MODELLING OF LAND MOBILE SATELLITE CHANNEL TO COUNTER CHANNEL OUTAGE

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ABSTRACT

A Land mobile satellite service (LMSS) is an arm of mobile satellite system (MSS), in which a number of services are its subset. To ensure network availability, high quality of service (QoS), and reduce outage on the channel as a result of channel interferences during propagation, it is important to understand channel behaviour in various transmission environments. Vast literature has been published on the subject of channel models that attempted to improve on impairments in communication links: a large number has focused on narrowband channels than wideband. Due to advances in recent technology wideband modelling of satellite channels becomes necessary, which this research study is focused, particularly model for Land Mobile Satellite (LMS) channel. This study models the complete behaviour of LMS Channel based on the Lutz's (1989) two-state statistical model but modified with two-state Markov chain for two different transmission environments, namely: shadowing (line-of-sight) and un- shadowing (non-line-of-sight) conditions. In order to reduce the effect of channel outages, satellite diversity approach was employed in addition to the 2-state Markov chain. Simulations of these conditions were performed using MATLAB programming language. The study concludes that satellite diversity reduces outage on the channel, and when mobile terminals have access to two geostationary satellites simultaneously network availability is assured compared to when it has only one satellite link. .

KEYWORDS

Land mobile satellite service, Land mobile satellite channel, Markov chain, Line of sight.

1. INTRODUCTION

The Space Age began in 1957 with the U.S.S.R's launch of the first artificial satellite, called Sputnik, which transmitted telemetry information for 21 days (Kolawole, 2002). Since then satellites have formed an essential part of telecommunication systems worldwide, carrying large amount of traffic in voice, video, and data traffic across great distance (Saunders and Zavala, 2007). Actually, the importance of this technology is so obvious judging from the deployment of antennas or "dishes" in many homes and offices to receive satellite broadcasts. The usefulness of satellites, as communication systems, cut across various aspects of life; for instance, from few distance point to point communication to communication over a great distance, including applications in the navigation, aviation, and maritime industries, or for earth observation (remote sensing), surveillance (security), and for space research (Kolawole, 2009). Thus, a communication satellite is basically an electronic communication package placed in orbit whose

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prime objective is to initiate or assist communication transmission of information or message from one point to another through space (Kolawole, 2002). Technically, it can be said that there will only be satellite channel if the communication is through the satellite, because it is the means through which this form of communication is achieved (Roddy, 2001; Sheriff and Hu, 2001). Channel can then be defined as the medium or signal path between the transmitting antenna and the receiving antenna. The types of channels in satellite communications include Narrow Band Channel, Wideband Channel, and Broadcast Channel. For an effective communication through the satellite, these channels must be well looked into particularly as they affect non-fixed (mobile) wireless receiving terminals' performance.

For a mobile terminal communicating through the use of satellite, there are impairments that need to be considered for effective communication in terms of Quality of Service (QoS), bandwidth efficiency, reliability, and the cost both from the operator's point of view and the user's point of view (Sheriff and Hu, 2001). It is also worth noting that the market for this communication medium continues to grow; as a consequence, there is need to ensure that the limited, assigned frequency is properly used for the services for which it is envisioned.

The characteristics of wireless signal change as it travels from the transmitter antenna to the receiver antenna. These characteristics depend upon the distance between the two antennas, the path(s) taken by the signal, and the propagation medium or environment (such as buildings, vehicular traffics, trees, etc.) around the path. The profile of received signal can be obtained from that of the transmitted signal if we have a model of the medium between the two; this model is called channel model.

The question is: which type? Whichever one we take, why is it different from, or what advantage does it have over others? For instance in this research, why modelling a Land Mobile Satellite channel? Other questions arise like: what is the preferred solution that ensures a good communication link for a mobile terminal communicating through a satellite link? And how will this solution prove that it has actually improved the link, implying quality of service. These questions informed this study.

The aim of this research study is to reduce outages on Land Mobile Satellite Communication Channel. The objectives of this research study are to: characterize a channel model, particularly for a Land Mobile Satellite channel, suitable for most transmission environments and evaluate the channel model's performance using MATLAB programming language.

The research paper contributes to knowledge by reducing fading and outages on satellite communication channels and delivering better Quality of Service that can ensure proper and faithful satellite communication especially when there is urgent need.

2. REVIEW OF CHANNEL MODELS

Vast literature has been published on the subject of Land Mobile Satellite (LMS) channel models by academics and researchers in the last three decades. Effective communication through LMS links requires real understanding of the impairments that can affect signal transmission, which might be due to blockage of line-of-sight (LOS) path, multipath effect, and even the transmission environments where the mobile terminal is located. There are two types of propagation impairments, namely: satellite propagation, and wave propagation. The two interact to affect signal transmission both in the uplink and downlink segments. For satellite propagation, the impairments are trees, buildings, and terrain (Saunders et al, 2007) while the wave propagation is affected by reflection, scattering, diffraction, and multipath.

One of the main differences between mobile satellite systems and terrestrial systems is that the former's elevation angles are much larger than that of the later, in which the range of its minimum elevation angle is 8^{o} to 25^{o}. As a result, immediate environment of the mobile terminal tends to affect the signal received by the terminal, which significantly impacts on the Quality of Service (QoS) expected, because the buildings that are close to the mobile terminal and, also, in the direction of the satellite tend to have a great impact on the signal received making the response of the mobile terminal to the signal received to change rapidly as the mobile changes location in within built up areas. Another factor to consider is the distinctive characteristics of different categories of where mobile terminals are put to use, for example, land, maritime, or aeronautical. This is in contrast to the terrestrial macrocellular that involves 1° or less elevation angle; this makes large buildings along the path to be insignificant. Due to this effect, the transitions between line-of-sight and non-line-of-sight may be rapid and frequent, thereby causing a variation in the statistics of the signal level of the fast fading, which can be referred to as *shadowing process*. In comparison to Mobile Satellite System, Terrestrial Mobile, and Fixed Satellite System, the fixed satellite system is completely different in that a fixed earth station or gateway can be located to ensure visibility to the satellite at all times, thereby the local environment's effect on the received signal is reduced to a minimal level but at frequencies above 10 GHz, the signal transmission is affected greatly by natural phenomena like rain andthus, climatic conditions must be taken into account rather than local environment. In all these, the percentage target link availabilities for each channel are specified by its different environmental condition. Thus, mobile-link has a targeted service availability of 80% to 99%, as against the fixed-link, availabilities of 99.90% to 99.99% (Omotosho et al., 2010).

Land Mobile Satellite Propagation Environment

Figure 1 shows the diagram of Land Mobile Satellite (LMS) network propagation environment. The signal received by a satellite mobile terminal can be divided into three components, namely:

1. The direct line-of-sight (LOS) wave: It is otherwise referred to as direct wave or unshadowed wave (Vucetic et al., 1994) , is the signal received by a Mobile Terminal or Mobile Earth Station (MES) unaffected by any obstructions. Irrespective of being unshadowed, any signal can still suffer from ionospheric and tropospheric effects, which are caused by the interaction between earth magnetic field and the ambient electron content in ionosphere. For tropospheric effect, at a frequency below 10GHz, it is of negligible effect on the signal received and it can thus be ignored. But ionospheric effect of which Faraday rotation is the main impairment, can still affect the received signal, but it can be minimised by selective use of transmission polarisation (Sheriff, 2001).

2. The diffuse wave: The diffuse component is made up of several signals that arrived at the mobile terminal at different times and phases, known as multipath. This is purely associated with local effects e.g., buildings, vehicles, and other structures which can interact with radio wave being received by the mobile terminal.

