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Why Mimo Dual Circular Polarisation Multiple Access Technique to Increase Satellite Channel Capacity

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Abstract

All multiple access techniques (like FDMA, TDMA, CDMA and combination thereof) are used to share the common node (satellite) for multiple users which are widely spread over a distance of thousands of rule or so. All these techniques have their own specific application, but none of the technique can increase the channel capacity dictated by Shannon Hartley Law. But MIMO is one such spatial division multiple access (SDMS) technique which increases channel capacity due to the fact that many parallel stream are transmitted from physically separate antenna and similarly there are many separate corresponding receive antennas. This not at present feasibly at satellites due to constraint of volume, weight & large physical size of many antennas to be used on Board Satellite. To counter this, dual circular polarisation is one technique which can be employed by using one antenna with a little more complicated feed on board satellite. By experiments it is found that a gain of 2-3 db can be achieved by using Dual circular Polarised Transmission & reception. This gain can be utilised either to increase link reliability or for increased data rate etc.

Key words: FDMA, TDMA, CDMA, SDMA, MIMO, channel capacity, Array gain.

I. Introduction

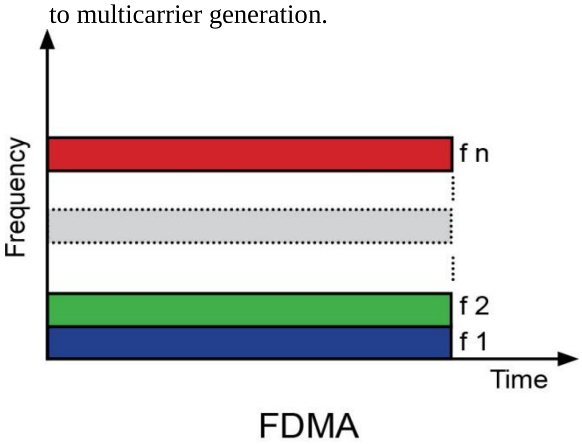
Multiple access techniques make available the ways & means of sharing the common network media (time, frequency, space and combination) node etc. (1) This is done since nodes (satellite) is a very costly resource up in the sky working as a reflector with few hundred Mbps or more as channel capacity. By multiplexing the information from different sources, each small requirement user, a sizeable information is collected and processed and the costly node such as satellite is used, so that per-user cost is reduced. Individual information can be as small as few thousand bits per second. Information from many such users is multiplexed and a carrier (stream) of few Hundreds of kilo bites to few Megabits and in some cases few tens of Megabits is made and a common satellite node (Transponder) is used to distribute the huge cost of satellite Transponder over few hundreds to few thousands users. Till recent past FDFA, TDMA, CDMA and combination of these multiple-access techniques were being used. Since frequency and time are natural resources and they are always in High demand. All feasible technique have already been tried and are being used to maximize the information to be Transmitted from Point to Point, Point to Multipoint and Broadcasting. In recent past Multiple Input Multiple out space Division multiple access technique in combination with TDMA, FDMA &CDMA is being used to augment Satellite channel capacity. The Basic requirement of MIMO techniques is to have multiple Transmit and multiple Receive antenna with as less channel coordination as feasible to take maximum benefit of MIMO technique. Since present day satellites are limited in size and weight, many antennas with sufficient separation (many wave lengths apart) cannot be mounted. To take care of this problem dual circular polarisation can be used to represent two separate antenna at the cost of little reduce benefit of doubling the information carrying capacity as compared to two independent antennas on satellite and one ground station with the same dual circularly polarised antenna. However on ground station more than two antennas can be used to take an additional advantage of array gain. To distinguish clearly the concept of how FDMA, TDMA, CDMA & SDMA and combination thereof works. Each is explained briefly from satellite access view point.

FDMA – When annalog information from different sources (may be from annalog phones) is multiplexed to make a carrier of few Hundreds of kilo Hz to few Mega-Hz and this carrier is used to access the satellite for transmission form one point to another may be as close as few yards away to as long as few thousand kilometre away. The type of access is called FDMA. Many such carriers of different sizes can access the satellite transponder/s simultaneously to share the costly/scares resource up in the sky.

