# CASE STUDY

# Bhutan:  Wireless IP based Rural Access Pilot Project

## *Use of VoWLAN (Voice over WLAN) for the Provision of Rural Communications*


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## Country Background

Bhutan is a small and landlocked kingdom located in the Northeastern Himalayas with a population of 700,000 people with a growth rate of 2.5 %. The country is administratively divided into 20 districts and 202 blocks. About 79 % of the population lives in the rural areas and only 21 % of the people live in the urban centers. The GDP real growth is 6 %.


*Figure 1: Map of the Kingdom of Bhutan*

Bhutan remained in self-imposed isolation for centuries until 1961, when the first basic infrastructure development started. The country is almost completely mountainous, rising from 200 meter above sea level to over 7000 meters in the Great Himalayan Range. Forest covers 72.5% of the land area of 46500 km$^2$. Free education is provided from the primary to the tertiary level, and English is the medium for instructions, particularly for higher education, which makes the English literacy level comparably high. Overall literacy of the entire population is about 65 %.

## Telecommunications Environment

Given the challenging geography, there is still considerable coverage of telecommunications services in all districts as of today. The National Telecommunications Network interconnects all twenty Dzongkhags and the major towns of the country. The extent of this service prevails in remote locations covering 113 blocks out of 202. The Tele-density has reached to 3 % as on July 2002. Internet service in Bhutan started from June 1999 and it has a customer base of about 3000 dial-up subscribers.

Regulatory and policy activities in information and communication technologies are carried out by two principle organizations within the Ministry of Communication. The Bhutan Telecom Authority (BTA) is the telecom and broadcasting regulator that oversees tariff and licensing policies. The Division of Information Technology (DIT) oversees capacity building, promotion, certification and standardization of ICT activities.. The Department of Telecommunications was transformed into a wholly government owned corporation, Bhutan Telecom (BT), on 1st July 2000. It is the only telecommunications service provider and is governed by a Board of Directors. Druknet, an entity fully owned by Bhutan Telecom, provides Internet services. B-Mobile, another entity owned by Bhutan Telecom has started GSM services in the three major towns in November 2003.

### *Rural Telecommunications*[1]

About 79% of Bhutanese live in rural areas spread over 201 geogs (village blocks) or approximately 2,000 villages in the 20 districts. They account for less than 10% of the total telephone connections and less than 1% of Internet connectivity in the country. The number of houses per village numbers from 2 to 100 with an average of 43, more than 50% of the population lives a few hours walk from the nearest road, and some villages is as remote as a five-day walk[2].

The objective of the 9th Five-year Plan for the telecom sector is to provide at least 10 phones per geog. However, such projects are technically challenging and would need huge investments. Robust systems that have possibilities of wide coverage are required. Technical survey estimates a total of 6,250 rural telephone lines by the end of the plan period. So far 76 of the 201 geogs (or 37%) in Bhutan have access to telephone lines.

Bhutan Telecom is planning to cover all the remaining geogs through its Rural Telecommunications Project. This project is being finalized and will be implemented through Mixed Credit scheme of the Government of Denmark. A combination of technologies will be deployed such as Wireless Local Loop (WLL), Voice Over Internet Protocol (VOIP) and Very Small Aperture Terminals (VSAT) with a total budget of approximately US$ 20 million.

The cost of providing a telephone in rural areas is estimated to be in the range of US$ 2,500 per line when relatively cheaper technologies like VHF, VOIP or WLL are used, while a VSAT solution including power costs US$ 17,500. The cost of connectivity from DAMA (Demand Assigned Multiple Access) satellite phones is approximately US$ 0.22 per minute (Nu 10 per minute) for a local call hence requiring BT to subsidize the use of this technology.

1 Adapted from Bhutan E-Readiness Assessment Report, Division of Information Technology, Ministry of Communications, June2003

2 http://www2.itu.or.th/telecenters/jakar/thesis.doc

## Project Background

Following the requirements of the government's objective in the 8$^{th}$ Five year Plan requires BT to provide telecommunications services to all Gewogs (Blocks) in the country. Simultaneously, the Division of Information Technology (DIT), on the other hand is responsible for the promotion of IT which requires the access to be provided. Therefore it seems most appropriate that, the two agencies should work on a joint pilot project to evaluate how appropriate this technology is for meeting the ICT requirements of the country.

