Satellite-based rural telephony: effective solutions for infrastructure development

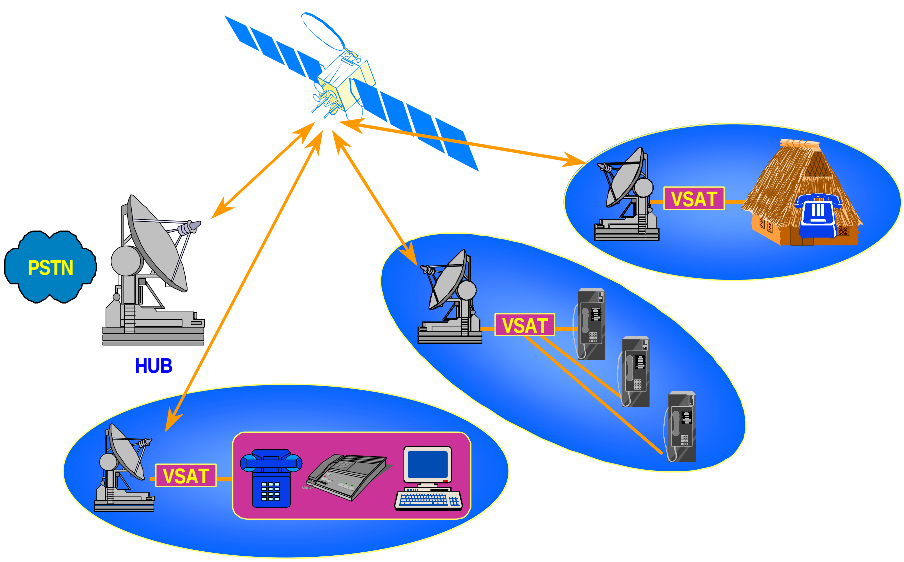
INTELSAT

Despite advances in digital technology that increase the availability and decrease the cost of communications, almost three billion people living in rural areas are still without basic telephone service. Satellite-based VSAT networks provide simple and economical solutions for quickly implementing communication infrastructure to link these areas to the rest of the world.

VSAT-based solutions are flexible enough to grow as requirements increase and a combination of VSAT and terrestrial technologies, such as wireless local loop, accommodates a wide range of population densities. Various solutions include:

- VSATs connected to subscriber lines to serve scattered populations (< 20 lines)
- VSATs connected to wired or wireless/cordless local loop to serve clustered populations (20-300 lines)
- VSATs connected to macrocellular networks to serve medium density populations (> 300 lines)

