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Effect of Sea Water Conductivity on GSM Signal Propagation in Riverine Area of Igbokoda, Ondo State, Nigeria

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Abstract: The next-generation wireless networks such as the fourth generation (5G) cellular systems are targeted at supporting various applications such as voice, data, and multimedia over packet-switched networks. In these networks, person-to-person communication can be enhanced with high quality images and video, and access to information and services on public and private networks will be enhanced by higher data rates, quality of service (QoS), security measures, location-awareness, energy efficiency, and new flexible communication capabilities. But the channel remains a challenge most especially the riverine areas. Recently, radio frequency (RF) propagation in the riverine areas has been the interest of much theoretical and experimental research. This research work is concerned with the statistical studies of GSM (Global System for Mobile communication) radio wave propagation over the sea path of Igbokoda, Ondo State, Nigeria, at the limits of line-of-sight range in order to determine or establish a relationship that exist between sea conductivity and signal propagation. At every point of observation where signal measurements were taken using Test Mobile system (TEMs) pocket, corresponding water samples were also taken using sample container for conductivity test at the laboratory. The only possible explanation for these large propagation distances is that the conductivity of seawater changes at small field strengths due to hydrogen bonding in water. Consequently, this research work has evaluated and presented a relationship that exist between sea conductivity and GSM signal propagation as *-0.98* correlation coefficient which implies inverse relationship (i.e. sea conductivity attenuates signal) the higher the sea conductivity, the lower the signal strength.

Keyword: GSM, Signal propagation, Sea water, Conductivity

1.1 INTRODUCTION

Nowadays, wireless and mobile communications are embraced by consumers globally. Sales numbers are growing at agreat rate andare expected to do so for the foreseeable future. During radiowave propagation an interaction between waves and environment attenuates the signal level. It causes path loss and finally limits coverage area. (Famoriji and Olasoji, 2013).The effects of natural environment on thepropagation of radio waves are highly dependent onfrequency used. The physical nature of the interveningpaths show significant effects on the propagation suchas the fluctuations in the T-S profiles of water massesexpected to be affecting. Radio waves inside the seaincrease with the frequency of the signal. This meansthat the lower the frequency a radio transmission, thedeeper into the ocean a useable signal will travel.Radio waves in the very low frequency (VLF) band atfrequencies about 20,000 Hertz (Hz) penetrates seawater to depths of only tens of feet. Whereas,extremely low frequency (ELF) waves penetrate sea tothe depths of hundreds of feet, permittingcommunications with submarines while maintainingstealth (Ronald, 2000). Our purpose of studies is to ensure good quality of service in the riverine areas. Theperformance of the communication link can bepredicted on the basis of typical characteristics of thepropagation path that is channeled by the fluctuationin the water masses profiles.

For wireless networks, since the capacity of a wireless channel varies randomly with time,an attempt to provide deterministic QoS (*i.e.*, requiring zero QoS violation probability)will most likely result in extremely conservative guarantees. For example, in a Rayleigh orRicean fading channel, the deterministically guaranteed capacity1 (without power control)is zero! This conservative guarantee is clearly useless. For this reason, only considerstatistical QoS was considered in this research work.

1.2 The Technology of GSM

One of the most important conclusions from the early tests of the new GSM technology was that the new standard should employ Time Division Multiple Access (TDMA) technology. This ensured the support of major corporate players like Nokia, Ericsson and Siemens, and the flexibility of having access to a broad range of suppliers and the potential to get product faster into the marketplace. After a series of tests, the GSM digital standard was proven to work in 1988. With global coverage goals in mind, being compatible with GSM from day one is a prerequisite for any new system that would add functionality to GSM. As with other 2G systems, GSM handles voice efficiently, but the support for data and Internet applications is limited. A data connection is established in just the same way as for a regular voice call; the user dials in and a circuit-switched connection continues during the entire session. If the user disconnects and wants to re-connect, the dial-in sequence has to be repeated. This issue,coupled with the limitation that users are billed for the time that they are connected, creates a need for packetdata for GSM(Scourias, 2014).

