Satellite Communication Link and Design: Improving Design Architecture in GEO satellite using 16-QAM TCM with DS-CDMA

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Abstract

This paper is intended for changing the satellite communication link and design to proper and more secure link and design. This paper demonstrate about the current technologies using in satellite and compare with new advanced technology, DS-CDMA using 16-QAM TCM. In this system, DS-CDMA is promoted to GEO satellite communication system. This makes it possible for communicating between subscribers with trusted security. But many satellite users are getting headache about justifying the dish. This makes the satellite to develop slower. Hence, this paper added the AST system for tracking the GEO satellite on behalf of users based on user's position.

1. Introduction

The wireless communication is the most amazing and most popular communication system over the world. In this new age, one can't live without wireless communication such as radio, television, microwave oven, remote control, mobile phones and GPS. Even using the Internet on the way is most popular in today. Among these variations, satellite communication is the major backbone for phone, video and data transfer services. The idea of using a satellite for communication is old enough for decade [1], [3]. But the enormous technologies are evolving to improve the performance of satellite communication link. Code Division Multiple Access, so called CDMA, is also a new technology for wireless communication. Currently, CDMA technology is using on cellular phone networks. The secure and marvelous capacity of CDMA persuades the people to transfer to CDMA era [6]. Because of the difficulty to jam or detect spread spectrum signals, the first applications were in the military field. However, nowadays, spread spectrum systems are gaining popularity also in commercial applications [11].

TCM is developed by Dr.Ungerboeck at IBM Zuerich Research Laboratory. TCM technology is used in many communication fields such as Digital Subscriber Line (DSL) and modems [21]. Because of the many advantages of TCM, new technologies are emerged based on the TCM [2]. Because of more probability in errors, QAM is mostly use in wired line. But 16-QAM is used for wireless satellite communication in this proposed system. As far as we know, this is possible by combining QAM and TCM.

In this paper, we show that how truly reliable secure and faster speed communication we can make in GEO satellite communication system. We present also about Automatic Satellite Tracking (AST) system for easier to use without prior knowledge about satellite communication. We introduce the idea of combining modulation and security for better enhancement on satellite communication link design.

The paper is organized as follows: In section 2, related works and problem issues about TCM and CDMA are described. Combination of TCM, 16-QAM and CDMA is described in section 3. In section 4, we demonstrate our proposed satellite link and design. After that, the important description about simulation system is explained in section 5. Finally, we conclude this paper with a brief discussion section.

2. Related Works and Problem Issues

The basic understanding of how amplitude and frequency are used to form the wave is explained in [7]. The frequency, amplitude, wavelength, and speed are defined precisely with math examples. Freeman [5] provides the basic idea of transmitting waves. This includes modulation and coding. This book explains the overview of telecommunication system. 16-QAM design and modulation is explained with figures and examples in Tomasi [21]. Wang and Speidel [23] give the analysis of how to recover the 16-QAM symbol for timing recovery. They investigate the performance of the digital symbol timing recovery schemes for 16QAM upstream transmission of DOCSIS Standard. Ungerboeck [22] introduces the idea of TCM and set partitioning. The extension of this work is also found in [16]. In [2], S. Baro, G. Bauch, and A. Hansmann extend the idea of TCM to increase spectral efficiency. They propose new trellis codes found through systematic code search. These codes achieve the theoretically maximal diversity gain and improved coding gain compared to known codes. To be better understanding of wireless communication, Dr. Feher [4], and Goldsmith [8], are the good books for fully understanding. Schlegel [17] describes the wireless random packet multiple access method using CDMA. Z. Schlegel analyses how to send a novel packet format which consists of a short header and a data portion. Each header is spread with a unique spreading code which is identical for all users and packets. Timotijevic [20] proposed how to improve the performance of ATM transmission over a DS-CDMA satellite link. The capacity of a DS-CDMA cellular system is analyzed by Kasengulu [9]. There is a problem in transmitting 16-QAM to the air because of closer points. So, current system uses QPSK as standard transmission in mobile system. Current system only uses QPSK and CDMA in LEO system for mobile network [10]. After observing detail, we can overcome the problem of 16-QAM by combining 16-QAM with TCM. This fact leads us to use new communication design in GEO satellites. Thus, we extend the concept of TCM by combining with DS-CDMA to form more reliable and secure system in GEO satellites.