3. Specular Ground Reflected wave. This type is a phase coherent reflected wave and may result into deep fading of the received signal, if it has relative amplitude to that of the direct component. Mobile terminals that operate at low elevation angle to the satellite, having low antenna gain and wide beamwidth, could easily be affected by this impairment.

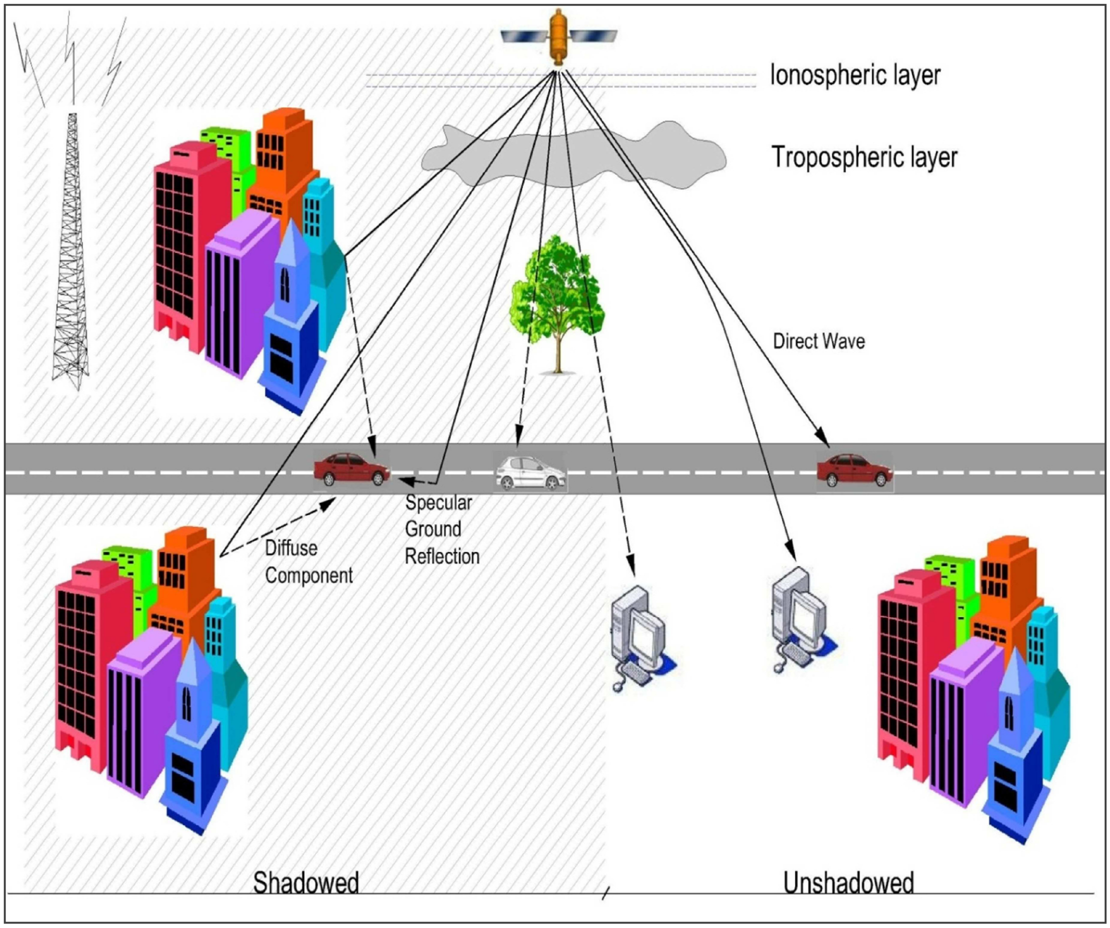

Figure 1: Land Mobile Satellite (LMS) network propagation environment

3. CHANNEL MODELS

The characteristics of signal propagation on the link between personal, or mobile user and the satellite, determine greatly the expected QoS and availability that satellite Personal Communication Network (PCN) can offer. It is in line with this that a number of satellite channel models and several propagation measurements were derived and performed, respectively, which have been used to describe transmission path between a mobile user, or personal user, and satellite either in the geosynchronous (GEO) or non-geosynchronous (NGEO) orbits.

Vast literature has been published on the subject of Land Mobile Satellite (LMS) channel models including

- Excess path loss measurements (Hess,1980).

- Propagation loss measurements using different instruments and platforms in L, S, and Ka bands (Corazza et al., 1994; Loo et al., 1998; Kanatas et al., 1998; Jahn, 2001; Werner, 2004; Steingass et al., 2006; King, 2007).

Many modelling activities are continuing on developing robust, statistical, empirical, and/or numerical channel models particularised to the researchers' environments across frequency spectrums (Alim et al. (2010); Olasoji and Kolawole, 2011).

4. METHODOLOGY

Using the Gilbert-Elliot's two-state equivalent of the Markov process, the following assumptions were made :

Transitions between states are modelled as a first order discrete-time Markov process; The variation of signals within each state is described by several possible distributions like Rayleigh and Rician.

Figure 2 has two states Markov process for a land mobile satellite channel with "Good" state or unshadowed condition corresponding to LOS (line of sight) condition and the "Bad" state corresponding to scenarios of NLOS (non-line-of-sight) or where the signal path is blocked by obstacles. For a mobile user that is moving with speed *v*, the mean extent (in m) of shadowed and unshadowed areas E_b and E_g, translating into mean time interval D_b And D_g , where the channel stays in the bad or good state, respectively (Lutz, 1998; Saunders and Zavala, 2007).

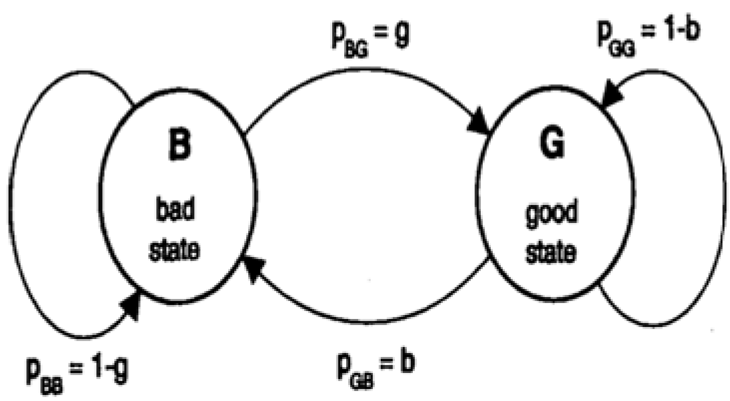

Figure 2. Two-state Markov process for a land mobile satellite channel (Lutz, 2000; Saunders and Zavala, 2007).

The transmission rate R, and the mean state durations normalised to symbol duration with transition probabilities $P_{BG} = g$, and $P_{GB} = b$, yield (Bischl, *et al.*,1996; Lutz,1998):

$$D_G = \frac{1}{P_{GB}} = \frac{1}{b} = \frac{R}{v} E_G \tag{1}$$

$$D_B = \frac{1}{P_{BG}} = \frac{1}{g} = \frac{R}{v} E_B \tag{2}$$

Where P_{GB} is the probability of transition from good state to bad state and P_{BG} is the probability of transition from bad state to good state. Also,

$$P_b = (1-g)P_b + bP_g \tag{3}$$

which translates to

$$gP_b = bP_g \tag{4}$$

If $(1-g) = P_{BB}$ is the probability that the mobile user moves from bad state to bad state or simply remains in the bad state, which is attributed to non-line-of-sight. Then, $(1-b) = P_{GG}$ is the probability that the mobile user moves from good state to good state or simply remains in the good state also attributed to availability of service scenario. Equilibrium state probabilities are derived as:

$$P_B = \frac{b}{g+b} = \frac{D_B}{D_G + D_B} = \mathrm{A} \tag{5}$$

$$P_G = \frac{\mathrm{g}}{\mathrm{g}+\mathrm{b}} = \frac{\mathrm{D}g}{\mathrm{D}_G + D_B} = 1 - \mathrm{A} \tag{6}$$

where probability P_B corresponds to the time share during shadowing and A corresponds to unavailability of service scenario. Definitely, P_G and (1-A) would be the time share during un- shadowing and availability of service respectively (Lutz, 1996).

