A THROUGHPUT AWARE ADAPTIVE CODING AND MODULATION SCHME FOR EFFICIENT SATELLUITE COMMUNICATION

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Abstract-Satellite communication is a promising technology due to its ability to serve very large number of users with high data rate services. Communication links are usually organized with a static modulation and coding scheme, stable data rate, and high communication link margin during the worst-case scenario. This worst-case planning approach ensures that communication links are preserved during bad expected Earth-to-Space propagation effects which include; free space loss, atmospheric loss, attenuation due to rain, and ionosphere loss, among others. For fixed modulation, worst-case design approach often results in an underutilized system and limits flexibility during a variety of receiving scenarios, while ensuring the BER to be within the acceptable threshold. As a step towards this long-term goal, this research work proposes a Throughput Aware Adaptive Coding and Modulation (TA-ACM) scheme where Link Adaptation (LA) technique is used for the Earth-to-Space communications link to optimally select the modulation scheme that can adapt as the signal energy fluctuates so as to maintain a desired BER. Results obtained from simulation showed that the developed scheme improve the network energy to noise ratio by 22.74% and improved throughput by 24.30%.

Index Terms- GSA, BER, ACM, Throughput, Link budget

1.0 INTRODUTION

Satellite communication is used for current communication facilities. It includes propagation environments used for radio signals transmission which are diverse from that in traditional terrestrial radios (Asad and Mohammed, 2010). Radio propagation amongst earth and satellite a ground earth station faces a lot of challenges during propagation. These challenges go a long way in affecting the operational efficiency of satellites. Ionospheric effects and resident fading issues are summarized in Table 1. These combined challenges or impairments on the earth satellite-link can result to random changes which can result in poor system performance of the quality of signal and thus led to an increase in the bit error level of the satellite communication system and low throughput (Asad and Mohammed, 2010). The orbit of operation for different satellite system determines the type of propagation effects they are exposed to. With respect to the distance from the earth, its orbit can be characterized into Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Geostationary Earth Orbit (GEO), and High Elliptical Orbit (HEO) categories. The different types of frequency bands in satellite communication are presented in table 3. In this work the s-band frequency band will be used in this work.

Table 1: Losses in Satellite Communication System (Carlos, 2012)

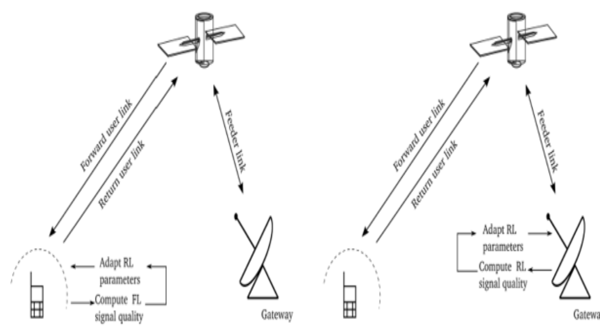
Transmission Losses	Propagation Losses	Free Space Loss		
		Atmospheric losses	Ionospheric effects	Faraday rotation
				Scintillation effects
			Tropospheric effects	Attenuation
				Rain attenuation
				Gas absorption
				Depolarization
				Sky waves
			Local effects	
		Pointing losses		
	Local losses	Equipment losses	Feeder losses	
		Environment losses		

Table 2: Frequency Bands for Satellite Communications (Karim *et al.*, 2018)

Frequency Band	Downlink Frequency	Uplink Frequency	Typical Bandwidth	Comments
L-band	0.9 -1.6GHz	0.9-1.6 GHz	15MHz	Shared with terrestrial
S-Band	1.610 -1.626 GHz	2.483-2.5 GHz	70MHz	Shared with ISM Band
C-Band	3.7-4.2 GHz	5.925-6.425 GHz	500MHz	Shared with terrestrial
X-Band	7.25-7.75 GHz	7.9-8.4 GHz	500MHz	Government military
Ku-Band	11.7-12.2 GHz	14-14.5 GHz	500MHz	Attenuation due to rain
Ka-Band	17.7-21.2 GHz	27.5-31 GHz	3500MHz	High equipment cost
Military	20.2-21.2 GHz	30-31 GHz	1000MHz	Attenuation due to rain

