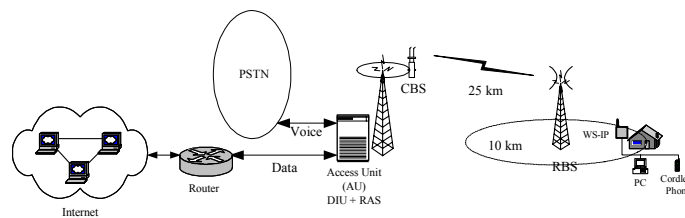


Figure 8: Deployment with RBS

c) *The deployment scenario w/ base station distributor*

The corDECT WLL with a base station distributor (BSD) can be used to extend coverage distances beyond 35 km as shown in Figure 9. The BSD is a remote unit connected to the DIU using a standard E1 interface. The maximum distance between DIU and BSD depends upon the E1 link (radio, fiber, or copper). At the BSD site, a cluster of CBSs is mounted on a rooftop tower to serve an area of 10-km radius. The system is suitable for serving a load pocket in a remote mid-sized town or city.

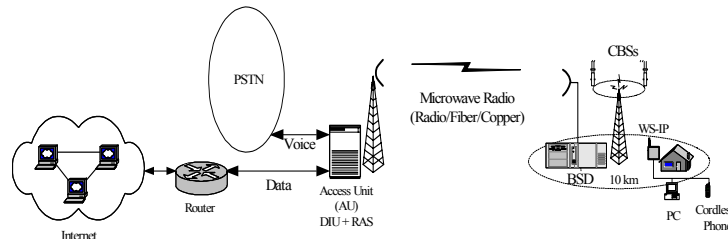


Figure 9: Deployment with BSD

4.2 Electric Power Requirements for the System

Unlike the high power demand per raised-floor area, which could be as high as 100 Watts/square foot in many industrialized countries, each element of corDECT WLL is designed to work without the need for air conditioning and thus calls for low infrastructure support. Table 2 summarizes maximum power consumption of each corDECT element. [13]

Table 2: Power Consumption for corDECT Element

corDECT Elements	Maximum Power Consumption	Power Supply Choices
DIU	528 W	Power from the existing local exchange or local power
RAS	43 W	
CBS	-	Remote power from DIU
RBS	13 W	Local power
BSD	48 W	Local power
WS-IP	6 W	Built-in 1.2-AH battery and local power

In the corDECT system, the DIU and CBS are usually powered from an existing local exchange at the transmitting end if available. An engine, usually diesel, with battery backup is used otherwise. The RBS, BSD and WS-IP are locally powered at the remote site. In addition, end-user appliances like computers, TVs, radios, and cordless phones are generally co-located with corDECT elements at the transmitting end and on the subscriber premises. Various end-user DC and AC appliances, their maximum power consumption, as well as their average consumption time are summarized in Table 3.

Table 3: Average DC and AC load power consumption and time for various appliances

Appliances	Maximum Power Consumption (W)	Average Load Consumption time (hours/day)
Desktop Computer		
- At the base station	150 W	24
- At the end-user site		4
Fax, printer combination	10 W	
- At base station	(standby mode)	24
- At end-user site		24
TV	20 W	4
Radio	8 W	4
Fluorescent Lamp	8 W	4
Ceiling fan	8 W	4
Cordless phone	2.7 W	-
	(w/ built-in 3mA battery)	

This paper classifies two types of centers for telecommunications or 'Telecenter' each of which includes certain telecommunication equipment and end-users appliances shown in Tables 2 and 3. Telecenter 1, (213 W) equipped with one WS-IP, contains a desktop computer, a fax and printer combination, a TV, a radio, a fluorescent lamp, a ceiling fan and a cordless phone. Telecenter 2 (912 W) contains 5 desktop computers, a fax and printer combination, a TV, a radio, 5 fluorescent lamps, 5 ceiling fans and 5 cordless phones. Since there are five computers as well as five phones, five sets of WS-IP is needed.

This paper examines electric power requirements to support corDECT elements and telecenters into four subsystems: at the transmitting end, at the relay base station, at the end-user sites with BSD and at the end-user sites without BSD. Apart from the telecenter, another desktop computer equipped with fax and printer (Y = 160 W) is always connected at the base station site (transmitting end) to perform centralized supervision and control of all subscriber stations, ensuring easy system management. Table 4 shows electric power requirements for supporting four subsystems, each of which combines certain corDECT elements 'X' with one type of telecenters.

