IoST: A Multi-CubeSat Cognitive Radio Network

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Abstract

Fifth- generation communication also known as internet of things is rolling out worldwide. It has provided higher network capacity and speed for mobile broadband communications; however, 5G network focuses only on terrestrial coverage. 6G and Cognitive Radio (CR) is expected to be the future solution to all heavy data traffic and globe coverage. Satellite communication is anticipated to cover rural areas, sea, spanning air, and space in what is known as Internet of Space Things (IoST). Low Earth Orbit (LEO) CubeSat orbits earth provide real time measurements with low transmission power and high data rate. Cognitive radio will focus on providing efficient spectrum use and resources allocations. In this paper, a multi CubeSat cognitive radio network is proposed to improve time delay, increase data exchange, and increase the Signal to Noise Ratio (SNR) of the communication system. simulation results demonstrate the convergence of the multi CubeSat system improving the signal to noise ratio for different number of CubeSats structure.

Keywords
CubeSat, Cognitive Radio, Internet of Space, Spectrum.

1. Introduction
Fifth generation communications are being deployed all around the world [1]. It has overcome many limitations of the previous generation systems from network capacity and reliability to higher data rate and reduced latency. However, the exponential rapid growth of data systems has exposed the limitations and challenges of 5G networks. Showcasing how it only focuses on terrestrial and urban areas leaving rural spaces uncovered, insufficient high-cost infrastructure, and unmatched downloading and uploading speeds [2].

Satellite communication in 6G is an emerging technology envisioned to provide a full coverage with high data rate wireless system to all uncovered areas even air, sea, and space [3]. Satellite communication can be categorized into three categories depending on the satellite altitude and their weight. Geosynchronous Earth Orbit (GEO) orbits the earth at 35,800 km and uses high frequencies, Medium Earth Orbit (MEO) orbits with altitude 8,000 to 12,000 km, while Low Earth Orbit (LEO) are at altitudes of 500 to 2000 km [4]. GEO satellites form a more reliable connection to ground and have a higher data rate than LEO satellites. On the other hand, The altitude of the CubeSats provides higher flexibility to configuring reliable links between ground station and non-terrestrial network. Furthermore, their close proximity to earth yields to a shorter delay, making them more suitable for cellular and Global Positioning System GPS communications.

Space/Satellite industry is a rapidly growing research topic nowadays. According to the Morgan Stanley's report, the estimated revenue from the space industry will reach $1 trillion by 2040. Cube satellite (CubeSat) are contriving a big share in this market. They emerged from teaching material in universities [5] to military and commercial applications [6] [7]. A standard CubeSat has a mass of 1.33 kg, dimensions of 10cm*10cm*10cm, and orbits at an altitude of 500 to 2000 km [8].

The concept to connect multiple CubeSats to maximize space-air-ground network was first proposed by NASA [9] where CubeSats are networked with each other to form a swarm on the orbit. A matching Game-Based approach to join LEO satellites was proposed in [10]. The CubeSats topology was modeled as a form of a mixed integer nonlinear programming to simplify the large-scale networks. In [11], the authors studied the power budget from the LEO satellite to the ground and modeled the inter-CubeSat links.

For Spectrum allocation and efficiency, cognitive radio is a well-known method to utilize the spectrum to its capacity. It is the concept of shared spectrum where secondary users (SUs) share the spectrum with licensed primary users (PUs) [12]. The exploitations of the SU to the unused spectrum also known as white spaces increases the network efficiency as shown in Figure 1 [13] [14]. Dynamic spectrum access solves the problem of spectrum scarcity and underutilization [15].

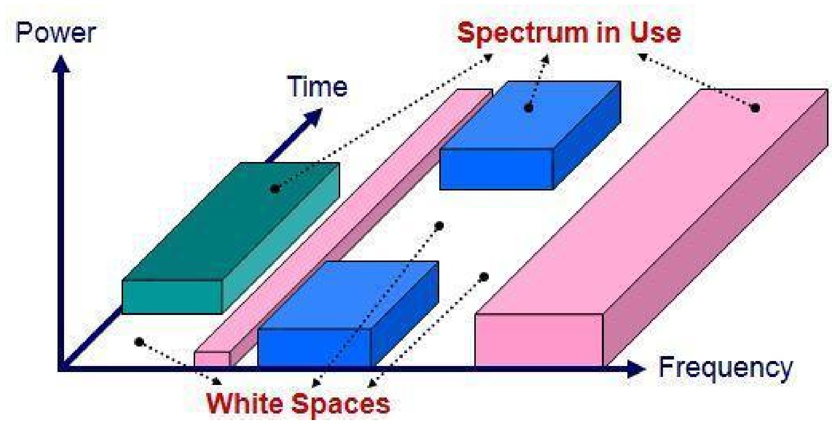

Figure 1. Unused spectrum for licensed primary users

The contribution of this paper is as follows:

- Establish a direct interconnection between CubeSats rather than go through the ground station and cause unnecessary traffic.
- Simulate the convergence of the CubeSats consensus algorithm
- Study the SNR effect by changing the number of interconnected CubeSats
- Improve the probability of detection significantly by implementing a cooperative LEO satellite network.