BT had already prepared a Master Plan for the provision of services to the rural areas of the country. In the plan it is recommended that the Digital Radio Multiple Access Subscriber System (DRMASS) technology be employed for the provision of rural services based on the fact that BT already has several DRMASS base stations in the country and has the skills to install and maintain the systems without external assistance. At the time the plan was prepared, this was the most realistic solution. However, times changed and BT was informed that the manufacture of DRMASS equipment would stop in one year's time as there is no market for this type of system. The cost per line for providing rural access using this technology has been estimated at US$ 5,600.

As the situation has changed it has become necessary for BT to change its rural telecom plan. The possibility of employing Wireless IP based networking technology in the construction of the rural network then started taking shape in early 2001. Since it was fairly new technology and it was hard to estimate its appropriateness for rural areas, BT could not confidently promote it. In order to actually evaluate the performance of this technology and to be able to confidently employ it for the construction of the entire rural access networks, BT and the DIT had to first implement a pilot project.

### *Choice of Technology*

There are many challenges to providing rural communications especially in a developing country. Geographical challenges such as the mountainous terrain makes line of sight over long distances not possible. The demographic distribution such as sparse population in pockets along valleys adds to the challenge. There is a lack of infrastructure such as roads or stable commercial power, which would greatly reduce the cost of transport and power besides easing the installation process. Hence the technology selected has to at least have the following features

- Preferably wireless due to terrain
- Has to be cheap
- Has to consume less power
- Should be interoperable with the existing PSTN and/or other supplier's equipment
- Remote network management should be possible
- Simple, small, modular and scalable
- Equipment should have long life cycle

Considering all the above, the most promising seems wireless IP technology since this allows for the coupling of voice and data services over one network. Limited local tests carried out in the early part of 2001 revealed that browsing with reasonable speed over a wireless link with distances of 7 km line of sight was possible.
Other factors contributing to the final choice of the use of IEEE 802.11b equipment as the transmission link were

- Relatively cheap equipment and falling prices

- Easy and fast to install
- More established than IEEE 802.11a
- Scalable
- Low power consumption
- Wi-fi compliance allows the use of other vendor cards

## The Pilot Project [3]

A pilot project was approved for implementation to definitively ascertain the following :

a) The suitability of the technology for the provision of rural access.
b) The equipment should meet the requirements of BT as well as the DIT.
c) Reliability of the available equipment.
d) Power consumption and reliability of the power supplies, as solar power supplies will have to be employed at some sites.
e) System flexibility and capacities.
f) Installation and testing methods. Ease of installation and testing.
g) Reaction of people using this system as compared to using the traditional systems.
h) Any other observations.

### *Site Selection Criteria*

Selection of the sites for the implementation of the Pilot Projects were based on the following criteria:

a) Must be considered a rural area with no telecommunications services available or extremely unreliable telecommunications services.
b) Must have over 10 potential customers (customers with the financial resources to pay for the services). Must have the potential to benefit as many people as possible in the future hence an area of relatively high population density would be preferred
c) Preferable to have mains commercial power supplies but at least one site without mains commercial power supplies is required.
d) If there is a school, health facility, agriculture facility and also a Gups (Municipal Head) office, preference should be given to such locations.
e) To provide as much information as possible within the shortest period of time, several sites, at least four sites should be selected.
f) These sites should be geographically spread to cater to different climatic conditions. North – South distribution is another important factor as the climatic conditions vary from South to North. In the foothills there tends to be more thunder and lightning as compared to the North.
g) Area of coverage. The more area that can be covered the better the site. At times the area of coverage is equated to the number of Gewogs or villages that can be covered.
h) Primary objective should not be to provide access to existing wait-listed customers. However one site could be selected where telephony is provided to wait listed customers so as to provide a direct comparison between services provided using both technologies.

[3] This part is adapted from "Project Document for an IP Based Rural Access Pilot Project" by Thinley Dorji, Bhutan Telecommunications Authority, Thimphu, Bhutan

*i)* Travel time from the capital, Thimphu. The maximum travel time should be limited to one full day’s travel. This will have a direct bearing on the cost and duration of project implementation and so travel time to the sites was limited to one day.

