Long Term Evolution (LTE): Next Generation Wireless Communication of NASA for Satellite Engineering

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Abstract—This research work is anticipated for verifying the implementation of Long Term Evolution (LTE) over satellite in forward link for the next generation communication of NASA for satellite engineering or extraterrestrial purposes. Recent developments in wireless communication such as MIMO technique that allow improving the received signal quality and capacity, in combination with OFDM makes the signals more robust against delay spread in frequency selective channel. A dual satellite Orthogonal Frequency Division Multiplexing and Multiple-Input and Multiple-Output (OFDM-MIMO) model is considered which provides a handy and robust resource over satellite channel for this purpose. It is OFDM in aggregation to Quadrature Phase Shift Keying (QPSK) with Turbo Coding using 2x2 MIMO as specified for LTE 5 MHz BW, transmitted with satellite power delay profile has analyzed in terms of Bit Error Rate (BER). Spatial multiplexing and diversity are the two features that MIMO provides which has also been investigated. The investigation has been conducted considering downlink transmission over satellite forward link over dual-satellite 2x2 MIMO channel.

Keywords—Wireless System; LTE; MIMO; QPSK; OFDM; Space Coding; Dual Satellite Channel

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1 INTRODUCTION

THE National Aeronautics and Space Administration (NASA) is set to launch Data Relay Satellite K (TDRS-K) which is LTE technology over satellite. However, first TDRS satellite launched in 1983. But recent activities of "curiosity" (Curiosity is a car-sized rover exploring on Mars) in Mars has brought concentration of researchers in this arena.

In terrestrial wireless communication, MIMO has demonstrated significant results. But as far as satellite channels are concerned it is not as straight forward as terrestrial. Satellite channels rarely produce independent delay profiles required for MIMO concept to work. It is dominated by LOS (Line of Sight), higher FSL (Free Space Loss). However, we can improvise in order to create different fading channels for satellite. Single satellite having similar delay profile would not help in having a condition for MIMO. Having multiple antennas in single satellite will not produce different fading channels. Due to correlation, two antennas in same satellite will appear to be single satellite 1].

Multiple satellites can be deployed in orbits and separated by a large distance in order to have sufficient correlation and different fading path for achieving diversity. Satellites in different orbits can also be used for creating diversity. Multiple ground station with single satellite would not be convenient as the distance for correlation would be very long extending hundreds of kilometers. But, polarization diversity achieved by using single satellite is remarkable. So far this concept has been successfully implemented over L-band [2]. The only problem is that it does not work in higher frequencies. So, in this project multiple satellite channels with 2x2 MIMO-OFDM configurations has been investigated in terms of BER and compared with traditional satellite channel capacity [3].

To start this research project, initially concept over MIMO (Multiple Input Multiple Output) is reviewed and found how it works to see various diversity offered by it followed by OFDM (Orthogonal Frequency Division Multiplexing) and see how it is a blessing for us in wireless communication. MIMO and OFDM together make a combined technology to support each other and deliver the maximum throughput which will be discussed next sections. Knowledge about schemes such as binary-phase shift keying (BPSK), QPSK will be gathered provided the addition of OFDM to them. Having a look at different channels (AWGN, Raleigh) is worthy as well. Finally, results are comprised of the simulation of BPSK and QPSK modulation over both AWGN channel and Raleigh channel which are compared in terms of BER against theoretical values. Concluding remarks with future direction have been represented at the end of this paper.

2 LITERATURE REVIEW

2.1 Satellite orbits, Constellations and systems

Single satellite can provide a limited service to a limited location. If we are to provide a larger global coverage then it is worth considering satellite constellations. A satellite constellation is a cluster of satellite system working together for a specific purpose or service. Generally the constellations are deployed in three different orbits based on their requirement. The three categories of orbits are GEO, MEO and LEO.

