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iJET International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 2 No. 3, March, 2012

Low Power Transceiver Based Approach to Extending Mobile Communication to the Rural Areas of Nigeria

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ABSTRACT

The paper introduces a low power transceiver based approach at extending Mobile communication services to rural areas without the use of conventional base stations. A hamlet cell arrangement is proposed for the clusters or hamlets of the rural areas eliminating the need of having coverage in unpopulated areas like rivers, mountains and forest. The system utilized a low power transceiver designed to be powered by solar cells. The Transceivers provide coverage to the hamlets by the use of corner reflector antennas and these hamlets are linked to the nearest base station by directional antennas. The results show that this approach can enable communication between dwellers in the rural and the urban areas with the mobile units in the rural area transmitting at minimum power thereby extending the battery life of mobile units in the rural areas and it eliminates the conventional base station and reduces both the capital expenses and the operational expenses required to set up a mobile communication cell site in a rural area.

Keywords: *Hamlet cell, corner reflector antenna, directional antenna, transceiver*

I. INTRODUCTION

The current approach to extending mobile communication to the rural areas of Nigeria involves the setting up of a base station and this comprises of the installation of generator sets, fuel tanks, stabilizers, battery banks, tower construction, the shelter installation ,antenna subsystems and the extensive earthing required for the site. The total cost involved in the setting up of the base station can be broadly categorized as capital expenses (CAPEX) and operational expenses (OPEX) [1].The capital expenses usually involve the cost of equipment and installation. This cost covers the purchase of all cell site equipment and it can be predetermined. Special financing arrangements can also be made with equipment manufacturers to ensure service roll out even with limited funds [2].The OPEX costs caters for all the expenses made to keep the network up and running. It is a very critical cost in that it is required to enable the network generate revenue and profit for the investors and also to ensure continuous running of the system.[1] A very major component part of this cost is the amount spent on fuel for the generators. In developing countries it is almost impossible to accurately forecast the actual amount that would be required to cater for the operating cost due to the inconsistencies in utility supplies, government policies and the effect of theft and vandalism at the cell sites [3].

The rural areas of Nigeria are characterized by clustered settlement distributions separated by farmlands rivers mountains and uninhabited spaces [4]. This population distribution makes the macro cell/micro cell structure for cellular communications a wasteful approach because coverage would be provided for uninhabited areas [5-7]. The approach being proposed in this work involves the use of specially designed low power/low cost non regenerative transceivers as replacements for the conventional base station. This transceiver is designed to serve as a bidirectional link between the users in the hamlet cell and the nearest base transceiver station (BTS) in the urban area. It is also designed to be transparent to both the mobile unit in the rural areas and the nearest BTS thereby eliminating any need for protocol/modulation change. The possibility of the design of corner reflectors without side lobes facilitated its use as the antenna between the user and the transceiver as this reduced the possibility of feedback and oscillations in the transceiver while the high gain directional antenna is used to link the transceiver with the nearest BTS in the urban area.

II. METHODOLOGY

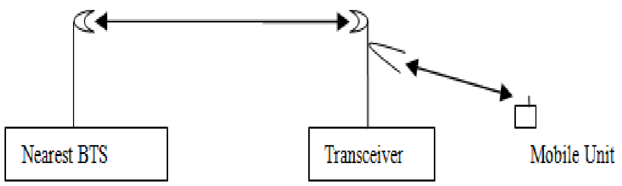

Fig1: Proposed system diagram

The methodology utilized in the design of this system involved the determination of the path loss of the links between the nearest BTS 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 it is considered to be in an urban environment since the BTS is usually sited in the center of the cell. The Cost231-Hata model is used to determine the path loss of the user's environment since the users are in rural areas. 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.