Advantages of FDMA (FDM – FDMA)

- Flexible, simple, very well established, legacy systems exist.
- Each station have its fore-fixed bandwidth, no coordination is required.
- IIIrd order intermodulation product falls well within pass band and degrades quality of communication.

- Proportionate power from Transponder & E/S is allocated.
  Small capacity Earth stations/terminals are simpler and less in cost while using FDMA.
- Diameter of E/S antenna (G/T) and cost is proportional to information requirements and power Amplifier is also of lesser size, resultantly cheaper in cost.
- It is well suited for small firms/homes as cost is affordable.
- No clock & carrier recovery required as no synchronisation is required.
- Implementation was very simple till digital electronics was not available.
- Single carrier operation can be implemented as users are separated in time domain. The TWT can be operated in saturation resulting in more efficient delivery of power by the TWT Amplifier on board satellite.
- For a allocated bandwidth of the order of 36 (full Transponder) it may be difficult to pool the entire information from a single location, for single carrier operation. Accordingly a multicarrier TDMA (MC-TDMA) may have to be implemented which will not give the advantages of running TWT into saturation due to multicarrier generation.



Frequency Division Multiplexed signal for satellite Application.
Fig. (1)

Disadvantages of (FDM-FDMA)

- Since information Transmitted is Annalog, it is difficult to encrypt FDM signal and resultant encryption is weak.
- No advantage of either source coding or channel code can be exploited.
- Digital means cannot be used for storage and processing of information.
- Limited modulation schemes are available like AM, FM etc. for communication which in somecases need more S/N as compared to digital modulation schemes.
- No advantage of FEC is exloited.

Third order Intermodulation Generation
Fa, Fb, Fc three grequencies of the carrier in the Input.
F(2) = F(3) Third order Intermodulation products
F(2) = 2Fa –Fb
F(3) = Fa + Fb – Fc
The Third order intermodulation products are the sum of absolute frequency value terms i.e $2+|-1|=3$ & $1+1+|-1|=3$. Third order intermodulation products are quit strong & fall in the pass band of allocated Transponder frequency/bandwidth and are most harmfull to the communication and add maximum distortion.

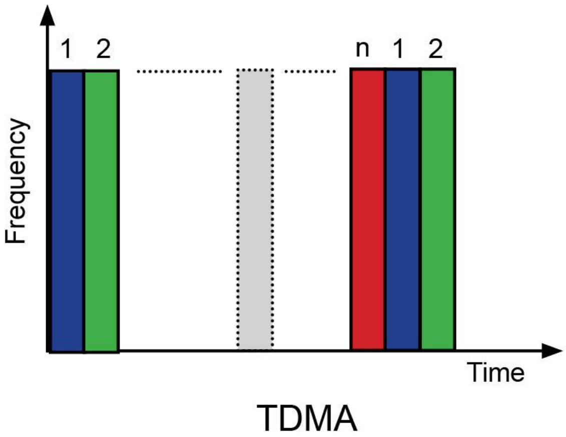
II. Limitation due to Capture effect

Due to the problem of Capture effect the weaker carriers become further weaker & stronger carrier become further stronger in a multicarrier operation, when the TWT is operated near saturation. The small terminals with moderate power Amplifier size and antenna size of the order of 1.2 m are most effected due to the fact that EIRP from the terminal cannot be increased beyond certain limit. The capture effect is most swear when the difference between intput signal powers is large and absolute value of back off is small. The magnitude of capture effect can be of the order of 2-3 db near saturation.

TDMA (TDM – TDMA)

The original information is analog is to be converted into digital form. This digital information called bits are multiplexed either synchronously or asynchronously also called statistical multiplexing. These days packets are also made out of information which are used in TDM – TDMA satellite access mode. These day most of the satellite communication takes place in the TDM – TDMA mode due to the fact it is simpler to manipulate.