2. System Model and Results

There are two stages in the proposed system model. In the first network, CubeSats are interconnected forming multiple clusters of CubeSats on the LEO orbit. In the secondary network, a decentralized cognitive radio technique is applied between the primary and the secondary users using the weight gain combining method as shown in Figure 2.

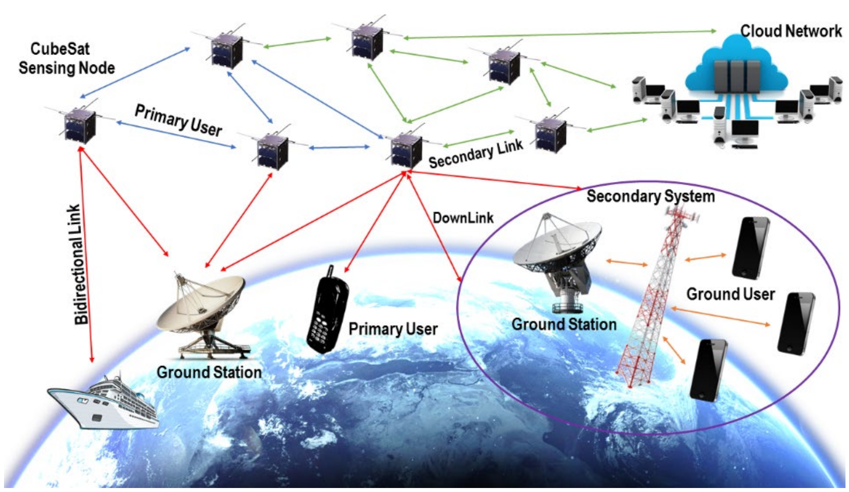

Figure 2. A Multi-CubeSat Cognitive Radio Network

CubeSats Consensus Algorithm

We conduct a Monte Carlo simulation for a cluster of $N = 10$ CubeSats. We assume every LEO satellite is independent and identically distributed Raleigh fading.

$$x_i(n+1) = x_i(n) + \frac{a}{w_i} \sum_{j \epsilon N_i} \left(x_j(n) - x_i(n)\right), i \, \epsilon \, J \quad (1)$$

Where $a = 0.01$ millisecond (ms) is the iteration step size [16] and $\rho_i \geq 1$ is the weight ratio is obtained from [17] as

$$w_i = \frac{\rho_i}{\sum_{i=1}^{N} \rho_i} \quad (2)$$

w_i is the weighted average estimated SNR at each LEO satellite. The global decision is the weighted sum of all the interconnected LEO satellites N. Figure 3 shows the convergence of 10 interconnected satellites under a fixed topology. We can observe that it takes the cluster 12 steps to converge which is 0.12 ms. The existing time delay for 5G from transmitting to receiving is 1 ms.

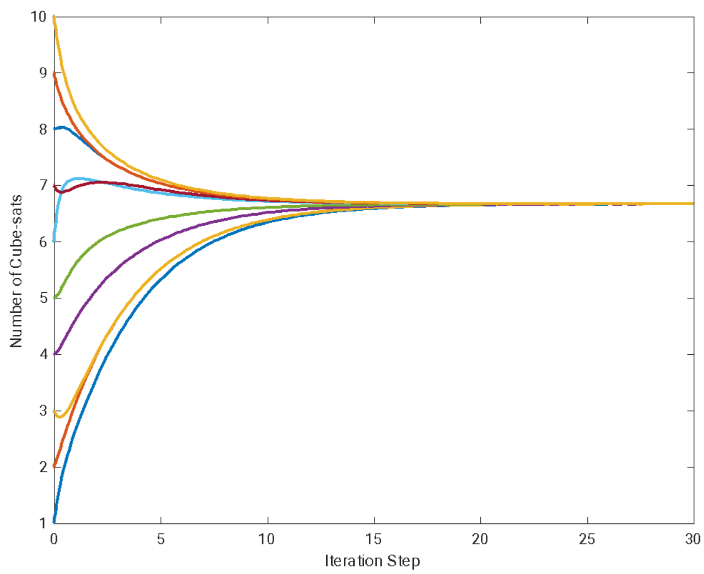

Figure 3. Convergence of the CubeSats consensus algorithm

Although the algorithm should always converge for any number of interconnected CubeSats, calculating the optimum cluster number to maximize the power while minimizing the time delay is the goal. Increasing the distance of interconnected CubeSats in a cluster will also increase the time delay. Also, the simulated topology assumes a fixed connection between 10 CubeSats. For more accurate results, we have to model for random connections between the satellites, account for link failure, and satellite movement.

