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Satellite Communication Link Budget Optimization Using PSO & Cuckoo Search Algorithm

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ABSTRACT

Satellite communication has become an integral part of socio-economic development and is facilitated due to the increase in communication and information technologies. It serves several communication needs of businesses and government agencies. The advancement and effective design has further increased the scope and reach of the communication satellites. The application of communication satellites is further implemented in power communication systems to monitor and control certain electrical data acquisition systems such as supervisory control and Data acquisition (SCADA) and power link communication. In this research, an effective algorithm is proposed to calculate the performance of link budget in terms of antenna power and transmission efficiency along with uplink and downlink frequency, transmitter and receiver antenna diameter. The effective optimization algorithms such as PSO and Cuckoo search algorithms implemented here so as to comprehend their performance in the context of link building. The results obtained shows that Cuckoo search algorithm is effective and provides better performance results as compared to PSO.

Keywords: Career to noise ratio, Cuckoo search, PSO, Satellite communication, SCADA

I. INTRODUCTION

Because of the development in automation system, the control, monitoring and the remote operation are considered for a modern system. In this regards, the SCADA provides the remote operation, as they are the controlled systems that monitor and control industrial processes that exist in the physical world [1]. The early type of SCADA systems used mainframe technology and required human operators to make decisions which were more expensive in early days. So, the SCADA used today is more automated and consequently most cost-efficient. The microwave communication network, remote control server (RCS) and remote telemetry unit (RTU) are considered as the backbone of the SCADA system.

The operational information of switchgears of the substation is gathered by RTU and transfers that to the central database through microwave linkage [2]. The SCADA control station comprises of local area network of remote communication server and workstations. The future generation of the SCADA equipment offers higher level of integration by placing the wireless communications and remote telemetry unit functionality together. To access and protect critical remote operations infrastructure is forcing industries to upgrade to the communication systems.

The advancements in the satellite communications (SATCOM) enable high speed two-way connectivity which supports the existing SCADA applications and meet the bandwidth requirements. The satellite IP connectivity is most functional and cost effective which delivers 99.8% availability [3].

A satellite communication generally includes a satellite and several ground stations. The system is a frequency division multiplexed system for providing signal paths between various nodes via the satellite.

The signal path consists of uplink signal, a downlink signal, a transponder Satellite communication services helps in providing the suitable communication infrastructures for a robust transmission of the large amounts of data in the grid present. The standard SATCOM services provided by the telecom operators will be used as the link in the grid. There are limitations which cause uncertainties in the communication system especially in the satellite communications where the losses are major [4]. To manage those losses and uncertainties, the most used approach is to store a required amount of link margin for SATCOM links. The challenge is observed in transponded SATCOM systems where each of the SATCOM systems consists of uplink and downlink. Thus, the transponded SATCOM link budget plan need to account for uncertainties in losses from the uplink segment losses in the downlink segment so that the transponded SNR should meet the required level. The attempt can be made such that the SATCOM link margins can be reserved based on the prior knowledge at the fixed levels. The power control algorithm for transponded SATCOM systems is developed effectively to utilize the information from channel SNR measurements [5]. The method of allocating power in a satellite transmission system consists of,

- Providing a satellite transponder
- Providing a set of geographically distributed ground stations
- Transmitting local uplink signal
- Receiving local signals at mentioned satellite
- Amplifying the received uplink signal by gain constant.

Thus, A system which helps in attenuation while allocating the power among the various signals in multiplexed satellite communication system to maximize information handling capacity of the system is required.

II. RELATED WORK

The various reliability characteristic of a satellite communication system is investigated [6]. The complete satellite system and the failure caused due to transmitter and receiver systems are evaluated. The proposed method uses Laplace transformations and Markov process theory, the transitions state probability, availability, reliability, sensitive analysis of the system and is determined. The mathematical modelling is developed which is helpful in evaluating the behaviours of the various characteristics of the reliability of the satellite communication systems. The numerical studies show that the availability of the system decreases with respect to time. The sensitive analyses reveal that the reliability is more sensitive to a change in failure rate of terrestrial system.

