Simulation of Diversity Techniques for Satellite Communications

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Abstract: - Diversity techniques are used to provide effective and establish efficient communication link between earth station terminals and satellites. Main two techniques of diversity are orbital and site diversity schemes. Currently both diversity schemes are modelled using parameters such as Time Division Multiplexer (TDM) and Frequency Division Multiplexer (FDM) in order to avoid signal interference. TDM is a technique for different signals to be transmitted in various intervals of time. FDM is a technique where more than one signal is to be transmitted using various different frequency channels which get affected by frequency-selective fading. This paper gives the illustration of rain fades and its effects in satellite communications, as well as it presents relevant techniques to void the affect of rain fades that have been implemented using various simulation tools such as Matlab, OPNET and Celplanner. The simulation gives the effect of the fading factors for a satellite communication, where this prediction will be useful for a supplier to inform customers.

Key-Words: - Satellite, Matlab, OPNET, Celplanner, Diversity technique, Simulation

1 Introduction
The performance of the communication system mainly depends on the strength of the signal power [1]. This signal power loss should be minimised over the entire bandwidth of the signal. Change of fading over time can cause a problem: as communication systems are designed to adapt the impairments caused by any means, thus when fading changes faster, adaptation is not easy. In such scenario, experiencing a fade margin the channel will become the limiting factor.

The effect of fading can be minimised with the use of diversity techniques for signal transmission over various channels, where independent fading is experienced and combining them coherently at receivers end.

Background of the satellite communication systems with diversity technique has been given in section 2. These diversity techniques are simulated with various fading factors using Matlab, OPNET and Celplanner and explained in sections 3, 4 and 5 respectively. Conclusion is given section 6.

2 Background
The educational graphical tool presented in this paper is for understanding and predicting the effect on the orbital and site diversity techniques [2]. Satellite communication systems use frequencies above 10 GHz for these diversity techniques to counteract impairments in the signal caused due to rain. The Satellite Communication Diversity Performance Tool (SCDPT) was developed using Matlab [3]. The main purpose of the tool is to illustrate overall rain fades effect.

The Diversity Techniques for Satellite Communication is based on Satellites and Earth Stations, that are the communication barriers in communication [4]. By using OPNET setup two satellites are connected with the internet and routers and implement the internet cloud for connectivity.

For number of prediction models this paper represents the performance evaluation of single-site, site-diversity, and orbital-diversity satellite systems. The Matlab [5] is used for Satellite Communication Diversity Performance Tool (SCDPT). SCDPT is not only a design tool, it can also be considered as a useful tool which helps in understanding rain fade effects in satellite communications, also to study various mitigation techniques. Celplanner is used to analysis the coverage of satellite and earth station for various scenarios.

The Diversity technique is defined as the method where two or more channels with different characteristics are used for improving the reliability of a message signal [6]. Diversity plays an vital role in handing fading and co-channel interference and avoiding error bursts. Thus fading and interference levels differ with the individual channel.
There are two types of diversity techniques: orbital and site diversity. These are explained herewith.

2.1 Orbital Diversity
Multiple versions of the same signal may be transmitted and/or received and combined in the receiver as shown in Fig. 1. Thus an alternate forward error correction code may be added which cause breaking of the message in to small parts transmitted through various channels. Multi path propagation is exploited by Diversity techniques resulting in a diversity gain. This gain is measured in decibels. The orbital diversity is the techniques to limit the barriers, and provides communication that is error free and efficient. This technique provides the less error free signal and efficient connectivity to the telecommunication devices.

Fig. 1 Orbital Diversity

2.1.1 Site Diversity
Site diversity as shown in Fig. 2 is a method used to minimize the effect of fading due to rain [7] in satellite communication systems, mostly in Ka band. The downlink transmissions of satellites cover large footprints that will have different weather in different regions. The site diversity technique consists of connecting two or more terrestrial ground stations receiving the same signal: if the signal to be received is severely affected in one region, other ground stations can accommodate for it. Areas of intense rain for example have super cells, they have a length only few kilometers: while placing the earth stations at a sufficient distance that the possibility of fading in the downlink signal path can be minimized.

