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Rural Mobile Telephony: A VSAT (Satellite) based Approach

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Abstract: This work presents a VSAT based approach for extending mobile communication access to rural communities in developing countries using VSAT and satellite technology. The rural areas are clustered into village community cells with each cluster being served by a non regenerative bidirectional repeater system. The telecommunication technology of choice is the GSM standard. Traffic from the rural areas is collated together at the access point which serves as an interface between the village community cells and the satellite. The access points perform a frequency translation moving the signal from the GSM band to the satellite band at the transmitter and vice versa at the receiver. The system maximizes the advantage of satellite communication technology over other types in linking remote areas to urban centers that are geographically far apart. The satellite then links the village cell to the operator's network via a dedicated BTS in the urban area. The system has the advantage of being modular, scalable and solar powered due to the low traffic from rural areas.

Introduction

The current high rate of increase in teledensity in most parts of the world is still yet to reflect in the rural areas. Rural areas both in the developed countries of Europe and America and developing countries in Africa are still faced with the challenges of low teledensity compared to their urban counterparts [1]. In India, as at 2009, the percentage of operator subscribers dwelling in rural areas ranged from 30% for Bharti's airtel while for Vodafone, BSNL, Reliance communications and Idea cellular it was 31%,34%,19% and 30% respectively. Of the 347 million subscriber base, the rural areas contributed only about 92million or 26%. The rural teledensity of India stood at 12.62% compared to the 81.3% of the urban areas bringing the overall teledensity to 32.23% [2]. The teledensity of Nigeria increased from 0.4% in 1999 to 3.3% in 2004 and as at 2010, the value was 56.32% with the urban areas having a higher teledensity value [3]. The first phase of mobile communications started in the affluent regions of the globe and with the saturation of these markets, the majority of new subscribers now come predominantly from emerging markets where the demand for connectivity is greatest and this is due to the lack of legacy fixed infrastructure [4]. Expanding into new areas has many positive financial advantages to operators but they must overcome the limitations imposed by the challenges of the rural communities. The most significant impediment to the increase in the number of telephones in the rural areas is the lack of service in these rural areas and the low economic power of the dwellers [1]. Infrastructure in the rural areas is almost nonexistent in many developing countries and for developed countries, the cost of extending this infrastructure (especially public utility power) is so high and does not make economic sense so governments are not usually keen on extending utility to these areas.[5][6][7][8].

Extending telecommunication (mobile communication) services to the rural areas would require several towers , antennas and generators for the total number of hops required to link the rural area to the nearest urban areas. The absence or inadequate supply of public power supply means that for operators to deploy service in the rural areas, they must provide their own source of power supply which in most cases is the diesel generator. The operators depending on the frequency of deployment (GSM 900 or GSM1800) must use either a few number high power transmitter based cell sites in the macro cellular configuration to be able to cover a wide area or a large number of cells with low power transmitter based cell sites in a microcellular configuration. Whatever configuration utilized will require the setting up of the base station cell sites and the attendant capital and operational expenses (CAPEX and OPEX costs). This cost structure of deploying mobile service in rural areas coupled with the low population densities in these areas make it uneconomical to deploy mobile telecommunication service to rural areas whether in developed or developing countries [9]. Table 1 shows the data of the Nigeria telecommunication market as at April 2010.The current teledensity is shown to be 56.32% and the GSM technology is the most predominant telecommunication standard.

Table 1 Mobile communication subscriber data for Nigeria (source NCC)