***Sites Selected***

As a lot of information needs to be collected within a very short time frame it was thought that one method of collecting useful information would be to implement the pilot project at a number of sites. The number of sites was set at four to collect information from different geographic locations. After detailed discussions the following sites were selected as most appropriate.

a) **Gelephu**, (on the border with India) was chosen, as this area is prone to heavy lightning and torrential rains. The effects of rain on the packet radios needs to be ascertained. Radio signals could be blocked by tall trees and heavy vegetation throughout the year. The area of coverage is fairly large.
b) **Limukha**, is halfway between Wangdi and Punakha Dzongs. Winters are very dry and even during the summer there is not much rain. Good line of site to several villages, Basic Health Units (BHUs) and schools. An ideal radio site. Should extend as many access points as possible from this location to study congestion problems.
c) **Tingtibi**, is approximately halfway between the North and South of the country. Fairly remote areas, even though the Gaylegphug-Trongsa highway runs close to this location. Very hot in the summer, with high humidity and fair amount of lightning.
d) **Paro** has temperate climate and is one of the fastest growing urban centers surrounded by equally fast growing rural communities with a fairly large unmet demand for voice and data services. The rural areas of Paro stretch far and wide. There are currently problems providing good voice/data connectivity because of the vast distances that need to be covered by cables. This location can test the distance that can be covered through wireless, as well as providing the much needed services to the potential customers.

## Project Implementation

The project was planned, co-ordinated and implemented by a team from Bhutan Telecom assisted by an Wifi expert funded by the ITU.

Planning started in early 2001. The combination of VoIP over wireless LAN (wifi) as a rural communications solution was not heard of. Moreover Wifi was not considered infrastructure and VoIP wasn’t doing too well other than replacing expensive international calls.
There were several doubts about this combination

- Not proven in the field in terms of stability and reliability
- The decision to go SIP or H323
- Pace of technological change makes equipment obsolete
- Ruggedness of equipment for rural use
- Degradation of voice quality due to delay, jitter etc.
- Bandwidth constriction in the future
- Environmental impact on performance

At the time of the project two Wi-Fi standards were avalible, 802.11b which operated in the 2.4GHz band and provided signaling rates up to 11Mbps, and 802.11a which operated in the 5.8GHz band

and provided signaling rates up to 50 or 100Mbps. 802.11b equipment was chosen because of the lower cost and higher availability.
Equipment vendors that were explored were Cisco/Aironet, Orinoco/Wavelan, Tri-M SBC for radios, Hyperlink, YDI for amplifiers, and Vocaltec, Nuera, Franklin for VoIP equipment, E-tel, Komodo, Symbol and Spectralink for end user equipment. Finally, the project used Cisco radios, Hyperlink amplifiers, Avaya wireless ethernet converters and Vocaltec gatekeepers and gateways.
For the Customer premise equipment, though a variety of vendors did exist none other than e-Tel offered wireless residential gateway. The mobile IP phones were only manufactured by Spectralink using a "spectralink proprietary" protocol.

The project was implemented in 2 sites, covering 84 households 14 villages. Preference was given to basic health units (BHU), schools and municipal offices.

***Site Details***

Site: Gelephu
Maximum number of customers: 40

*Table 1: Details of Gelephu Site*

| S.No | Location | No. of subscribers | Distance from Repeater | Commercial power available | Repeater needed |
|---|---|---|---|---|---|
| 1. | I bridge | 4 subscribers | 500m | Yes | Yes |
| 2. | Dana Bari | 4 subscribers | 1 km | No | Yes |
| 3. | Lalai & taklai | 4 subscribers | 5 km | No | Yes |
| 4. | Bhur | 8 subscribers | 1 km | Yes | Yes |
| 5. | Jigmeling | 8 subscribers | 2.5 km | Yes | Yes |
| 6 | Norbuling | 4 subscribers | 5.5km | No | No |
| 7 | Sershong | 4 subscribers | 1 km | Yes | Yes |
| 8. | Lodrai | 4 subscribers | 5.5 km | Yes | Yes |