The orbit period for GEO constellations is 23 hour and 56 minutes and 4 second and deployed to a height of 35 786 km. Therefore the satellites in GEO constellations revolve eastward from the earth and seem to be immobile from the earth. GEO satellites are very popular for services such as Direct TV or VSAT. One example of GEO satellite system is INMARSAT-3 which is used for portable mobile telephony. To find out more about INMARSAT-3 characteristic [10] can be referred.

One of the key problems with GEO satellite is long delay in signal propagation. LEO satellite constellations are used to tackle the problems for mobile satellite systems. LEO system reduces the round trip delay to few milliseconds. The altitude for this system ranges from 700-1500 km. How- ever, due to lower altitude the satellite in LEO can cover less area. For covering larger area, more satellites are required. Also for proper function requires inter satellite links and complex on board processing. Global star is a simple satellite system in LEO for cellular networks. The system utilizes 48 satellites for a service in dual mode for real-time data transfer, paging and voice. The multiple- satellite concept is used in this system for achieving satellite diversity. Iridium also uses LEO system and uses inter satellite links and on board processing. It has a constellation of 66 satellites [6].

For satellite services which require certain parameters in between GEO and LEO, there is an intermediate orbit called MEO. The altitude for the orbit ranges from 5000 to 7000 km and capable of covering the globe with only 10-15 satellites. Advantages of both LEO and GEO converge in MEO.

2.2 Long Term Evolution(LTE):

In order to meet the demand and develop a promising solutionover existing system in wireless system, LTE has evolved. It is a 4G technology and 3GPP standard that exploit the latest advances in physical layer technologies comprising OFDM, MIMO, OFDMA, SC-FDMA etc. These sophisticated methods allow very highly features for LTE. For example, with minimum 2x2 MIMO configurations it provides an uplink speed up to 50 Mbps and downlink speed up to 100 Mbps along with lower latency and scalable bandwidth. Beside physical layer developments, flat IP architecture for LTE provides a simplified and effective network. LTE, upon deployment over satellite keeps the ability to have major impact over global communication systems [4,5].

2.3 Multiple input and multiple output (MIMO):

Traditionally SISO (Single Input and Single Output) systems are used in wireless communication systems. The disadvantage of SISO systems is that we cannot increase the capacity unless more spectrum or transmit power is used. There are three categories of MIMOs which is shown in table 1.

Using more antennas for communication systems instead of a pair of them provides multiple channels with different fading for information signal to travel. If the receiving antennas are able to get a signal with enough strength from any of these channels then it can easily retrieve the information signal. If the fading channels are independent of each other then chances of recovering the signal is very high [6, 7].

To get a clear perception of MIMO Functions, we need to know different usages of MIMO. They are as follows:
MIMO can be used in different ways

a. Pre-coding is the process where same signal transmitted from different antennas in such a way that at the receiver end a particular antenna will experience maximum gain. This process not only helps in getting increased gain at the receiver but also combats multipath fading. Pre-coding is used in the scattering environment where using multiple antennas may not provide the same signal strength at all receiver. Therefore prior knowledge about the channel is also required in the process.

b. Frequency diversity or Spatial multiplexing is used for interleaving group of fragmented low data rate frequencies from a high data rate frequency and transmit them over the channel after which they are de-multiplexed at the receiver to get the higher data rate. More the number of antennas more are the number of channels and more data streams allowable to be sent leading to higher data rate.

c. Spatial diversity is where antennas have to be separated by sufficient space achieving low correlation of different channels in order to achieve diversity in space domain.

For large number of antennas in MIMO system
$M_T = M_R > 1$

$$C \log_2 \rightarrow (\det[I_M + \left(\frac{\gamma}{M_T}\right) I_R]) = M_R \log_2(1 + \frac{\gamma}{M_T}) \ldots\ldots (1)$$

The capacity of MIMO system increases linearly with the number of transmit-receive antennas.

2.4 Orthogonal Frequency Division Multiplexing (OFDM)

We know the fact that in wireless communication, frequency selective fading is successfully mitigated by using the OFDM (Orthogonal Frequency Division Multiplexing) technique. This multiplexing technique also helps solving the multipath fading by taking advantage of it and is very spectrum efficient. For several other reasons beside these, OFDM is growing its popularity day by day.