1 - VSAT connected to subscriber lines

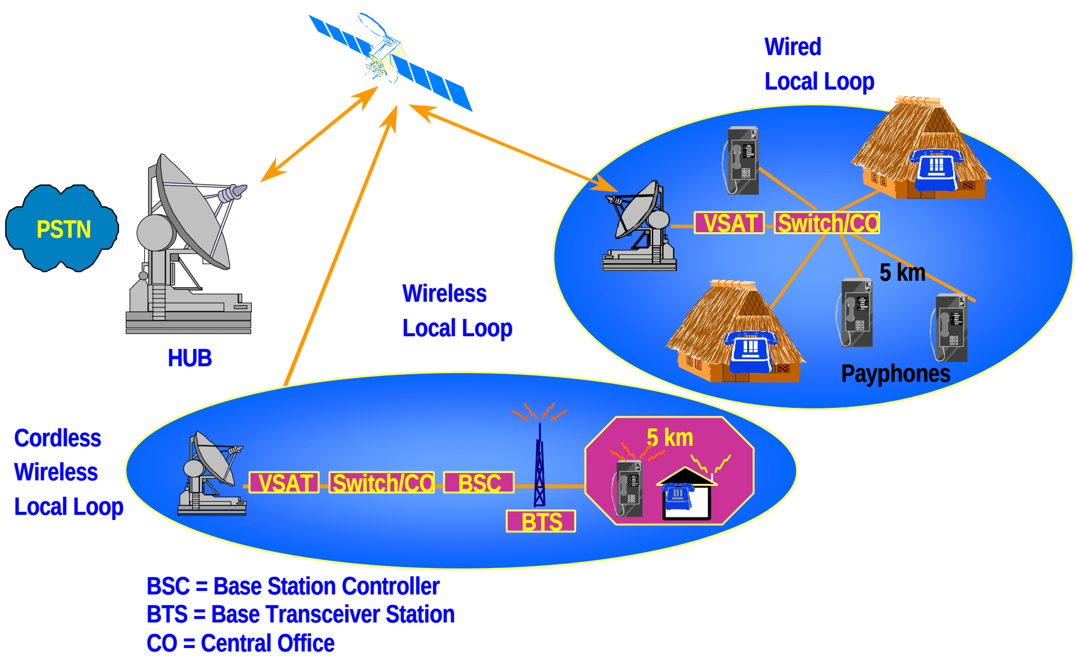


VSAT stations connected to a small number of phone lines are an ideal solution for serving the initial demand of remote telephony, usually fewer than 20 lines per VSAT site. VSAT networks can be connected to pay phones or a small number of lines to serve scattered populations with a dispersed subscriber base. VSAT stations can be located at an individual home or co-located with a public phone.

The public phone network can be composed of individual pay phones connected to a VSAT station (typically a 1.8m C-Band or a 1.2m Ku-Band antenna), or phone shops (telecenters) where multiple “community” lines/phones/fax are connected to a single VSAT station. In summary, this solution offers the following advantages:

- A cost-effective solution for implementing high quality and reliable communications in locations that terrestrial facilities cannot economically accommodate
- Rapid installation, as quickly as 2 days per site and low cost of operation and maintenance
- VSAT hub facilities which may be shared among multiple users and applications
- Provision of high quality narrow and wideband communications (voice, fax, tele-medecine, tele-education, Internet access)
- Available alternative power supply such as solar energy (35 to 60 watts per channel)
- No requirement for separate power supply for subscriber terminals wired to the VSAT station

2 - VSATs and Local Loops



2.1 VSATs and wired local loops

This solution is well suited to serve concentrated populations in rural areas, especially clusters of populations located within a 5 km range. VSAT networks connected to a local switch may provide high data rate transmission for local traffic. Wired local loop areas can be co-located with a VSAT station or interconnected to the VSAT using a microwave solution. Because this configuration relays more traffic at higher data rates than single lines, antenna and transceiver sizes increase (minimum 2.4m C-Band or 1.8m Ku-Band). Main advantages are summarized as follows:

- Seamless connectivity via VSATs between wired local loop networks and PSTN.
- Service offerings include voice, fax and broadband data.
- Alternative power supply such as solar energy can be used, with no separate power requirement for subscriber terminals wired to the local switch.
- Optional battery reversal and 12/16 kHz signaling available for pay phone connections.

2.2 VSATs and microcell/cordless WLL technology

VSATs and microcell/cordless WLL technology (small wireless cell site coverage of less than 5 km and limited mobility) provide communication solutions for subscriber densities greater than 20 lines. In this configuration, VSATs are used for long distance communication, while microcell/cordless WLLs are used for local communication. WLL microcell standards include DECT (Digital Enhanced Cordless Telephone) and PHS (Personal Handyphone System). DECT operating frequency ranges from 1850 to 1900 MHz while PHS frequency ranges from 1895 to 1918 MHz. Cordless telephony was originally designed to provide wireless access to residential and business areas and has recently developed into a cost-effective WLL solution for low density areas. Cordless telephony has significant advantages in terms of scalability and functionality. Compared to cellular, cordless telephony is capable of carrying higher levels of traffic (more adapted to fixed telephony as opposed to mobile traffic), provides better voice quality (32 kbps ADPCM) and can transmit data at higher rates (currently 14.4 kbps with migration to 64 kbps by end of 1999). Other advantages are summarized as follows:

- Non-compressed WLL voice call processing maintains voice quality over the VSAT network.
- Power requirements are low for both equipment (< 700 watts) and subscriber terminal (5 Watts)
- Cost per line is significantly reduced by integrating WLL and VSAT hardware and network management systems (refer to later chapter “VSAT/WLL – what to integrate?”)
- Optional battery reversal and 12/16 kHz signaling available for pay phone connections.