Site 2: Limukha
Maximum number of customers: 48

*Table 2: Details of Limukha site*

| S.No | Location | No. of subscribers | Distance from Repeater | Commercial Power Available | Repeater needed |
|---|---|---|---|---|---|
| 1. | Limukha school | 4 subscribers | 1 km | No | No |
| 2. | Mendaygang | 4 subscribers | 3 km | Yes | Yes |
| 3. | Thinlaygang | 8 subscribers | 3 km | Yes | Yes |
| 4. | Talo | 8 subscribers | 200 km | Yes | Yes |
| 5. | Lhapchekha | 4 subscribers | 4.5 km | Yes | No |
| 6. | Nobgang | 8 subscribers | 500 m | Yes | No |

## *Technical Details*

### Network Operation Centre (NOC)

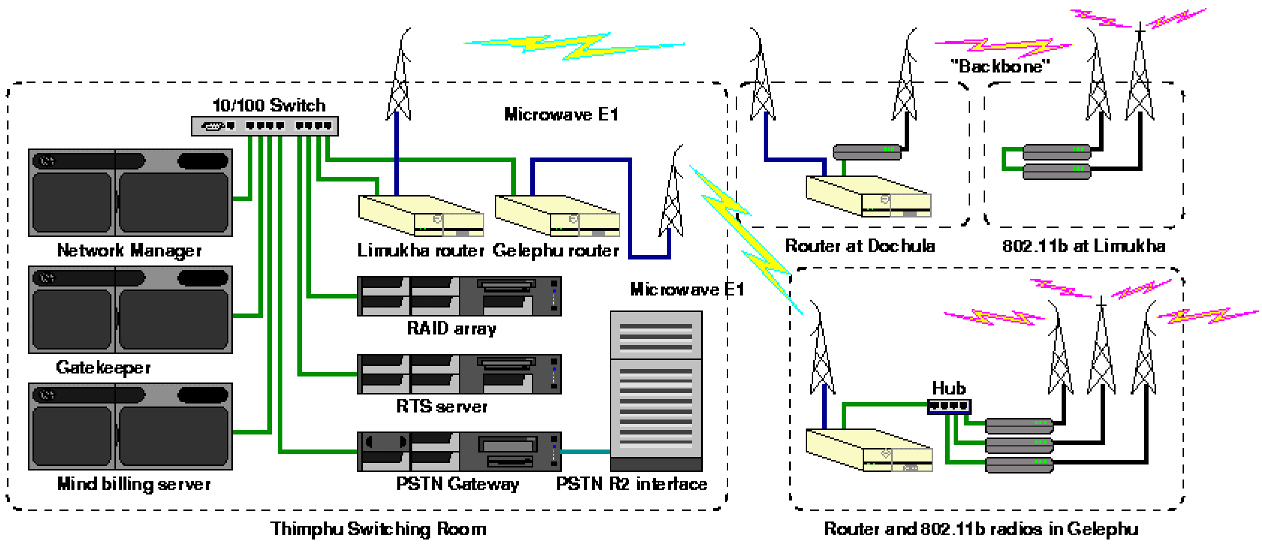



*Figure 2: Network Operation Centre in Thimphu. Source: Clif Cox, ITU Consultant," Bhutan: Migration to New Technologies"*

The NOC in Thimphu has the Gatekeeper, Gateway, Network Management system and Billing Servers. The network manager centralizes the management functions of for the VoIP network. The Gatekeeper controls the placing, routing, and logging of calls. The Real Time Server (RTS) logs the calls in real time and updates customer accounts. The PSTN gateway connects via an E1 line to the PSTN using the R2 protocol. The software controlled calling card solution is a useful value-added service that is provided by the Vocaltec gateway with no additional hardware required, amongst others such as Voice VPNs if required. The core network can be deployed in a month's time.

### BackBone

Spare capacity on the existing microwave was used to backhaul the traffic to the NOC. The traffic was carried straight from the NOC in Thimphu to Gelephu on a spare 2mbps after which it was distributed over 3 hops. The other site Limukha obtained 2 Mbps from the microwave node at Dochula, after which the radios carried it to the customers at a maximum of 3 hops.