The Hata model which was originally developed to estimate pathloss in the 200MHz to 1500MHz range was modified by the European committee on scientific and technical research to extend its range to 2GHz.This model now known as the COST231-Hata model is used extensively in pathloss prediction in the Digital Communication System (DCS1800) band for urban areas with factor built in for rural area pathloss estimation. [8-9]

The specified parameters for the model include:

Frequency range =1500MHz to 2000MHz
Distance from the base station= 1km to 10km
HT =base station antenna height=30m to 200m
HR=mobile station antenna height=1m to 10m

From the proposed system diagram in Figure 1, the pathloss between the nearest BTS and the repeater is computed using the free space pathloss formula due to the fact that the link between the BTS and the Transceiver is a point to point link. [10].

The expression for the pathloss is defined in equation 1

$$PL(d) = PL(do) + 10n\log_{10}\left[\frac{d}{do}\right]dB \qquad 1$$

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 [10].

$$PL(do) = 20\log\left[\frac{4\pi do}{\lambda}\right] \qquad 2$$

Where $\lambda = \left[\frac{C}{F}\right] = \frac{3 X 10^8}{1.8 X 10^6} = 0.16$

Assuming do = 1000m (for propagation in outdoor environments.)[10]

(With do= 100m the PL(do) will be 77.9dB.The maximum value is utilized for worst case scenarios) [10]

$$PL(do) = 20\log\left[\frac{4\pi(1000)}{0.16}\right] = 97.9dB \qquad 3$$

Thus from equation 1

$$PL(d) = 97.9 + 10n\log_{10}\left[\frac{d}{do}\right]dB \qquad 4$$

For a distance of 10Km between the BTS and the Transceiver with a typical average path loss coefficient of an urban of 3.3[11], the path loss is computed to be

$$PL(10Km) = 97.9 + 10(3.3)\log_{10}\left[\frac{10000}{1000}\right]dB \qquad 5$$

From equation 5,

PL(10km) = 97.9 + 33log10 = 130.9dB.

The pathloss between the BTS and the Transceiver is computed to be 130.9dB for a 10km span. This is shown in Figure 2.

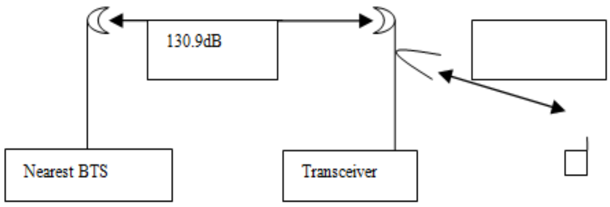

Figure 2: System block diagram showing the pathloss between the BTS and the transceiver

With the ETSI specified transmit power of the BTS of +43dBm and the transceiver sensitivity of -100dBm. [12], the transmit power of the transceiver placed 10Km from the BTS is derived from equation 6,

Power received at the transceiver is given by

Pr(TRX) =Pt(BTS) – Pathloss (BTS-TRX link) 6

Where Pr(TRX) = Power received at the transceiver

Pr(BTS) = power transmitted by the BTS = +43dBm(ETSI specification)

With the pathloss in The BTS-TRX link computed to be 130.9dB, (from equation 5)

Pr(TRX) =+43dBm - 130.9dB = -87.9dBm.

The power received by the transceiver placed 10km away from the BTS (transmitting at +43dBm) is computed to be -87.9dBm which is of better signal strength than the -100dBm sensitivity level requirement of the ETSI standard for GSM receiver design. The design was implemented with commercially available Coaxial cables (the RMC12 ½ inch radiating cable with loss of 13.2dB/100m) [13], A type N connector with a loss of 0.15dB at 2GHz [14] and a

21dB parabolic dish antenna [15].The transceiver unit is tower mounted due to its small size and as such the cable lengths will be very small.