TDMA is a channel access method for shared medium Networks. In this technique several users share the same frequency Band by dividing the signal in to small parts(slots). The users transmit in a round robin manner is quick succession, one after the other, each user using its pre allocated time slot. Between each user a guard time is kept to avoid overlapping of inter-user time slot. These days packet communication is a preferred use of TDMA type of satellite access.



Time Division multiplexed signal for satellite TDMA Application.
Fig. (2)

Advantages of TDM – TDMA type of access.

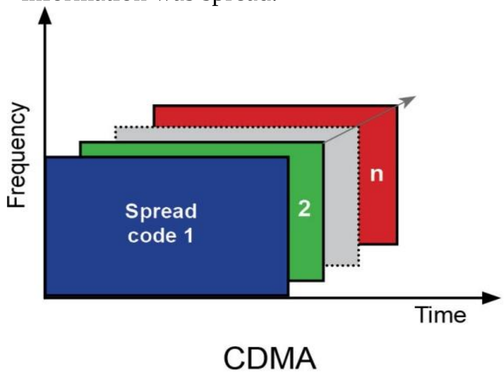
- Information is in the form of bits & bytes, can be stored and manipulated digitally.
- A very strong encryption (compared to FDM – FDMA) can be implemented.
- Advantage of source coding to compress the information and channel coding to archive FEC (forward error correction coding) gain can be exploited with some coding schemes coding gain of the order of 5-8 db have been realised. We are at present 2-3 db away the Shannon Limit.
- Can be implemented without much central station timing control in the form of Aloha and with a little control by using slotted Aloha but at the cost of efficiency. The efficiency of Aloha is 18 % and that of slotted Aloha is 36 %.
- E/S station/node infrastructure has to be same for all participating nodes, irrespective of information requirement.
- Carrier recovery & synchronisation along with clock recovery and synchronisation is required which was difficult before the introduction of VLSI chips.

CDM – CDMA

Code division multiplexing is a spread spectrum technique which uses frequency domain and time domain simultaneously to transmit and receive information. Users are separated in code domain, so to say each user is given a separate code to spread and de-spread/collapse his information. The different users sharing the common time & frequency domain all allocated orthogonal codes. Ideally the cross co-relation between codes be zero but practically some cross co-relation always exists.

Comparative Advantages/Disadvantages of CDM – CDMA are as follow

- Since there can be single carrier the Power Amplifier on satellite can be run into saturation. It is more efficient to run the Amplifier in saturation and draw maximum power.
- It is difficult to intercept the communication as the power spectral density is less.
- Having intercepted the communication it is difficult to decode/demodule the intercepted signal, before S/N enhancement (collapsing of spectrum), which only occurs after carrier synchronisation and correlating the signal the locally generated replica & which is synchronised to the code with which the information was spread.

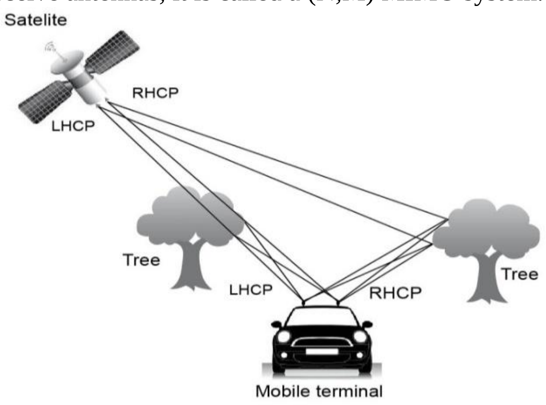


Code Division Multiplexed signal for Satellite CDMA Application
Fig. (3)

- Implementation is more complex.
- Near far problem exists.
- Receiver consumes more DC power, due to fast and more information for correlation to be processed.
- A little higher Talency is involved, one many find difficult to transmit information in small bursts due to latency & requirement of synchronization every time, which may consume considerable time if the transmitted bust is of lesser duration typically of the order of a fration of millisecond to 2-3 milliseconds. This problem is more swear for longer codes with higher Anti-jamming margin.
- CDMA is effective against multipath fading.
- Since there is one carrier spreeded to the entire bandwidth, the TWTA can be operated in saturation without generating IM Products.
- No external control is needed for multiple access to function as by design the technique is a multiple access technique.
- In a big network when the users accessing the network drop, the jamming Margin becomes available to the network.
- It is an effective anti-jamming technique.
- When allocated bandwidth is of the order of 36MHz(full Transponder), it not required to spread the spectrum to the total of 36MHz Bandwidth, Multicarrier will have to be used.