3. Using 16-QAM TCM with DS-CDMA

The following sections explain the components necessary for our proposed system.

3.1. Quadrature Amplitude Modulation

Quadrature Amplitude Modulation (QAM) is the combination of voltage and phase angle. The basic QAM can get 4 different waveforms. In this paper, we emphasize on 16-QAM to get 16 different waveforms. That means we can transmit 4 bits at a time. The serial input from file is buffered to get 4 bits and these 4 bits are transmitted parallel to I, I´, Q, and Q´ channels. QAM equation is:

$$s(t) = v_1 \cos(\theta(t)) \cos(2\pi f_c t) - v_2 \cos(\theta(t)) \cos(2\pi f_c t) \quad \text{--- (1)}$$

The I and Q bits determine the polarity (logic 1= positive and logic 0 = negative) at the output. The I´ and Q´ bits determine the magnitude (logic 1=0.821V and logic 0=0.22V) [21].

Table 1.Truth tables for the I and Q channel

I	I'	Output
0	0	-0.22 V
0	1	-0.821 V
1	0	+0.22 V
1	1	+0.821 V

Q	Q'	Output
0	0	-0.22 V
0	1	-0.821 V
1	0	+0.22 V
1	1	+0.821 V

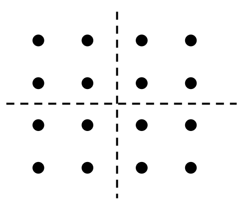

Figure 1. Constellation diagram

The bit rate in each channel is $f_b/4$, f_b is the input data rate. Currently, QPSK is used in mobile transmission. QPSK only take two bits whereas QAM take four bits at a time [12], [18], and [21].

3.2. Trellis Code Modulation (TCM)

To understand the TCM, we have to understand the basic idea of lattice, cosets, and convolutional code

3.2.1. Lattice. A lattice is a simple concept to visualize. It is just a set of points that have some "regular ness". The lattice below is a general 2 dimensional lattice and it has a specific name called Z^2. Z stands for a field consisting of integers and 2 for the order of the dimension. A Z^N lattice would the same thing in N dimensions.

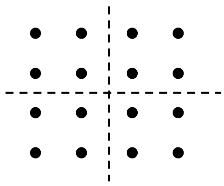

Figure 2. Two dimensional lattice, Z^2

3.2.2. Coset. A translation of a sub-lattice (or a subset) by an element of the original lattice is called a coset.

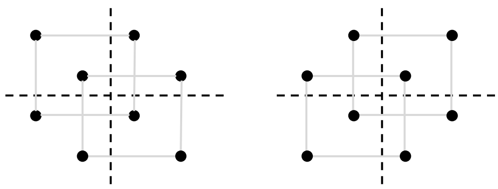

Figure 3. Two unique cosets which when combined give the general Z^2 lattice

Together the two cosets make the original lattice of Z^2. A subset can have many cosets. All cosets are disjoint which means they do not share any points. The union of all unique cosets gives the parent subset [15]. The simple rules for partitioning the cosets are:

1. The distance between each point in the divided subset is the same.
2. The distance is larger than the distance between the points in the previous level subset.
3. There are equal numbers of points in each coset.

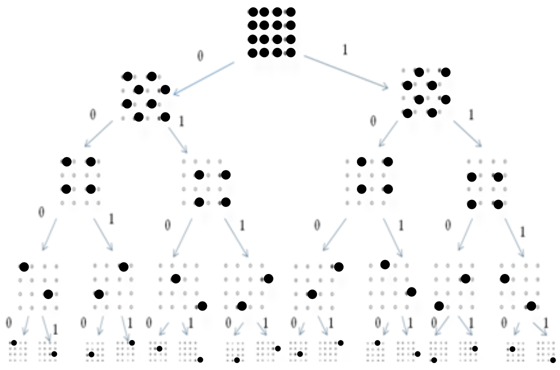

Figure 4. Partition of 16-QAM lattice into cosets

3.2.3. Convolutional code. Convolutional codes are commonly specified by three parameters: (n, k, m).

- **n** = number of output bits
- **k** = number of input bits
- **m** = number of memory registers