Why a microcell coverage?

The appropriate coverage area of the WLL cell site obviously depends on the terrain and the population distribution over the terrain. As part of INTELSAT R&D activities, a total of nine rural telephony models were defined, which were representative of rural environments on various continents as they included jungle, mountains, islands and flat terrain. They are summarized in Table 1.

TABLE 1 : OVERVIEW OF RURAL MODELS

	Rural Population	Required Range (km)	Distance Between Villages (km)
Brazil		30	7.5
Mexico-1	<2,500	5	10
Mexico-2	<500	5	10
Indonesia	<9,000	5 to 10	20
Philippines (1)	<4,000	12	5
(2)	<3,000	7	5
(3)	<500	3	5
India North	<2,000	5	20
India Central	<1,000	30	5
Romania (1)	<5,000	10	15
(2)	<1,000	5	15
Sudan	<20,000	30	10-20

An examination of the unique demographic patterns and geographic features in three Asian countries reveals how difficult and dangerous generalizations are. Indonesia has many relatively large villages (1,500 to 9,000 inhabitants) where the potential subscribers are clustered within 5 to 8 km. India has at least two models, North and Central/South. The North is mountainous and characterized as having isolated towns or villages up to a population of 2,000. The Central/South model is generally flat with towns separated by 5 km or less. A unique island-based model is found in the Philippines. Both mountains and large bodies of water isolate towns and villages. Ten or more villages on multiple islands can be found within a 30-km radius but line of sight is restricted. In almost all of these villages a high percentage of the traffic would leave the local area. Other Asian prototypes can be similarly characterized; however, these four diverse scenarios demonstrate the problem in attempting to construct a single homogenous network model for basic rural services.

Analyzing the data in Table 1 led to the following three main conclusions: (1) rural topography and distribution of subscribers are not governed by one particular model in terms of total population, population density and required number of lines, (2) the subscriber distribution is not uniform due to the establishment of village clusters, separated by mountains or rivers, and (3) the villages appear to be served in a more efficient and economical way by a microcel architecture, i.e. several cells with a coverage area around the base station of no more than 5 to 10 km. This in contrast to what is commonly called a macrocell, where the power is uniformly broadcast in all directions over a range of around 30 km.

The use of a macrocell allows amortizing common equipment (antennas, tower, amplifiers, channel units, etc.), over the maximum number of subscribers. However, this approach may waste resources and leave many pockets of poor coverage in all but flat terrain. Examples of microcell standards include cordless standards such as DECT and PHS. Examples of standards providing macrocellular coverage are GSM, TDMA and CDMA.

VSAT/WLL – What to integrate?

As indicated in Figure 1, which shows the conventional chain of non-integrated DECT-VSAT components, there are many elements that could potentially serve as the basis for integration. From left to right are illustrated: the DECT Base Station, which is the radio interface, the Base Station Controller (BSC assigns the WLL channels, monitors the base stations and performs call processing and fault management functions), the switch or local exchange (since DECT typically does not perform local switching as part of the base station or base station controller), and the VSAT elements, in this case the DAMA indoor unit and the outdoor unit, comprised of up and downconverter, amplifier and LNA.