This is called Multicarrier CDMA(MC-CDMA). Here again we can not operate the TRWT into saturation to avoid generation of intermodulation products.

MIMO :- Multiple Input & multiple out is technique in which the bit stream to be transmitted form one node to another is split up into many streams and each stream is separately processed at base band (source coding, channel coding, encryption etc.) and each stream is modulated on same carrier and amplified separately and transmitted with separate transmit antenna. The location of these antennas is physically separated by up to few wavelength of the carrier frequency. The carrier is transmitted collectively from these separate antennas in the direction of the receiving node. At receiving node there are also multiple antennas to receive all these transmitted carrier form different antennas physically separated. If there are N transmit antennas and M receive antennas, it is called a (N,M) MIMO system.



SDMA (MIMO) Duel Circular Polarisation, for Satellite Communication

Fig. (4)

All other access techniques i.e FDMA, TDMA, CDMA and combination thereof follow the Shannon Hartley capacity formula i.e

$$C = Bw\log_2(1+S/N) \quad (1)$$

Where C = channel capacity

Bw = bandwidth allocated

S/N = signal to noise Ration

It is seem that with increase in S/N the capacity does not increase linearly but it increases logarithmically.

Where as for (N,M) MIMO system the channel capacity can be represented as follows. N is number of Transmit enter and M is number of Receive antennas.

$$(uncorrelated = Bw.N.\log_2(1+\frac{M}{N}.SNR) \quad (2)$$

$$(correlated = Bw.N.\log_2(1+M.N.SNR) \quad (3)$$

SNR consists of multiplicative & additive noise i.e

$$SRN = \frac{S}{Nmul + Nadd} \quad (4)$$

It is seen from that for TWO transmit Antennas and two receive antennas, the Information carrying capacity becomes two times, of course at the cost of increased complexity of the system, with the same Tx(RF) power and bandwidth.

The MIMO implementation in case of satellite communication can be accomplished by using Dual circular polarise feed of the reflector antenna on board satellite to reduce hardware and weight of the second antenna for (2, 2) MIMO system. The dual circular polarizing/depolarising feed is comparatively more complex compared to the single polarized counterpart with dual circular polarization system the number of diversity routes are definitely two, but at the same time it is slightly less effective than a two antenna system counterpart. The correlation between two polarisations will be further reduced if the angle of elevation is less than 15^0. Similarly for LEO providing communication to mobile terminals having shadowing effect due to long road side trees and high rise building in the urban and suburban territory the shadowing effect can be used to the benefit, to reduce the correlation between two polarisations or either to increase channel capacity or diversity gain.

MIMO system provides channel capacity gain & diversity gain simultaneously.

For $M \neq N$ case. (5)

The maximum diversity gain is total number of independent signal paths that exists between the transmitter and receiver