### Last Mile

The last mile delivery was typically structured with one or more repeaters serving the surrounding customers which need LOS or Near LOS (NLOS) to a repeater. In order to account for rain fade and get better range each repeater in the system has a one watt amp to boost the transmit and receive signals. For the repeater antennas 8dBi omnis were chosen. These seemed to be a good balance between gain and a radiation pattern which wasn't too flat. This also provided service to customers who were below the antenna at about a 30 or 40 degree angle. For the Customer sites 13dBi Yagi antennas were used since they were always served by one repeater and it wouldn't have been cost effective to put amps at each customer site[4].

[4] "Bhutan: Migration to New Technologies", Clif Cox, ITU Consultant

**Power**
For sites where commercial power was unavailable, solar panels and charge controllers were used. There were both solar powered repeater sites and solar powered customer premise sites. The solar panels batteries at the repeaters were designed with 8 days autonomy. The solar power/batteries at these customer premises have been designed with 2 days autonomy. The panels were purchased from Tata BP solar and were 70 watts each. The provision of solar power adds to the cost per line and also the installation time since shelters and structures have to be laid out.

**Grounding and Lightning Protection**
There was a lot of concern over proper grounding and lightning protection especially since in Gelephu, there are lightning storms several times a week in the summer. For the repeaters, 4 earthing pits were connected in parallel supplemented by copper stakes, if required. The provision of two ground paths -one for equipment and one for lightning increases the installation time and hence as far as possible “protected “ areas were located for antennas. For the CPE sites where only an equipment ground was needed, copper stakes were used connected together by the grounding wire, which then ran to the equipment.

**Equipment Considerations**[5]

Wireless radios

At the time of this project Cisco had two product lines that were considered. The older 340 series which are basically the Aironet products and the newer 350 series. For the repeaters BR342s were used which have 100mw output. For the site surveys, Cisco 350 series PCMCIA cards were used since they have 100mw output.
While planning omni repeaters have been assumed to cover 8 km, a combination of omni-parabolic dish repeaters have been assumed to cover 12 km while 24dBi dish repeaters cover 30 km

Wireless Ethernet converter

The customer premise Vocaltec gateways were not wireless, so each CPE also needed a wireless client adapter. The Avaya Wireless Ethernet Converter (EC) was used and worked well for this pilot project, though it had some shortcomings. The Avaya ECs could only handle just one network device on the wired side and hence it wasn’t possible to connect more than one gateway limiting the number of phone connections that could be given. The other missing feature for these products is that there is seems to be no way to monitor signal strength or to use SNMP with them. The pigtail connectors are also very delicate and so not very suitable for rugged use.

Amplifiers
Since 802.11 is simplex system, ie the radios transmit and receive with the same antenna on the same frequency, amplifiers if used need to be bi-directional. This increases the cost since unidirectional amplifiers which can be used on full duplex links are far cheaper. The 802.11 repeaters used the Hyperlink 2.4GHz one watt amps.

Gateways
Primarily the search was for a fixed wireless VoIP residential gateway rather than mobile wireless VoIP phone. E-tel provided the former in their GW210 model and Symbol's NetVision phone is an example of the latter.The E-tel GW210, even though it was only a two port unit, was felt to be cost

[5] More details are provided in the ITU consultant’s Mission report ”Bhutan: Migration to New Technologies”, can be found at http://www.bhutan-notes.com/clif/

effective because it combined the VoIP and wireless components of a CPE into one unit. However it was difficult to confirm in the time available that it would interoperate with any of the gatekeepers (GK) that the project was looking at.

VocalTec was unable to interoperate with third party gateways (GWs) so other products could no longer be considered, but this also had it advantages because the two models available from Vocaltec had four and eight ports, compared to most (but not all) of the others that had been looked at which were one or two port units. This allowed the CPEs (Customer Premise Equipment) to be consolidated so they served a small cluster of buildings with one antenna. This is preferable to many CPEs and antennas because there is less contention for the radio channel. It was also advantageous in the fact that for solar powered sites, it was less of a hassle to install one site for 4/8 customers instead of individual solar power for each.

## Results

### *Network Functionality*

The network at Limukha was commissioned in June and customers were billed starting July 2002. Besides occasional individual complaints, we have reason to assume that the project has been a success at this site.
The network at Gelephu though commissioned at the same time faced many problems thought to be environmentally caused by the lightning and excessive rain. Several efforts were made to determine cause of fault. The vendor was very supportive and finally the customer premise gateways were redesigned for outdoor use. The network at Gelephu has now been functioning smoothly since November 2002.