The digital nature of GSM allows the transmission of data (both synchronous and asynchronous) to or from integrated service digital network (ISDN) terminals, although the most basic service support by GSM is telephony. Speech, which is inherentlyanalog, has to be digitized. The method employed by ISDN, and by current telephone systems formultiplexing voice lines over high-speed trunks and optical fiber lines, is Pulse Coded Modulation (PCM).From the start, planners of GSM wanted to ensure ISDN compatibility in services offered, although theattainment of the standard ISDN bit rate of 64 Kbit/s was difficult to achieve, thereby belying some of thelimitations of a radio link. The 64 Kbit/s signal, although simple to implement, contains significantredundancy.Since its inception, GSM was destined to employ digital rather than analog technology and operate in the900 MHz frequency band. Most GSM systems operate in the 900 MHz and 1.8 GHz frequency bands,except in North America where they operate in the 1.9 GHz band. GSM divides up the radio spectrumbandwidth by using a combination of Time- and Frequency Division Multiple Access (TDMA/FDMA)schemes on its 25 MHz wide frequency spectrum, dividing it into 124 carrier frequencies (spaced 200 KHzapart). Each frequency is then divided into eight time slots using TDMA, and one or more carrier frequenciesare assigned to each base station. The fundamental unit of time in this TDMA scheme is called a 'burstperiod' and it lasts 15/26 ms (or approx. 0.577 ms). Therefore the eight 'time slots' are actually 'burstperiods', which are grouped into a TDMA frame, which subsequently form the basic unit for the definitionof logical channels. One physical channel is one burst period per TDMA frame(Bach, 2000).

The development of standards and systems spans well beyond the technical realm and often into the political;this is best exemplified by what happened with GSM. Shortly after the suitability of TDMA for GSM wasdetermined, a political battle erupted over the question of whether to adopt a wide-band or narrow-bandTDMA solution. Whereas France and Germany supported a wide-band solution, the Scandinavian countriesfavored a narrow-band alternative. These governmental preferences were clearly a reflection of therespective countries' domestic equipment manufacturers as German and French manufacturers SEL andAlcatel had invested substantially into wide-band technology, whereas their Scandinavian counterpartsEricsson and Nokia poured resources into the narrow-band alternative. Italy and the UK, in turn, were thesubjects of intense lobbying on behalf of the two camps with the result of frequently changing coalitions(Gozalvez and Jose 2001).

The culmination of this controversy between the two camps was a CEPT (Conference des AdministrationsEuropeans des Posts et Telecommunications) Meeting in Madeira in February 1987. The Scandinaviancountries finally convinced Italy, the UK and a few smaller states of the technical superiority of narrow-bandtechnology and left Germany and France as the only proponents of the wide-band alternative. Since CEPTfollowed purely intergovernmental procedures, however, decisions had to be taken unanimously, andGermany and France were able to veto a decision that would have led to the adoption of narrow-band TDMAas the technology underlying the GSM project(Bach, 2000).

A unique feature of GSM is the Short Message Service (SMS), which has achieved wide popularity as whatsome have called the unexpected 'killer application' of GSM. SMS is a bi-directional service for sendingshort alphanumeric message in a store-and-forward process.SMS can be used both 'point-to-point' as wellas in cell-broadcast mode. Supplementary services are provided on topof teleservices or bearer services, and include features such as, among others, call forwarding, call waiting,caller identification, three-way conversations, and call-barring.The most novel and far-reaching feature of GSM is that it provides most of Europe's cellular phone userswith a choice – choice of network and choice of operator. Also, international roaming was and continues tobe the cornerstone of GSM. For this to be possible, all networks and handsets have to be identical. Withmany manufacturers creating many different products in many different countries, each type of terminal hasbeen put through a rigorous approval regime. However, at the time, no approval process was available, andit took nearly a year before the handheld terminals were tested and fit for market entry(Bout *et al*, 2000).

Another of GSM's most attractive features is the extent to which its network is considered to be secure. Allcommunications, both speech and data, are encrypted to prevent eavesdropping, and GSM subscribers areidentified by their Subscriber Identity Module (SIM) card (which holds their identity number andauthentication key and algorithm). While the choice of algorithm is the responsibility of individual GSMoperators, they all work closely together through the Memorandum of Understanding (MoU) to ensure security of authentication. This smartcard technology minimizesthe necessity for owning terminals - as travellers can simply rent GSM phones at the airport and insert theirSIM card. Since it's the card rather than the terminal that enables network access, feature access and billing,the user is immediately on-line(Bratton *et al*, 2000).