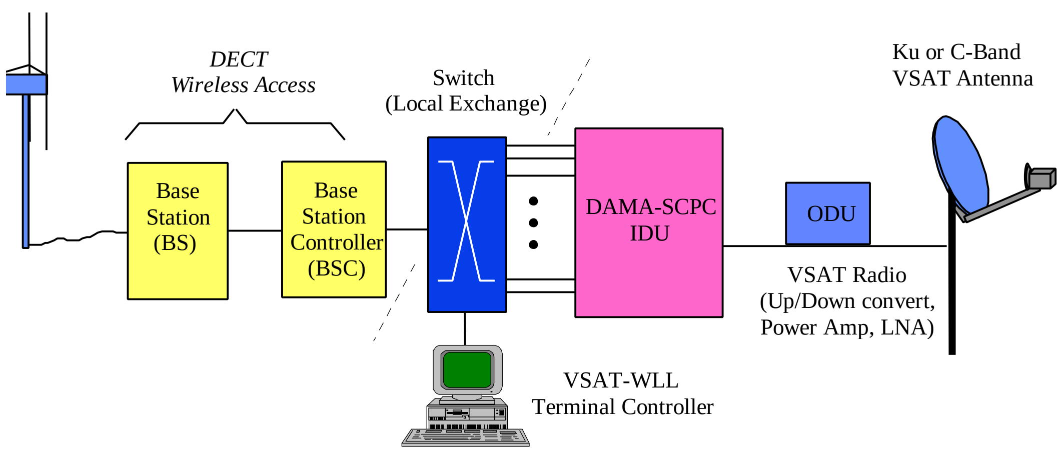


Figure 1 : Conventional (non-integrated) WLL/VSAT terminal components

An analysis of the relative cost of the functions was performed for the various components and led to the conclusions that the following tasks are essential to achieve any substantial cost reduction:

- Integration of the BSC functionality into the existing VSAT baseband processing functionality
- Simplification and cost reduction of the local switching within the WLL/VSAT terminal, in order to avoid the use of satellite power and bandwidth for local calls
- Elimination of channel banks and any digital to analog signal conversion
- Ruggedization of the equipment to avoid the need for costly shelter and to simplify terminal installation

Integration can lead to cost savings of approximately 40%. INTELSAT will take delivery of several WLL/VSAT prototype terminals in the fall of 1999 from STM Wireless and plans to deploy them in rural isolated remote areas, in Senegal, as part of its current undergoing trial with SONATEL. In addition, INTELSAT may decide to embark in further development efforts to integrate management of call records, fault monitoring and diagnostic information that is now typically gathered separately by WLL and VSAT networks. An integration of both network management systems into one platform would simplify operations, administration and maintenance (OA&M), and results in more efficient allocation of satellite resources and a simplified hardware configuration of the traffic terminals.

Trial in Senegal: DAMA VSAT/ DECT WLL configuration

During the first quarter of 1999, INTELSAT began a trial with the cooperation of SONATEL in Senegal to serve multiple villages with two VSAT/WLL DECT stations. The objective of the trial is to demonstrate the technical feasibility of providing satellite interconnection for WLL installations through INTELSAT satellites, including backhauling telephony services to the public switched network. To conduct the trial, INTELSAT is using a DAMA network provided by STM Wireless operating over the INTELSAT 603 satellite. Each VSAT/WLL site houses a single chassis with the VSAT and DECT WLL controller equipment co-located. This pre-integrated solution is a precursor to the fully integrated version being developed by STM Wireless that will be made available end of 1999.

Figure 2 contains the hardware configuration deployed in Senegal. As shown in the middle of the Figure, a Southeast Zone Beam transponder on the INTELSAT 603 satellite connects the Standard A station in Gandoul, which is used here as the DAMA hub station to two remote sites in Senegal : Tivaouane and Kafrine. Each remote site is equipped with a 2.4m antenna, and a 5W HPA. In addition, each indoor unit holds three Voice Channel Units (VCUs), one Data Channel Unit (DCU) dedicated to the transfer of the WLL call data records (CDR), and a PC-based terminal to run the WLL Network Management System (NMS). The VSAT traffic terminals are connected via a multiplexer (E&M to E1) to the DECT WLL Base Station Controller, which is also incorporated in the same chassis as the VSAT baseband equipment. Two DECT/WLL antennas (provided for space diversity) are mounted on an already existing microwave tower, which transmits and receives to a maximum of 20 pay phones, installed in villages surrounding the WLL/VSAT site. The DECT radio power and antenna gain specifications limit the coverage radius to 3 to 5 km. A solution has been established to gather all CDR at the DAMA hub site in Gandoul. First, the WLL Call Detail Records are collected locally by the WLL NMS and then transferred to the central DAMA NMS using an Ethernet connection via a dedicated data channel.