Fig. 2 Site Diversity

Parameters used for the simulation are as follows:

Signal Switching: In this type of reception, only one signal is fed to the receiver as long as the Signal to Noise Ratio (SNR) or power of that signal remains above threshold [8]. When the signal strength goes below the threshold, the system switches to another antenna. Switching receiver is the easiest and least power consuming, less complex and cost effective of the diversity processing techniques available, but periods of fading and synchronization problem may occur while the quality signal degrades and switches to another antenna link.

Signal Select: In this technique, selection of the signal to be presented to the receiver at any given time is based on SNR. The antenna having the signal with best SNR is chosen and fed into the receiver. This requires all antennas to be powered-up all the time and connected. A pre-measurement of SNR is to be known to determine the best available signal to be fed to the receiver.

Signal Combining: The signals are combined and sent to the receiver. Depending on the how good the system is, signals can be added directly (equal gain combining) or maximal-ratio combining can be used. Such a system provides the greatest hindrance to fading, but since all the reception paths must powered-up, it consumes alot of power.

Dynamic control: Receivers are capable of selecting from the above processing schemes as per the situation demands. Complex controlled receivers can optimise the power vs. performance trade-off. Transitions between different modes and/or antenna connections are signaled by a change in the perceived quality of the link. In case of low fading, the receiver can adapt to the situation, no diversity technique will be employed and use a single antenna. As conditions degrade, the receiver can then use the more highly reliable modes explained above.

Maximal-Combining Ratio: It is a probabilistic approach used in diversity combining, which offers:
• Signals from each carrier (channel) are summed together,
• The gain of each channel is made proportional to the RMS signal power and inversely proportional to the mean square noise power in that carrier.
• Different proportionality coefficients are used for each carrier, also known as ratio-squared.

2.1.3 SimpleModel to implement Site Diversity
The following mathematical formulas are used for simulation purpose:
Site Diversity Gain
\[ G_{SD} = G_D(A_s)G_fG_pG_v, \]
Dependence of gain Frequency
\[ G_f = \exp(-0.025f), \]
Dependence of gain Separation Distance
\[ G_D = a[1 - \exp(-bD)] \]
Dependence of gain Base-Line Term
\[ G_p = 1 + 0.002\psi \]
Dependence of gain Elevation Angle
\[ G_v = 1 + 0.006\phi \]

3 Matlab simulation
The Satellite Communication Diversity Performance Tool (SCDPT) was developed using MATLAB’s graphical user interface (GUI) as shown in Fig. 3. This tool explains the overall effect of rain fades and the diversity as a fade mitigation technique on the design of satellite communication systems [9].

The parameters used in Matlab are diversity gain, space diversity and polarization diversity which are as follows.

Diversity gain described as increase in signal-to-interference ratio which is caused by diversity scheme, or without any performance loss during implementation of the diversity scheme how transmission power is minimised. Diversity gain is expressed in terms of decibel and sometimes as a power ratio [10].

Space diversity: The signal is transmitted over multiple different propagation paths [11]. It can be achieved by transmitting via multiple channels for the wired transmission. In the case of wireless transmission, it can be achieved by antenna diversity using multiple transmitter antennas and/or multiple receiving antennas.

Polarization diversity: At the receiver end diversity combining technique is used in polarization diversity, where antenna transmits and receives multiple versions of a signal with different polarization.

In orbital diversity GUI as shown in Fig. 3 changes the value for different parameters as the gain changes by increasing and decreasing the attenuation. Results show that gain is directly proportional to the attenuation.

This technique works well when the attenuation is not great at the two terrestrial stations simultaneously. This is usually a valid assumption. Site diversity systems are used to minimize satellite outage time.

Empirical models provide a simple solution when an approximation of the diversity gain, G, is required for satellite link design, while taking into account the random attenuation caused by rain. This is probably the most complicated part of the design procedure, since rain fades behave random, both in time and space, in contrast to all other deterministic factors (e.g., the free-space loss) affecting the link[12].