Inserting 21dB parabolic dish antennas at both the BTS and the TRX and assuming a cable length below 5m between the antenna and the transceiver module, the power received at the transceiver (Pr (TRX)) is derived from equation 7

Pr (TRX) = Gtrx +Gbts +Pt(BTS) - Pathloss(BTS-TRX link) – PLoss (cables+connectors) 7

Where Gtrx and Gbts are the gain values of the antennas used at both the TRX and the BTS. =21dB
Pathloss (BTS-TRX link) = 130.9dB (computed from equation 5)

Pr (BTS) = +43dBm (Typical transmit power of a GSM BTS)

PLoss (cables+connectors)=0.15dB (connector loss) +0.66dB(cable loss at 5m between Antenna and TRX)
PLoss (cables+connectors) = 0.81dB

Inserting these values into equation 7,

= 21dB + 21dB +43dBm - 130.9dB – 0.81= - 46.71dBm

From the result of equation 7 the TRX can be located beyond 10 Km from the nearest BTS and the received signal will still be above the sensitivity level.

The Hamlet cell

The Hamlet cell is the area under coverage of the transceiver antenna in the rural area. A commercially available corner reflector antenna with a gain of 17dB [16] is utilized in providing coverage to users within the hamlet cell. The pathloss between the user and the TRX is computed using the COST 231-Hata model.

The model defines path loss as

PL(urban) = 46.3 + 33.9 Log Fc + (44.9 + 6.55 Log Ht) Log D – a(HR) -13.82Log Ht +Cm 8

Where,

PL(urban) =Path loss in the urban environment
Cm is a correction factor used in the model
Cm= 0dB for medium cities and suburban areas
Cm = 3 dB for urban centers
Fc=Carrier frequency
D= Distance of the cell from the transmitter in km
a(HR)= mobile antenna correction factor
Ht=Transmitter antenna height
Hr=Receiver height
PL(suburban) = PL(urban) – 2[log (Fc/28)]^2 -5.4
PL(rural) = PL(urban) – 4.78[log (Fc)]^2 + 18.33 log Fc – K
a(HR) = (1.1log(Fc) – 0.7)HR –(1.56log (Fc) -0.8)dB
Matlab codes for the determination of the pathloss based on the COST231-Hata model

```
clc
%Where, PL(urban) =Path loss in the urban environment
%Cm is a correction factor used in the model 0dB for medium cities and suburban areas and 3dB for urban centers
K=35.94;%for country side(Where K is a constant ranging
%from 35.94 (country side) to 40.94 (desert))

Hr=1.5;%User height in M
Ht=30;%BTS antenna height in M
Cm = 0;%for suburban areas
Fc=1800 ;%Carrier frequency in MHz
D=3;%Range of the Cell in Km
aHR=((1.1*log10(Fc)-0.7)*Hr)-((1.56*log10(Fc) -0.8));
%mobile antenna correction factor
PLurban = 46.3 + (33.9*Log10(Fc))-(13.82 *Log10(Ht))-aHR + (44.9 - (6.55*Log10(Ht)))* Log10(D) + Cm
PLsuburban = PLurban-2*([log10(Fc/28)])^2 -5.4
PLrural = PLurban-4.78*([log10(Fc)])^2 + (18.33* log10(Fc))-K
```

Generating the pathloss for the following specifications

Fc =1800MHz
Hr =1.5m
Ht= 30m
D= 3km
The results are;
PLurban = 153.00dB
PLsuburban = 141.07dB
PLrural = 126.08dB

From the results of the pathloss for the rural area, the transceiver's (TRX) transmit power must exceed the rural area pathloss and provide a signal stronger than the mobile unit's sensitivity value of -100dBm. The transceiver' transmit power (Pt (TRX)) radiated in the direction of the mobile unit is given by equation 9

Pr(MS)min = Pt(TRX) +Gtrx(corner reflector) - PLoss(cables+connectors) - Pathloss(rural area) 9

Where Pr(MS)min= minimum signal at the mobile unit= sensitivity= -100dBm

Pathloss (rural area) = 126.08dB (computed from the COST231-Hata model)

Gtrx(corner reflector antenna gain) = 17dB.