At the Hub site, the DAMA Network Control Terminal (NCT) consists of 4 VCUs, a DCU and Control Processors to transmit and receive the DAMA signaling and traffic information from the remote sites. The DAMA NMS resides on a Sun Microsystems computer which is located at the premises of the Standard A earth station in Gandoul. The E&M leads from the VCUs at the hub connect via a multiplexer to the Switching Center in Dakar where normal call processing and routing procedures are applied. Communications between the remote sites and the hub occur via 9.6 kbps channels; a continuous TDM carrier is used in the outbound direction (to the sites), while the remote sites use slotted Aloha TDMA for DAMA network login, logout, status and call setup and tear down in the inbound direction.

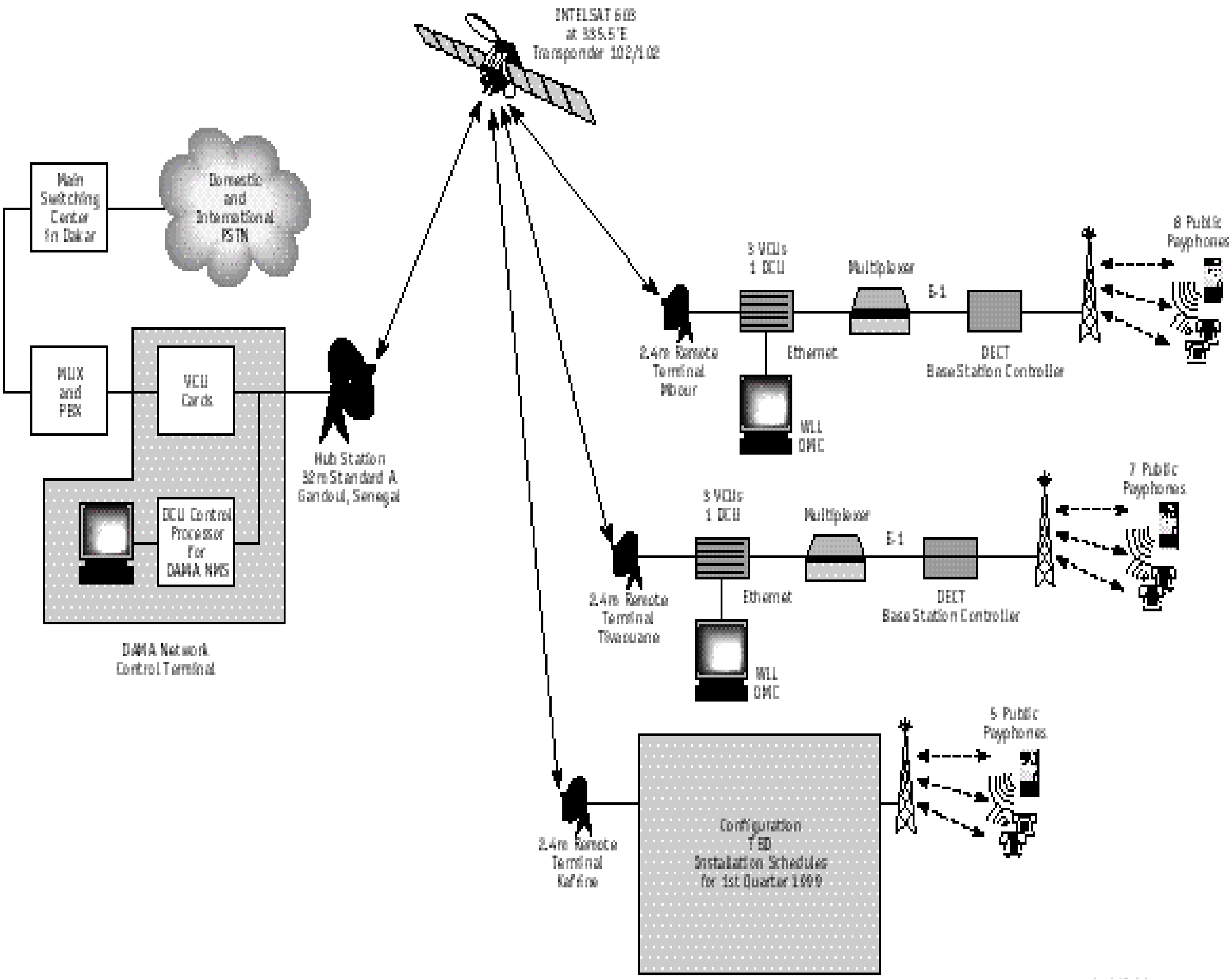
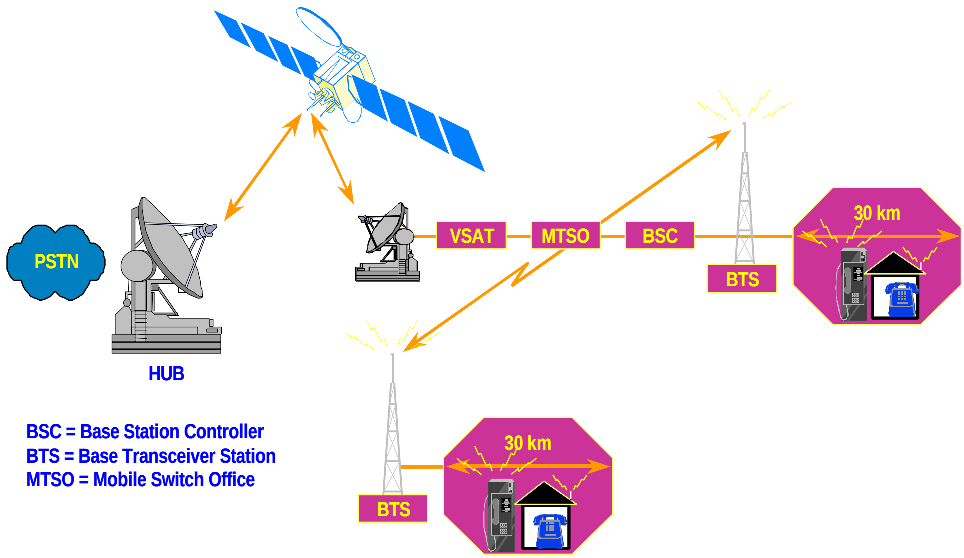