The principle behind OFDM is to divide a high data rate information bit stream into several low data rate bit stream which are transmitted over narrow orthogonal subcarriers. These subcarriers are received by the different receiving antennas and combined to produce the initial higher data rate. Therefore it allows having frequency diversity [8].

In single carrier systems with just a pair of antennas, as the data rate goes higher, the complexity at the receiver for equalization also shoots up as the bit duration becomes smaller. For OFDM getting as low data rate subcarriers are received at the receiver end, it does not enforce the high complexity of equalization. So, using multiple antennas and OFDM, multiple subcarriers which is shown in figure 1,allow much higher data rate of signal transmission [9].

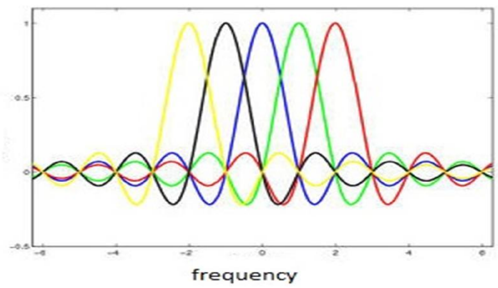

Figure 1: Different orthogonal subcarriers in OFDM signal

Let the number of subcarriers be N and the K_{th} subcarrier be $g_k(t)$ where k=0,1..N-1. The frequency distance for each subcarrier is Δf. Therefore symbol duration $T_s=1/\Delta f$.

The subcarrier is given by

$$g_k(t)= e^{j2\pi k\Delta f t} \; ; t\in [-T_g, T_s] \text{……………..} (2)$$

After modulation of subcarriers, complex symbols Sn,k is given by

$$S_{n,i} = 1/\sqrt{N}\sum_{k=0}^{N-1} S_{n,k}\, e^{j2\pi iK/N} \text{…….........}(3)$$

Where i= 0,1..N-1; n is the time and k is the subcarrier.

Finally these symbols are transmitted to channel by up converting through digital to analog converter. The receiver part collects these signals and converts them back to digital. Then the guard intervals are removed and fed to FFT after converting serial to parallel streams of bits. After removing the CP, the received signals are given by

$$R_{n,k} = 1/\sqrt{N}\sum_{i=0}^{N-1} R_{n,i}\, e^{-j2\pi iK/N} \text{…......…} (4)$$

These parallel bits are again converted to serial streams of symbols and demodulated to get information bits.

As the orthogonal subcarriers carriers are placed very close to each other oscillator clock has to be very accurate. And due to High peak to average power ration it becomes harder to implement for power limited systems [10].

We see that OFDM efficiently finds its application in the wideband (ISI) channel. In satellite systems the channels are usually narrow band due to little multipath and delay spread, high elevation angles, directional antennas and dominant LOS. But satellite mobile systems make sense for OFDM use as it experiences significant delay spread, scattering and multipath by the surrounding buildings and other terrestrial structures [11].

But when MIMO concept is combined with OFDM to enforce a spatial diversity beside frequency, it boosts the possibility of OFDM to an incredible height.

3 MIMO-OFDM MODEL FOR THE SYSTEM

3.1 MIMO – OFDM system

As mentioned earlier, MIMO-OFDM technique offers diversity in both space and frequency. Assuming the same scenario and configuration shown in figure 2, the channel impulse response from transmit antenna i and receive antenna j is

$$h_{i,j}= \sum_{l=0}^{L-1} \beta_{i,j}(l).\,\delta(\tau-\tau_l) \text{……..…} (5)$$

L is the number of independent delay paths and same power delay profile.

