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Augmenting Satellite Channel Capacity by Appropriate Techniques

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Abstract: The satellite channel capacity depends on available bandwidth (B_w), transmit power, receiver sensitivity, sometimes referred as gain-to-noise temperature ratio (G/T), ambient noise density etc. The other parameters which dictate channel capacity are type of modulation scheme, access technique, use of FEC (forward error correction) technique, area illuminated by the satellite beam at a particular period of time, required probability of bit error rate, under identical assumption of channel conditions. Digital information transmission and reception is being considered for study and analysis purpose. The satcom. Network throughput optimization depends on many techniques like using proper Modulation scheme to optimally use the power equivalent bandwidth of the transponder, the frequency allocation to allot the central BW of transponder to location falling beyond 3 dB. BW contour, use of spot beams with on board satellite switching, adaptive bit rate to reduce the fade margins which sometimes are of the order of 10 dB. Or so. , appropriate access schemes like carrier-in-carrier (CnC), also called paired carrier multiple access (PCMA) for satellite where enough onboard power generation capability is available. Techniques like MIMO, which in the form of Dual-Circular polarization for one onboard antenna and multi antennas on ground stations fits best into requirement as on today's limitations of satellite having constraints of less space, weight and available DC power still exists. MIMO is more suitable for Power limited satellite channel. The access techniques like TCP/IP accelerator, firewall, virtual private network (VPN), traffic shaping, intrusion prevention system (IPS) – antivirus/antispyware/antimalware, web filter and antispam for internet application will further optimize the capacity of a given satellite channel. Some of the techniques like modulation and FEC (Forward Error Correction), PCMA, frequency allocation for optimal communication can be implemented by configuration of modem or changing the itself but the few of them demand on board hardware change. These techniques are MIMO and SSTDMA Satellite Switched TDMA.

Keywords: PEMA, Paired Carrier Multiple Access, MIMO, Multi Input Multi Output, TCP, Transmission Control Protocol, E_B/N_O- Bit energy-to-noise Power spectral density, IP, Internet Protocol, PCMA, Power equivalent bandwidth

I. INTRODUCTION

Satellite communication is specifically useful for wide area coverage, communication on mobile platforms like moving vehicles, trains and aircraft, etc. Network topology and the "anywhere and everywhere", benefit of global coverage, better reliability, immediacy and scalability versatility, point-to-multipoint and broadcast capability. The communication is distance-insensitive and end-to-end, it does not depend upon the terrain in between two stations. It is attractive, particularly for hilly, unreachable and remote areas. The major limitations of satellite communication are latency, expensive, large upfront capital costs, congestion of frequencies and limited orbital slots. There are specific situations where only satellite communication is a viable solution. There are numerous applications of satellite communication but the B_w spectrum is limited. There is always a move to increase the channel capacity of satellite links by utilizing different latest techniques like modulation schemes, access techniques, higher and higher power generation both at ground station as well as onboard satellite. Bigger and bigger aperture antennae are being installed onboard satellite and ground station (in case application permits) depending on the design and cost of satellite in question.

However there are some disadvantages like, latency, limited spectrum for GEO satellite, the number of satellites that can be placed in the equatorial plan are limited to 180 in number with 2° separation.

To enhance throughput improvements required in the subsystem/system, software, hardware, choice of suitable type of protocol for specific applications, etc as following:

- Using power efficient modulation schemes as power onboard satellite is a limiting factor.
- Use of suitable modulation schemes to be suitable for operation even when power amplifier onboard satellite working in saturation i.e. minimum I/P back off and minimum O/P back off.
- Use if these channel coding schemes requiring Eb/N_o near to Shannon's Limit of – 1.59 db E_b/N_o for near error free communication.