The novel approach for the power control transmission in SATCOM is proposed [5]. The transponder present in the satellite communication provides exclusive link margins present for both uplinks and downlinks against the losses from different sources present. The algorithm proposed works effectively with the information from SATCOM radio frequency situation to establish transponded SATCOM links which achieves desired quality of service requirements. The algorithm also provides solutions for the set of SATCOM links that satisfies end-to-end carrier power to noise density ratio requirements with sufficient uplink and downlink margins. The simulation results show that the joint power control algorithm proposed with appropriate link margins is able to effectively tackle random uplink and downlink losses.

The wireless-based communication is quite popular from few years and the SCADA industries also use the wireless media for deployment in production. The use of SCADA systems to access remote networked devices which is located all over and the best solution is satellite communications. The study proposes [7] a satellite-based communication facility for SCADA water station. Few mechanisms are suggested which provides relevant protection and security issues linked with the satellite transmission is considered.

The communication satellites play a very important role in the development of the country where the satellite communication system design trade-offs increase with the complexity of the payload. Before the satellite is deployed the design of all the attenuation scenarios is performed. The fundamentals of the satellite link budget are presented [8]. The gravitational search algorithm based on the law of gravity and mass interaction is presented as search algorithm. In the design the number of factors is considered for the robustness of the satellite link. The GSA algorithm is proved effective and showed that it performs well.

The study presented consists of the configuration of link between an earth station to broadcast multimedia service and user through geo stationary satellite in Ka band [9]. The application used helps in calculating the link budget in uplink and downlink. The design of the future communication satellite for Ka band is proposed by considering the simple architecture. The software is developed for checking the feasibility of the proposed system. The simulation results show margin of error at 8.17 dB for the uplink and at 8.2 dB in the downlink.

The new modulation and demodulation circuit superposed modulation is presented [10] for multilevel APK signals were presented. The advantages of this technique are circuit simplicity and high-speed performance. The feasibility of multilevel digital carrier transmission at high bit rate is demonstrated. The experiment was conducted at higher clock a rate which shows the viability of the approach. The technique proposed is used in high speed digital microwave, millimetre-wave and satellite communication systems. Measurement accuracy of the parameters required for system control plays an important part in determining the link availability achieved using a particular control philosophy.

III. RESEARCH METHODOLOGY

In this research, particle swarm optimisation and cuckoo search algorithm are considered for finding the best desired link. The main objective of this paper is to design and calculate the Link budget performance in terms of transmit antenna power, transmit antenna efficiency, transmit antenna diameter, uplink frequency, downlink frequency, receive antenna efficiency & receive antenna diameter by constraining the parameters for the uplink, downlink & total carrier to noise ratio. The detailed steps considered for the implementation are shown as follows:

III.I Carrier to noise ratio of a Transponder block:

Here the transponder block is taken into consideration where the noise is transferred to the input of the block. The C/N ratio at different points in the system is mentioned by 1, 2 and 3 as shown in the below Fig.

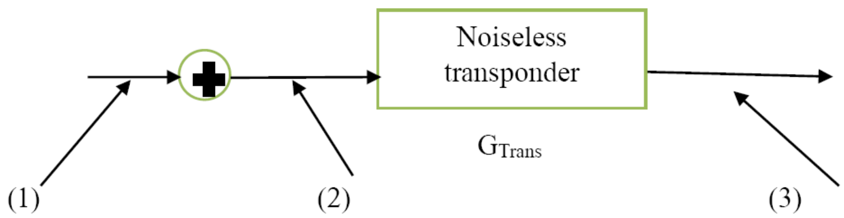

Figure 1: C/N Ratio of Transponder

At 1: [C/N] = $\frac{C}{k.T_{Ant}.\ B_N}$ ……………………. (1)

At 2: [C/N] = $\frac{C}{k.(T_{Ant+T_{Trans}}).\ B_N}$ ……………... (2)

At 3: [C/N] = $\frac{C}{k.(T_{Ant+T_{Trans}}).\ B_N}$ ………………. (3)

Where Gtrans is the transponder

B_N is the wavelength

The C/N ratio is computed once it is enough to move to its input. The C/N ratio before and after each of the block is same.