i.e $1 \leq d \leq d\max = M * N$

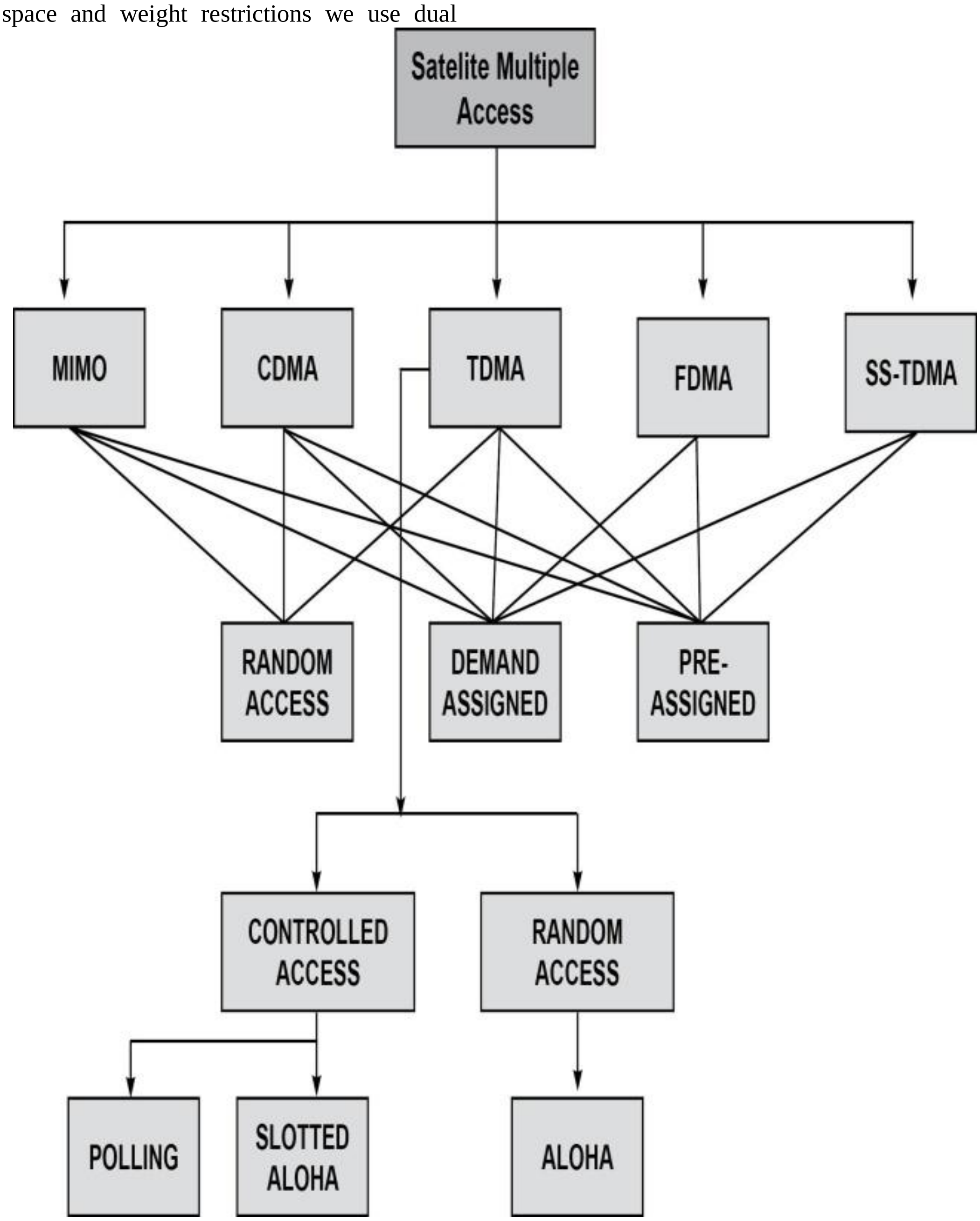
where d = diversity gain

The higher the diversity gain the lower the probability of error.

In satellite communication systems there are very few or no scatters at the satellite side. It may be a matter of doubt weather there will be any MIMO gain in case of satellite communication or not. However, transmitting from multiple satellites introduces the phenomenon of scattering which is in the form of a 'distributed' scatterer. Such distributed space-time schemes have to solve the problem of synchronisation between satellites and to introduce some form of equalisation in the receiver to for the different & possibly continuously varying difference among the signals.