- Maximum gain-to-noise temperature (G/T) of earth station receiver and onboard satellite Transponder utilizing best state-of-the-art LNAs and other components, for a fixed diameter antenna at both places, i.e, onboard and at ground station.
- Suitable protocol for specific applications so that B_w is not wasted in re-transmissions and making available required bit error rate (BER) for protocol to work optimally.
- Using appropriate access scheme for specific application[8]

With the continuous developments in technology we are in a position to generate higher power onboard satellite as well on ground station. It is also possible to improve the G/T of onboard transponder by both optimizing gain of a fixed dia. Antenna and reducing the noise temperature of electronic components being used. New modulation/demodulation schemes are being developed with lesser and lesser E_b/N_o required for Particular BER requirement. New access techniques suitable for specific applications are being used. Better channel codes are being evolved to give maximum coding gain with minimum latency. Polarization diversity is being used to increase the channel capacity. Space division multiple access techniques in the form of MIMO are being used to increase channel capacity and improve BER for a given satellite system. it is also used to encounter fading due to rain, fog, etc. MIMO technique is also used to provide communication at locations up to 75^o latitude satisfactorily, i.e., at sites where satellite elevation angle is of the order of 15^o.

II. CHOICE OF SUITABLE MODULATION/ DEMODULATION SCHEME [5]

The schemes will be normalized to bits/S/Hz over the existing satellite channels. It has been observed that terrestrial digital radio systems use high level amplitude modulation (QAM) to increase spectral efficiency, but this is not feasible in satellite communication due to following reasons:

a) Even as on today, satellite links are severely power limited.
b) The onboard satellite transponder amplifier has to run in nonliner region to get more power efficiency, due to the fact that dc power puts a constraint on satellite.

In satellite communication, the decrease in bit error rate provides better quality of service, must not be dependent at the expense of scarce power resource onboard satellite. At the same time, modulation schemes which do not work well with nonlinear amplifiers are not suitable for satellite applications as power amplifier onboard satellite cannot be backedoff considerably to run it into linear region at the cost of reduced power efficiency.
It may be observed that for a long time, QPSK was at a powerful position as being almost the only exclusive modulation method in virtually all-digital satellite systems. It may be observed that as the modulation levels increase, constant envelope M-PSK becomes in efficient. On the other hand, QAM suffers more degradation in a nonlinear environment such as a satellite channel.

Table 1 shows the relative spectral efficiency and radio frequency (RF) power utilisation for four common modulation and coding schemes. The spectral efficiencies assume a channel filter alpha value of 20 per cent.

Table 1. Relative spectral efficiency and radio frequency (RF) power utilisation for four common modulation and coding schemes.

Modulation and coding	RF Power required (E_b/N_o Required) at 10 BER	Spectral efficiency bits/S/Hz
QPSK 3/4	Low	1.3
8PSK 3/4	Moderate	1.9
16 APSK 3/4	High	2.5
32 APSK 3/4	Very high	3.1

Table 1

Due to costly satellite bandwidth and limited spectrum available, there is ever increasing demand for higher information rates, B_w efficient modulation schemes are the demand of the time. While trying to increase B_w efficiency, care must be taken to design "balanced" link design so that onboard power amplifier I/P may not be required to backed off as much as 7db or so, to strike a balance between bandwidth and satellite power resources, at least for the time till we can generate 4-6 times more power as compared to present day's power levels being generated with the help of solar panels onboard a satellite.

Using high-level modulation schemes requiring E_b/N_o more than the order of 10 db for 10^{-6} BER are not recommended on power-limited satellites. For example Insat series satellites in C-Band 40 dBw of EIRP in 36 MHz of bandwidth are available. In a hired carrier of 128 Kbits, the Max(saturated) power available will be 37.5 watt i.e., 15.74 dB_w. For

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multicarrier operation the power amplifier will have to be backed off by 4-6 dB. The available power will be 11.74 dB_w in 128 Kbits B_w. This available power will have to satisfy the power Budget equation as:

$(C/N)_{down}$ = $(Sat)_{down}$ EIRP – Path loss + Earth station G/T-Bandwidth + 228.6 dB