III.II C/N ratio for uplink station

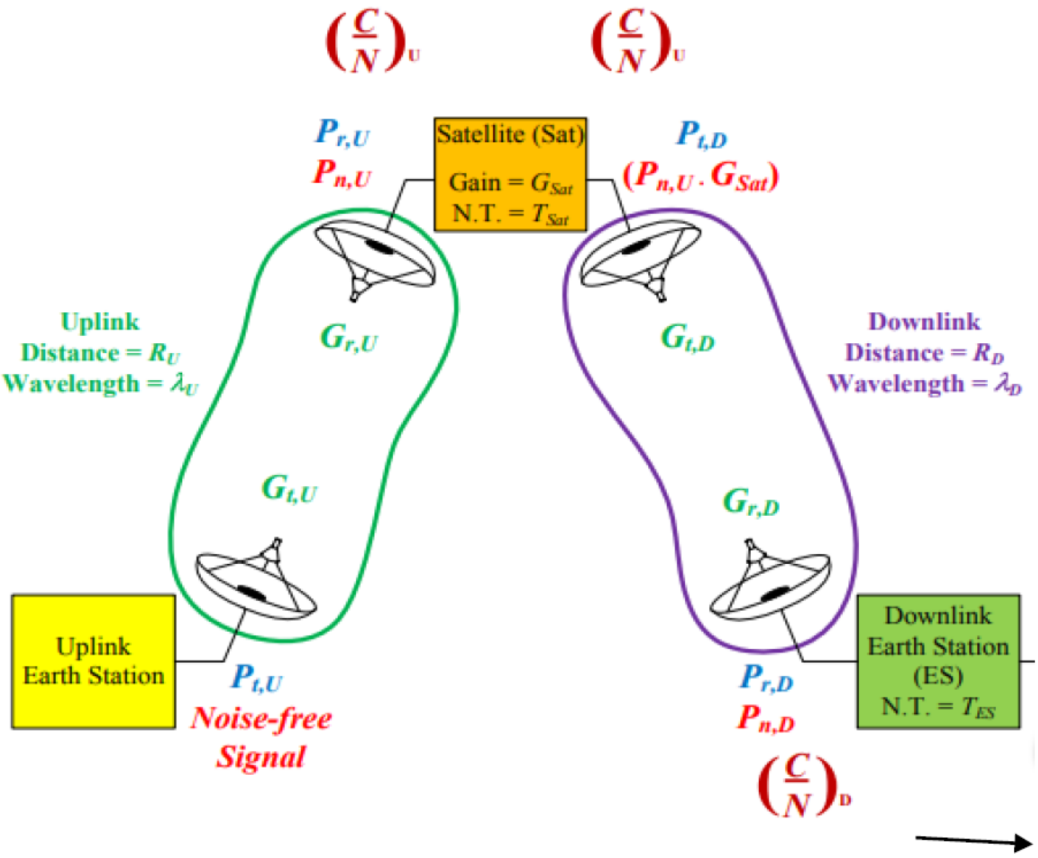

Figure 2: Overall satellite communication system [11]

Considering the uplink earth station which is noise free, transmitted signal and the received signal at the satellite are,

:$P_{r,U} = \frac{P_{t,U} * G_{t,U} * G_{r,U}}{\left(\frac{4\pi R_u}{\lambda_u}\right)^2}$ …………………. (4) (uplink Received Signal Power)

The uplink of the noise at the input of the satellite is shown below where the bandwidth of all the carrier signals and noise signals are equal to B_n.