Modelling Scenario

The two-state Markov chain, the parameters for each state, the entire states, and the transition matrices for different environments are calculated. Thus, absolute state and the transition probability matrices, W and P have been used to model the state occurrences and durations, with

$$\sum_{i=1}^{2} \mathrm{P}_i = 1 = \mathrm{P}_{\mathrm{GOOD}} + \mathrm{P}_{\mathrm{BAD}} \tag{7}$$

where elements of state probability P_i matrix for two element state is: fulfil equation 7. Also elements of transition probability

$$\sum_{i=1}^{2} P_{i|j} = 1 \tag{8}$$

where Pi|j is the probability of transition from state j to state i (or probability of state j given state i). The convergence property of Markov chain allows:

$$[P][W] = [W] \quad \text{i.e} \begin{pmatrix} P_{1|1} & P_{1|2} \\ P_{2|1} & P_{2|2} \end{pmatrix} \begin{pmatrix} P_1 \\ P_2 \end{pmatrix} = \begin{pmatrix} P_1 \\ P_2 \end{pmatrix} \tag{9}$$

with [W] equals absolute probability matrix, and [P] equals transition probability matrix Another parameter needed for the model is the minimum state duration or frame (discrete-time Markov chain), L_{Frame}–this is taken as 1m, which is a reasonable frame-length for a state duration. Note that "duration" can both be used for length of distance travelled (in m) and time duration (in sec), the two are related by the terminal speed *v*, which is assumed constant. The state duration depends on the transition probabilities $P_{i|j}$ and the probability that the Markov chain stays in an assigned state i, given j for n consecutive frames or equivalently for nL_{Frame} (in m) or nL_{Frame}/v (in sec) is given by (Fontan and Espineira, 2008):

$$P_i\,(N = n) = P_{i|i}^{n-1}\,(1-P_{i|i}) \qquad n = 1, 2, \ldots \tag{10}$$

And the cumulative distribution for each state's duration is given as:

$$P_i\,(N \le n) = (1-P_{i|i}) \sum_{j=1}^{n} P_{i|i}^{j-1} \tag{11}$$

Random number generator is used to get an update of the current state, which is made by drawing random number of each frame L *(in m)*. The variations within GOOD state are modelled by means of Rician distribution while the Rayleigh distribution is used for modelling the BAD state. Figure 3 shows the block diagram used for modelling the entire channel scenario; a combination of two-state Markov chain and Lutz's Rayleigh/Rice LMS channel simulator, which has a time-series generator. In addition, Butterworth filter was used to introduce autocorrelation due to its peculiarity for having a flat response without ripples at its passband.

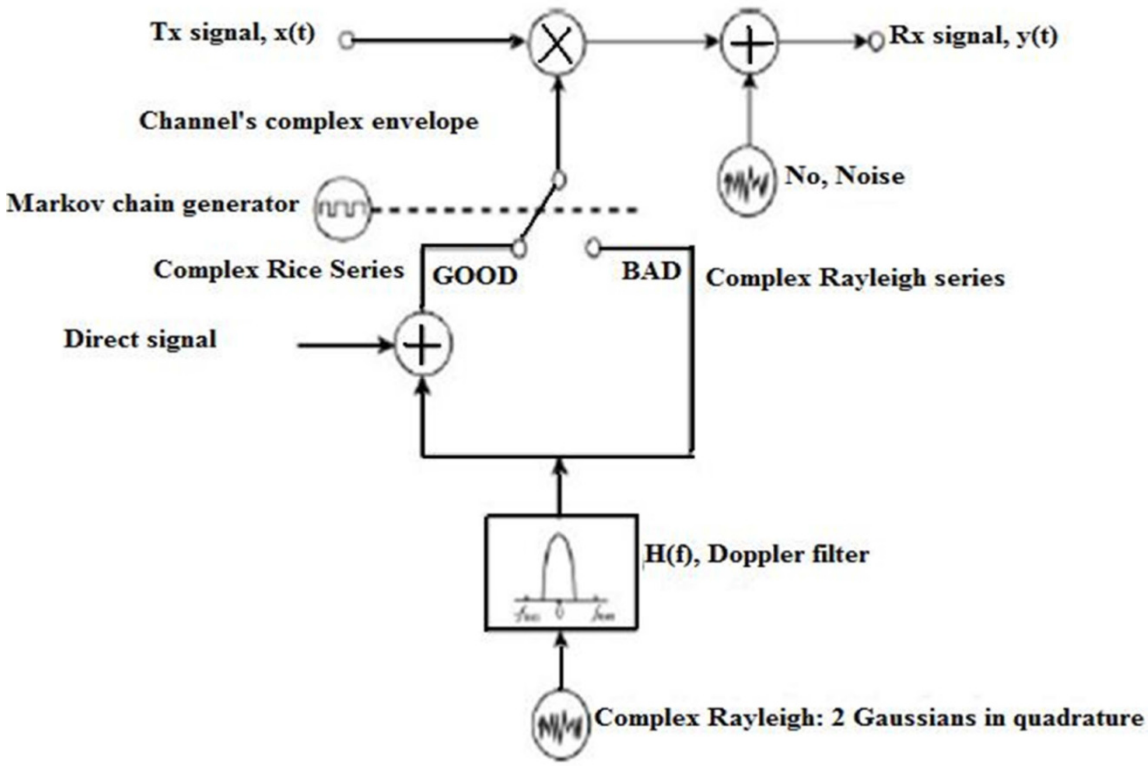

Figure 3. Two-state Markov plus Rayleigh/Rice LMS channel simulator. (Milojevic, 2008)

5. ANALYSIS OF THE MODEL

In this analysis, the carrier frequency is set at 1540-MHz (L-band frequency), L-band is the approved allocated band for satellite phoning. Frame-length is set at 1m as explained previously. For optimum performance of models with wavelength less than 0.250m,sampling rate of at least 5 should be considered in the simulation (King,2007). Hence, in this study wavelength sampling rate of 6 was considered to give better output resolution. The standard deviation for the GOOD state that is, the Rician condition is 0.2 (Lutz and Werner, 2000). For two Gaussian generators in quadrature using $10\log(2\sigma^2)$, the losses give approximately -11.dB/LOS . Similarly, the BAD state standard deviation was set at 0.15, by using same formula the losses on the channel is equivalent to -13.47dB/LOS . For optimum performance, the following Butterworth filtering parameters were set as follows because of the Doppler shaping: $wp = 0.09$, $ws = 0.16$, $Rp = 3$, and $Rs = 50$ where wp is defined as Pass band corner frequency *;* ws is Stop band corner frequency in ; Rp is Pass band ripple in decibels; and Rs is Stop band attenuation in decibels. This is a low pass filter configuration because wp is less than ws. The transition matrix is a 2x2 matrix set in accordance with the presumed transmission environment.