III. Conclusion

Multiple access techniques are fundamental to all type of signal and type of medium. For satellite multiple access techniques the major are FDMA, TDMA, CDMA, SDMA(MIMO). These techniques have evolved during few decades, depending on advancement in digital technology. The use of a particular type of multiple access technique depends upon cost, traffic requirement, complexity and availability of particular type of technology/technique. All multiple techniques have their own specific applications also where that particular technique is most appropriate to use. A hybrid of two or more techniques is also quite common like Multifrequency Time Division Multiple access (MFTDMA), Multifrequency code Division multiple access (MFCDMA) etc. SDMA is a special technique which is used to increase the channel capacity of the link by utilising multiple Transmit and multiple antennas. For satellite communication due to space and weight restrictions we use dual circular Polarisation Multiple Input Multiple Output scheme (DCP – MIMO), which provides an additional gain of 2-3 db, which can be traded against capacity increase or for better probability of but error rate or better availability (fading) etc. SDMA is always used in combination with FDMA, TDMA, CDMA or combination thereof. SDMA is a channel capacity enhancement technique which follows strictly Shannon Harley law but increases capacity due to multiple streams of data being transmitted and received from physically separate antenna or by way of separating the frequency in polarisation domain, as is done in satellite DCP – MIMO systems.



Summary (variation of) Satellite Multiple Access Techniques.
Fig. (5)

Table 1 : Comparison of Different type of Multiple access Techniques.

	PARAMETER	FDMA	TDMA	SSMA	SDMA (MIMO)
1	Status	Well established & proven concept.	After availability of VLSI technology, used most frequently & proven system.	Till recent times was mostly used in military applications. Technology is well established.	To use many transmit antennas on the satellite is not feasible today. As a SDMA concept, we find hardly any satellite using the concept as on today systems at conception level.
2	Cost	Less in cost.	Less to moderate in cost.	Comparatively costly.	No practical system exists.
3	Continuous bandwidth requirement	Do not need continues Bandwidth.	Needs continues chunk of Bandwidth.	Need continues Bandwidth atleast equal to spread bandwidth.	Useful for continues and fragmented Bandwidth.
4	Flexibility	Very Rigid	Very flexible	Rigid .	Fixed & inflexible system.
5	GIT of E/S Antenna Required	Less for small station.	Same irrespective of size & amount of Traffic.	Same for all stations.	Less for small station.
6	Intermodulation generation Problem	High level Problem.	Nill except in MC-TDMA.	No problem except MF-CDMA	LESS COMPARED TO FDMA
7	Coordination Requirement	Negligible	High level	Nill	No coordination is required.
8	Eavesdroping	simplest	Comparatively	Very Difficult	Depend on weather FDMA, TDMA or CDMA is used along with SDMA.
9	Examples:	SCPC, MCPC, DAMA.	TDMA, MFDTMA, ALOHA • Multiplaces with collision avoidance (MACA) • Carrier sence multiple access(CSMA) • SLOTTED ALOHA	DS-SSMA FH-SSMA TH-SSMA MF-SSMA Combination of DS, FH & TH.	Access are • SDMA/FDMA • SDMA/TDMA • SDMA/SS/FDMA • SDMA/SS/TDMA/FDMA • SDMA/DH(TH)/TDMA • SDMA/SS(FH)/CDMA • SS-Satellite switched • BH-Bandwidth Hopping • TH-Time Hopping FH-Frequency Hopping.

References

[1.] Multiple Access Techniques – An Review By S.L Maskra, Dept. of Electrical & Communication Engineering, IIT Kharagpur – 721302 Defence Science Journal Vol. 43, No 1 Jan 1993 pp 53 – 58.

[2.] Introduction to Satellite communication Third Edition By Brue R. Elbert. Artech House Boston (London)
[3.] Satellite Communication systems By Gerard Maral & MICHEL BOUSQUET Fifth Edition WILEY.
[4.] Polarization Diversity – Variable Polarisation Technology and the Mibile Broadcasting Environment, White paper By Jay Martin, Director, Broadcast Sales & Business Development. Feb 2011.
[5.] A Thesis Submitted to the Graduate School of Natural and Applied Sciences or Middle East Technical University June 2013 By Bukak Soker.