τ is the time delay of l_{th} path between a set of transmit and receive antennas. Time delay and variance $\delta^2{}_l$ are assumed same for each link. So the channel response is given by

$$H_{i,j}(f) = \sum_{l=0}^{L-1} \beta_{i,j}(l).\, e^{-j2\pi.f.\tau_l} \text{…………….} (6);\; j = \sqrt{-1}$$

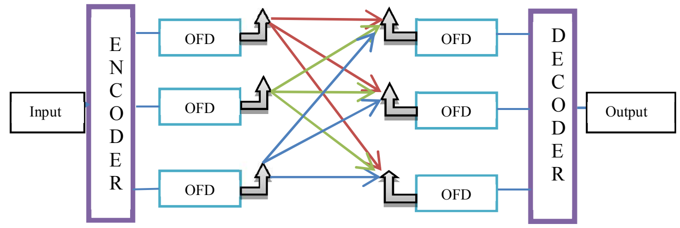

Figure 2: Summarized diagram for LTE processing.

The input bits stream after passing through channel encoder is converted into 2^b symbols where b is the number of bits per symbol. The symbols are mapped over space-frequency code and transmitted over multiple antennas. Each of these codes can be defined as

$$C = \begin{bmatrix} C_1(0) & C_2(0) & C_{M_T}(0) \\ C_1(1) & C_2(1) & C_{M_T}(1) \\ C_1(N-1) & C_2(N-1) & C_{M_T}(N-1) \end{bmatrix} \text{………} (7)$$

Where $C_i(n)$ is the symbol transmitted over nth subcarrier and i_{th} antenna and i=1,2..M_T.

From equations 6 and 7, at the receiver, the received signal after taking the cyclic prefix off and being passed through FFT, on nth subcarrier and j_{th} receiving antenna is

$$Rj(n) = \sqrt{\frac{\gamma}{M_T}}C_i(n).H_{i,j}(n) + N_j(n) \text{…………………} (8)$$

3.2 MIMO Satellite Channel

Although satellite channel modeling work has not been done so far, a preliminary assumption about typical MIMO-Satellite channel is worthy. Let us consider the configuration shown below

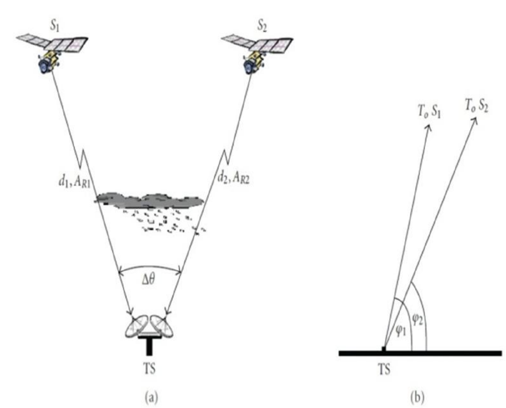

Figure 3: (a) Configuration of 2x2 MIMO satellite channel and (b) relevant elevation angles

We assume 2 satellites and 2 terminal stations configuration as shown in the figure 3(a) above. Two highly directional antennas are pointed towards two satellites s_1 and s_2 with an angle difference $\Delta\theta$. The distance between satellite and TS is d_i (i=1,2) and attenuation caused by the rain A_{Ri} (i=1,2) and $\emptyset i$ (i=1,2) is the elevation angle. $\Delta\theta$ is taken sufficiently large that with rain fading it enables enough correlation for spatial diversity. Also we assume total loss to be $A_i = FSL_i + A_{Ri}$ (i=1,2). FSL is the Free Space Loss [12].