	Operator	Dec '09	Jan '10	Feb '10	Mar '10	Apr '10
Connected Lines	Mobile (GSM)	N/A	N/A	N/A	83,432,487	85,565,255
	Mobile (CDMA)	N/A	N/A	N/A	10,310,367	10,545,283
	Fixed Wired/wireless	N/A	N/A	N/A	2,753,753	2,561,923
	Total	N/A	N/A	N/A	96,496,607	98,672,461
Active Lines	Mobile (GSM)	65,533,875	66,738,944	67,851,706	68,690,462	69,649,955
	Mobile (CDMA)	7,565,435	7,772,670	7,795,564	7,664,302	7,745,377
	Fixed Wired/wireless	1,481,954	1,422,593	1,433,736	1,417,700	1,459,271
	Total	74,518,264	75,934,207	75,934,207	77,772,464	78,854,603
Installed Capacity	Mobile (GSM)	121,785,526	126,785,526	124,125,308	124,125,308	124,125,308
	Mobile (CDMA)	14,829,931	15,253,699	15,272,405	15,312,224	13,148,043
	Fixed Wired/wireless	9,388,145	9,408,838	9,437,757	9,305,914	9,327,586
	Total	146,003,602	151,448,063	148,835,470	148,743,446	146,600,937
	Teledensity %	53.23	54.24	55.06	55.55	56.32

This paper presents a VSAT based approach to extending mobile communication services to rural areas. It utilizes the hamlet settlement structure of the rural areas to form a hamlet cell. The Hamlets are linked to a mini MSC which has a bank of transceivers (TRX) attached to it. An access point which comprises of low noise amplifiers and a satellite modem is used together with the mini MSC to transfer calls between the hamlets which make up the Village community cells and locations outside the hamlets. This is achieved by a process of modulation and demodulation of the GSM traffic to convert it to the satellite band for transmission over the satellite system. The GSM standard due to its wide range of market penetration as shown in the Table 1 is the standard of choice.

System Design

Users in each hamlet are linked to the mini MSC by Low Power Transceivers (LPT) run on solar arrays. The MSC and access point which transfers the GSM signals into satellite KU band for transmission over the satellite to designated BTS/MSC in the urban area. The signal is received and reconverted to the GSM band for onward transmission to its destination. The architectural diagram of this network is shown in Figure 1.

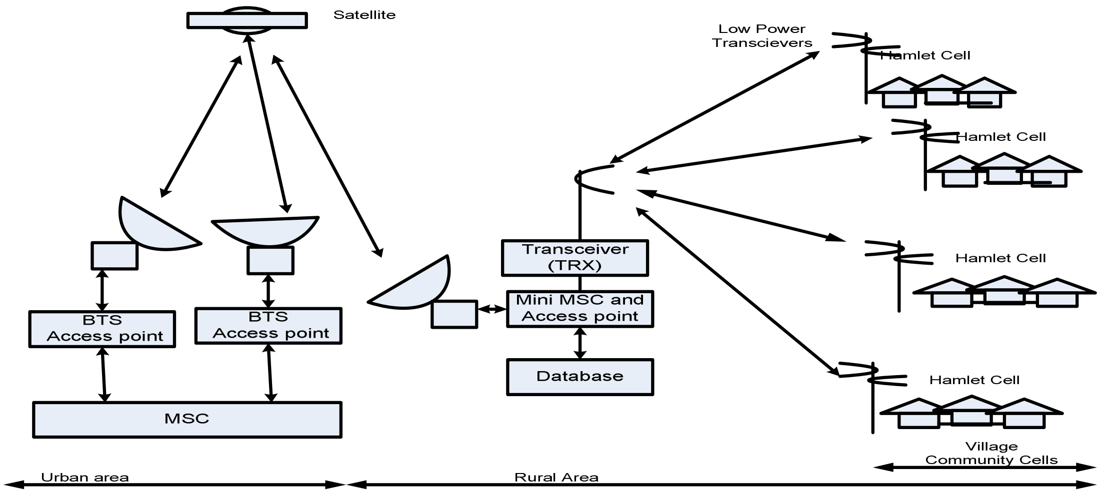

Figure 1 System architectural diagram

From the diagram in Figure 1, the users are organized into hamlets and when a SIM card is activated in a particular hamlet cell, the Mini MSC records that location as the home cell. The mini MSC maps each user in a hamlet cell to the particular transceiver covering that cell. With this arrangement, it is able to perform location update, handover and it also performs the billing of the subscribers in its database.