For a noisy channel the transmission matrix is $P = \begin{pmatrix} 1 & 0 \\ 1 & 0 \end{pmatrix}$ and by reversing the columns of the present transmission matrix, it yields elements of fading channel, that is, $P = \begin{pmatrix} 0 & 1 \\ 0 & 1 \end{pmatrix}$ Either of the two cases described above is practically impossible to realise, as there cannot be a practical channel that is experiencing availability at all times or outage at all times as well. By varying this transmission matrix in line with the transmission environments, plots that give the behaviour of a complete channel is generated and in this scenario, the transmission matrix: $P = \begin{pmatrix} 0.95 & 0.05 \\ 0.1 & 0.9 \end{pmatrix}$ was used. This matrix was decided for as it gives a clear and optimum output in simulation. The measurement distance in all these described channels' conditions is 200 m, under which the mobile is expected to have transited in the two examined mobile environments.

MODELLING OF SATELLITE DIVERSITY

Transmission environment plays a significant role in the communication between a mobile terminal or mobile earth station, and satellites with LOS condition. In real environment, the received direct signal is typically affected by diffused and scattered signals from objects near mobile terminal or mobile earth station, specular reflection both from the ground and near the user at any elevation angle, and from the inclined smooth terrain in the direction of the satellite at low elevation angle (Vogel, 1997). This study models scenario where a mobile user is transiting between built up areas—where height of buildings around caused major blockage to the LOS from the satellite—to countryside—where trees and ground specular reflection can also affect the received signal. The set of parameters used is $P = \begin{pmatrix} 0.95 & 0.05 \\ 0.1 & 0.9 \end{pmatrix}$ and distance of 200 m, but here the mobile user simultaneously receives signals from two satellites. Two geostationary satellites were considered, with two satellite links. Here the second satellite is introduced with transmission matrix $Q = \begin{pmatrix} 0.85 & 0.15 \\ 0.3 & 0.7 \end{pmatrix}$ and the two satellites' links were not correlated. In this scenario, it is expected that in any circumstance the two satellite links will not be shadowed at the same time all through the measurement distance. The MATLAB programming language was run for this and the responses were generated.

6. RESULTS AND DISCUSSION

SINGLE SATELLITE RESULTS

For a noisy channel with transition probability matri $P = \begin{pmatrix} 1 & 0 \\ 1 & 0 \end{pmatrix}$, there is no state transition as the channel remained in one state throughout the measured distance, the state series and multipath parameters for both Rician and Rayleigh are as shown in Figures 4 and 5 respectively, which can be likened to a LOS situation.

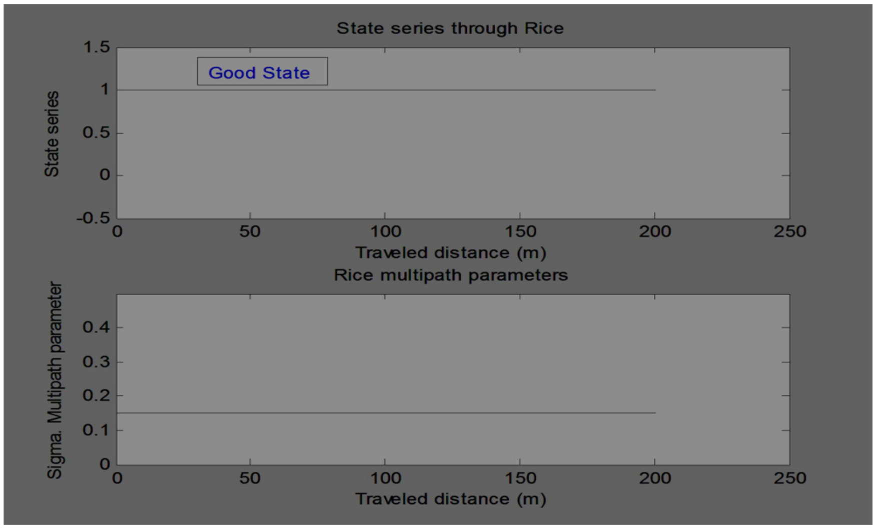

Figure 4. State series and multipath parameters for Rician distribution

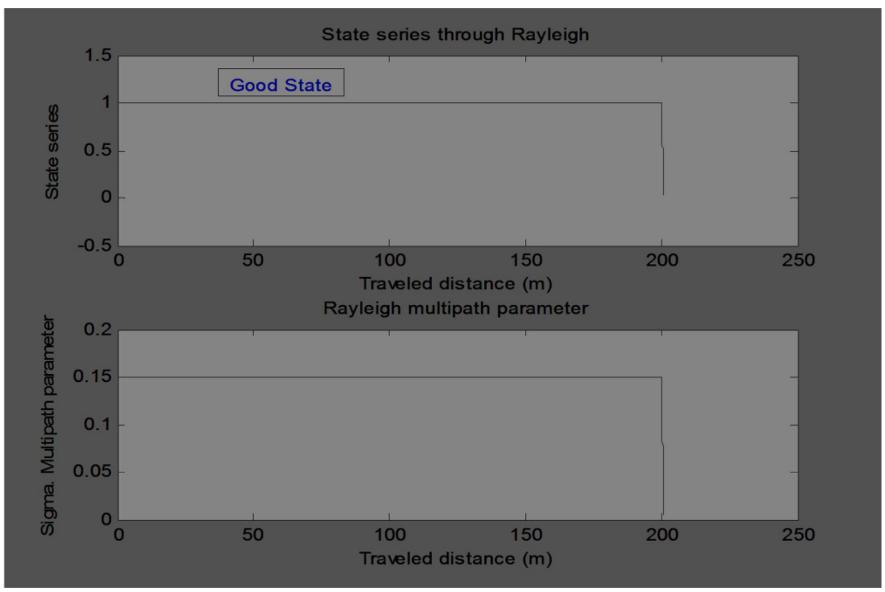

Figure 5. State series and multipath parameters for Rayleigh distribution

For the multipath parameter and filter response of the entire channel, this remained unchanged throughout this experiment since the Butterworth filter parameters remain constant all through, as shown in Figure 6.

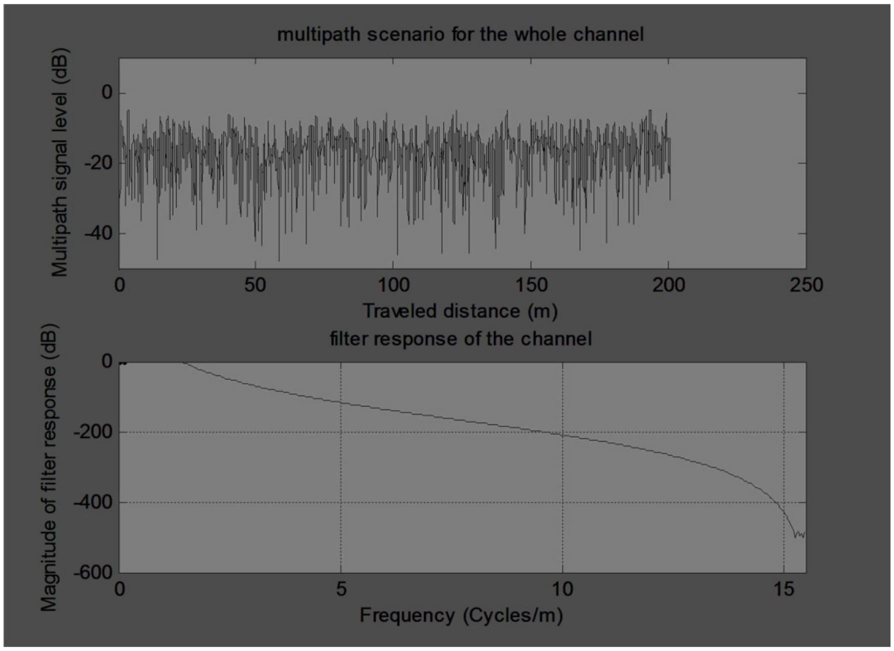

Figure 6. Channel's multipath effect and filter response

Figure 7 shows the channel behaviour, both in linear and decibel forms, indicating availability at all times in which the channel response is well above the threshold: this is the attribute of an ideal channel--otherwise referred to as un-faded channel—but it is actually unrealizable in the practical sense.

