Modulation systems used in satellite communications ii computer science

Satellite is the one of the greatest means of communication carrying a large chuck of voice and data stream from one part of the horizon to the other as compared to other medium. In this modern age, communication satellite networks are an indispensable part of the major telecommunication systems. Satellite interconnects the nodes and provides some better advantages in application than the traditional communication systems such as combine massive data connections, mobile communication and direct connection for last-mile users, television and other broadcasting for public [1]. To provide the optimum quality of services (QoS) different types of design techniques needs to be consider for different purposes like distinct types of modulation and coding (channel and source) techniques are used for specific purpose, link budget calculations, selection of radio frequency (RF) etc. Other dominating factors are: permitted earth station size and complexity, the size and the shape of the service area etc [2].

The objective of this paper is to describe different types of modulations systems using for satellite communications. In this report, first I am trying to give some basic information related to the modulation systems and then bring all possible modulation schemes used in satellite communications.

Modulation:

In general view, modulation is the process where the characteristics (phase, frequency or amplitude) of high frequencies are varied along with baseband information. The baseband signal carries the basic information such as the output of video camera, voice coder or digital television. In practical point of view, it is more convenient to carry the modulation at the intermediate

frequency-typically 70MHz [1]. Satellites are usually operate at Gigahertz range of frequency [1]. Sometimes Pulse code modulation (PCM) and Pulse amplitude modulation is used to describe modulation process for baseband information [2].

Modulation Systems for Satellite Communications:

We can divide the modulation systems in two broad categories like

Digital Modulation and Analogue Modulation

Different types of analogue modulation are possible like Amplitude Modulation (AM), Frequency Modulation (FM) and the phase Modulation (PM). Digital Modulation is divided into several categories and each of those uses in specific purpose.

Analogue Modulation:

Let consider a sinusoidal wave k(t):

k(t) = J* cos {2*A? a,¬*f c(t)+AZA±}.....(A)

Where J indicates amplitude, f c(t) denotes carrier frequency and AZA± is the phase of the wave. When high frequency carrier amplitude is changed, then the wave is called amplitude modulated and scheme is known as the amplitude modulation. Likewise when carrier phase or frequency is changed then it called frequency modulated and phase modulation respectively and techniques are known as frequency and phase modulation respectively [1].

Amplitude Modulation In preceding section the definition of AM modulation is given where amplitude of the carrier frequency is changed with information signal. An amplitude modulated signal can be given as

V(t)= J{1+g(t)*cos (2*A? a,¬*fc) .....(1)

In equation (1), g(t) is the message signal and the fc represents frequency of carrier . J{1+g(t)} is the amplitude of the carrier and it varies accordance with the signal m(t). If g(t) is the sinusoidal signal and Am and fm is the amplitude and the frequency of the g(t) respectively, then it can be written as follows

V(t)= A{1+Am sin2*pi*fm}cos (2*A? a,¬*fc) .....(2)

The efficiency of spectrum of (t) is obtain by expanding equation (3) and it can be shown that there are two side bands in the spectrum like upper and lower. The upper and lower sidebands consists of similar shape of spectrum like message signal g(t) [1]. The main advantage of the AM is those modulated carriers easily detectable by using a simple process called envelop detection. An envelope detector is the simple large time constant RC circuit. But the difficulty is that AM modulation is rarely used for satellite communications because [1]:

An amplitude modulated signal is very susceptible to the signal fluctuation

It requires very high Signal to Noise ratio for desire amount of quality.

AM is used in laser inter-satellite links (ISL) in an alternate form called “ ON-OFF” keying.

There are two forms of AM systems:

Double Side Band Suppressed Carrier (DSB-SC)

Single Side Band Modulation (SSB)

In DSB-SC, two side bands are transmitter while carrier is omitting. In this case, modulated wave amplitude and the signal amplitude is not same. As a consequence of that it reduces the simplicity of the demodulation in FM. DSB-SC is currently not using for the satellite transmissions but this technique is good for understanding the SSB modulation [1].