Thus implementation requires different values in parameter slots as shown in Fig.4. To get the different gain and less attenuated signals with good transmission and reception of the signals.

Fig. 3 signal strength for orbital diversity

Fig. 4 signal strength for site diversity
Site Diversity performance has been evaluated using different tools, it requires only the appropriate handful system inputs from the user, and will tells about the fading distribution based on those parameters. It is very simple and easy to understand.

4 OPNET Simulation

The project Diversity Techniques for Satellite Communication is based on Satellites and Earth Stations that define the communication barriers which one can face in communication. OPNET simulation includes communication barriers which we overcome using the different scenarios.

As shown in Fig.5 two satellites are connected with the routers and the internet cloud. The following components are used for OPNET simulation:

- **Satellites**: For Orbital Diversity using two Low Earth Orbits Satellites.
- **Internet Cloud**: It will provide the Internet connectivity to the other components.
- **Personal Computers**: They are serving internet to the users.
- **Server**: Gathering connectivity from the internet and work as an Administrator.
- **Switch**: Switch provides connectivity between routers and PCs.
- **LAN (Local Area Network)**: Local Area Network serves the wired connecting between client and servers.
- **Earth Stations**: Triggering two satellites by single Earth Station.
- **Application Server Definition**: This component provides the coverage and managing the threshold values of Voice, Data, and Video conferencing. In the application server we also entered the Decibels [dB], and different threshold values for parameters.
- **Profile Server Definition**: Its shows the client to server connectivity.

Following are the system parameters which are used to model Orbital Diversity.

- **EIGRP (Enhance Interior Gateway Routing Protocol)**: It is an advanced distance vector routing to minimize the routing instability incurred after topologies. It also provides Bandwidth and processing power to the router.
- **IGRP (Interior Gateway Routing Protocol)**: Provides Stable Routing to very large complex networks, fast Response to changes in the network topology and splits traffic among several complicated routes.
- **MPLS (Multi-Protocol Label Switching)**: It provides network operators a great deal of flexibility to divert traffic when the link fails.
- **IP(Internet Protocol)**: Differentiate Networks and enables Internetworking.
- **MANET (Mobile Ad-Hoc network)**: Protocol’s functionality is suitable for wireless routing application for both static and dynamic topologies with increased dynamics due to motion of the node and also due to other factors.
- **Simulation Efficiency**: It shows the results of simulations and differentiates the parameters.
- **WLAN (Wireless Local Area Network)**: Provides connectivity to network by means of wireless.

Fig. 6 illustrates the signal level and attenuation (blue and red) signals. Defining the original signal and distorted signal. The above results illustrates the communication barriers which attenuates the signal strength between satellites and earth stations.

By using the world topology implementation as shown in Fig.7 for the diversity network, where three different subnets as a earth stations are
selected across the world in three different countries and are connected through cloud which is acting as a satellite for the three earth stations which are on different location.

Fig. 8 has an individual subnet and multiple LANs are used which are connected to a local Cisco router which is provided with a firewall and with a main server for global connectivity.

In another individual subnet of Australia, provided with multiple LANs of 1000 pcs, are connected to a switch. Firewall is included in the main server connecting to the satellite.

5. Celplanner simulation

This paper focuses on an empirical tool for understanding and studying the underlying analysis of site and orbital diversity in satellite communication. Celplanner describes the overall effect of rain fades and the application of diversity as a fade mitigation technique on the design of satellite communication systems.

Prediction and Analysis of Results:

Head quarter is connected to the other earth stations with the help of satellite providing data access through its main servers, has four services file server, database server, voice server, video conferencing.

Fig. 9 of client server connectivity shows very high utilization with the average throughput with zero queuing delay. Thus the above results show that the communication glitches causes the major disruption in the transmission of the data. In turn, attenuates the signal strength between satellites and earth station. The site diversity is the techniques which helps in mitigating the fade margin and the gain limitations for the better and efficient data service.