The quantity k/n called the code rate is a measure of the efficiency of the code. Commonly k and n parameters range from 1 to 8, m from 2 to 10 and the code rate from 1/8 to 7/8 except for deep space applications where code rates as low as 1/100 or even longer have been employed [10]. Another parameter is constraint length of the code (L). The constraint length L represents the number of bits in the encoder memory that affect the generation of the n output bits and is defined by:

$$\mathbf{L = k\,(\,m - 1\,)} \qquad \text{--- (2)}$$

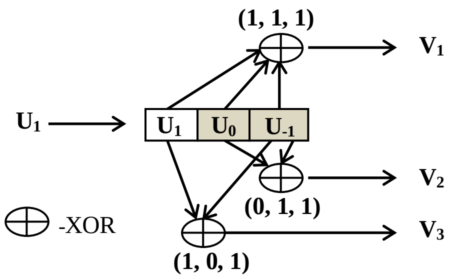

Figure 5. (3,1,3) Convolutional code with 3 memory registers, 1 input bit and 3 output bits

The number of combination of bit in the shaded registers are called the states of the code and are defined by: Number of states = 2^L. For example, in above figure 5, we get L = 1 . (3 - 1) = 2, and number of states = 2^2 = 4 [14].

3.2.4. Trellis code modulation (TCM). TCM is the combination of coding and modulation. TCM use Euclidean distance instead of Hamming distance. Euclidean distance is the straight line distance between any two points, and is calculated from the given formula.

$$\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \qquad \text{--- (3)}$$

Squared Euclidean Distance(SED) is the squaring of the Euclidean distance. TCM limit the allowed sequence to reduce the errors in decoding. Only the points with largest SED are allowed to transit. And coding gain is calculated from the SED before and after the coding. TCM take k bits and produce k+1 bits in another words it doubles the constellation points. TCM use convolutional coder to encode the input sequence. TCM take 2 bits as convolution code inputs and produce 3 coded bits. Another input bit is transmitted without coding. When we transmit first, we use coded bits and then we use uncoded bit at the last. It is because in cosets top levels have smaller SED than the lower levels. Smaller SED means more errors or misinterpreting can occur. To get interference in uncoded bit, we need an error of 180°. Thus, TCM control the occurrences of error. That fact cause increases in coding gain. The coding gain from 8PSK to 16-QAM with 16 states is 6.1dB. Langton [16] explain how to partition the subset for 16-QAM and how to calculate the coding gain of TCM. TCM can't fulfill the need of multiple users. Therefore, we need multiple access system.

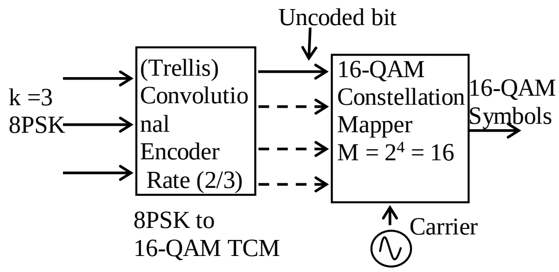

Figure 6. TCM encoder diagram

3.3. Code Division Multiple Access System

Multiple access system is the system in which many users share the some transmission medium to communicate [4], [11]. This medium can be frequency, time, or code. In code sharing, each transmission uses unique code but using same frequency and at the same time.

Spread spectrum is the technique of spreading the data over given bandwidth (spectrum). This causes the transmitting power to distribute to all frequency. Thus, it generates only a little interference to other sources. Again, it causes the spread data to receive incorrectly without same spreading code. This fact innovate the idea of security. Currently, there are two types of spread spectrum. They are Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS) [4] and [21]. FHSS is mostly used in military communication and it is very complex to use. DSSS is mostly used in commercial and everyday usage. DSSS use spreading code to spread the data. We require only less expensive device to generate spreading code (chip code).