4 Simulation Model

We have simulated the model in two steps. At first, data transmission over AWGN channel and after that over Rayleigh channel and their simulated BER/SER compared to theory for checking compatibility of the developed simulated system [13].
A block diagram which is shown in figure 4 was followed for simplicity in developing the simulating codes. The diagram is given below

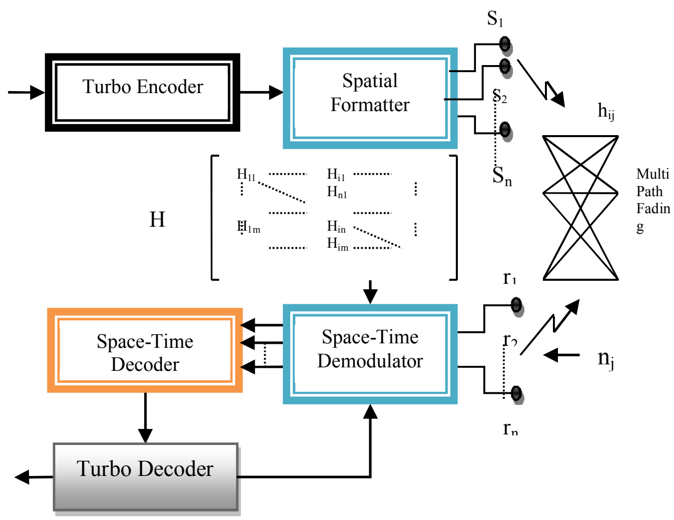

Figure 4.System Block Diagram

Turbo codes are used for simulating which are high performing FEC codes that closely approach Shannon's capacity. This code is useful to achieve reliable information transfer over bandwidth and latency constraint communication link. And this is why it is extensively used in both communication such as HSPA, Wi-MAX and Space Missions [14].

General model for simulation [15]:

- **i.** Generation of random bits
- **ii.** Modulating the bits into symbols +1's and -1's or 00,01,11,10
- **iii.** Adding Additive White Gaussian Noise to the signals or Pass through Rayleigh Channel when required.
- **iv.** Demodulation of the received symbol based on the location in the constellation
- **v.** Finding the difference between Transmitted bits and received bits
- **vi.** BER found by dividing the number of errors to bits that was transmitted.
- **vii.** Recap the same for other Eb/No values BER graphs are plotted.

5 Results and Analysis

5.1 Experimental Analysis

In this section we have described the outcome which has been simulated using MatLab.

The following figure 5 shows the BER against E_b/N_0 of BPSK and QPSK in AWGN channel. Its shows the simulated BER is very close to theory over the channel. Parameters those have been used for simulations are- number of bits = 600, modulation = QPSK, bandwidth =5MHz, FFT size = 512, cyclic prefix = 128, turbo coding, code rate =1/3, channel = AWGN.

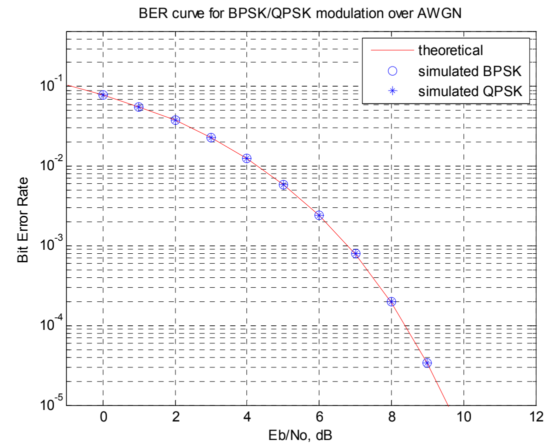

Figure 5: BER performance analysis for BPSK/QPSK over AWGN channels

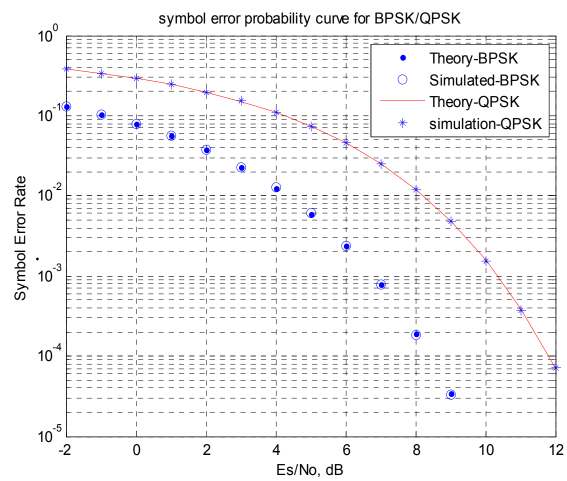

Figure 6: SER analysis for BPSK/QPSK

The above figure 6 shows the comparison for BPSK/QPSK SER over AWGN channel. We see that in order to maintain same SER as BPSK, QPSK requires higher E_b/N_0. The reason is that it transmits two bits per symbols. Therefore per symbol it requires double the symbol energy of BPSK.