SSB is another alternative form of the AM systems. This technique is suitable for the application where the bandwidth is the premium. In AM modulation, both the side bands consist of baseband information and transmission of same information twice showing the redundancy. In this case, SSB removing one sideband so bandwidth of the RF signals is similar base band signal. Sometimes the carrier is also removed then it is called SSB-SC (suppressed carrier) [1]. SSB is detected at the receiver end using synchronous detector. There are two factors playing an important role to make the SSB suitable for the satellite communications: bandwidth and carrier to noise ratio. SSB is using in satellite communication where voice signals are multiplex to make a baseband composite signal. Another form of SSB is using in the mobile satellite communication is known as the ACSSB (Amplitude Companded SSB) because in mobile satellite service efficiency of the bandwidth is desired.

Frequency Modulation:

In satellite communications FM systems are used to use for different applications. In FM, carrier frequency is changed with the signal information [1]. This modulation systems are using where receiving technique is simple and low-cost [4]. An example is Inmarsat Paging system because of that paging system is the need for simple and inexpensive receiver [1]. The common methods of modulation used in the fixed-satellite service are FM for analogue signals [5].

FM has been largely used in satellite communications. It is particularly convenient when a single carrier per transponder is used and where the constant envelope of the FM signals allows the power amplifiers to operate at saturation, thus making maximum use of the available power.[5]

Digital Modulation:

Like analogue modulation , in digital modulation systems carrier parameters like phase, frequency or amplitude are varied with information signals. According to this there are three basic modulation schemes in digital modulation like Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK). There are many variations and combination of these techniques. The combination of ASK and PSK is also known as the QAM (Quadrature Amplitude Modulation).

As the advance in technology and limitation of analogue modulation it is now most of the satellite using digital modulation techniques and providing some advantages over analogue modulation like better performance, error detection and correction efficiency, signal to noise ratio etc. So in this paper focus are mainly given to the various types of digital modulation systems.

We can divide digital modulation systems into two large categories [1];

Constant Envelop Modulation and

Non- Constant Envelop Modulation and

The constant envelop class is generally considered as the most suitable for the satellite communications because it minimizes the effect of non-linear amplification in the high power amplifier like TWTA (Travelling Wave Tube Amplifier) or KTA (Klystron Tube Amplifier). In this case the generic FSK is not suitable for satellite communication because it has very low bandwidth efficiency as compared to PSK systems [5]. In this section of the report a brief description of different types of digital modulation systems using in satellite communication is given.

PSK BPSK QPSK:

In PSK system, envelop is constant but the phase changes discontinuously from symbol to symbol. There are two types of classic PSK schemes like BPSK (Binary PSK) and QPSK (Quadrature PSK). Generally, PSK modulation systems with M-ary signals can be used and it’s known as MPSK [5]. MPSK is more suitable than MFSK because it provides better Power Nyquest efficiency than MFSK.

In mobile satellite communication, the most commonly used digital modulation system have been BPSK and different forms of QPSK. It is not surprising that higher order modulation are providing the better performance and efficient as well but they are more sensitive to the channel impairments. Recently, higher order PSK, 16-QAM is using for this purpose. [1]

PSK modulation systems easily represented in the I-Q plane where I and Q planes are perpendicular to each other. One point in I-Q plane is providing the information about the signal state [1]. PSK scheme include two basic techniques like BPSK and QPSK. In BPSK one binary code is represented by the two phases 0 and 180 where in QPSK two binary codes is represented by the four phases: 0, 90, 180 and 270. In multi level PSK, the higher the order the more requirement of power to achieve the same amount of performance [5]. PSK is using for satellite communication because PSK signal can be transmitted through the non-linear channel of a satellite and it depends on the proper choice of the modem filters [5].

Other types of modulation systems use in communication satellite are Quadrature systems where the modulated signals are represented in terms of two channels like I and Q. Three schemes of Quadrature modulation are given below.

OQPSK, offset QPSK or OKQPSK (offset keying QPSK), also known as the SQPSK (Staggered QPSK), is a modified variety of QPSK. In the OQPSK, the value of Q and I channel not changing at same instant because value of Q-channel baseband is delayed by the duration of one symbol. By using this property, OQPSK signals provide the reduction of the non-linear distortion when passing through non-linear element. So in this case, a better performance can be expected in the non-linear space satellite links as compared to the QPSK [7]. In OQPSK systems, maximum phase change is limited to 90o. It’s one of the reasons why OQPSK is advantageous for satellite channels and is used in satellite links [1]. MSK (minimum shift keying) is another coherent frequency shift keying modulation systems with

modulation index 0. 5. It also shows the non-linear property through a non-linear satellite channel and the signal has constant envelop.[5] MSK is spectrally more efficient than the QPSK and OQPSK because its spectrum has wider main lobe than QPSK and OQPSK [9].