When a call originates from any of the hamlets, the MSC identifies the destination and performs the routing. If the destination address is located in another hamlet cell, the calls are rerouted to that hamlet. The hamlets have fixed frequencies and the receiver station attached to the min MSC has different antennas such that a group of hamlet cells are tied to an antenna at the mini MSC as shown in Figure 2.

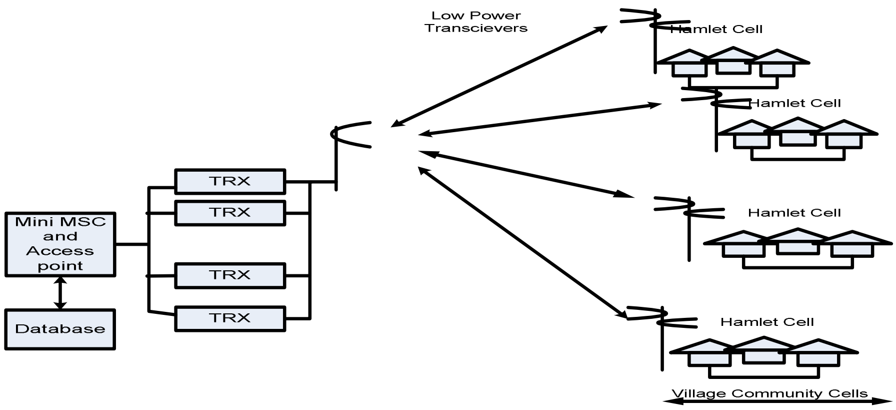

Figure 2 Antenna Connections between the hamlet cells and the mini MSC

The mini MSC is designed to handle a smaller number of subscribers and is designed to require low power and to be scalable [10]. The scalability of the design enables its capacity and functionality to be increased as the need arises. The GSM 900 is the preferred standard for deployment in the rural area because it has a wider cell range due to the better resistance of signals at the 900MHz frequency band to attenuation. It has 25MHz of bandwidth with 125 carriers each having a bandwidth of 200 KHz [11]. A channel in the GSM system can accommodate up to 8 users at a time using the Time Division Multiple Access with frequency Division duplexing.

The Database and Access Point: The database stores the subscriber details. It supports the MSC in the storage and retrieval of subscriber data. The data pertaining to the mobile units are tied to specific transceivers which serve as the home address and are stored in the database. As the user moves the location registration system updates the subscriber data by changing the transceiver number attached to the subscriber data so that the location of the user can be easily identified and retrieved when required. The access point is responsible for the conversion of the GSM traffic to traffic suitable for satellite transmission. It comprises of a low noise amplifier stage and a satellite modem. The Modem performs the modulation and demodulation from the GSM band to the KU band and vice versa.

Satellite System: Telecommunication Networks can be split into 3 major sections. These are the backbone, the user premises and the network. The backbone provides high speed, high capacity connections between the networks and it is the most expensive part of telecommunication systems and it can be implemented using optic fibers, wire line or wireless technologies. The most popular backbone technology is the microwave links. Microwave links operate in frequencies between 2 to 40 GHz and can provide back haul links of up to 60km and radios have to be added to increase the links. Micro waves require line of sight and it connects up to 60% of the world's base stations [4]. The high cost of deployment of microwave links coupled with the time intensive nature of the installation of towers and antennas especially in rural areas which are most of the time located far away from the urban areas make it a uneconomical approach for the deployment of telecommunication backbone in rural areas.

Satellites are placed in orbits round the earth and these orbits are Geosynchronous (GEO), Low earth orbit (LEO) and the Medium Earth Orbit (MEO). Communication satellites are placed in the geosynchronous orbit such that it has the same speed as the earth round the sun. It appears stationary to the earth station and with this arrangement three satellites can provide over 90% coverage of the earth except for polar regions. LEO orbit require 30-80 satellite to provide global coverage [12] A satellite receives radio signals and transmits these signals using transponders. It can carry up to 5000 simultaneous voice and data channels. Satellites have up to 32 transponders with each transponder having 36MHz and a 2.0 48Mbit/s. The ground station equipment consists of a very small aperture terminal, a remote router and a 1.2m – 3.8m dish.