1.3 Water Conductivity and Signal Attenuation

Water in its pure form is an insulator, but as found in its natural state, it contains dissolved salts and other matter whichmakes it a partial conductor. The higher its conductivity, the greater the the attenuation of radio signals which passthrough it (Pieracchini*et al* 2009).Conductivity (σ) varies with both salinity and

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temperature. Sea water has a high salt content and high conductivity varyingfrom 2 mhos per metre in the cold arctic region to 8 mhos per metre in the warm and highly saline Red Sea. Averageconductivity of the sea is normally considered to be about 4 mhos per metre. What this means is that one metre cube ofsea water has a conductivity of 4 mhos or a resistance of 0.25 ohm, (it's reciprocal) (Watt, 2004). Fresh water has lower conductivity and as a guide to this, asample analysis of Adelaide water taken in 1983has been used. This sample was taken from an area principally supplied by the Barossa reservoir and the analysis showstotal dissolved salts as approximately 300 mg/litre and a conductivity of 0.0546 mhos per metre (Ong and Hu, 1997).

Attenuation of radio waves in water (and, in fact, in any conducting medium) increases both with increase in conductivityand increase in frequency. It can be calculated from the given formula in equation 1:

Attenuation (α) in dB/metre = 0. 0173 $\sqrt{(f\sigma)}$ (1)

where f = frequency in hertz
and σ = conductivity in mhos/metre

Algor (2012) investigated propagation losses over sea paths up to 40 nautical miles (74km) during one-month period in September 2011. Three frequencies were used: 30, 140 and 412 MHz. The receiving site was an existing shore based radar station and the transmitter was a "mobile" 9-ft surfboard subjected to sea wave motion and variation. The antennas were vertically polarised and of particular interest is the 140 MHz receiving antenna as it is a log periodic type and similar to the cases employed in this thesis. The receiver elevation ranges from 50 to 100 ft. Part of the objectives for this experiment is to determine the system parameter and analyse the signal levels and fading characteristic at various distances or frequencies. The effects from any other meteorological conditions are taken into consideration.

Figure 1 shows the normalized propagation signal strength against the various distances for all the three frequencies. It shows the usual decrease in signal strength as the distance increases.

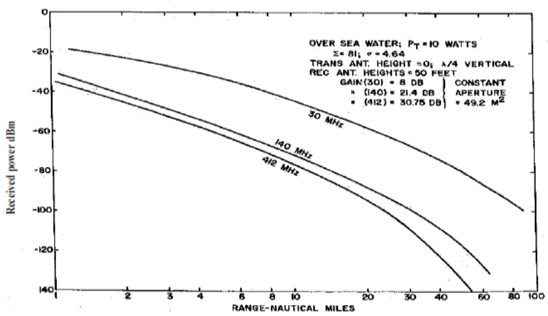

Figure 1: Normalised propagation signal strength against various distances (Algor, 2012)

Griffiths *et al* (2006) conducted a similar experiment on two occasions in year 2000, with the exception of investigating the signal variation as a function of different sea states from 2 to 5 and ranges up to 30 Nm (55.56 km). From the experiment, the research derived a realistic model for the radio link over the sea surface and also determined the required transmitted power to guarantee a 20 dB of signal to noise ratio at a range of 20 Nm (37 km). The frequency band in this experiment ranges from 136 to 173.5 MHz with two bandwidths of 180 and 300 kHz.

Cumulative results from sampled signal strength showed a variability not exceeding 4.5dB for 90% of the time. Equation (2.2) was applied to the signal strength received during the experiment.

$$P_r(dBm) = 10logC - nlogr + 30 \quad (2)$$

Where:
C is the propagation constant
r is the range of floating transmitter
$n$is the number of points

The results concluded that the signal strength for non-line-of-sight VHF propagation over the sea surface varies with range approximately 1/r4, independently of sea states.

Barrick (2008) derived a method of analysing radiation and signal propagation above a sea surface by employing an effective surface impedance method to describe the effect caused by different sea states.

The main area of concern in the experiment was the estimated effect on both HF and VHF ground wave propagation on perfectly smooth and rough sea surface. Figure 2 shows the basic transmission loss across the ocean with increasing frequency and range.

Figure 3 shows the added transmission losses due to various sea states and range at 50 MHz. From both figures, Barrick (2008) concluded that the transmission loss is higher during rougher sea states, higher frequencies and longer ranges.