Table 4: Electric Power Requirements to Support ICT Subsystems and Telecenters

Sub System Demand	Power Requirement (W)			
	1: Transmitting end 'X' = DIU + RAS + Y	2: RBS site 'X' = RBS	3: End-user site with BSD 'X' = BSD	4: End-user site 'X' = N/A
None	-	13 W	-	-
Telecenter1	944 W	-	261 W	213 W
Telecenter2	1,643 W	-	960 W	912 W

Several subsystems can be combined to provide alternative service opportunities to households in remote areas. For instance, subsystems 1 and 4 jointly refer to the deployment scenario at the railway station; subsystems 1, 2 and 4 together can be viewed as the deployment scenario with RBS; subsystems 1 and 3 collectively refer to the deployment scenario with BSD.

5. THE ASSESSMENT OF ENERGY RESOURCES IN BANGLADESH

Electric power is a prerequisite to the operation of telecommunication and Internet connection. Thus, in order to enable ICT connection and provide electricity to telecenters in remote areas of a country, power requirements of each subsystem must be met by certain generation scheme. In other words, power schemes must be identified to all ICT subsystems (including Telecenters) at the transmitting end, at the repeater station, and on the subscriber premises. These schemes depend very much on the locally available resources, which vary from country to country. Energy resources such as solar energy, wind energy, and agricultural waste are decentralized and can be harnessed to produce electrical energy for remote locations. This section investigates renewable energy resources as well as some fossil fuel options in a target country.

5.1 Solar Energy

Due to its location, Bangladesh is ideally located for utilizing solar energy. It is situated between 20.30 – 26.38 degrees north latitude and 88.04-92.44 degrees east. Solar energy has been used in Bangladesh for drying crops and fish since time immemorial. The average solar insolation is between 3 to 6 kWh/m²/day, which is quite good for photovoltaics applications.

5.2 Wind Energy

In Bangladesh, other than in coastal areas, there is very little wind power potential for electricity generation. Wind speeds at most meteorological stations appear to be low with typical annual mean wind speeds of 3-5 km/hour, at heights between 5 to 10 meters above ground level. The shape of frequency distribution curve is generally found to be skewed due to low frequency for high-speed values and high frequency for low speed values. By analyzing wind roses, which were developed for all meteorological stations in the country, it was found that wind blows mainly from two directions, NE and SE, in most stations [14].

5.3 Biomass Energy

Biomass is the most important renewable energy sources in Bangladesh since most of the rural people are fully dependent on biomass energy for their daily energy needs. Biomass is estimated to provide as much as 70% of the total final energy requirement in Bangladesh. The main sources of biomass energy are: rice husk (26%), cow dung (19%), and rice straw (16%). At present, there is acute shortage of wood fuel in Bangladesh with the bleak future projection for supply to meet the need. On the other hand, agricultural residues or crop production contribute significantly to the biomass sector of Bangladesh and generates considerable amounts of residues that can be used as energy source. It is indicated that the residue from rice (rice husks) constitutes the majority portion of agricultural residues production in Bangladesh [15].

5.4 Fossil fuel resources

Natural gas is one of the most important commercial energy needs in Bangladesh, constituting 71% of the total needs. Currently, as high as twenty gas fields have been found in the country, two of which are located offshore. On an average, the daily gas production of the country is as high as 1,000 million cubic feet. The average heating value of these indigenous resources is between 1006 to 1062 BTU/ cubic feet. Its wellhead price is 1.68 Taka/cubic meter [16]. Although natural gas is abundant in Bangladesh, per capita commercial energy consumption in the country is low. Only 6 to 7 percent people of the country have access to natural gas [17].

Thus, transportation is needed if natural gas is utilized for power production in remote areas. Note that more than four-fifths of the present gas production goes into the generation of electricity and production of fertilizer.

On the other hand, Bangladesh imports large amount of petroleum products, including diesel oil. Total yearly (2000-2001) import of petroleum fuels is about 3.44 million tons, of which 1.34 million tons is imported as crude, while the rest are import of refined products like Petrol, Diesel, Kerosene, etc. In comparison to this, indigenous production of liquid fuels is only about 2.5% of total annual demand.

6. DISTRIBUTED GENERATION SOLUTIONS

According to the assessment of four energy sources in Bangladesh, it is found that solar energy, biomass (especially rice husks) and natural gas are the potential resources for electricity production in the country. However, since the peak power demand for the proposed telecenters is less than 2 kW (from Table 4), the paper recommends four promising small-distributed power schemes in far-flung remote areas of the country.

These include:

- (1) solar photovoltaics (PV) with battery storage,
- (2) diesel engines with battery storage,
- (3) gas engines with battery storage, and
- (4) fuel cells fueled by natural gas.