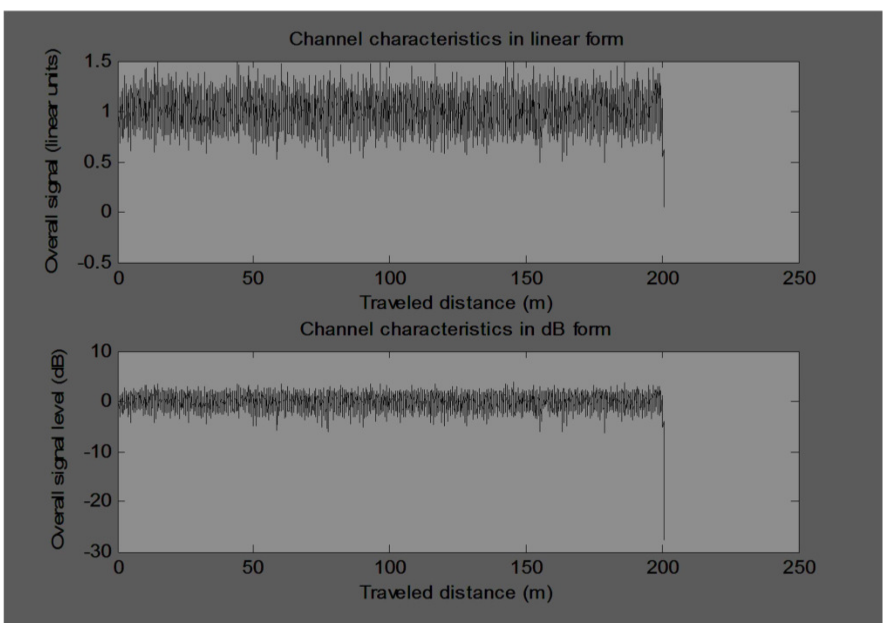

Figure 7. Channel behaviour of a noisy channel

On the other hand, when $P = \begin{pmatrix} 0 & 1 \\ 0 & 1 \end{pmatrix}$

It indicates that there is a total fading scenario in the channel, similar plots but in total opposite response to Figures. 4, 5 and 7 were generated and as shown in Figures. 8, 9 and 10 respectively.

Figure 8. State series and multipath parameters for Rician distribution

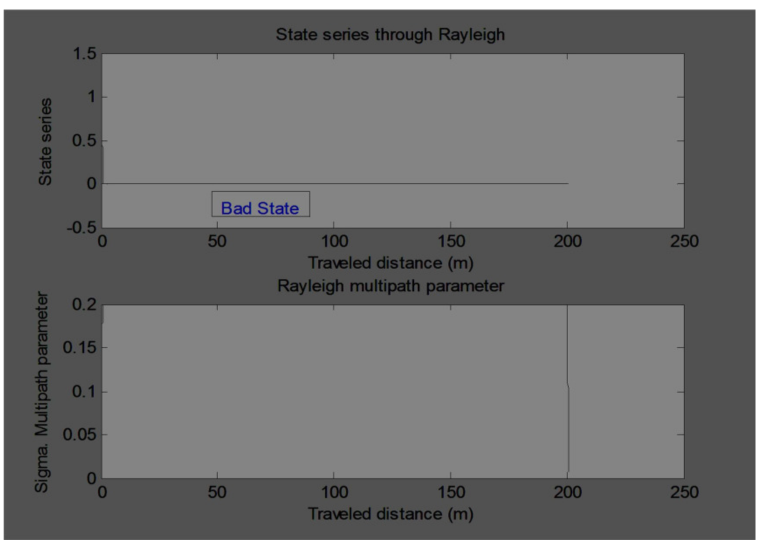

Figure 9. State series and multipath parameters for Rayleigh distribution

The multipath parameter and filter response of the channel were not re-plotted as it is exactly the same as Figure 6. Analysis of these figures shows that there is no state transition as this is well below threshold. It is the attribute of a fading channel with service unavailability at all times, practically it is also quite impossible.

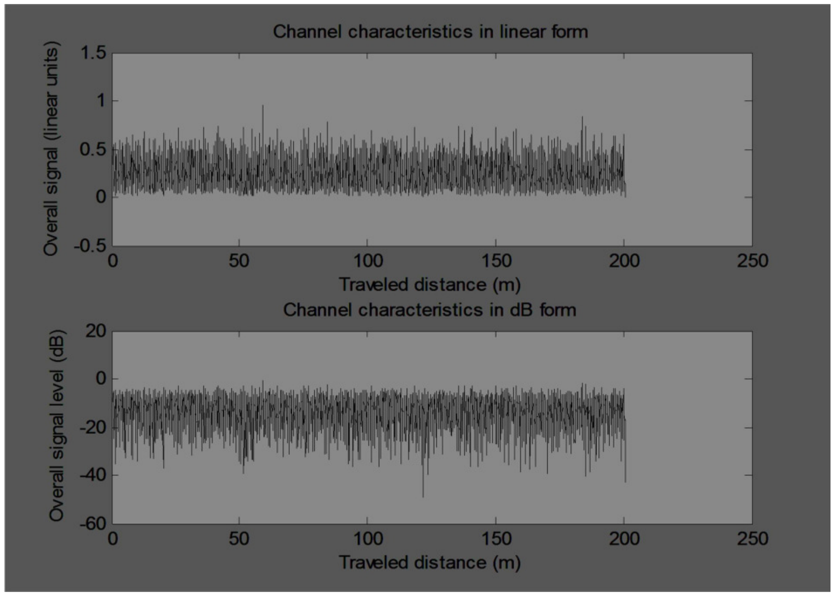

Figure 10. Channel behaviour of a fading channel

But for the same distance travelled, under a similar scenario with the parameters of this transition probability matrix adjusted to have $P = \begin{pmatrix} 0.95 & 0.05 \\ 0.1 & 0.9 \end{pmatrix}$, so as to have a representation of a realistic channel. When this was simulated, the channel characteristics in line with the state series both for Rician and Rayleigh distributions with their respective multipath parameters, the entire multipath for the channel with the filter response of the channel and the channel behaviour both in linear and decibel form are as shown in the Figures 11, 12, 13 and 14 respectively.