=11.74 - 196.5 + 21 + 228.6 dB, number 51 corresponds to log 128 K

=64.84 dB

E_b / N_o = $(C/N)_{down} - 10\log_{10} 128 * 10^5$ = 13.84 dB

12.84 dB, considering 1 dB as the consolidated loss like antenna-pointing loss, loss in power cables, etc. i.e, maximum EIRP in 128 Kbit carrier will be 15.74 –(4.0) = 11.74 dB_w. Accordingly $(C/N)_{down}$ for a GEO satellite, (taking a distance of 40,000 km, the receiver station may be at high altitude) will be 13.84 dB. Taking 1 dB as overall loss due to miss pointing of antenna, etc. the available $(C/N)_{down}$ will be 12.84 dB using M array modulation schemes like 16 APSK, 8PSK to increase the data rate will not help since E_b/N_o for 10^{-6} BER is of the order of 16 db for 8PSK. Undoublingly, using QPSK will give an advantage of 3 db since B_W gets reduced by 50 per cent, for the same date rate, accordingly C/N goes up by 3 db whereas E_B/N_O remains same (as data rate doubles up). By employing QPSK instead of BPSK, one can double the information capacity with the same available B_W power. However to transmit 3 bits/Hz, i.e., 8 PSK, one will need E_b/N_O which is of the order of 14 dB. Since there will be 33 per cent savings in spectrum B_W, the inband white noise decrease will push the E_B/N_O by 1.23 dB, making available E_B/N_O = 11.84 + 1.23 = 13.07 dB. Whereas E_b/N_O requirement is of the order of 16 dB, obviously the link will not function and BER will increase beyond designed value of 10^{-6}.

To achieve the optimum result, one has to go in for appropriate FEC which will reduce random errors and will provide a coding gain of the order of 5-7 dB. The suggested scheme is convolutional encoding and Viterby decoding along with concatenated Read Solemon (RS) codes. The Read Solemon codes will reduce the bunch errors due to some spike, etc. Accordingly, a concatenated code is suggested.

III. EFFECTIVE USE OF TRANSPONDER BW, USING BW EQUIVELENT POWER OF SATELLITE TRANSPONDER.

It will be shown below why that high gain FEC techniques are required to achieve a reliable (of the order of 99.999%) link and BER of the order of 10^{-6} or better. For a regional satellite system like INSAT series Satellites at C-Band Transmit a power of the order of 40 dBW in a transponder BW of 36 MHz. Without using any appropriate FEC scheme the achievable S/N or E_b / N_o of is of the order of 10 dB. Without considering any fade margin etc. It is clearly seen that if the signal of C-Band Regionl Geo. satellit like INSAT series satellites is received by an antenna diameter of 2.4 meters the S/N ratio for a BPSK modulated signal cannot be more than 10 dB. without any fading margin. 10 dB. S/N ratio or E_b / N_0 = 10 dB. This is not even sufficient for satisfactory communication requirement. In case we want to take advantage of the total BW of the transponder either we have to use power of the transponder which is higher than the ‘power equivalent bandwidth of the transponder’ or have a apoor link quality along with high BER, which is undesirable in most of the today’s requirements. It will be shown below why high gain FEC techniques are required to achieve a reliable (of the order of 99.999%) link and BER of the order of 10^{-6} or better. For a regional satellite system like INSAT series Satellites at C-Band Transmit a power of the order of 40 dBW in a transponder BW of 36 MHz. Without using any appropriate FEC scheme the achievable S/N or E_b / N_o of is of the order of 10 dB. Without considering any fade margin etc.

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Description	Value
Tx. Power at C-Band Transponder of 36 MHz. BW	= 40 dBW.
Spreding loss at a distancce of 40000 KM.	$= 1/4\pi R^2$ = 163 dB.
Power Spectral Density(PSD)	$= \phi$ =40dBW-163 dB= -123 dBW
Power received by 2.4 M Dia. Antenna at efficiency of 80 %	=-123+5.6=-117.44 dBW
Per Hz. Poer Recived	=117.44dBW- $10 \log (36000000)$ =117-44dBW-75.63 dB = -193.07 dBW
Power Per Hz. To Noise Power Spectral Density	=-193.07 dBW-(KTB), T= 290^o K , Band with= 1 Hz.=-193.77-(-204)=10.93 dB.