Code Division Multiple Access (CDMA) is the code sharing system that use spread spectrum technology. CDMA that use DSSS is called DS-CDMA. DS-CDMA is widely used and accepted as de-facto standard for wireless communication. 802.11 families used DS-CDMA as their multiple access system [11]. This proposed system use DS-CDMA as multiple access system. Later on the term CDMA means DS-CDMA. Because of the spreading code, only user who has same spreading code can receive the data correctly and others only seen this data as noise. This adds the security feature to CDMA system. We use this security feature to get better communication design.

CDMA is the basic idea of mathematic calculation. Let's find out about that. First data sequence *d(t)* is multiplied with spreading sequence *g(t)*. The resultant signal is

$$s(t) = v.d(t).g(t) \qquad \text{--- (4)}$$

And then multiplied with carrier for modulation.

$$s(t) = v.d(t).g(t).\sin(2\pi f_c t) \qquad \text{--- (5)}$$

This is transmitted to the antenna to destination. At the receiver side, we multiply this signal again with the carrier. So, we get

$$rcv(t) = v.d(t).g(t).\sin^2(2\pi f_c t) \qquad \text{--- (6)}$$

By the trigonometric identity

$$\sin^2(2\pi f_c t) = 1 - \cos(4\pi f_c t)\text{, so} \qquad \text{--- (7)}$$

$$rcv(t) = v.d(t).g(t).(1 - \underline{\cos(4\pi f_c t)}) \qquad \text{--- (8)}$$

We can filter out the underline part. So, we left

$$rcv(t) = v.d(t).g(t) \qquad \text{--- (9)}$$

Now, we multiply this remaining signal with *g(t)*, the code sequence and we get

$$rcv(t) = v.d(t).g(t).g(t) \qquad \text{--- (10)}$$

g(t) is the orthogonal sequence and can be filter if we use same sequence otherwise this multiplication will give zero value. Like this

$$a * b = \sum a_j b_j = a_1 b_1 + a_2 b_2 + \cdots + a_n b_n = 0 \qquad \text{--- (11)}$$

$$a * a = \sum {a_j}^2 = {a_1}^2 + {a_2}^2 + \cdots + {a_n}^2 = n \qquad \text{--- (12)}$$

$$b * b = \sum {b_j}^2 = {b_1}^2 + {b_2}^2 + \cdots + {b_n}^2 = n \qquad \text{--- (13)}$$

Thus, we only left with *n*, this value is determined by only two values, positive or negative. If *n* is positive, we use 1 otherwise we use -1. Finally, we get our data back.

$$rcv(t) = v.d(t) \qquad \text{--- (14)}$$

In current CDMA system such as IS-95 and CDMA 2000, we use three spread sequence [19]. First with Walsh Code, then with a code called Short Code and then with one called Long Code. For simplicity in simulation, our system only uses Walsh Code as a spreading code.

3.3.3. Walsh Code. Walsh codes are created out by Haddamard matrices and transform. All codes are orthogonal to each other. The code length is the size of the matrix. Each row is one Walsh code of size N.

$$H_0 = [0] \qquad H_1 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$$

$$H_{N+1} = \begin{bmatrix} H_N & H_N \\ H_N & \overline{H_N} \end{bmatrix} \qquad \text{--- (15)}$$

In our system, we use Walsh Code of size 4 to simulate the code for 15 users. All zero is used for broadcasting to all members. The full examples and description about Walsh Code, Short Code and Long Code can be available at [8] and [13].

4. Proposed Satellite Link and Design

The proposed system design is described in the following figure. In this figure 7, three input bits from the file are entered into the TCM encoder. This process will produce four outputs and these output bits are fetched into CDMA slot. All the slots are multiplied with Walsh Code and resulted bit sequences are mapped with constellation mapper. Finally, data sequences are multiplied with carrier and produce 16-QAM waveform output. At the receiver side, above procedures is worked as reverse.