A. Link Adaptation

Link adaptation is a concept that refers to the ability of a system to regulate the mode of transmission to channel current conditions by adjusting the modulation and coding scheme for time efficient transmission (Jyrki, 2015). This adaptation is done according to the Channel State Information (CSI). The CSI is estimated by the transmitter to choose a Modulation and Coding Scheme (MCS) accordingly (Kilcoyne, 2016). There are mainly two methods to estimate CSI, they included the method of the open loop and the closed satellite loop method. This is shown in Figure 2.1. Open Loop CSI estimation is dependent on channel operation reciprocity, that is, channels in the uplink and downlink can be strongly correlated. The Closed Loop CSI depends on a network receiver measuring the response of the channel and back-feeding this response to a transmitter, by making use of a quantized feedback channel (Rico*et al.*, 2015). LA introduces realistic link budget balancing in order to improve the spectral efficiency of a system over fading channels (Rico *et al.*, 2015).



(a): Open-Loop Method (b): Closed-Loop Method

Figure 1: Adaption Configuration

Channel model conditions are measured at the receiver and the CSI is transmitted back to the transmitter to adapt the transmission (Sauders*et al.*, 2007). LA is a broad term for a technique that monitors a communications link and alters system parameters to meet certain conditions. There are a few different methods of link adaptation traditionally recognized, such as (Kilcoyne, 2016):

i. Adaptive Coding and/or Modulation (ACM):

ACM is a concept of modulation where the transmitted modulation and/or coding schemes are altered. ACM is also referred to as rate adaptation, because the data rate of the link does vary as modulation and coding schemes change (Kilcoyne, 2016). Based on the estimated Bit Error Rate (BER) of the received signal, the ACM scheme adapts the channel to varying modulation scheme such as BPSK, QPSK and QAM in order to improve the data rate of the communication link. Hence, a user undergoing higher SNR is serviced with greater bitrates, however a user undergoing bad channel conditions is serviced with lesser bitrates to ensure stable connections with less error bits. It is worth to note that the different types of modulation schemes used during transmission are limited. Thus, the network throughput is usually upper-bounded with respect to a

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specific defined system threshold (Al-Saegh *et al*., 2014).

ii. Adaptive Power Control (APC)

APC is the method in which the transmitted power is adjusted. These power adjustments mitigate power while ensuring a constant bitrate with an additional advantage of boosting the power to reduce network losses when a greater modulation and coding scheme are choosing, thus, increasing the Bit Error Rate (BER). The aim is to keep the expected error rate below a target threshold (Al-Saegh*et al*, 2014). Table 2.4 shows the properties of a variety of modulation schemes which are usually adopted in satellite communication. The main figure of merit of adaptive power for space communication is to enhance the transmitter power *'*P_T*'* of individual receiver to obtain the minimum bit energy *'*E_b*'* for its separate communication specifications and channel model conditions (Kilcoyne, 2016).

Table 3: Properties of Satellite Modulation Schemes (Kilcoyne, 2016).

Modulation scheme	Bits/ Symbol	Complexity	BER at 10^{-5}	Bandwidth usage	Susceptibility to noise	Power consumption
BPSK	1	Simple design	$\leq -86\,dbm$	Less efficient	Less	Less
QPSK	2	Simple design	$\leq -83\,dbm$	Less efficient	Less	Less
QAM-16	4	Complex DSP	$\leq -74\,dbm$	Efficient	More	More
QAM-64	6	Complex DSP	$\leq -68\,dbm$	More efficient	More	More