QAM:

As there is a very inadequate bandwidth available for each of satellite channels, it is necessary to employee spectrally efficient modulation technique. For wideband satellite communication systems, modified signal constellation QAM is used. [8] Its constant envelops combats with non linearity of the satellite channel; M-ary PSK is typically used in satellite communications systems. But when higher spectral efficiency is expected it cost more power than the other schemes.

FSK:

As described above, in Frequency Shift Keying systems, frequency is shifting in accordance with the message state change [1]. Binary FSK is the easiest type of the FSK allowed only two frequency states and this system capacity can increase by M level of frequency shifting then it is known as the M-ary FSK. In M-ary FSK N numbers of bits are combined to form a symbol. [1]

M-FSK is one of the modulation techniques which efficiency can be increased by increasing the frequencies (M) at additional complication and lesser bandwidth efficiency. In low-data rate and low power applications such as Global paging via satellite communications where M-FSK is using [10]. M-FSK can be used for in land mobile satellite communications where the numbers

of user are stationary. It is valid for low data rate application like paging via satellites [10].

OFDM (Orthogonal Frequency Division Multiplexing) Modulation

OFDM is a mature digital multi-carrier modulation technique has been used in physical layer of broadband wireless air interface standard like IEEE 802. 11/Wi-Fi and 802. 16/WiMax as well as digital video broadcast-Terrestrial DVB-T [11]. Simultaneously, OFDM modulation is attracting more attention for satellite communications and now it is using for DVB-TH. OFDM modulation systems also use in Military satellite communication.

Coded Orthogonal Frequency division Multiplexing Modulation (C-OFDM)

A COFDM modulation system is resistance to the frequency selective fading. This type of fading is seen in the wideband mobile communications. This system is useful for the digital audio and video broadcasting over a long distance. In future, C-OFDM systems would be one of the candidates for direct sound broadcast satellite systems [1].

Trellis Coded Modulation (TCM)

Modulation systems and Error correction coding are combined in Trellis coded modulation systems. To transmit information over the power-limited and band-limited channel, the modulation and the channel coding must be optimized jointly [12].

TCM with Octal Phase Modulation or 8-PSK

8-PSK is a fixed envelops modulation system with greater efficiency in bandwidth. The first TCM application to satellite transmission occurred with the 8-PSK trellis codes. Using a 72 M Hz transponder bandwidth, transmission at up to 155. 52 Mbits/s have been realized [5]. TCM with 8-PSK provides high bit rate which is essential in future for the high bit rate application like images, TV and HDTV services over the satellite transmission [5]. There are various forms of TCM like PTCM (pragmatic) and PPTCM (Punctured PTCM).

The PTCM codes are interesting for satellite transmissions. As an example, a new coding systems using the PTCM 2/3-8PSK code concatenated with Reed - Solomon code in the INTELSAT IDR service and is expected to increase the capacity up to 25% base on the standard A earth station and INTELSAT VII space segment conditions [5]. As the demand is increasing for higher bandwidth efficiency, the QAM trellis codes could find the potential applications in HDTV satellite transmissions in the future. But the main limitation of trellis codes applying in the QAM using in the satellite communications is their non-constant amplitude and more distortion occur when pass through the NLA (Non-linear amplifier) [13]. A precise amplitude control must be used in the receiver end [5].

Trellis coded 16-Phase Shift Keying (PSK) and 16-Quadrature Amplitude Modulation (QAM) modulation systems are used for satellite communications. But the fact is that when the modulation level increases, the constant envelop M-ary PSK modulation systems are inferior to the QAM systems. On the other hand, QAM suffers more distortion in the non-linear satellite communications channels [14]. QAM is suitable for geostationary orbit satellite channel with only Gaussian impairments because of being amplitude

and phase modulated signal, QAM is more sensitive to the effects of interference and fading than MPSK [15].