Cognitive radio system

In this stage, we will adopt the weight combing technique [18] to simulate the receiver operating characteristic where we plot the probability of detection versus the probability of false alarm. We can clearly see in Figure 4 how the performance has significantly improved by increasing the cluster number of interconnected CubeSats. When using 10 LEO satellites, at a false alarm of 0.01 the detection probability reaches 0.9, the probability of detection reaches 0.7 and 0.5 when using 7 and 3 CubeSats clusters respectively.

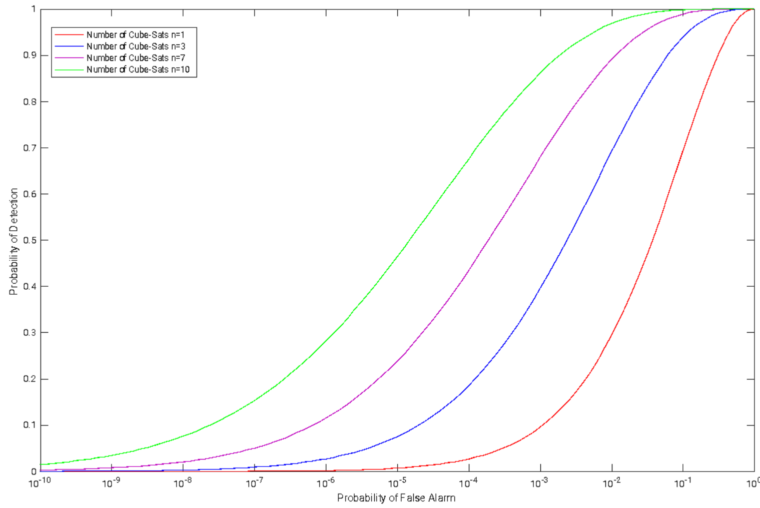

Figure 4. Receiver Operating Characteristic ROC

We also simulated the probability of detection with respect to the average SNR for different number of CubeSats interconnected clusters. We can clearly observe how increasing the number of interconnected satellites improves the SNR as expected.

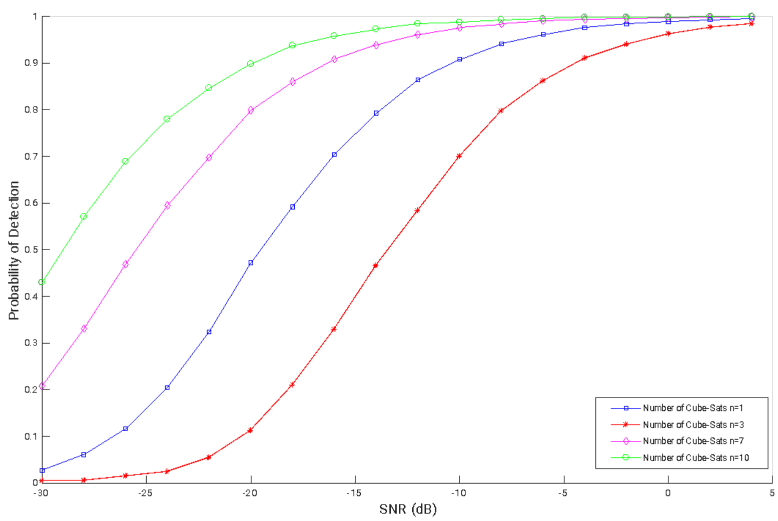

Figure 5. Probability of detection versus the average Signal to Noise Ratio

3. Conclusion

In this paper, we have presented a multi-CubSat cognitive radio network. The satellites were interconnected forming multiple clusters on the LEO orbit. To improve spectrum efficiency, a decentralized cognitive radio technique is applied. Simulation results demonstrate the convergence of the CubeSats consensus algorithm and how does the number of interconnected satellites effect the probability of detection.

For future work, we should study and interconnection cluster that accounts for link failure, and satellite movement. Also, a thorough study of the design of the physical layer will help obtain an accurate modelling of the satellite channels.

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Biography

Enfel Barkat received her Master of Science in 2013 and PhD in 2019 both degrees in Electrical Engineering from the University of Colorado, USA. Currently, Dr. Enfel is an Assistant Professor at the department of Electrical and Computer Engineering, Effat University, KSA. She is also the department head and Director of the Master of Energy Program. Her research interests include cognitive radio networks, internet of space and satellite communications. Dr. Enfel is a *Senior Member* of *IEEE*