B. Error Vector Magnitude

Complex digital modulation schemes are used for meeting stringent spectral and SNR requirements in wireless communication systems. Usually the overall quality of the transmission and reception of the system are determined by various baseband and RF system specifications. Among these, BER and Error Vector Magnitude (EVM) are two primary specifications that determine the performance of the wireless system in terms of transmitted and received symbols corresponding to a given digital modulation scheme (Kilcoyne *et al.*, 2016). EVM is one of the widely accepted figures of merit used to evaluate the quality of communication systems. In the literature, EVM has been related to SNR for data-aided receivers, where preamble sequences or pilots are used to measure the EVM, or under the assumption of high SNR values (Sami *et al*, 2011). A signal transmitted in a no-noise environment to a receiver with ideal hardware has all constellation points exactly positioned at the expected locations. In any real system, noise causes the constellation points to shift from the ideal positions (Sami *et al*, 2011) EVM is a quantization of the disparity between the received symbol and the ideal symbol and is a common metric to assess the quality of digitally modulated communication signals. It can be used as an approach to estimate SNR at the receiver as well. There are applications for SNR estimation through EVM measurement in both data-aided and non-data-aided receivers (Kilcoyne, 2016). EVM can be defined as the Root-Mean-Squared (RMS) value of the difference between a collection of measured symbols and those of ideal symbols. The value of the EVM is averaged over typically a large number of symbols and it is often expressed as a percentage (%) or in dB. The EVM can be represented as (Kilcoyne, 2016):

$$EVM = \left[\frac{\left| S_{ideal} - S_{recieved} \right|^2}{\left| S_{ideal}{}^2 \right|} \right] \qquad (1)$$

C. Gravitational Search Algorithm (GSA)

GSA is a novel heuristic optimization method. The basic physical theory which GSA is inspired from is the Newton's theory that states: Every particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them (Rashedi *et al.*, 2009). GSA considers agents as objects consisting of different masses proportional to their value of fitness function. During generations, all these objects attract each other by the force of gravity. This force causes a global movement of all objects towards the objects with heavier masses. Hence, masses cooperate using a direct form of communication, through gravitational force (Eldos and Al, 2013). The heavy masses which correspond to good solutions move more slowly than lighter ones, this guarantees the exploitation step of the algorithm. The GSA could be considered as an isolated system of masses. With the small artificial world of masses obeying the Newtonian laws of gravitation and motion (Rashedi*et al*, 2009). GSA is used in the optimization of the satellite communication parameters during link budgeting. The major challenge in the design of satellite communication systems is the link budget optimization of C/N_0 for uplink and downlink. The C/N_0 is known as the "objective function" since it is what is optimized (Rashedi*et al.,* 2009). Capacity of satellite communications system optimization must take into account the limitations imposed by the payload and platform technologies. The limitations include (Eldos and Al, 2013):

i. RF power.
ii. Power consumption.
iii. Power dissipation.
iv. Mass, volume, cost.

Link budget calculation involves the determination of the SNR at the level of the satellite for the uplink and at the level of the receiving station for the downlink. For the uplink, it is given as Rashedi *et al., (*2009):

$$(C/N_0)u = P_{t,b} + G_{t,b} - L_{feed,b} - L_f + G_{r,s} - L_{feed,s} - T_{s,s} - k \quad (2)$$

$$(C/N_0)u = EIRP_b - L_f - T_{s,s} - L_{feed,s} + 228.6 \ dBHz \quad (3)$$

where:C is the power of signal at the receiver input, N_0 is the spectral density of the noise, EIRP is the Equivalent Isotropic Radiated Power, K is the Boltzmann constant ($1.38\text{x}10^{-23} J/K$), $G_{t,b}$ is the transmitter gain, $G_{r,s}$ is the systems receiver gain, $T_{S,s}$ is the system temperature, L_f is the free space loss, $L_{feed,s}$ is the free space loss of the ground station feeder, $P_{t,b}$ is the transmitter power.

For the downlink it is given as (Rashedi *et al*, 2009):

$$(C/N_0)_D = P_{t,s} + G_{t,s} - L_{feed,s} - L_f + G_{r,b} - L_{feed,b} - T_{s,b} - k \quad (4)$$

$$(C/N_0)_D = EIRP_s - L_f + T_{s,b} - L_{feed,b} + 228.6 \ dB \quad (5)$$

where:C is the power of signal at the receiver input, N_0 is spectral density of the noise, $EIRP_s$ is Equivalent Isotropic Radiated Power, K is Boltzmann constant (1.38.10-23 J/K), $G_{t,s}$ is the system transmitter gain, $G_{r,s}$ is the systems receiver gain, $T_{S,b}$ is the downlink temperature, $L_f$is the free space loss, $L_{feed,b}$ is the free space loss of the ground station feeder at the download, $P_{t,s}$ is the system transmitter power