Table 2

IV. REQUIRED BER FOR TCP/IP PROTOCOL [6]

The round trip transmission delay (RTT) in case of GEO satellites for TCP is of the order of 560 ms. The maximum throughput which can be obtained is giver by

$$\text{Throughput}_{MAX} = \frac{\text{Receiver buffer size}}{\text{RTT}}$$

The maximum buffer size in TCP is 64 Kbps, so the maximum throughput = 64 Kb/.560 = 117 Kbytes, i.e, 936 Kbps. Even if one error occurs in 936 Kbits the packet will be discarded, which corresponds to a BER of 1 $\approx 10^{-6}$, where the efficiency of link falls to 50 per cent. Accordingly for TCP/IP Protocol to work satisfactorily well on GEO satellite, a BER better than 10^{-7} has to be made available to get better efficiency, to permit TCP flow at the rate of 1 Mbps for a buffer size of 64 KB. In TCP receiver window is defined as the number of bytes a sender can transmit without receiving an acknowledgment. TCP uses a receiver window that is 4 times the size of the maximum segment size (MSS) negociated during connection set up time, up to maximum of 64 K Bytes.

V. INCORPORATE SATELLITE SWITCHED TDMA

To achieve better efficency the the wide coverage beam can be split in to many narrow/ spot beams and switchind of the beams can be done by ob board satellite microwave switch matrix. One this type of matrix has been implemented in VI satellite/s, which provide Geo-Global coverage communication. The similar concept can be implemented in INSAT series Regional Satellites to increase the throughput of satellite systems in terms of bits/sec/Hz. This cocept will limit the braod area coverage advantage of the satellite up to some extent. With on board processing (Regeneration Satellites) demultiplexing and multiplexing can be implemented on board so that traffic for a particular region can be seprated and accordingly routed to that region by SSTDMA on board hardware. This will increase the throughput of satellite systems in terms of bits/sec/Hz many times.

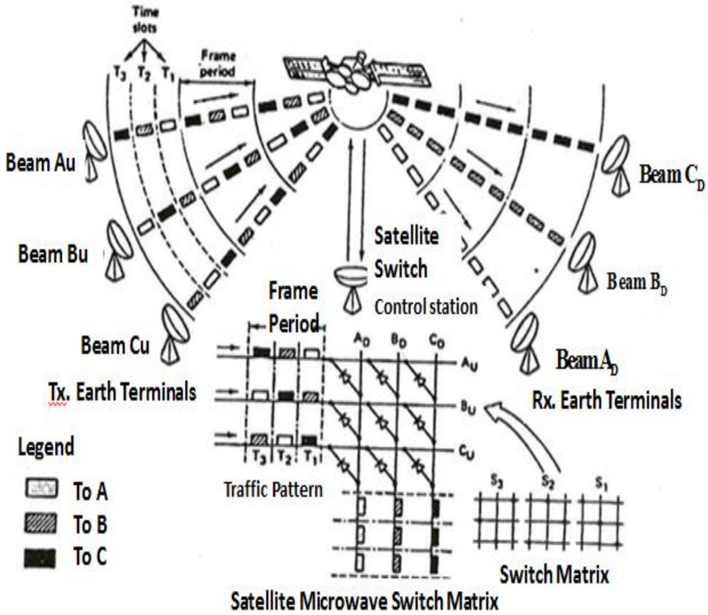

Fig 1. Satellite Switched TDMA.

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VI. CHOICE OF APPROPRIATE ACCESS TECHNIQUES

There are many multiple access techniques for satellite communication. These are frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), SDMA, paired carrier multiple access (PCMA), multiple input-multiple output (MIMO), etc. Each multiple access technique has specific advantages and disadvantages, but FDMA is almost outdated and in most digital applications TDMA is being used. CDMA has specific advantages of low probability of intercept, and anti-jamming capabilities along with selective addressing. The techniques of spread spectrum, namely direct sequence and frequency hopping are used for military applications. Since the spectrum is precious and limited in nature, we want to use it most efficiently. The recent techniques to maximize bits/s/Hz are MIMO and paired carrier multiple access (PCMA). The MIMO increases channel capacity with no additional power, whereas PCMA needs more power.
PCMA can be applied to FDMA, TDMA, CDMA and SDMA (MIMO). The utility of PCMA power-limited satellite may not be there at all since the power is consumed by both carriers of station A and station B while being transmitted through satellite. But in future, more powerful satellite with higher rating power amplifiers will be available onboard satellite to support PCMA. The PCMA may not yield the same B_w saving in case of asystematic carrier which is being used in the most internet applications.