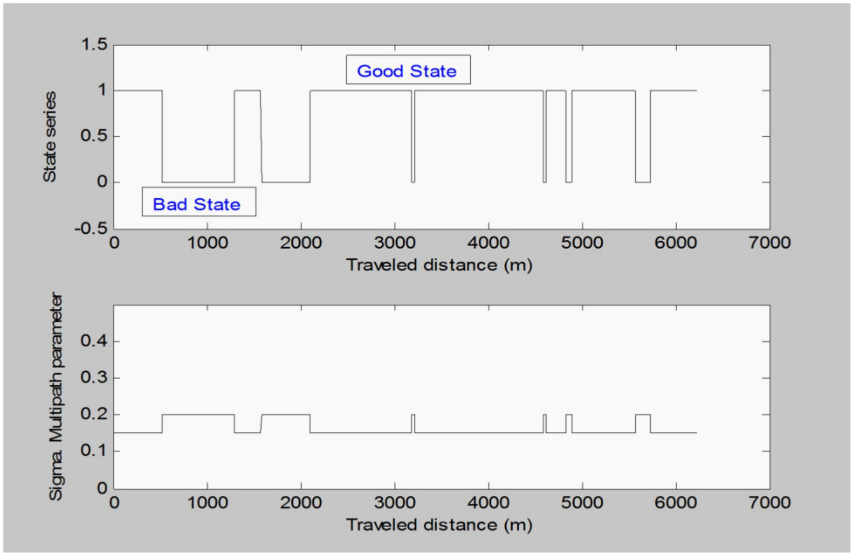

Figure 11. State series and multipath parameters for Rician distribution

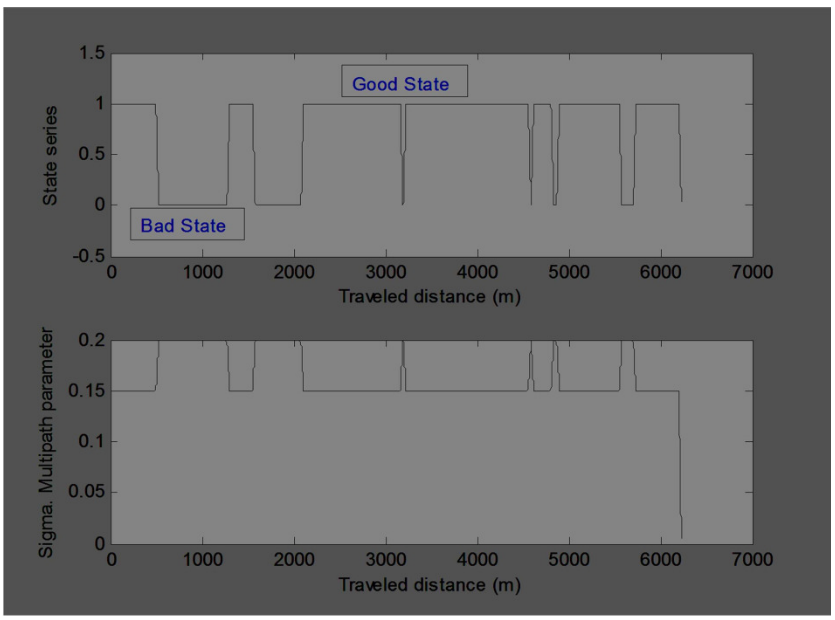

Figure 12. State series and multipath parameters for Rayleigh distribution

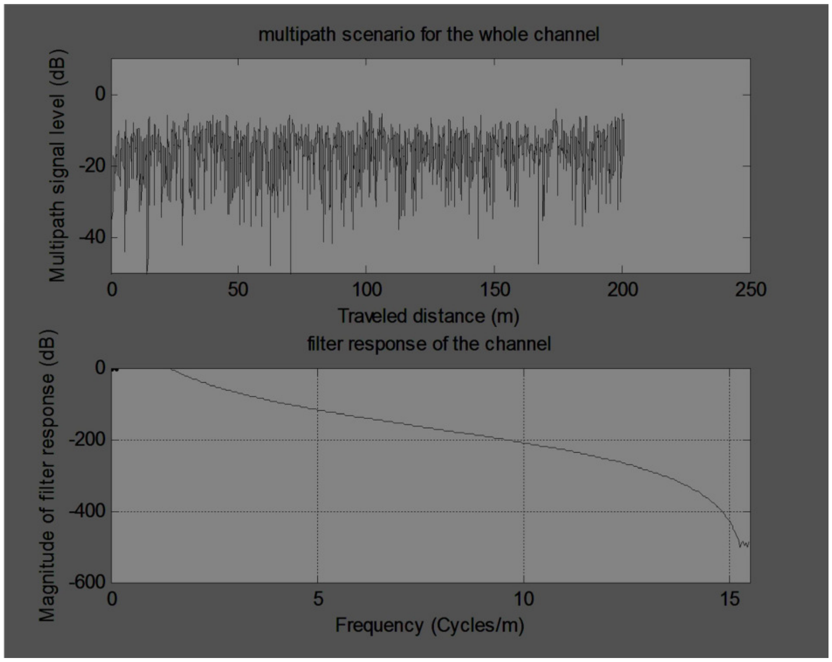

Figure 13. Channel's multipath effect and filter response

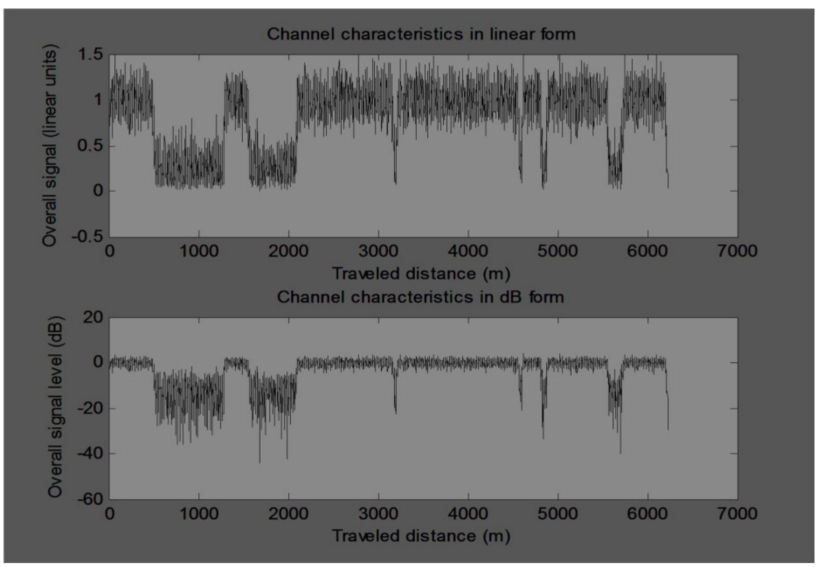

Figure 14. Channel characteristics in linear and decibel form

SATELLITE DIVERSITY RESULTS

Considering Figure 14, it was noted that there are outages on the channel, in within which service will be unavailable to a mobile user. In order to overcome this or to simply reduce the probability of outage on a channel the method of satellite diversity (that was discussed in the previous chapter) was employed and the channel characteristics from the two satellites were generated. Figure 15 is the Rician state series through the two satellites that shows when there is availability of the satellite to a mobile user corresponding to Good State and that of unavailability corresponding to Bad state respectively.