The paper neither considers wind turbine nor biomass plant in Bangladesh because (1) there is insufficient wind resource in the country to economically operate wind turbines, and (2) efficient biomass plants in general have capacities in the order of 100's of kilowatts, which is much higher than the requirement (<2kW). Note that although Bangladesh has to import diesel oil, diesel engines are considered as an alternative due to its popularity and ease of operation by village farmers. The technical and economic data, i.e. heat rate, heating value, investment costs, fuel costs, maintenance costs and service life of these alternatives are summarized next.

6.1 Assumptions

For the *photovoltaic* system, the paper assumes the average solar insolation of 4.73 kWh/m²/day at Dhaka, Bangladesh [18]. Components of the system are PV array, inverter, battery and controller. Their current market prices are \$6.16/watt peak, \$0.828/continuous watt, \$1.63/watt output and \$5.87/ampere, respectively [19]. Except for the PV array, which has a service life of 20 years, the rest are assumed to last for 10 years.

Reciprocating engines, diesel and gas engine, are the most mature distributed generation technologies. This study assumes both engines have the same capital costs of \$600/kW with the same heat rate of 17,065 MBTU/MWh. Maintenance costs are 0.5 cents/kWh and 0.7 cents/kWh for diesel engines and gas engines, respectively [20]. Diesel price is \$1.29/gallon and its heating value is 128,000 BTU/gallon. On the other hand, gasoline price is \$1.35/gallon and its heating value is approximately 115,000 BTU/gallon [21]. The paper assumes that transportation cost of a fuel to the remote site, i.e. subscriber premises, is half of the fuel price itself. Diesel engines are assumed to have a useful lifespan of 25,000 hours (approximately 3 years for base-load operation and 7 years for peak-load operation), but this can be drastically reduced if maintenance is poor. On the other hand, gas engines tend to have a much shorter lifespan than their diesel counterparts. They are assumed to have a useful life span of 5,000 hours running time (approximately 2 years for base-load operation and 3 years for peak-load operation).

Lastly, the *Fuel cell* is considered as an emerging electro-chemical technology used to generate electricity. For fuel cells, the paper uses capital investment of \$4,000/kW [20] and heat rate of 13,652 MBTU. Gas price is \$4.52/thousand cubic feet and its heating value is approximately 1,027 BTU/cubic feet [21]. Maintenance costs is 10 cents/kWh. The fuel cell is fueled by natural gas with the same assumptions as above. Note that the maintenance costs used in the calculations are the aggregate values from large machine aspects due to the unavailability of data for small machines. The generating units have to be replaced every 7 years for reciprocating engines and 10 years for fuel cells. 10% discount rate is used.

6.2 Power Solutions at the Transmitting End

At the transmitting end (subsystem 1 in Table 4), three power schemes are compared: small diesel engines, gas engines, and fuel cells. The installed capacities of these distributed power options are determined according to their possible size to meet the demand. Prototype sizes for both the reciprocating engines - gas and diesel are taken to be 500 Watts, and for the PEM fuel cells 250 Watts. Thus, for the Telecenter1 and Telecenter2, for which the demands are 944 and 1,643 watts (from Table 4) respectively, 1kW and 2kW are the chosen installed capacities for these DG options.

Life cycle cost of each system is calculated from the net present value (NPV) of: total construction cost, maintenance cost, fuel cost, salvage value at the end of plant life, as well as plant replacement cost over 20 years. In other words, life cycle costs are calculated according to (1).

$$LCC_j = \sum_{y=0}^{20} \left[\frac{C_{ij}}{(1+r)^i} + \frac{E_{ij}}{(1+r)^i} \left(M_j + HR_j \times \frac{1}{HV_k} \times P_k \times 1.5 \right) - \frac{S_j}{(1+r)^{20}} \right] \quad (1)$$

Where:

- LCC_j = life cycle costs of plant j (\$);
- C_{ij} = capital investment of plant j year i (\$);
- E_{ij} = energy production by plant j year i (kWh);
- M_j = maintenance costs of plant j (\$/kWh);
- HR_j = heat rate of plant j (BTU/kWh);
- HV_k = heating value of fuel type k (BTU/gallon or BTU/cubic feet);
- P_k = price of fuel type k (\$/gallon or \$/cu ft);
- 1.5 = cost factor of fuel transportation;
- S_j = salvage value straight line depreciation of plant j at the end of its service life (\$);
- i = year ($i = 1, 2, \dots, 20$);
- r = discount rate (10%);
- j = type of plant: diesel engine, gas engine and fuel cells; and
- k = type of fuel: diesel oil and natural gas.

Table 5 summarizes these three power schemes, and their life cycle costs that provide electric services for ICT transmitting equipments as well as telecenters in subsystem 1.