VII. MIMO[2-4]

Multiple input multiple output (MIMO)[3] is a technique in which by using multiple antennae and both transmitter and receiver, the information carrying capacity of the channel can be increased many-folds. If there are M transmit antenna and N receiver antennae, the capacity gain is expressed as:-

$$G = \min(M, N)$$

In case there are two transmit antennae and two receiver antennae, the capacity of the links nearly doubles with the same bandwidth and transmit power.

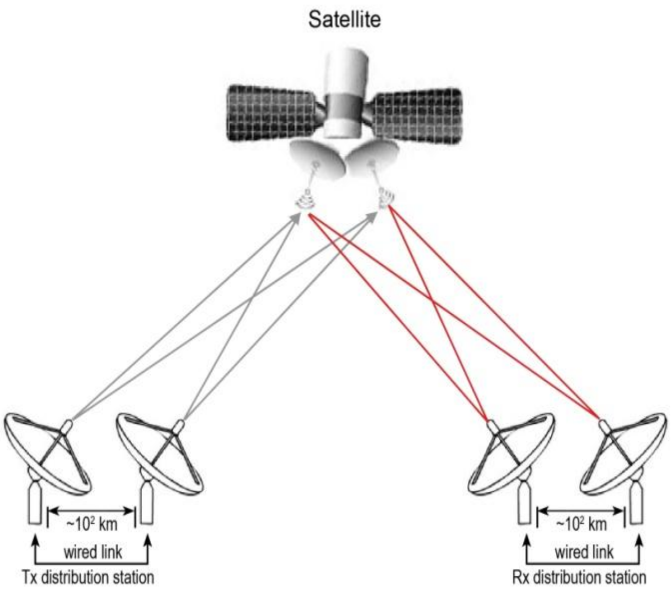

Figure 2. 2x2 satellite MIMO nearly double channel capacity for the same transmit Power and B_w.

The MIMO is relatively a new concept in satellite communication. This is due to restrictions of space, weight carrying ccapcity of satellite, etc. To minimize additional weight and space requirements, the circular dual-polarized MIMO system is proposed. At ground station 2 antennae are required, the concept is shown in Fig. 2., whereas onboard satellite only one antenna with proper feed to respond to both RHCP and LHCP[7] with one common antenna is proposed to be used to minimize the increase in weight onboard a satellite. This will nearly double the information carrying capacity of the satellite channel with the available B_w and available onboard Power.

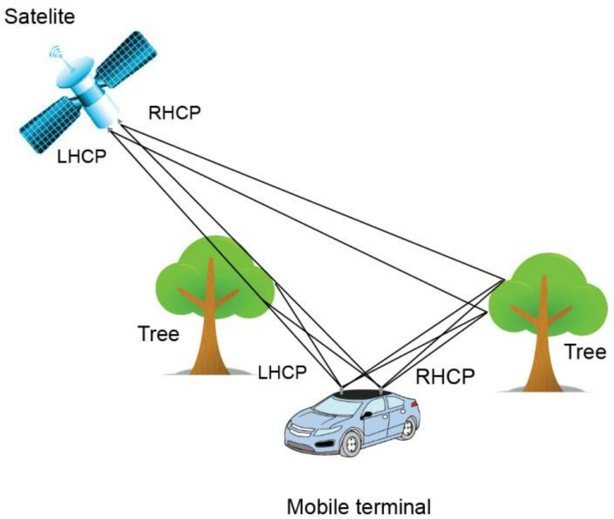

Figure 3. SDMA(MIMO) duel circular

One antenna each on two separate satellites and two antennae on land mobile system (LMS) is shown in Fig. 3. However the limitation is that two satellites are required to be used and inter-satellite synchronization is also needed.