:$P_{n,U} = k.\ T_{sat.}\ B_n$ ………………………… (5) (uplink Noise Power)

Where k is Boltzmann constant

Tsat is the saturated temperature

So, the uplink C/N ratio is given as,

$$:\left(\frac{C}{N}\right)U = \frac{\frac{P_{t,U}*G_{t,U}*G_{r,U}}{\left(\frac{4\pi R_u}{\lambda_u}\right)^2}}{k*T_{sat}*B_n}$$

$$= \frac{P_{t,U}*G_{t,U}*G_{r,U}}{\left(\frac{4\pi R_u}{\lambda_u}\right)^2 k*T_{sat}*B_n} \text{ ……………… (6) (uplink carrier to Noise ratio)}$$

Where $P_{t,U}$ = is the transmitted power in uplink

$G_{t,U}$ = Gain of the transmitter in uplink station

$G_{r,U}$ = Gain of the receiver in uplink station

λ_u = Wavelength in the uplink

III.III C/N ratio for Downlink station

Now considering that the satellite transmits in the downlink and noise-free signal, the received signal at the downlink earth station is,

$$:P_{r,D} = \frac{P_{t,D}*G_{t,D}*G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2} \text{ …………………. (7) (Downlink Received Signal Power)}$$

The noise present in the downlink earth station is given below. Again, same as uplink station the bandwidth of all carrier signals and noise signals are equal to B_n

$$: P_{n,D} = k.T_{ES}.B_n \text{ ……………………… (8) (Downlink Noise Power)}$$

So, the downlink C/N ratio is,

$$:\left(\frac{C}{N}\right)D = \frac{\frac{P_{t,D}*G_{t,D}*G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2}}{k*T_{ES}*B_n} = \frac{P_{t,D}*G_{t,D}*G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2 k*T_{ES}*B_n} \text{ ……9) (Downlink carrier to Noise ratio)}$$

III.IV Overall C/N ratio

Here, the evaluation of the complete C/N ratio of the system and is related to the C/N ratio of the uplink and C/N ratio of the downlink. Assuming that the transmitted signal by the uplink earth station is noise free, the received signal at the satellite is,

$$:P_{r,U} = \frac{P_{t,U}*G_{t,U}*G_{r,U}}{\left(\frac{4\pi R_u}{\lambda_u}\right)^2}$$

The above signal gets amplified by the satellite that has a gain of GSat such that the transmitted signal by the satellite becomes,

$$:P_{t,D} = G_{sat}.\,P_{r,U} = \frac{\text{Gsat.}*P_{t,U}*G_{t,U}*G_{r,U}}{\left(\frac{4\pi R_u}{\lambda_u}\right)^2} \text{ ……………… (10)}$$

Where $P_{t,D}$ is the power of the transmitter in the downlink.

The results which are obtained in the received signal at the downlink earth station is,

$$: P_{r,D} = \frac{P_{t,D} * G_{t,D} * G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2} = \frac{\text{Gsat.} * P_{r,U} * G_{t,D} * G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2}$$

$$= \frac{\frac{\text{Gsat.} P_{t,U} . G_{t,u} . G_{r,u}}{\left(\frac{4\pi R_U}{\lambda_U}\right)^2} . G_{t,D} . G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2} \text{ ………………. (11) (Downlink Received Signal Power)}$$

The noise signal transmitted from the uplink and downlink is assumed to be noise free and thus the noise and the gain gets amplified as it passes through the satellite and produces equal amount.

$:G_{sat} . P_{n,U} = G_{sat} . k . T_{sat} . B_n$ ……………… (12) (noise power at the earth station)

The noise power at the earth station has two components such as,

1. The component that was generated by the satellite and got amplified and transmitted to the earth station.
2. The noise generated by the earth station itself. So, the total amount of noise at the receiver because of the two components becomes,

$$:P_{n,D} = \underbrace{\frac{\text{Gsat . k. Tsat. } B_n . \; G_{t,D} . G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2}}_{\text{Component 1}} + \underbrace{k . T_{ES.} B_n}_{\text{Component 2}} \text{ …………………. (13)}$$