Single Channel Per Carrier Frequency Modulation with syllabic Companding (SCPC FM)

The main advantage of using SCPC FM modulation with syllabic Companding in satellite communication is to increase the limited capacity and this capacity increment is fully depends on the syllabic companding. The compadors in the transmission side take a wide volume of speech signals and reduce by the compressor with small amount of deviations. As a consequence of that in the same bandwidth it would be possible to employee more channels for transmission. And at the receiver end , the expender returns the original voice signals and during the speech pauses suppress the noise link[16]. This bandwidth efficiency can also be applied to the domestic satellite systems where the use of a small earth station and a large number of routes operating with few channels are important [16]. In future for the larger satellite (IntelSat IVA or V), the inefficient use of bandwidth of satellite channel by small carriers, especially in the transponder one of the factors which limits the total achievable capacity of bandwidth. In this case, the use of a SCPC Companded FM would significantly increase the total capacity of the satellite bandwidth without increasing the total segment cost of the earth stations like other modulation systems [16]. From research it can be shown that the use of SCPC FM with compandors will significantly improve the economic scenario associated with the small earth stations.

Wavelet Packet Modulation (WPM):

WPM is a multicarrier modulation system like OFDM using Discrete Wavelet Transform (DWT). DWT is a transformation technique which is a presentation of the composite signal in time and frequency domain. So in WPM, packets structure is divided into time and frequency domain. So when any interference is realize, in TDMA or FDMA system all packets are degraded but in case of WPM, packets are keep away from the interference with the help of providing the appropriate packet structure [17]. Both WPM and OFDM are multicarrier modulation system but the difference is OFDM uses FFT to combine the transmission where WPM use DWT and Bit Error Rate of Wavelet Packet Modulation is much better than the OFDM. Similarity between these modulation systems is High Peak to Average Power Ratio (PAPR). For getting better performance of OFDM, single carrier OFDM (SC-OFDM) is proposed where decreasing PARP was the main goal. It is seen that the PARP is also high in WPM so SC-OFDM can be used to improve efficiency of the WPM. SC-WPM also can be used by exploiting the principal of SC-OFDM [17]. Some experiment shows that the Wavelet Packet Modulation is the effective modulation systems for satellite communications and with lower PARP, SC-Wavelet Packet Modulation (WPM) would enable the broadband satellite communications [17]. PARP performance of SC-WPM is superior to WPM and OFDM. The Bit Error Rate performance of the WPM is better than OFDM.

Multi-Level Gaussian Frequency Shift Keying (MGFSK)

For specific reasons, MGFSK modulation systems uses in the satellite communications. It also exploiting the technique of narrow band FM which has constant envelop throughout the signal. MGFSK is suitable for satellite communications where the transponders are in saturations and it is also

useful for the transmitter where output amplifier is also saturated [18]. As compared to the 8PSK bandwidth efficiency (3 bit/s/Hz), MGFSK providing bandwidth efficiency is 6 bit/s/Hz [18]. BW efficiency of MGFSK is very similar to the 64 QAM but 64 QAM is not feasible to use in satellite communication because it requires highly linear and well-equalised satellite channels [18]. The key applications of MGFSK are in those satellites which dedicated for ISP traffic, news gathering satellites and some specific military applications.

Pulse Code Modulation (PCM)

Pulse code modulation system is another technique which is employed in the satellite communications. Here in PCM the main aim is to coding the analogue signal for digital representation and then transmitter by using digital techniques. In PCM, analogue signals are sampled in a periodic manner of time in a rate of Nyquest Sampling rate (twice the highest of baseband frequency) and then quantized in agreed manner. To keep the error in certain level, quantization step should keep as low as possible. [5] Different types of pulse code modulation are seen like DPCM and ADPCM.

Other Modulation Systems use in Satellite Communications

Delta modulation (AM), Pulse amplitude modulation (PAM), Pulse Time Modulation (PTM) etc. Spread Spectrum modulation systems are closely related to the PCM [1].

Conclusion: In this report it has been trying to make an overview of the modulation system used in the satellite communication channels. A different type of modulation systems has been described. The selection of modulation

systems is depends on the various factors like type of the channels; constraints imposed by the earth stations, hardware limitations, bandwidth limitations, power limitation etc [1]. One fundamental characteristic of the satellite communications channels is the trade-off between the bandwidth and the power to obtain the received signal with certain level of quality. In case of the bandwidth limited channels, spectrally efficient modulation systems are used where penalty is paying for additional carrier power. In the power limited links, bandwidth efficient modulation is using which related to the hardware constraints as well.