Table 5: Power Solutions and their Life Cycle Costs (NPV-20 years) for Subsystem 1

Demand	Power Schemes for Subsystem 1: Kiosk with DIU/ RAS		
	Diesel Engine	Gas Engine	Fuel Cells
Telecenter1 944W	1kW (\$14,092)	1kW (\$17,569)	1kW (\$21,439)
Telecenter2 1,643 W	2kW (\$24,669)	2kW (\$30,955)	2kW (\$33,774)

6.3 Power Solution at Relay Base Station

At the relay base stations, subsystem 2 in Table 4, which are usually situated in remote sites without easily accessible road, photovoltaics and battery backup are the only suitable options for the task. To size the PV array and battery capacity, the total AH load requirement must first be calculated as in (2).

$$\text{Corrected AH load (AH)} = \sum \left[\frac{\text{Total load power (W)} \times \text{operating hour/day}}{\text{Operating voltage} \times \text{DC-DC conversion efficiency}} \right] \quad (2)$$

In this subsystem, the total load power is 13 watts. Given the estimated time the RBS would be operated (24 hours a day), it gives a total of 28.9 AH per day for 12-V PV system, considering power conversion efficiency of 0.9. The battery capacity is sized at 110 AH according to (3), taking into account 3 storage days; wire efficiency factor of 0.98; battery efficiency factor of 0.9 and maximum depth of discharge of 0.9.

$$\text{Battery capacity (AH)} = \frac{\text{Corrected AH load} \times \text{storage days}}{\text{eff}_1 \times \text{eff}_2 \times \text{eff}_3} \quad (3)$$

Where:

- eff_1 = wire efficiency factor: the decimal fraction accounting for energy loss due to wiring.
- eff_2 = battery efficiency factor: this factor accounts for the losses due to battery storage.
- eff_3 = maximum depth of discharge: the maximum discharge allowed by the designer.

On the other hand, the PV array is sized based on the required AH-load, insolation data and module efficiency as shown in (4).

$$\text{PV Array (Watt)} = \frac{\text{AH-load} \times \text{System voltage}}{\text{Peak sun hour} \times \text{eff}_4} \quad (4)$$

In this case AH-load is 28.9AH; system voltage is 12V; peak sun hour is 4.73 hours/day and eff_4 is the efficiency of PV module, which is 0.85. Thus, the required size of PV panel is 80W. The life cycle costs are determined according to (5).

Sizing the stand-alone PV array with battery backup is similar to the examples in the previous sections. However, instead of three storage days needed in subsystem 2, the PV systems in subsystems 3 and 4 are designed to cover end-user demands for two storage days. To size diesel engines, gas engines and fuel cells, the paper considers their possible capacity to meet the peak demand. These generating units will operate for four hours a day to cover all end-user appliances, especially computers, and charge batteries. The battery capacity is chosen in such a way that end-user appliances, except computers, can be operated without the engine for another four hours a day. Note that the ways LCCs are determined are corresponding to those in the previous section. Table 7 summarizes these power schemes as well as their life cycle costs of operation to serve end-user kiosks with and without BSD in the subsystems 3 and 4.

Apparently, from the economic point of view, PV and fuel cell options are costly. Although PV systems are suitable to serve small loads, they are much more expensive to serve the higher demand since two storage-day requirement will double the size of the array and battery capacity. Alternatively, PEM fuel cells are the emerging technologies, clean, quiet and efficient, but it is too new to be deployed in remote areas. On the other hand, the hybrid engine-battery system, fueled by either diesel oil or gasoline, is the better alternatives to the PV-only system. It results in more efficient operation of the engines since the engines can always operate at high capacity factor. By this means, the hybrid engine-battery scheme is found to provide continuous high quality electric power, reducing life cycle costs of overall system, fossil fuel consumption, as well as minimizing environmental impacts.

7. CONCLUSIONS

To enable ICT access to people in remote areas, two issues must be properly addressed: (i) expansion of telecom and Internet network at a reasonable price, and (ii) provision of power for ICT infrastructure as well as end-user appliances in Telecenters. Since affordability is a key issue, the corDECT WLL system is recommended as the most suitable telecommunication technology for the conditions considered in this paper. However, it is meaningless to provide just the telecom services without the supporting infrastructure and electricity needed by Telecenters. The paper has identified and compared various power schemes. At the transmitting end, the proposed DG schemes are reciprocating engines with battery backup. At the relay base station, PV is an only means to provide clean, affordable and long lasting low-load electricity to such markets. At the end-user kiosk, four power schemes are compared. While showing the merits of hybrid engine-battery system instead of the PV-only system, the paper points out the prospect of utilizing fuel cells as a promising competitor. To this end, the proposed power solutions will very much vary from one country to another, depending on energy resources, potential demand and ability to pay for the services.

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