PLoss (cables+connectors) =Cable and connector losses. The cable length is negligible due to the mounting of the transceiver on the tower close to the corner reflector and the connector loss of 0.15dB is negligible compared to the rural area pathloss.

To determine the required transmit power of the transceiver to achieve a reception above the sensitivity level at the mobile unit, the equation 9 is used and Pt (TRX) is made the subject of the formula. Substituting the given values into equation 9

Pt(TRX) = -100dBm + 126.08dB -17dB = 9.08dBm
The required transmit power of the transceiver to the mobile unit is 9.08dBm.
The transceiver gain can thus be computed from equation 10
Pt(TRX) =Pr(TRX) + Gain. 10
Gain = Pt(TRX) - Pr(TRX)

Where
Transceiver's transmit power to the mobile unit = Pt(TRX) = 9.08dBm (from equation 9)

Transceiver's receive signal from the BTS Pr(TRX) = -46.71dBm.(from equation 7)
The transceiver gain in decibel is computed to be the difference between the input and the output signals in decibels. This is shown in equation 11

Gain = 9.08 – (-46.71) = 55.79dB. 11

The transmit power specifications for the different types of DCS1800 mobile units are shown in Table 1.Utilizing these specifications in the spreadsheet analysis, the results for the uplink and down link signal values at the BTS , TRX and the user are displayed in Table 2

Table 1: DCS mobile unit classes [18]

Class	Max(Tx) power	Min (Tx) power	Sensitivity
1	+30dBm	+10dBm	-100dBm
2	+24dBm	+4dBm	-100dBm

Table 2: Downlink (From the Nearest BTS to the Mobile unit in the rural area. Distance =13km)

BTS	Pathloss. BTS-TRX dB	Gtrx TRX antenna gain	Connector/ cable loss	Gbts BTS antenna gain	TRX input	TRX Gain	TRX output	TRX corner reflector gain	Rural pathloss	MS dBm
+43dBm	130.9	21	0.81	21	-46.71	55.79	9.08	17	126.08	-100

Table 3 Uplink (From the Mobile unit in the rural area to the Nearest BTS. Distance =13km)

MS Transmit power Class 1	MS	Rural Pathloss. dB	TRX corner reflector gain	TRX input	TRX Gain	TRX output	TRX antenna gain	BTS antenna gain	BTS – TRX pathloss	BTS dBm
Max	30	126.08	17	-79.08	55.79	-23.29	21	21	130.9	-112.19
Min	10	126.08	17	-99.08	55.79	-43.29	21	21	130.9	-132.19

DISCUSSION

The results in Table(s) 2 and 3 indicate that with the mobile units in the rural area transmitting at maximum power, the signal arriving at the BTS will be below the ETSI approved sensitivity minimum signal of -100dBm [12] required by the BTS for effective communication to take place. The infrastructure condition prevalent in most rural areas makes it necessary for mobile units to have longer spans between battery charging. This requirement can be achieved by causing the mobile units to transmit at minimum transmit power. The transparency of the transceiver to both the BTS and the mobile units causes the BTS to classify the transceiver signal as that of the mobile units and an increase in this signal value will cause the BTS to send power control signals to the mobile units causing the mobile units to transmit at minimum power. From the results in Table(s) 2 and 3, the signal in the uplink path is below the sensitivity level at the BTS. To ensure the reception of the signal at the BTS above the BTS sensitivity levels, the following options can be utilized.

(1) Increase in the transceiver gain by utilizing variable gain amplifiers blocks and/or Power amplifiers with higher output power ratings in the transceiver design.
(2) Increase in the antenna gain values by the utilizing parabolic antennas with higher gain or directivity.

Analyzing the options listed, the increase in transceiver gain by the use of more variable gain amplifier blocks and/or power amplifiers will also lead to an increase in the energy consumption, heat generation and component cost [19].while the antennas with increased gain have smaller beam widths. This beam width dimension does not pose any negative effect on the link because the parabolic antennas are required for point to point communication between the transceiver and the BTS. The most feasible option involves the spreading of the required gain increase between the antennas and the transceiver by utilizing antennas with the highest possible gain and acceptable beam width and utilizing variable gain amplifier blocks in the transceiver design.