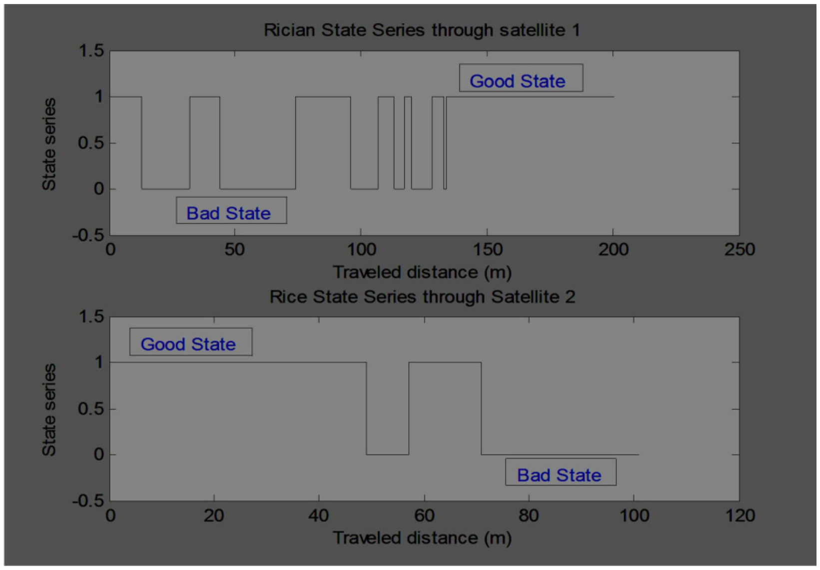

Figure 15. Rician state series corresponding to the satellites 1 and 2

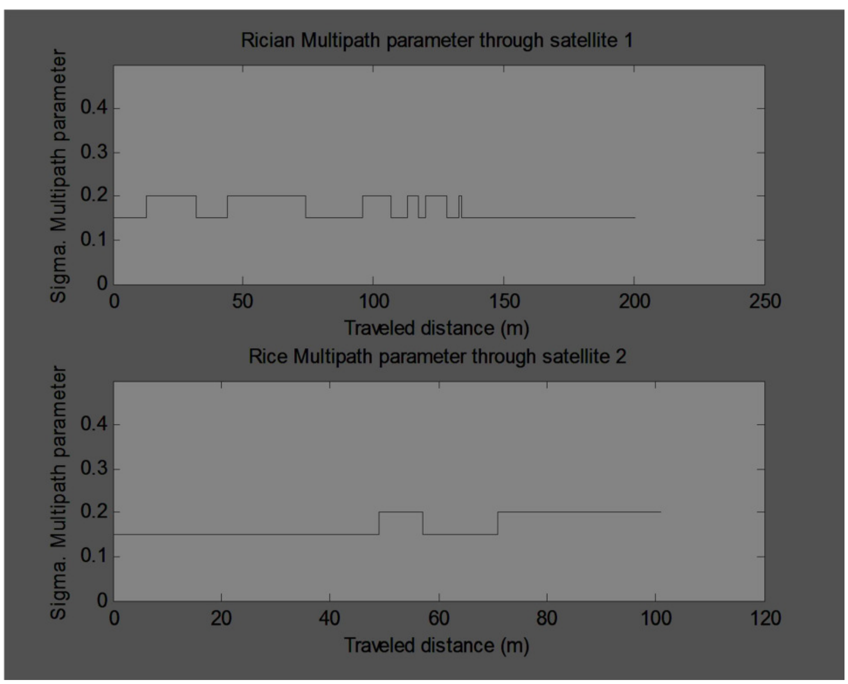

Figure 16. Rician Multipath parameters corresponding to the satellites

Similarly, the Rayleigh state series and multipath parameters through the satellites were shown in Figure 17 and 18 respectively.

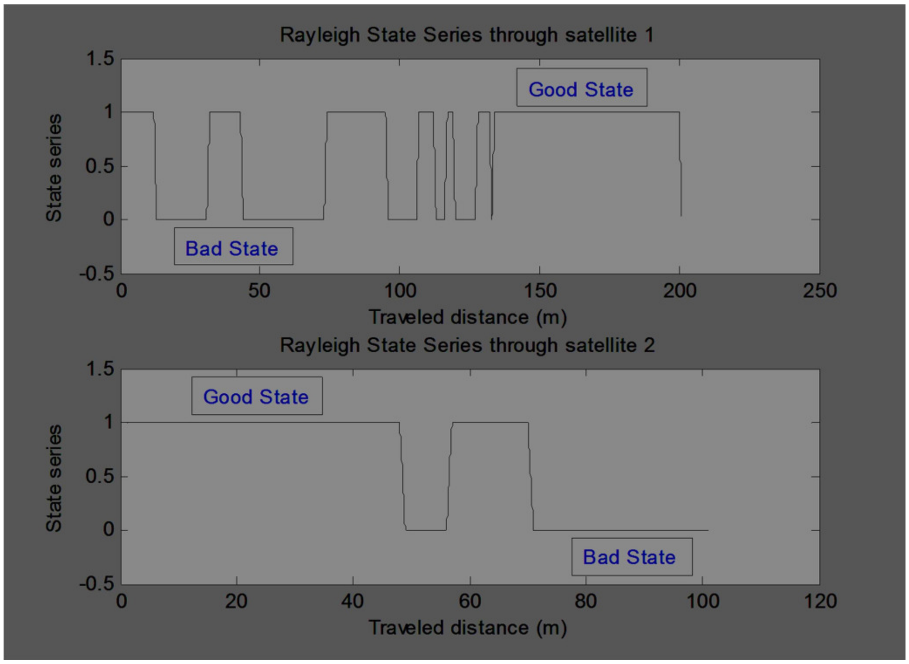

Figure 17. Rayleigh state series corresponding to the satellites

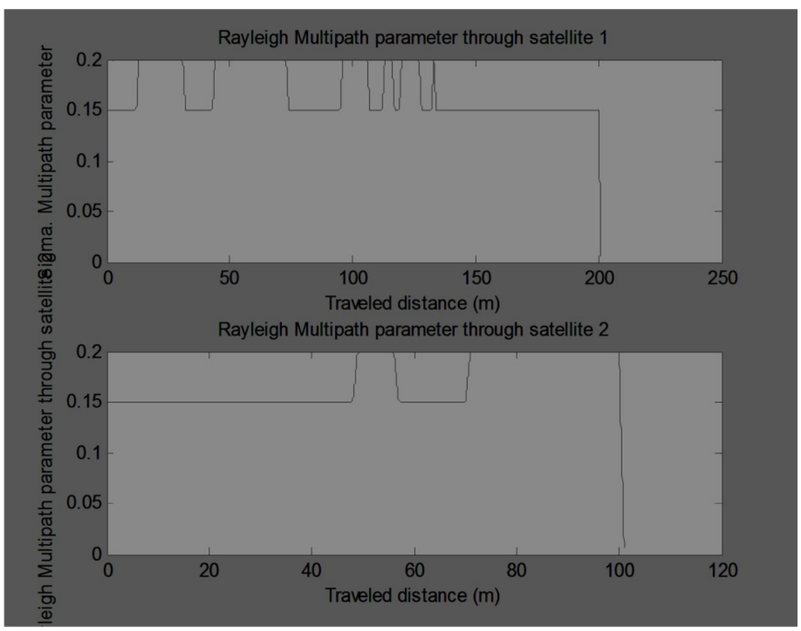

Figure 18. Rayleigh Multipath parameters corresponding to the satellites

A similar plot for entire multipath parameters received by mobile users through the satellites and the unchanging filter response were shown in Figure 19 and Figure 20.