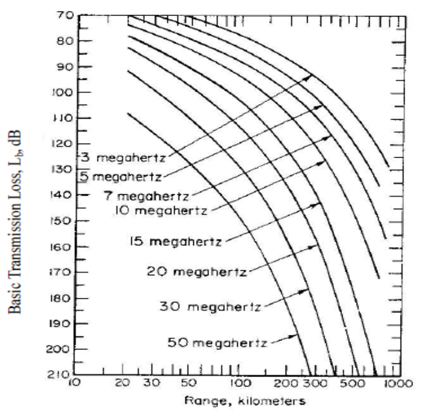

Figure 2: Basic Transmission Loss across the Ocean between Points at the Surface of Smooth Spherical Earth. Conductivity is 4mhos/m and an Effective earth Radius factor of 4/3 is assumed (Barrick, 2008)

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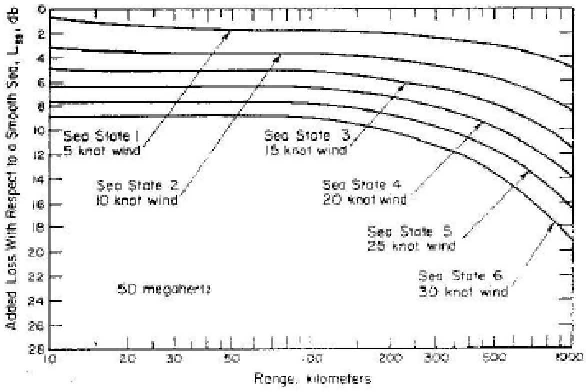

Figure 3 : Added transmission losses due to sea state at 50 MHz (Barrick, 2008)

2.1 Methodology

Radio signal are prone to losses due to many factors such as obstruction, reflection, refraction, scattering and absorption. This research was carried out in the riverine area of Igbokoda, Ondo state to investigate the GSM signal losses in the area. The research methodology is in stages namely, Pre-measurement field activities; Measurement activities and Laboratory Tests (see Figure 4)

Figure 4: Research Procedure

2.1.1 Pre-Measurement Field Activities

The pre-measurement field activities involve physical survey of the entire area such as topographical study of observation spots, coordinate measurement and determination of the distance of each observation spot to the MTN radio base stations within the area. The pre-measurement field activity was performed using Google maps in conjunction with Global Positioning System (GPS) Receiver (see Plate: 1 and 2).

Plate 1: GPS Receiver

Plate 2: Pictorial View of a Mast in IgbokodaOndo State

2.1.2 Measurement

The measurement stage involves Test Mobile System (TEMs) investigation and collection of water samples at the selected observation spots. The TEMs investigations deal with measurement of GSM signal strength at the different observation spots as well as measurement of quality of service.

The TEMs investigation was performed using NET MONITOR software installed in a TEM pocket device to measure the MTN signal strength over the water surface at the selected observation spots (see Plate 3 and 4).

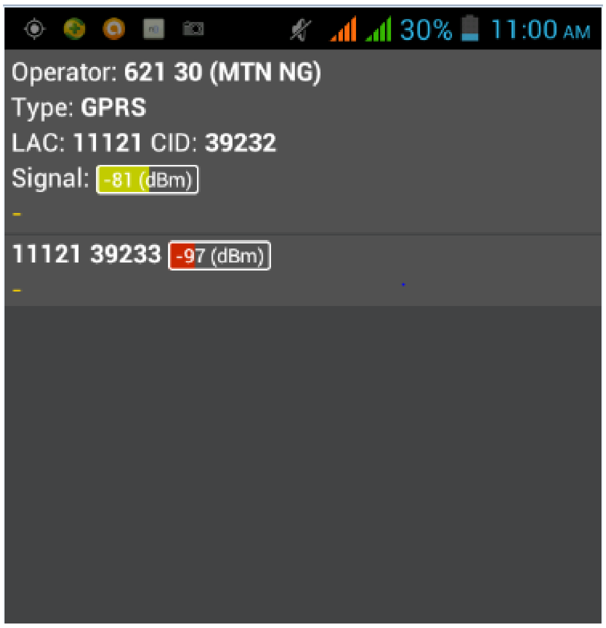

Plate3: TEM Pocket Device Display at a Point of Observation

Plate 4: Observation Point during Measurement

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2.1.3 Water Sample and Conductivity Test

Water samples at a depth of almost 20 centimetre were taken using sample-container at each observation spot and were taken to the laboratory for conductivity test. The conductivity test was performed in the laboratory using a refract meter (in plate 5).

Plate 5: Display of the Conductivity Test Performed using Refractometer

3.1 Results and Discussion

Figure5 is the plot of the measured signal strength against the distance for both over water measurements and relatively over water measurements; this shows the disparity between the signal strength measured on the surface and 20cm in-depth of the sea.