The global link budget is given as:

$$(C/N_0)_T = \left[\frac{1}{(C/N_0)u} + \frac{1}{(C/N_0)D}\right]^{-1} Hz \quad (6)$$

D. Overview of Research Works

Zalonis *et al.,*(2010) reviewed the channel capacity and Adaptive Modulation and Coding (AMC) techniques. From the possible link adaptation strategies, the work discussed the AMC framework, highlighting the need for compact link-level performance modeling in the AMC algorithmic design for multi-parametrical systems. The work presented a small summary of open issues for AMC design in multi-modal and multi-parametric emerging standards. Showing its limitations under various conditions such as the selection of the available modes of operation to be used by the AMC algorithm, for as the number of modes increase, the optimization algorithm itself can become very complex. However, AMC optimization algorithms rely on information provided by measurements and estimated parameters which lead to system robustness analysis that requires a variety of complex process that increases the round trip delay of the GEO. .Link adaptation mechanisms in a reliable multicast scenario was developed by Sali*et al.*,(2012) , where the challenge lied in finding the optimal transmission rate to suit all terminals in the multicast group. From the simulation results, MLA and MIN are shown to be the best link adaptation algorithms, by providing the highest user fairness and the highest throughput. However, the channel conditions experienced by the terminal deteriorate as the number of terminals increases. This is due to the error signal generated by solar panel shadowing effect on the satellite antenna that eventually leads to high bit error modulation by the modulation schemes adopted in the work. The problem of modulation and coding scheme selection in the return link of a mobile satellite system was analyzed by Alberto *et al.,* (2013). The work used a weighted combination of both open loop and closed loop signal quality indicators to perform this selection. Numerical results showed the good performance of the proposed method compared to previous algorithms, and its robustness to environment changes. However, the target BER might not be achievable in very high or very low SNR scenarios. Berrezzoug*et al.*,(2015) established a list of parameters that must be considered when the link power budget of a communication system satellite is established, and the conditions in which these settings applied. Their simulated values took into account a number of factors in order to model a robust communication link and the results showed an improvement in the objective function of the satellite link budget. Kilcoyne*et al.,* (2016) characterized propagation environment experienced by a software-defined radio on the NASA Scantest bed through a full link-budget analysis. The work proposed, designed, and modeled a link adaptation algorithm to provide an improved trade-off between data rate and link margin by varying the modulation format as the received signal-to-noise ratio fluctuated. The result of the work showed an improvement on the throughput of the network. However, to address any data that might have been demodulated incorrectly and taking into account the round-trip delay, the transmitter would re-transmit the data that was sent when the channel conditions changed thereby degrading the general performance of their system in terms of throughput and the effect of path loss was high.

Despite the various interventions by other researchers, there is still a need for improvement with the aim of having better link budget that will improve the throughput of satellite network. This research work developed a throughput aware ACM (TA-ACM) scheme that made use of GSA during link budget estimation.

Section 3 of this research discusses the methods used in the development of the throughput efficient ACM scheme. Section 4 presents the obtained results and section 5 presents the conclusion of this work.

2. DEVELOPMENT OF TA-ACM SCHME

The following are the steps carried out in the development of TA-ACM scheme for efficient operation of satellite communication.

a. Set-up the International Space Station orbit (ISS) using System Toolkit (STK) and load the ISS by searching the STK satellite database.
b. Installation of antenna and sensor at the JPL SDR location on ELC-3, which allows for accurate simulations of both the uplink and downlink.
c. Estimate:
   i.. Link budget using GSA where G/T and C/N are the figure of merits.
   ii.BER in terms of E_b/N_0 with BER_{th} value of $10^{-5.}$
   iii.normalized EVM_{th} using the $BER_{th.}$ and normalized EVM as decision statistics for SNR.
d. Adapt selected modulation scheme for symbol modulation

In this work more emphasis will be made on how the process of link budgeting is carried out using GSA and the normalized EVM.