On the other hand, figure 7highlightsover Rayleigh channel. In the figure, the simulated BER is almost similar to theory. But it requires higher E_b/N_0 compared to AWGN channel.

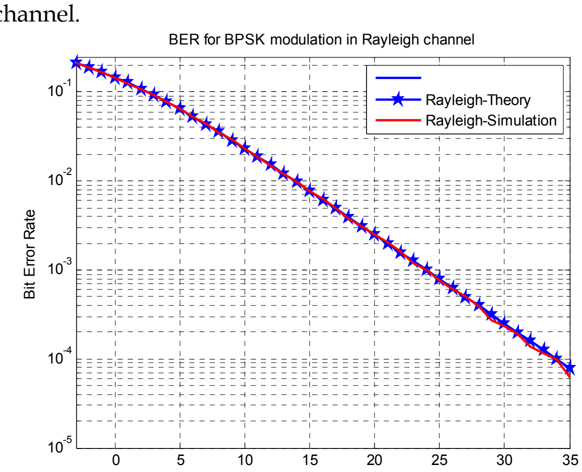

Figure 7: BER performance analysis for BPSK in Rayleigh channel

5.2 Evaluation

The main goal for this research work was to investigate the suitability of LTE over satellite systems using dual-satellite MIMO systems. Therefore satellite links were modeled as MIMO transmission model:

a. The satellite channels were assumed to be identically independent fading channels.
b. As per Alamouti coding the receiver had perfect channel state knowledge.
c. In LTE, OFDM splits a wide band into smaller narrowband signals.

The summarized results are:

a. The MIMO integrated with LTE and Satellite fading channels and behavior studied.
b. We have successfully verified the implementation of MIMO-OFDM model over satellite in forward link to enhance the capacity and provide a suitable means for LTE transmission over satellite channel.

6 CONCLUSION

This research concentrated on developing a simulator for QPSK and OFDM system with turbo coding. The scenarios assumed are 2x2 MIMO with AWGN, Rayleigh and Rician channels. The basic modulation schemes used are BPSK and QPSK. Turbo coding has been used for encoding and decoding. LTE pre-coding has been used for designing MIMO pre-coder. For OFDM parameters, LTE specification with 5MHz bandwidth has been used. Finally the models designed are integrated and implemented on satellite fading channels. The results were plotted in terms of Bit Error Rate (BER) against Signal to Noise Ratio (SNR) and the plots were discussed.

LTE implementation over satellite has a great potential. For simplicity here in this project LTE transmission over 2x2 MIMO using just 5 MHz and basic modulation scheme QPSK has been examined.

7 FUTURE WORK AND DIRECTION

This project concentrated particularly on single code word for code word to layer mapping as rank 1 transmission for simplicity. In future we can check out rank 2 transmissions with two code words for code word to layer mapping on two antennas. Consequently the pre-coding scheme from LTE code book to follow will differ from the one followed in this dissertation. Hence, we may have to use composite pre-coder for better performance by adding a Cyclic Delay Diversity pre-coder on top of the existing pre-coding.

In future, LTE over satellite in uplink can also be investigated. Since LTE does not support MIMO in uplink, SIMO can be a perfect and ideal choice for mobile and cellular data transmission and thereby a good opportunity to have a look at for investigation. For modulation and multiplexing, obviously Single Carrier OFDM or Hybrid Single Carrier OFDM as mentioned in LTE standard can be used which would help further in satellite communication, keeping in mind about large satellite back-off required and also because in this case we are using GEO satellites .

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