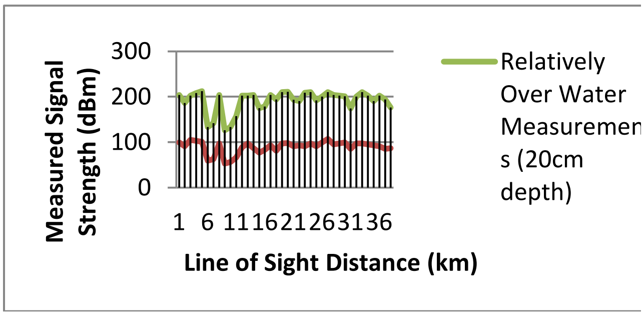

Figure 5: Measured Surface and Relatively Surface Signal Strength against Distance

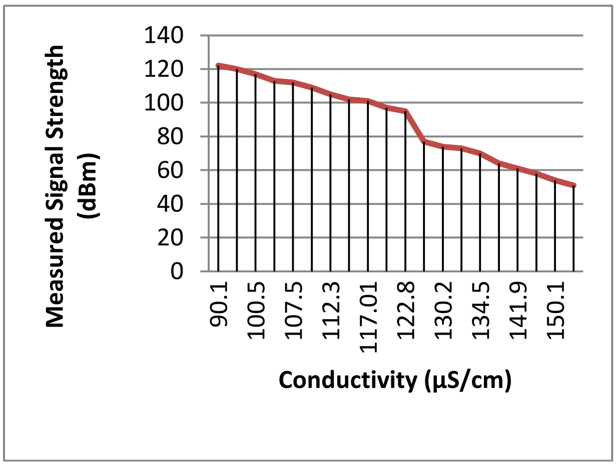

Figure 6: Graph showing relationship between relatively over Water Signal

Strength and Sea Conductivity

Figure 6 shows the relationship that exists between sea conductivity and relatively surface signal strength. Also, statistical correlation between under-water measurements and corresponding conductivity results was obtained using eqn. 4.1 as adapted from Freeman (2007).

$$Correlation(r) = \frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{[N\sum X^2 - (\sum X)^2][N\sum Y^2 - (\sum Y)\text{^}2\,]}} \quad (3$$

Where;

N is the number of measurements taken

X is the underwater signal strength measured

Y is the corresponding conductivity value

$\sum X^2$*is sum of square of underwater signal strength measured*

$\sum XY$*is the sum of the product of the underwater signal strength and conductivity*

$\sum X$*is the sum of underwater signal strength measured*

$\sum Y$*is the sum of conductivity value*

$\sum Y^2$*is the sum of square of conductivity value*

The correlation coefficient gives *-0.98*. This implies that as the value of conductivity gets larger, the signal strength measured gets smaller which implies inverse correlation. The result obtained here is in accordance with equation 1 which gave a relationship between signal attenuation and conductivity as direct correlation (i.e attenuation increases with water conductivity). Based on the results of measurement, it could be said that underwater signal strength is inversely proportional to the conductivity at constant frequency. The relationship is specifically:

$$U_w \propto \frac{1}{\sigma} \quad (4)$$

This implies:

$$U_w = \frac{f}{\sigma} \quad (5)$$

Where:

U_w is the underwater signal strength

σ is the conductivity value

f is the frequency (900MHz in this case)

It can therefore be generally stated that conductivity and relatively under water signal strength are inversely related. The free space path loss equation can be modified as:

$$Modified\ Free\ Space\ Path\ Loss = \left(\frac{4\pi df}{c}\right)^2 + \sigma (6)$$

whereσ is conductivity.

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4.1 CONCLUSION

A physically realistic model for the variation of the relative permittivityof seawater for varying conductivity and at relatively constant temperatures was derived. Themodel derived is in excellent agreement with existingempirical fits to experimental data. Also, the model usesonly two parameters that need to be determined fromexperimental data as opposed to more than 10 parametersused by most empirical fits. Furthermore, the remainingparameters in our model have a physical interpretationand could hence theoretically be determined by independentexperiments. Moreover, because this model has aphysical foundation, it can be said to be valid overa wider parameter (frequency, temperature and conductivity)range and can be used for extrapolation in regions whereno experimental data is available. The only possibleexplanation for these large propagation distances isthat the conductivity of seawater changes at small fieldstrengths due to hydrogen bonding in water. However, this research work has evaluated and presented a relationship that exist between sea conductivity and GSM signal propagation as *-0.98* correlation coefficient which implies inverse relationship.

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