The difference between the sensitivity values of the BTS and the actual values of the signal arriving at the BTS when the mobile transmits at minimum power is given by the equation 12.

Gain Differential =-100 – (-132.19) =32.19dB 12

The results in equation 11 indicate that an increase of 32.19dB in the transceiver gain and the utilization of a 23dB parabolic antenna for the transceiver to BTS link will cause the output signal of the mobile unit transmitting at minimum transmit power to be received at the BTS with a signal strength stronger than the BTS sensitivity level of -100dBm and this is sufficient for communication to take place. The required transceiver gain is determined by the addition of the 32.19 dB to the 55.79dB (computed from equation 11) as shown in equation 13

Transceiver gain = 55.79 + 32.19 = 87.98dB 13

Table 4 show the uplink signal level with the 87.98dB Transceiver

Table 4 Uplink signal level with the 87.98dB Transceiver

MS Transmit power Class 1	MS	Rural Pathloss. dB	TRX corner reflector gain	TRX input	TRX Gain	TRX output	Cable and connector loss	TRX antenna gain	BTS antenna gain	BTS – TRX pathloss	BTS dBm
Max	30	126.08	17	-79.08	87.98	8.9	0.81	23	21	130.9	-78.8
Min	10	126.08	17	-99.08	87.98	-11.1	0.81	23	21	130.9	-98.8

The results in Table 4 shows that an increase in the transceiver gain to 87.89dB in the uplink path of the mobile unit will cause the signal received at the BTS to meet the sensitivity level specification of the BTS taking into consideration the required signal to noise ratio of the DCS which is considered in the determination of the sensitivity value of the BTS. This uplink transmission ensures that the mobile unit in the rural area transmits at the minimum transmit power and thus ensures a longer battery life for the units.

Transceiver Transmit power (Down link. Transceiver to Mobile Unit)

From Table 2, the Down link transmit power is computed to be 9.08dBm.
Converting this to mW using equation 13

$$Pt(TRX)mW = 10^{\left(\frac{dBm}{10}\right)} \quad 13$$

$$Pt(TRX)mW = 10^{\left(\frac{9.08dBm}{10}\right)} = 8.09mW$$

Transceiver Transmit power (uplink. Transceiver to BTS)

From equation 13 and Table 4, the uplink transmit power ranges from -11.1 dBm to 8.9dBm converting this to mW yields the following values

$$Pt\ (TRX)mW = 10^{\left(\frac{-11.1dBm}{10}\right)} - 10^{\left(\frac{8.9dBm}{10}\right)}$$

Pt (TRX)mW = 0.77mW to 7.76mW.

CONCLUSION

From the results above, the inclusion of a bidirectional transceiver with 55.79dB gain in the downlink path and 87.98 dB gain in the uplink path 10km from the nearest base station extends the coverage of the base station to the users within a cell up to 3km from the transceiver. The mobile unit transmitting at a minimum power of +10dBm at the edge of the transceiver cell generates a received signal strength of -98.8dBm at the base station by causing the transceiver to transmit at -11.1dBm (0.77mW). With this transceiver specification, the mobile unit will not be required to transmit at maximum power thereby extending the talk time and the battery life of the units. The transceiver which is a non-regenerative type performs frequency translation (up and down conversion), amplification and transmission of the RF signal and as such the design is simpler and energy consumption is minimized enabling the use of solar energy as its power supply source. A 90 degrees corner reflector antenna designed with no back lobes is used to provide coverage for users in the transceiver cell and the parabolic antenna used to link the transceiver to the BTS. This low cost approach will enable a rapid deployment of low cost and economical mobile communication service to rural areas.

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ISSN: 2049-3444