The above carrier and noise powers is given, the overall C/N ratio becomes.

$$: \left(\frac{C}{N}\right) overall = \frac{\frac{\frac{\text{Gsat.} P_{t,U} . G_{t,u} . G_{r,u}}{\left(\frac{4\pi R_U}{\lambda_U}\right)^2} . G_{t,D} . G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2}}{\frac{\text{Gsat . k. Tsat. } B_n . \; G_{t,D} . G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2} + \text{k.TES.Bn}} \text{ … (14) (Overall carrier to Noise ratio)}$$

The above equation can be re written as,

$$:\left(\frac{C}{N}\right) overall = \frac{\frac{\text{Gsat.} P_{t,U} . G_{t,u} . G_{r,u}}{\left(\frac{4\pi R_U}{\lambda_U}\right)^2} . G_{t,D} . G_{r,D}}{\text{Gsat . k. Tsat. } B_n . \; G_{t,D} . G_{r,D} + \left(\frac{4\pi R_D}{\lambda_D}\right)^2 \text{k.TES.Bn}}$$

Multiplying both the numerator and denominator by the inverse of numerator gives,

$$:\left(\frac{C}{N}\right) overall = \frac{1}{\frac{\left(\frac{4\pi R_U}{\lambda_U}\right)^2 \text{Gsat . k. Tsat. } B_n . \; G_{t,D} . G_{r,D} + \left(\frac{4\pi R_U}{\lambda_U}\right)^2 \left(\frac{4\pi R_D}{\lambda_D}\right)^2 \text{k.TES.Bn}}{\text{Gsat.} P_{t,U} . G_{t,u} . G_{r,u} . G_{t,D} . G_{r,D}}} \text{…… (15)}$$

Further classifying the denominator into two parts and cancelling the quantities produces

$$:\left(\frac{C}{N}\right) overall = \frac{1}{\frac{1}{\left(\frac{C}{N}\right)U}+\frac{1}{\left(\frac{C}{N}\right)D}} \ldots\ldots\ldots\ldots (16)$$

The above equation shows that the uplink and downlink carrier to noise ratio allows us to compute the overall carrier to noise ratio of the system. The overall carrier to noise ratio is smaller than the either of the carrier to noise ratios. The above equation can be extended while considering the m uplinks and m downlinks.

Now, the two algorithms are considered such as particle swarm optimization and cuckoo search algorithm which is compared later.

III.V Particle swarm optimization

This algorithm is used for optimization and the error value should be minimized and total carrier to noise ratio should be maximized. The link optimization is performed using this algorithm. The performance is measured in terms of transmit antenna power, transmit antenna efficiency, transmit antenna diameter, uplink frequency, receive antenna efficiency by using the carrier to noise ratio and constraining parameters for uplink and downlink.