The satellite band used in this design is the KU band. This is due to the available bandwidth. The L band which was used by Globalstar and iridium created a large base of users most popular is the Thuraya. It had a wide coverage area, is not affected by rain attenuation and less prone to shadowing due to trees than the KU band. However, the lack of band width meant a very high cost of bandwidth and these defeats the purpose of the low cost design. To overcome the bandwidth scarcity, a migration to a higher frequency the KU band (11-18GHz) became necessary. The cost of service in the KU band is a fraction of those in the L band [13].

Losses occur in the earth's atmosphere as a result of energy absorption by the atmospheric gases. These losses are treated quite separately from those which result from adverse weather conditions, which are also atmospheric losses. To distinguish between these, the weather-related losses are referred to as atmospheric attenuation and the absorption losses simply as atmospheric absorption. The atmospheric absorption loss varies with frequency, as shown in Figure 3. The figure is based on statistical data of the CCIR Report 719-1 of 1982. Two absorption peaks exist with the first one at a frequency of 22.3 GHz, resulting from resonance absorption in water vapor (H_2O), and the second one at 60 GHz, resulting from resonance absorption in oxygen (O_2). However, at frequencies well clear of these peaks, the absorption is quite low. The graph in Figure 4 is for vertical incidence, that is, for an elevation angle of 90° at the earth station antenna [14].

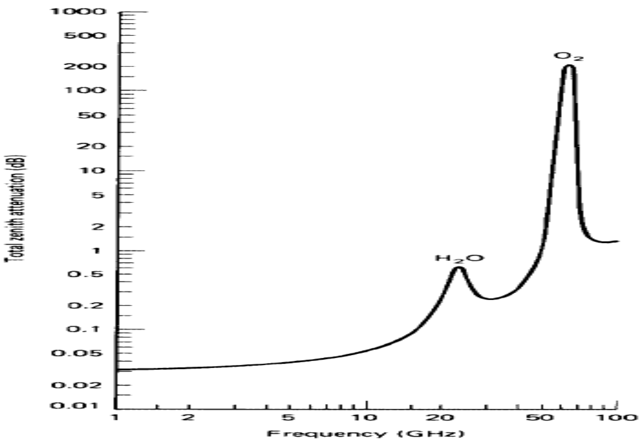

Figure 3 Atmospheric attenuation rates

The major challenge however is the fact that the KU band is highly vulnerable to rain. The ITU classifications states that the rain intensity that will cause an interruption of a communication link for 0.01% per year is 145mm/hr such rain intensity also known as the rain rate can cause 28dB rain attenuation for a link working in the 14GHz band. This attenuation can be compensated for the use of powerful RF transmitter equipment. The value of the compensation is calculated using the link budget. Another approach at overcoming the rain attenuation at KU frequencies is a regenerative system called the Automatic link control which enables the satellite compensate for rain attenuation up to 10 dB. On the ground segment there is the Automatic uplink control which controls the transmit power in line with the rain attenuation. Other schemes employed in the grand segment include the turbo coding and Adaptive coding [15].

Link Analysis: Link budget calculations are often carried out using powers measured in dBW. The power is measured relative to a 1 watt reference power. This is represented in Equation 1

$$Power\ in\ dBW = 10 log \frac{Power\ in\ Watts}{1\ Watt} \tag{1}$$

The power received is represented by Eq 2

$$P_R[dBW] = EIRP[dBW] + G_R[dB] - 20 log\left(\frac{4\pi R}{\lambda}\right) \tag{2}$$

Corrections must be added to P_R for additional losses due to

1. Antenna efficiency - power is lost in the antenna feed structure, also in connections to the receiver
2. Atmospheric absorption due to water and oxygen molecules
3. Polarization mismatches of Tx and Rx antennas
4. Antenna misalignments - ie boresights of Tx and Rx antennas not aligned

An *additional loss factor L* is introduced to the link budget equation to take account of these losses. The equations become (Equation 3)