Fig. 10 Server details

Orbital diversity is the technique to minimize the outage time of a satellite cause of rain operating at frequencies greater than 10 GHz the prediction of orbital diversity performance is includes the methodology obeyed by two different rain models.

- Stratiform rain
- Convective rain

Fig. 10 are tested with a set of corresponding data from an operating Earth-space. Number of cells are added as shown in Fig. 11. The results in Fig. 12 and 13 gives coverage of individual BTS and overall BTS. Fig. 14 shows the coverage area after adding more number of cells.
Fig. 12 Individual BTS coverage area

Fig. 13 Overall BTS coverage

Fig. 14 Composite Forward Additional cell sites

Fig. 15 Morphologic Traffic

Fig. 16 Detailed Morphologic Data

Traffic In Morphology:
Morphologic situation as shown in Fig. 15, explains more number of users at different locations. Also describes the detailed knowledge regarding the traffic capacity. It further explains by zooming the morphologic condition as shown in Fig. 16.

After zooming a particular cell site, shows more details, as shown in Fig. 16. It provides the computational statistics that may be executed in parallel users or can be executed by a single user. It also provides great strength in designing telecommunication network by showing the communication details between BTS and MSC.

Signal Fading Factors considered for simulation are:
- Atmospheric Absorption (Gaseous Effects)
- Cloud Attenuation (aerosol and ice particle effects)
- Tropospheric Scintillation (refractive Effects)
- Ionosphere scintillation (a second ionosphere effect)
- Rain attenuation
- Rain and Ice crystal Depolarization
- Doppler effect

By adjustments to the parameters to achieve acceptable performance as shown in above Fig. 16 we observe several types of Losses which are explained below.

**Beam spreading loss:** results from the spreading of the earth-satellite signals as they pass through the Earth's atmosphere.

**Scintillation loss:** results from rapid variations in the signal’s amplitude and phase due to changes in the refractive index of the Earth's atmosphere.
**Polarization Loss:** results from a rotation of the polarization of the signal as it passes through the Earth's atmosphere.

**Weather losses:** results from attenuation of the Earth-satellite signals by hydrometers as they pass through the Earth's atmosphere.

**Doppler’s Effect:** means the frequency change of an electromagnetic signal that the receiver feels or detects due to relative speed of the satellite and the Earth Station. When the orbital parameters of a satellite system are known, Doppler shift can be used to determine the position of the Earth Station. When an Earth station's position is known then the Doppler shift can be used to evaluate the orbital parameters of a satellite system. When the satellite’s (or the Earth station) mobility is greater then, the Doppler Effect is an important parameter to look at in satellite communication.

The Celplanner simulation results are shown in Fig. 17, 18 as Composite Forward Plane area and plane areas of grid cells. Subscriber and antenna selection configuration used in this simulation are shown in Fig. 19.

The objective of site diversity using cell planner is to investigate the operation of cellular networks and network links. Multiple Mobile Switching Centre and Base Station Controller will be created and linked together to form one larger network as shown in below Fig. 20 of network links.

The morphological model of the different BTS is shown below in Fig. 21, explains the total coverage area that is covered and the traffic handling capacity of the network. System parameters for radio BTS are given in Fig. 22.
6. Conclusion

In this paper, with the help of numerous tools, incorporating different prediction models for performance evaluation of orbital-diversity and site diversity in satellite systems are presented. The simple tool makes use of windows to provide a simple implementation of the prediction models or empirical models as physical models are difficult to understand and analyse. This tool will help students or researchers understand the effect of fading due to rain in satellite communication systems, as well as the relevant techniques to reduce it.

Celplanner is a tool which incorporates a number of prediction models; including the diversity techniques here we came across the wide knowledge of celplanner and its specifications which can get the desired results. Use of this tool will develop a basic understanding about the effect of rain fades in wireless or specifically satellite communication, as well as the relevant techniques to reduce it.

Our future work will focus on designing an optimal diversity technique tool, that can be used widely in industry.

References