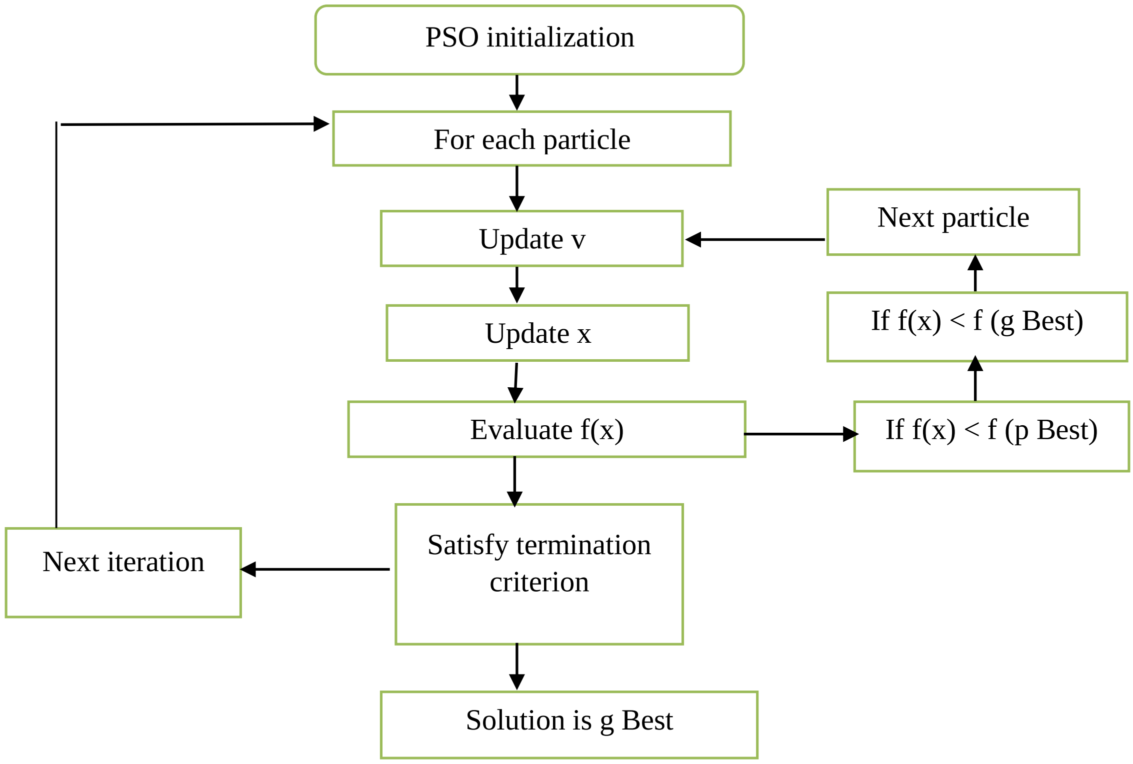

Figure 3. Flowchart of the PSO algorithm

PSO algorithm is an evolutionary based computation technique which was developed with the inspiration of socialistic behaviour of the flocking bird and the fish schooling. The population of the individuals is selected as the particles and the same is given with some initial velocity to fly in the problem hyperspace. The velocities of every iteration are stochastically adjusted by considering the previous best position of the particle amongst their neighbourhood best position. These positions are calculated with respect to predefined fitness function. The optimal value in every iteration keeps on changing and this process is continued until near optimal solution is achieved.

III.VI Cuckoo search algorithm

Cuckoo search algorithm is introduced to enhance performance of the SATCOM systems and is used as an optimization algorithm to improve the performance in variety of fields such as industry, communication etc. By considering this algorithm, the desired parameter can be obtained more and undesired parameter can be determined less but the optimum value of the parameter is obtained using this algorithm. The error value should be minimized and the carrier to noise ratio is maximized. The link optimization is performed and the performance parameters are measured.