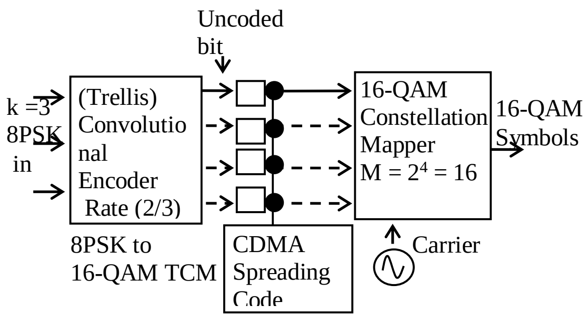

Figure 7. Proposed Design of 16-QAM TCM with DS-CDMA

This proposed design solves the problem of 16-QAM TCM to transmit in the air (wireless). Currently, QPSK is used in mobile system. But data capacity is only 2 bits at a time. Because of the prone of errors, 16-QAM is not used. So, we use TCM to handle this problem and to correct them according to the allowed sequences. And also CDMA is used to lessen the interference from other. Thus, this proposed design adds not only the data capacity but also the security to current system.

4.1. Satellite System

The idea of using satellite for communication medium is started in 1945 by Arthur C. Clarke. He said that satellite with circular equatorial orbit and radius of about 42,242 km will circle the earth as earth's speed (means 1 circle for 24 hr). So, this satellite will fix in sky and move as the earth's rotation. This type of satellite is known as Geostationary Earth Orbit (GEO) satellite. GEO satellites are orbit in the equator (latitude zero). There are three types of satellite based on their destination from the earth surface. They are LEO (Low Earth Orbit) satellite, MEO (Medium Earth Orbit) satellite, GEO (Geostationary Earth Orbit) satellite [3].

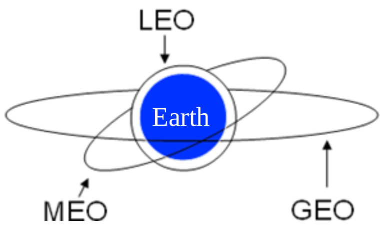

Figure 8. Satellite Orbits

This paper is designed for GEO satellite system. Because we have to track only one time to the GEO satellite and no further tracking is needed. Most GEO satellite users are fixed stations so we can get desired power to transmit the 16-QAM output without worrying about attenuation. To cover nearly the whole earth, we need only three satellites facing 120° to each other. We need security for broadcasting program that are only allow to the prepaid customers or members. Because the footprints of GEO satellite are large, every user can get the data easily. Thus, we add the security feature of our proposed system in GEO satellite communication for better data capacity and security.

4.2. Automatic Satellite Tracking

Automatic Satellite Tracking (AST) system is the added extra feature for user who doesn't know about how to justify the dish. AST is very simple to understand. We need two values to justify the dish: elevation and azimuth. Elevation is the angle of upward tilt of the dish from the ground. The equation for elevation (*EL*) is:

$$EL = \tan^{-1}\left[\frac{m\cos(A)\cos(B)-1}{m\sqrt{1-\cos^2(A)\cos^2(B)}}\right] \qquad \text{--- (16)}$$

A = Latitude of earth station (positive for northern hemisphere, negative for southern hemisphere)
B = Longitude east of the earth station minus the longitude east of the satellite
m = 6.61, the ratio of geostationary orbital radius to that of the equatorial radius of the earth

Azimuth (swing of dish) is the angle from true north that targets the chosen satellite. The equation for azimuth (*AL*) is:

$$AZ = 180 + \tan^{-1}\left[\frac{\tan(B)}{\sin(A)}\right] \qquad \text{--- (17)}$$

180 is deleted for the southern hemisphere.

Suppose that our satellite position is (19.2°E) , the earth station is in England (53.20°N, 2.90°W). To get longitude east, subtract the west value from 360°. So, we get, 360° - (2.90°W) = 357.1°E.

According to the A and B values.