### *Quality of Service*

The quality of voice over IP has always been an issue. The nature of packet voice-queues, delays and jitter have been source of concern. But as any other system it depends on the design. For the network implemented, congestion or delay were not the problems. The 2mbps was ample bandwidth for the number of calls that were processed. Moreover, since there was no internet usage, the major hog of bandwidth, dimensioning was simpler. The round trip time was surprisingly low even for 3 hops one way. The quality of calls was equivalent to that of the mobile phone. In bad weather, quality would drop but to an acceptable level. There are many variables but it is believed that fine tuning on an individual line basis is required to segregate the causes.

### *Cost per Line*

The total investment made for the entire pilot project is 15 million Ngultrums or USD 300,000. This includes an entire packet billing system, and a network management system, which are capital intensive in their own right. Besides it also includes radio and core equipment , power supply (solar panels, batteries and chargers), transport and freight, civil structures, installation materials and installation costs. The total number of lines is 84. The Limukha network provides service to 44 households in 6 villages while the Gelephu network covers 40 households in 8 villages. Cost per line based on these 84 customers is USD 3,570.
This metric though useful is sometimes misinterpreted. For instance, if the 4 port gateways were replaced by 8 port gateways, increasing the number to customers to 120 instead of 84 at an additional cost of USD3,600, the cost per line drops down by 30% to USD 2,530

It must be added that the core equipment, which comprises the bulk of the cost (more than two thirds) is capable of handling many more customers.

- The gatekeeper used can process 52 CAPS (call attempts per second) which under standard calculations equates to 5000 ports. While currently the system in place uses 30. Of course licenses need to be purchased for number of calls in progress.
- Billing server can process 500,000 minutes per month and is currently processing about 40,000 minutes/month.
- Similarly the E1 gateway once fully equipped can handle 4 E1s while currently half an E1 is occupied

Hence, incremental cost per line till at least 1000 customers will be much lower.

### *Revenue*

Currently the revenue from the 2 networks stand at approximately 50,000 Ngultrums(USD 1000) per month. The interesting point to be noted here is that the monthly spending of this “rural customer” is as much as a “city customer” This is also due to the fact that the phones were provided to relatively wealthy farmers but at least it proves that reliable potential customers do exist in rural areas. The payback period for the current total investment is approximately 20 years. But again this is drawn up against the huge capital spent and divided over the 72 first customers. To be noted is that additional cost per line till 1000 customers is substantially lower and hence the payback period can only improve.

## Conclusion and Recommendations

### *Recommendations*

Stable and regularized power supply – Currently where possible, to save cost, we depend on commercial supply. This supply is erratic more so in rural places and not very stable creating unwanted problems. Therefore all power systems should supply stable and regulated power.

Grounding of equipment– Grounding of equipment - Grounding requires careful consideration especially in lightning prone areas, and one should try to achieve a grounding value of not more than 5 to 10 ohms

Dial up on gateways – Presently dial up is not provided on the CPE equipment, though leased line connectivity will be possible with multi-port wireless hubs. If national rural coverage is to be provided, the maybe dial up should also be possible from these gateways if leased line connectivity is not preferred.

Open source gatekeepers – License fees make up most of the recurring calls in such a system. There are license fees for number of calls processed, number of devices that can be managed by the network management system, and number of billing minutes and so on. Of course the fees are justified for the support given, but if costs could be cut for such a system, it would have to be in software licenses. Hence an open source gatekeeper is an alternative. But then again, the resources (trained and able manpower) involved in maintaining an open source system is usually absent which is why the commercially supported versions are bought in the first place.