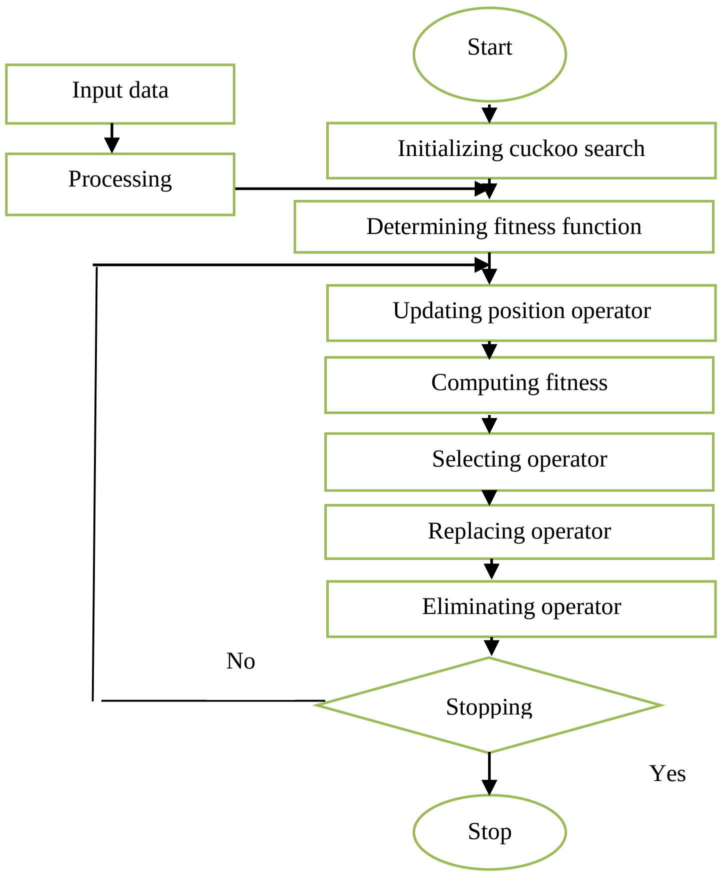

Figure 4. Flowchart of cuckoo search algorithm

The flowchart of the algorithm is shown above. This is a population-based algorithm inspired by the behaviour of cuckoo species in combination with the levy flight behaviour. To obtain the best link the selection is based on the optimized total carrier to noise ratio value. While generating new links the search ability is performed thereby optimization rate is changed and more number of new links is generated after the search operation. Thus, the new link model is obtained to determine the optimal best total carrier to noise ratio value.

IV. EVALUATION AND RESULTS

In this research, the two algorithms are considered and compared to obtain the best optimization value. The design parameters are evaluated with the range values and compared between two algorithms and their obtained values. MATLAB 2017 a is considered for the simulation purpose and the program is written on the basis of the same software. The ranges are mentioned in the below table and is as follows,

Table 1. Comparison between Ranges of Design Parameters

DESIGN PARAMETERS	RANGES
Uplink frequency	5.9-7 GHZ
Downlink frequency	3.8-4.2 GHZ
Earth transmit power	26-30 dB
Earth transmit and receive antenna efficiency	50-70 %
Earth transmit and receive antenna diameter	2.5-4.5 m

The carrier to noise ratio which is obtained for both uplink and downlink earth stations and overall satellite communication system is analysed for both the algorithms and reference satellite model (Telstar v) is also included for the comparison purpose and is given as,

Table 2. Comparison between PSO and CUCKOO Carrier to noise ratio

CARRIER TO NOISE RATIO	TELSTAR V (REAL)	PSO	CUCKOO SEARCH
Uplink (dB)	105.7	137.033	150.601
Downlink (dB)	85.4	117.81	150.437
Total (dB)	84.5	117.759	147.508

The simulation is performed for the design parameters and comparison table is formed below.

Table 3. Comparison between PSO and CUCKOO Design Parameters

DESIGN PARAMETERS	RANGES	PSO-OPTIMIZED VALUE	CUCKOO SEARCH-OPTIMIZED VALUE
Uplink frequency	5.9-7 Ghz	7 Ghz	6.85 Ghz
Downlink frequency	3.8-4.2 Ghz	4.2 Ghz	4.16 Ghz
Earth transmit power	26-30 dB	30 dB	29.60 dB
Earth transmit antenna efficiency	50-70 %	70%	59.04%
Earth receive antenna efficiency	50-70 %	70%	64.90%
Earth transmit antenna diameter	2.5- 4.5 m	4.5 m	2.57 m
Earth receive antenna diameter	2.5-4.5 m	4.5 m	4.31 m

V. CONCLUSION

In this research, an efficient technique comprising both PSO and cuckoo search algorithm is proposed for providing the best optimized link value in satellite communications. The PSO algorithm is used to enhance the efficiency of the system by optimization and cuckoo search algorithm gives the best carrier to noise ratio in all the earth stations including overall satellite communication systems. In the evaluated results different design parameters such as uplink frequency, downlink frequency, antenna transmit efficiency etc is considered and simulated for the same. The results obtained shows that cuckoo search algorithm is more effective compared to PSO in terms of data transmission. Furthermore, in future different machine learning algorithms is considered for evaluation of SATCOM and to obtain more efficient approach.

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