Figure 2: Functional configuration for the WLL/VSAT trial in Senegal.

2.3 VSAT and macrocell WLL technology



VSAT networks combined with wireless macrocellular networks provide cost effective solutions for more than 300 lines to populations uniformly distributed over a 30 km range. Macrocellular standards include AMPS (FDMA), GSM (TDMA) and CDMA. Given its wide availability resulting from serving more than 50% of the high mobility market, the analog cellular AMPS is best suited to serve economically low density to medium density markets (> 150 lines). Digital cellular such as GSM also benefits from wide availability; however these systems have been designed to serve higher capacity subscriber lines (> 300 lines). Another digital cellular solution, CDMA, employs a spread spectrum modulation technique in which a wide range of frequencies are used for transmission and the system low power signal is spread across wide frequency bands. Like GSM, CDMA becomes more cost-effective for larger population densities (> 500 lines). Advantages are summarized as follows:

- Supports large coverage area with single base station transceiver (up to 30 km).
- Provides seamless connectivity via VSATs between local loop networks and the PSTN.
- Supports FDMA (AMPS), TDMA (GSM, IS-54) or CDMA (IS-95).
- Service offerings include voice, narrowband data and mobile telephony.

Case Study: trial in Peru

In 1998, INTELSAT and Telefonica del Peru conducted a rural telephony trial using a combination of a VSAT station and a macrocell wireless local loop to serve three rural locations in Peru: Chuambra, Santa Rosa de Tiestes and Succlla. The installed VSAT/WLL network included three major components: the subscriber telephones to access the WLL network, the WLL equipment to provide local wireless access and the VSAT network to ensure interconnection to the main PSN center in Lima. The network features a 2.4m DAMA VSAT station with three voice channels using the INTELSAT 603 satellite at 335.5^{o}E and an AMPS WLL cell site with 3 voice channels. The network used coin operated pay phones. This trial has demonstrated INTELSAT satellites' feasibility for interconnection of WLL and backhauling telephony services into the PSN. It also provided valuable statistical and operational information about communication service in a rural environment. For instance, the percentage of incoming (versus outgoing) calls was quite high and increased steadily after the trial began. In the beginning, more than 80% of the calls made with the pay phones were outgoing. After 3 months, the split was about 60%/40% for outgoing versus incoming calls.