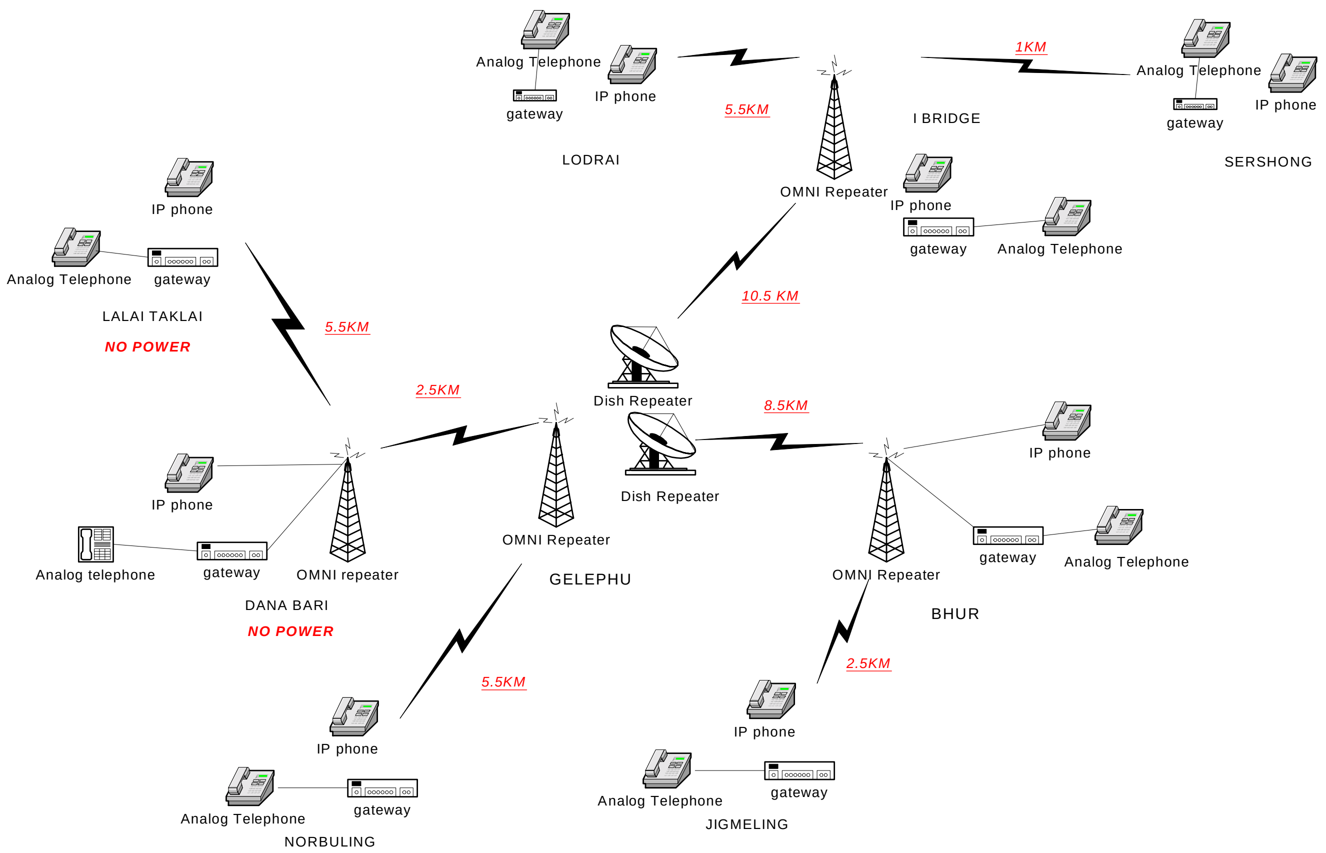
Training of staff – This follows on from the previous recommendation. Nothing is possible without proper training of staff. And at the end of the day more is lost in maintenance than saved, by not according the relevant training to staff.

Spectrum interference should be considered – Though IEEE 802.11b has 3 completely separate frequency channels for operation, it still seems to intermittently clash with other radio equipment (namely the DRMASS system from NEC) sometimes completely disrupting their service. Changing the polarization of the antenna and using the extreme frequencies, alleviates this. However, the notion that not many airwaves will be in use in the rural areas is a consolation.

### *Conclusion*

The relative cost effectiveness, reasonable quality, fast and easy installation, flexibility and scalability make it a likely candidate for rural communications. The system seems functional and workable. Though being a pioneer has its disadvantages, the immense attention that wireless IP and Voice over IP have been receiving is an indication that  the world is moving towards IP and so hopefully the technology will only get better and cheaper.

# Annex 1: Network Layout for Gelephu



# Annex 2: Network Layout for Limukha