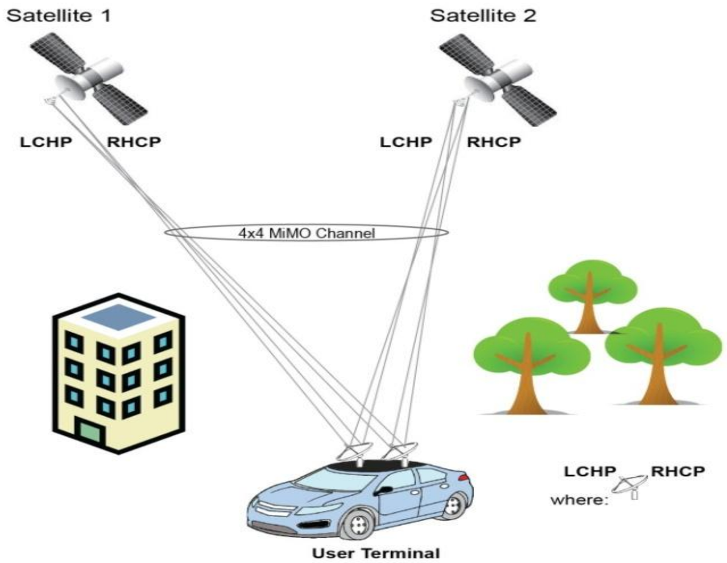

Figure 4. 4x4 Satellite MIMO system will provide nearly 4 multiplexing gain.

VIII. PCMA PAIRED CARRIER MULTIPLE ACCESS[8]

Paired carrier multiple access almost multiply the channel capacity by two, whereas MIMO can multiply channel capacity by Min(M, N) with the same available satellite onboard Power and B_W. The techniques PCMA is described in little more detail. As shown in Fig. 5, the carrier f_1 carrying the information of station A is going to satellite. The satellite being a bentpipe passes it to station B, which may need frequency of W_{Hz}. Similarly, the station B fires a carrier f_2 carrying station B's information and which is received by satellite and passed on to station A. It is obvious that two frequencies f_1 and f_2 are needed for full duplex link. But in the case of PCMA, the station A and station B use the same frequency (f_0) to send their information, still the signal is extracted satisfactorily. The technique used is that while station A transmits carrier f_0 to satellite, keeps a digital copy of the carrier at its own location. The station B, now transmits its information on carrier with the same frequency f_0 instead. As the carrier f_0 from station B reaches to station A through satellite, the station A is having two carriers, both at f_0 (composite carrier) one transmitted by station A and the other received form station B. The station A subtracts its own carrier f_0 from the composite carrier f_0 and is left with the information carrying carrier of station B and demodulates and extracts the information. The same process is carried

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out at station B to demodulate the information received from station A. The concept is shown in Figs. 5, 5(a)-5(b). In this way we save nearly 45 per cent of B_w. for symmetric bandwidth carrier. The percentage of B_W saved decreases as carrier become asymmetric, which is the case when we are using internet through satellite. The forward carrier B_W is very small, whereas backward carrier B_W is very large. Accordingly, the B_W saving is less compared to symmetric carriers.

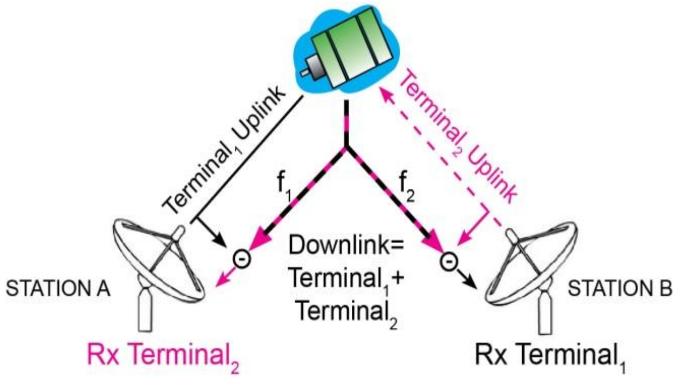

Figure 5. PCMA through satellite, for symmetric channels saves B_w up to 45 per cent.

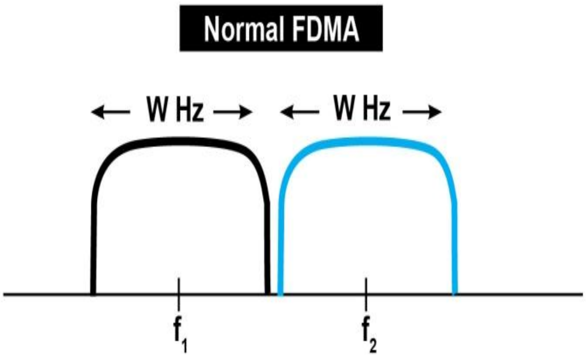

Figure 5(a). How PCM saves B_w up to 45 per cent by subtracting its own transmitted signal.