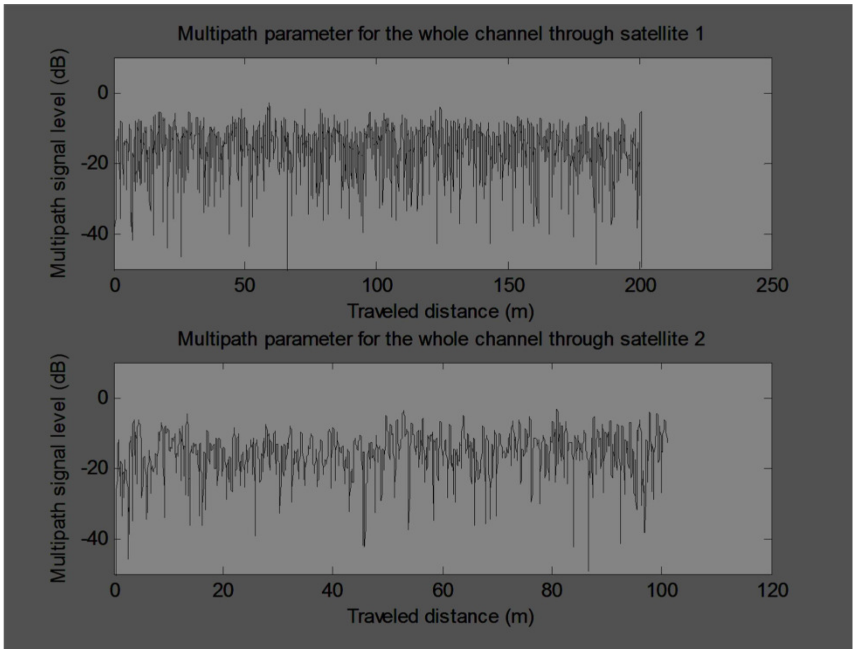

Figure 19. Multipath effects through satellites 1 and 2

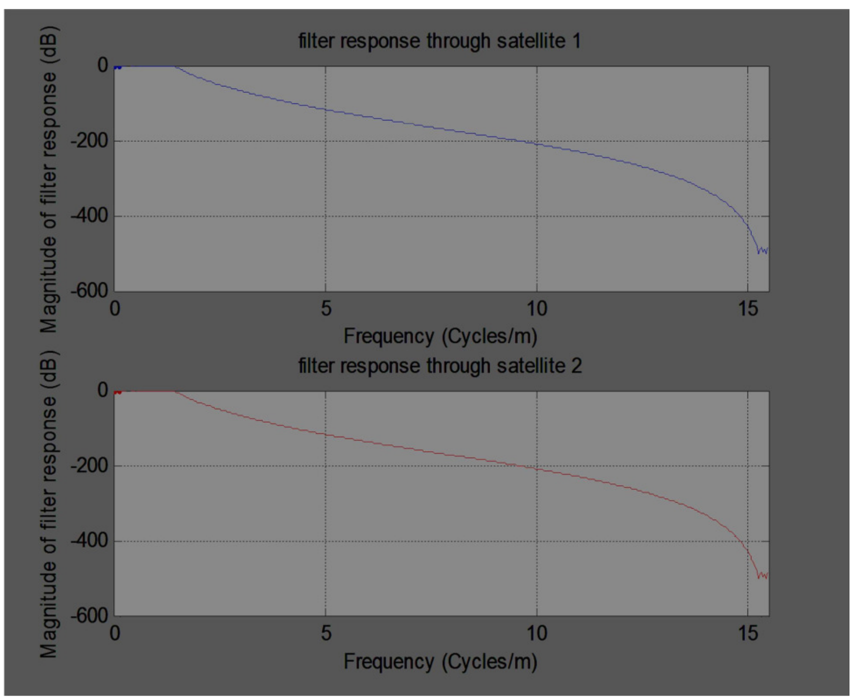

Figure 20. The filter responses through the satellites remain unchanged

Lastly, the overall channel characteristics through the satellites were plotted both in linear and dB form. These were shown in Figure 21 and Figure 22 respectively.

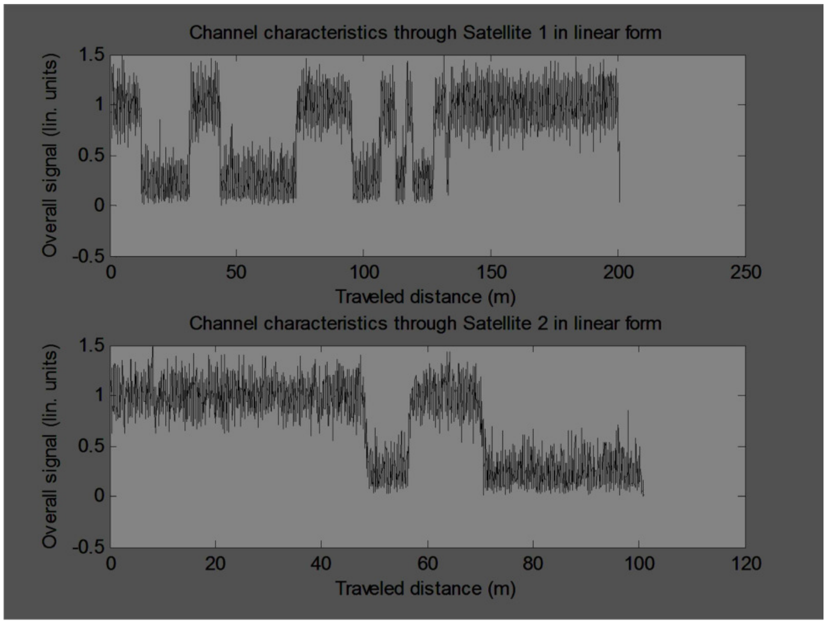

Figure 21. Overall channel characteristics through the satellites in linear form

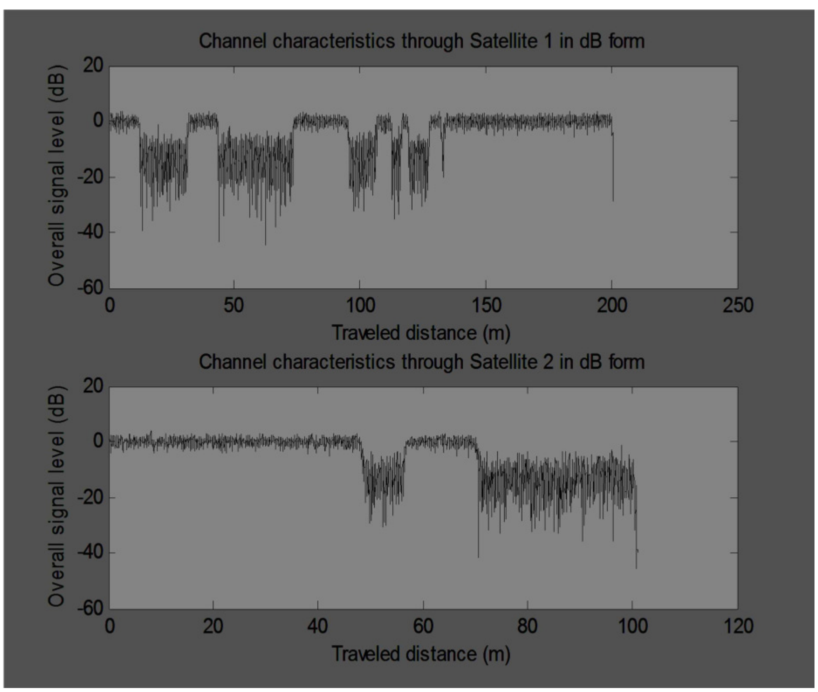

Figure 22. Overall channel characteristics through the satellites in dB form

7. CONCLUSION

The need to model a land mobile satellite (LMS) channel has been made visible by its usage in many areas of life in which security of life and properties is a topmost, as well as ensuring a better quality of service for the users—implying availability of the satellite communication services to mobile terminal users at all times.

Due to different transmission environments where the mobile terminal operates, it is actually impossible to achieve availability to mobile terminal at all times through one satellite and for that reason, making use of more than one satellite is of great advantage. This is otherwise known as satellite diversity. In this study, two satellites in geostationary orbits have been used to provide access to a mobile user. Also by ensuring that the mobile terminals have access to two satellites simultaneously, it has in turn increased the availability of the satellite to a mobile terminal irrespective of the transmission environments where the user is located and reduces fading experienced by a mobile user compared to when it has only one satellite link.

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