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi R}\right)^2 \frac{1}{L} \tag{3}$$

$$P_R[dBW] = P_T[dBW] + G_T[dB] + G_R[dB] - 20 log\left(\frac{4\pi R}{\lambda}\right) - L[dB] \tag{4}$$

Typically L is about 5dB [17]

Rural Deployment and Connectivity: There are so many other challenges faced in attempts to provide communication services to rural areas especially in developing countries. Geographical challenges such as mountainous terrain makes line of sight over long distances impossible and the demographic distribution of population e.g. sparse distribution in pockets along valleys and lack of infrastructure such as roads or stable commercial power supply are some of the challenges[17][18]. The technology appropriate for providing telecoms services to areas with these characteristic must have the following features as a minimum standard.

1) Wireless due to terrain
2) Cheap
3) Consumes less power
4) Interoperability with existing PSTN or other suppliers' equipment
5) Remote network management possible.
6) Simple, small, modular and scalable
7) Equipment should have a long life cycle

The methodology utilized in the design of the link in the rural areas involved the determination of the path loss of the links between the Mini MSC/access point and the transceiver and the path loss between the transceiver and the user in the rural environment. The analysis assumes the link between the BTS and the transceiver to be a point to point link and Path loss prediction models are used to determine the path loss of the user's environment [19][20]. The computed path loss values and the parameters of both the BTS and the mobile units are used to determine the optimum value of the transceiver gain.

From the system diagram in Figure 1, the pathloss between the TRX at the mini MSC/access point and the LPT is computed using the free space pathloss formula due to the fact that the link the Transceiver is a point to point link. [21].
The expression for the pathloss is defined in Equation 5

$$PL(d) = PL(do) + 10n\log_{10}\left[\frac{d}{do}\right]dB \tag{5}$$

Where
n = pathloss coefficient
do = Reference distance for the antenna's far field. This value is 1m for indoor environments and between 100m to 1Km for outdoors [21].
With the ETSI specified transmit power of the BTS of +43dBm and the transceiver sensitivity of -100dBm. [21], the power received at the transceiver is derived from Equation (6),
Power received at the transceiver is given by

$$Pr(LPT) = Pt\ (TRX) - Pathloss\ (TRX\text{-}LPT\ link) \tag{6}$$

Where Pr(LPT) = Power received at the Low Power Transceiver
Pr(TRX) = power transmitted from the mini MSC = +43dBm(ETSI specification)

Discussion

The advantages and characteristics of satellite communication make it suitable for communication between rural areas and urban areas where line of sight is impossible. The access point has a modem for the conversion of the GSM signal to the satellite band thereby enabling the transportation of the GSM signal over satellite links. The repeaters covering the hamlet cells, the mini MSC and the access points are designed to be scalable, compact and powered by solar arrays.

Conclusion

The initial high cost of setting up satellite communications (spectrum and hardware cost) is also much lower than the cost required to set up the same communication link using other terrestrial and wireless transmission media. The round trip delay time experienced by calls through satellite systems can be calculated and such time delays not billed.

The VSAT approach will not only enable communication, it will also facilitate data transfer and ultimately broadband access to rural communities. Other benefits of the system include:

1. Calls between users in the rural areas do not have to go though the satellite as the mini MSC can route them within the rural areas from source to destination. This reduces the cost to both the operator and the users
2. Due to the wide area of the satellite foot print, the traffic from the satellite can be routed to any BTS within its footprint in the event that the primary BTS is overloaded. This reduces the call drop rates for calls originating from the rural areas
3. Traffic will be paid for on the basis of actual transmission as against time since the communication is IP based.
4. The distance from most rural areas to urban areas especially in the northern parts of Nigeria is so large that a large number of hops will be required for a rural urban telecommunication link and this leads to very high infrastructure cost. This system overcomes this cost limitation.
5. The low population of the hamlet is such that the number of nodes the switch will be required to handle will be very small as such the MSC and database can be of low capacity and housed in Personal Computers.

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