A = 53.2, and B = 357.1 – 19.2 = 337.9°

Now, we calculate Equation 16 and 17 with given values.

$$EL = \tan^{-1}\left[\frac{6.61\cos(53.2)\cos(337.9)-1}{6.61\sqrt{1-\cos^2(53.2)\cos^2(337.9)}}\right]$$

$$= \tan^{-1}\left[\frac{2.667}{5.499}\right] = \tan^{-1}(0.485) = 25.87°$$

$$AZ = 180 + \tan^{-1}\left[\frac{\tan(337.9)}{\sin(53.2)}\right]$$

$$= 180 + \tan^{-1}\left(\frac{-0.406}{0.801}\right)$$

$$= 180 + \tan^{-1}(-0.507) = 153.11°$$

Note that latitudes above about 81° cannot see any part of the geo-arc of satellites. Also, the longitude difference between the earth station and the wanted satellite cannot exceed this value.

Both the value of EL and AZ is in degree. We use these two equations to get the elevation and azimuth angles of dish based on the user position. In our system, user only need to select which country is currently in, the calculation is carried out automatically by the system and result is give back to the user. This result tells which degree to enter for the elevation and azimuth. The more explanation about satellite tracking concepts and essential equations are in [10].

5. Simulation

We demonstrate our system with computer simulation written in Java. In the simulation, we demonstrate how users can connect with predefined GEO satellite with AST system. We allow 15 users to test the satellite connection. These 15 users only need to choose the country in their regions, AST system calculates the degrees for their dish. And we install our new proposed transmitter design in each dish to communicate using 16-QAM TCM proposed design with DS-CDMA system. The simulation gives the clear demonstration of how the data is change from 3 input bits to 4 output bits. And show the transformation of TCM outputs to CDMA spreading code in digital forms. After that the simulation shows how the 16-QAM waves formed in order to transmit the data. First, user must choose which country they want to install dish. And AST will connect for you with calculated azimuth and elevation. After user has been connected, user can send the required data to other users. In our simulation, one GEO satellite is used for easier to demonstrate. In real world, we need three GEO satellites facing 120° to each other in equator.

Figure 9. AST system

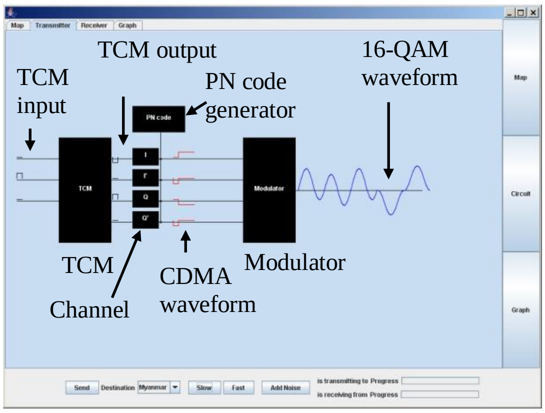

Figure 10. Transmitter design

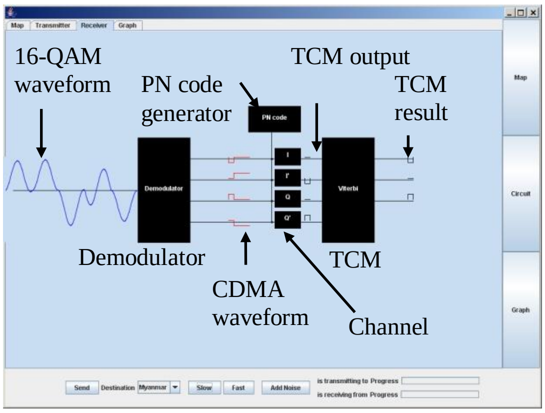

Figure 11. Receiver design

6. Conclusion

This paper is intended to develop new design of satellite communication. In this proposed design, satellite link can carry more information with a little errors and retransmissions in GEO satellites. We present how to combine TCM with 16-QAM to get more bits to transmit at a time and to correct the errors automatically. In addition, Great security feature of DS-CDMA is combined to get security and less interference in data communication. Satellite tracking is resolved by AST system to get connection with GEO satellites without knowing about satellite knowledge. This proposed system is not only design for satellite system but also for other communications. Further analysis of how to integrate this proposed design in LEO and MEO system is required.

7. References

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