Model Equations for TA-ACM

This sub-section presents the model equation for the development algorithm with respect to the objective functions of this work. The SNR equation for the developed algorithm is given as:

$$SNR = \frac{1}{f}\left[\frac{E_s T_s}{N_0 G_r}\right] \qquad \textbf{(9)}$$

where: f is the channel transmission frequency in MHz, T_s is the system noise temperature., G_s is the receiver gain of the antenna.

Also, equation (7) is modified as:

$$\frac{CT_s}{N_0 G_r} = \frac{1}{f}\left[\frac{1}{EVM_{RMS}^2}\right] \qquad (10)$$

where: EVM^2_{RMS} is the normalized EVM value

The normalized EVM is given (Carvalho and Schreurs, 2013) as:

$$EVM_{RMS} = \left[\frac{\frac{I}{T}\sum_{t=1}^{T}\left|I_t - I_{0,t}\right|^2 + \left|Q_t - Q_{0,T}\right|^2}{\frac{1}{N}\sum_{n=1}^{N}\left[\left(I_{O,n}\right)^2 + \left(Q_{0,n}\right)^2\right]}\right]^{\frac{1}{2}} \qquad (11)$$

The design parameters for TA-ACM are given in table 5. The system model and the flowchart for TA-ACM are giving in Figures 2 and 3 respectively.

Table 5: Design Parameters for the developed scheme

Designs parameters	Ranges
Uplink frequency	[2.483 2.5 GHz]
Downlink frequency	[1.610 1.626 GHz]
Earth transmit Power	[26 30] dBW
Satellite transmit Power	[8 11] dBW
Earth transmit and receive antenna efficiency	70%
Earth transmit and receive antenna diameter	2.4m