Overall, both organizations gained a better understanding about technical and operational challenges faced by an operator in a rural environment, especially when implementing a combination of technical solutions such as VSAT and WLL. New operational issues such as the power requirement for multiple equipment and the centralization of call data records via various communications links (satellite and terrestrial wireless) emerged and required special attention. In addition, both organizations gained a better understanding about the rural telephony subscriber market in this region and what factors drive the demand for such a service. Many of these statistics, such as the percentage of dropped calls and the percentage of incoming calls, reflect a general trend seen in many emerging markets in Latin America and elsewhere (Bangladesh, for instance). Finally, this particular experience also revealed an instance where the combination of VSAT and WLL can serve economically rural areas by combining wireless thin-route services offered to suburban and rural subscribers under one umbrella. This particular solution will also stand on its own in remote areas with larger population densities where there is a requirement for at least 200 lines.

2.4 Conclusions

A number of VSAT based rural telephony solutions are available to serve various population densities. Each solution holds its own technical specifications as described in the table summarizing the product portfolio choices (see table 2 below). For instance, the macrocellular WLL option offers the widest coverage area and mobile telephony, but is limited in terms of data rate (as of today with the second generation cellular systems, the third generation will offer at least 384 kbps), and requires the installation of a large tower as well as high power. In contrast, the cordless solution is limited in coverage but offers higher data rate and requires lower power supply and a pole for the antenna installation

Overall, the challenge of the rural telephony operator is to select the optimum solution carrying the lowest installed and operated cost per line (recurring and non-recurring expenses), given the subscriber population distribution, the environmental conditions and the service offering demanded. Most often, import taxes, local transportation expenses, lack of reliable power supply and many operating inefficiencies negatively impact the installed and operated cost per line, and, thus, the business case for rural telephony services. Finally, the development of the integrated VSAT/WLL solution not only provides an expansion path for traditional VSAT applications, but also positions this new technology extremely competitively in other markets traditionally occupied by microwave technology.

Table 2: Technical Feature of Rural Telephony solutions

Variables	**VSAT Alone**	**VSAT & Wired Loop**	**VSAT & Wireless Loop / Cordless Access Solution**	**VSAT & Wireless Macrocellular Solution**
Population Distribution	Scattered	Concentrated & clustered	Clustered	Uniform
Subscriber Density	Very low (<0.1/sq. km)	Low to medium	Low to medium	Medium (<0.1/sq. km)
Traffic Capacity (erlang)	Low	Low to high	Low to high	Low to medium
Applications	Voice, data, fax	Voice, data, fax	Voice, data, fax	Voice, data, fax
Data Rate	Broadband	Broadband	Up to 64 kbps	Narrowband, up to 14.4 kbps
Mobility	None	None	Limited	Yes
Area of Coverage	< 300 m	< 5 km	< 5 km	< 30 km
Power Supply – Equipment	Low (< 250 Watts)	Medium (< 600 Watts)	Medium (< 700 Watts)	High (~2000 watts)
Power Supply – User Terminal	None	None	Low (< 5 Watts)	Medium (< 30 Watts)
Voice Compression	Selectable (4.8 to 32 kbps)	Selectable	32 kbps	8 to 13 kbps
Access to Switching Facilities	Required	Not required	Optional	Not required
Terrain	Insensitive	Sensitive	Insensitive (No tower required)	Insensitive except tower installation
Installation	Rapid (2-3 days)	Lengthy (wired network)	Rapid (2-3 days per site)	Rapid, except tower installation
Maintenance	Very Low	Medium	Low	Low
Security issues	Antennas and shelter	Wire theft and shelter	Antennas and shelter	Antennas, tower and shelter
Regulatory Issues	VSAT license (C or Ku band)	VSAT license	Cordless and VSAT licenses	Cellular and VSAT licenses