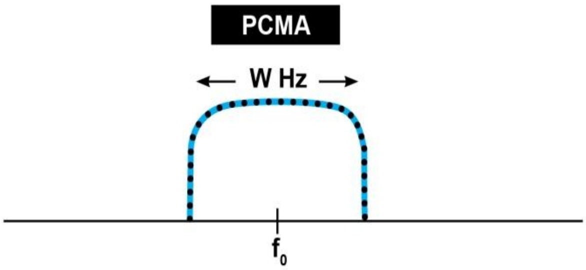

Fig. 5(b)

The benefit of PCMA is that it may effectively double the throughput of satellite systems in terms of bits/sec/Hz, with a minimal impact on the Eb/No required to achieve a desired Bit Error Rate. Using PCMA, you can choose the system benefit that's best for you:

- More capacity to serve more customers in the same bandwidth

Reduced bandwidth requirements/costs to save money

- Allocate more bandwidth per customer to improve service levels with no increase in costs

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IX. MISCELLANEOUS TECHNIQUES TO INCRESE SATELLITE CHANNEL CAPACITY

- **By increasing the G/T of the satellite transponders** the uplink quality of the link will improve which intern will imptove the downlink quality of the link thereby increasing the satellite channel capacity. The G/T of INSAT series transponders used to be -2 dB./K a few years ago, where as ISRO is in the rpocess of launching new satellites with G/T of the order of +5 dB./K. this increase in transponder's G/T will directly augment the satellite channel calicy for the same type os Eeath Station. This increase is implemented by either increasin the diametr of Rx. Antenna of the satellite or decteasing the Noise Temperture of the frount end electronics. Similty the output power of Pwer Amplifie/s in being increased by 4-6 times. This has been possible by generating on board power of the solar arrays, either by increasing the area of solar arrays or by increasing the efficiency of solar cells. Similarly the G/T of earth stations is being ugmented eiter by lowering the noise temperature of LNA or by increasing the diameter of the Rx. Antenna.
- **Frequeny Allocation to various Eeath Stations appropriately.** The frequency allocation to various participating/ Networked terminals/ Earth station terminals can be done in such a way that the terminals which are located outside the 3 dB. Contour should be allocated band width in the center of the transponder and terminals which are located well within 3 dB. Contour may be allocated the BW in at either edge of the transponder as the power density in the center of the transponder is higher by 3 dB. Compared to the power density at the edge of the transponder.
- **Decrecing the saturation flux density of satellite frount end.** By on board attenuator setting from ground control station**.** For on th**e** move systems and systems required for strategic defence applications the size of the antenna should be as less as possible and power of the power amplifier is also limited due to power the fact that the size and weight of battries has to be kept to minimum, accordingily the EIRP of such systems is limited. To achieve a particular drive to the down-link amplirier the saturation flux dissity of the translonder of satellite is lowersd to effectively compensate for lower EIRP of defence communication (Satellite) systems. The lowering of the saturation flux density (SFD) is at the cost of inter satellite interfirence and some other noise present at the receiving antenna input.

X. CONCLUSION

Satellite communication is having unique features of broadcasting, point-to-multipoint communication, wide area coverage, communication on move, access to difficult and infrastructure deficient locations, etc. It has become an active area of research to find how to optimize different techniques like modulation schemes, FEC coding, access techniques especially the newly discovered ones like PCMA and MIMO, to increase the channel capacity. Since the spectrum is limited and most satellites at present are also having power-limited systems. Accordingly, it has been shown that modulation schemes like QPSK, FEC yielding more gain by utilizing B_w optimally with the fast speed digital signal processing are being used. The concept of satellite switched TDME is to be used to increase the PSD of received Satcom. Signal. In case we ase in a position to use 3 by 3 switch matrix on board satellite, will provide an additional S/N increase of 4.5 dB. under ideal conditions. We can afford to introduce more processing power (complexity) to achieve the objective.

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