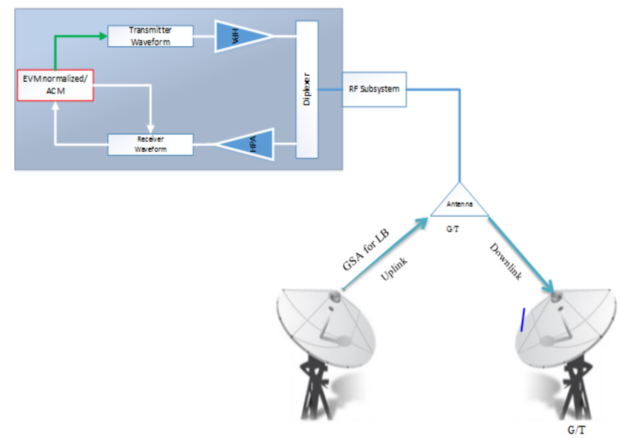

Figure 2: System Model for the Developed TA-ACM

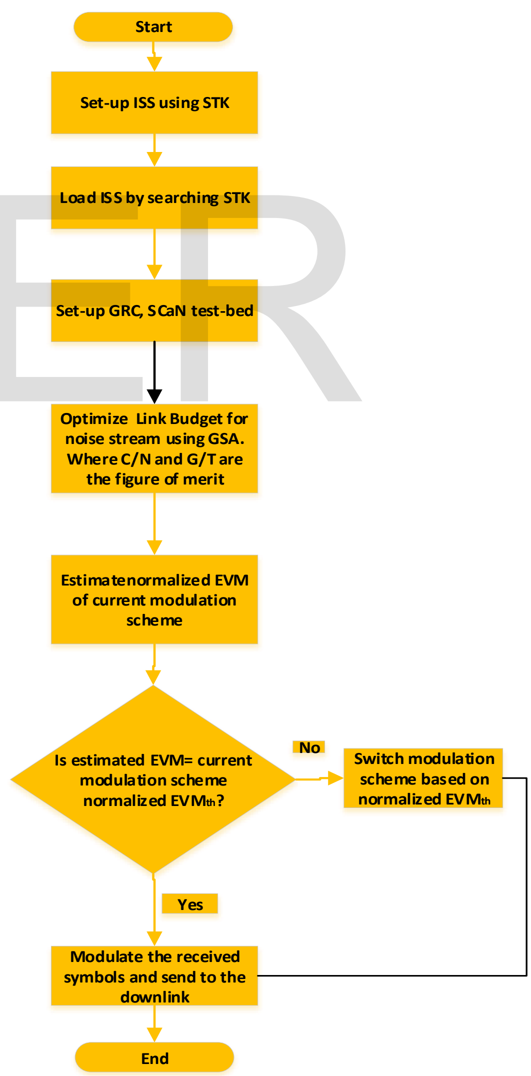

Figure 3: Flowchart of the Developed TA-ACM Scheme

3.0 RESULT

A. BER AND *ES/NO* AT VARIOUS PERIOD OF TIME

The relationship between the BER and *Es/No* at various period of time is presented in Figure 3. The use of GSA for optimal link budgeting ensures that BER is maintained below the 10^{-5}threshold before switching modes. Figure 3 shows that the TA-ACM shows a lower BER and a higher *Es/No* as compared to the ACM scheme at a BER threshold of 10^{-5}. The ability of the improved scheme to efficiently find an efficient modulation type to aid better data transmission in the presence of channel impairments is the reason for better performance of TA-ACM. A reduce BER ensures better system throughput of the satellite network.

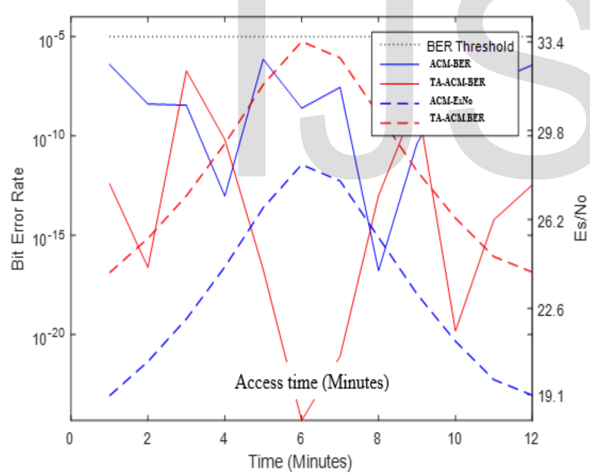

Figure 3: BER/E_s/N_o for ACM and TA-ACM

B. THROUGHPUT OF ACM AND TA-ACM SCHEME

The measure of the successful transmitted data reaching the satellite is of paramount importance in satellite communication. This is also referred to as the good bit received at the receiver side. From Figure 4.5, it can be seen that there is a general increase in the throughput of the network**.** This is due to the use of the link adaptation algorithm by the adaptive receiver that provides opportunity for the receiver to leverage on the higher link conditions with higher modulation modes. In addition, the TA-ACM scheme shows better performance in terms of throughput. This is due to the accurate estimation of EVM of the received bits at the receiver that helped in the selection of accurate system parameters for the transmission of data. Also, the figure of merits employed in the TA-ACM algorithm also optimized the link budgeting process which reduced the computational time and hence improved the throughput.

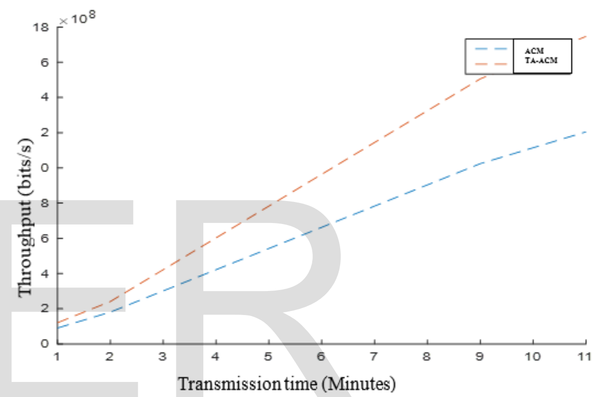

Figure 5: Throughput of ACM and TA-ACM

4.0 SUMMARY AND CONCLUSION

This research work has developed a Throughput-Aware Adaptive Coding and Modulation (TA-ACM) scheme for enhancing the performance satellite communication systems. GSA was used for optimal link budget allocation and the normalized EVM was also used at the receiving satellite station. TA-ACM scheme reduced the effect of path loss on the communication during transmission that may have led to fast communication interval which improved system throughput. The GSA considered two figure of merits which include; *C/N* and *G/T* for better communication process.

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