Enhancing performance of slotted ALOHA protocol for IoT covered by constellation low-earth orbit satellites

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ABSTRACT

Recently, constellation of satellites has drawn a lot of interest from academia and industry as potential solution for extensive coverage of wide range of internet of things (IoT). In this work, IoT devices was assumed to be covered by constellation of low-earth orbit (LEO) satellites where the medium access control (MAC) technique called slotted ALOHA is employed. In this article, we use a constellation of satellites to reduce the collision domain and enhancing performance in order to obtain maximum results. We have carried out some modeling and simulations to optimize the number of satellites with different erasure probabilities with respect to IoT devices in order to enhance throughput and stability of slotted ALOHA protocol using the network simulator 2 (NS2). The numerical results have shown an improvement in terms of throughput and stability. And the simulation of the same system using NS2 is conducted and shows a good correlation with the theoretical study. Where the throughput reached 0.82% instead of 0.52%. Our findings offer proof that this method helps to use large number of IoT, and reduce collisions compared to conventional slotted ALOHA.

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1. INTRODUCTION

The past few years have seen a steady rise in interest in multiple access protocols for wireless networks. Emerging applications in this field are distinguished by the large number of internet of things (IoT). In our study, IoT refers to a wireless sensor device used in several application areas to monitor ocean conditions, weather conditions, animal tracking, smart agriculture [1], [2]. Medium access control (MAC) mechanisms used in satellite networks, regardless of their architecture direct, indirect, or a hybrid of the two, were not intended to offer scalable approaches for the increasing number of IoT. Many of which have low hardware or power capacities that share a single channel for short-duration data packet transmissions [3]. Random access (RA) policies seem particularly appealing in the context of medium access, as schedule-based solutions are inefficient when small data transferred with unpredictable manner. Time division multiple access (TDMA) lose performance with low-earth orbit (LEO) satellite constellation due to complexity and synchronization [4]. The same disadvantage exists with code division multiple access (CDMA). Slightly modified versions of ALOHA [5], [6] have already found their way into commercial solutions. However, collisions naturally restrict the performance of such schemes [6], [7]. In order to close this gap, protocols that incorporate the diversity principle into ALOHA have been developed as a result of RA's resurgence in popularity. Several protocols have been developed based on this concept, ranging from the time synchronous coded slotted ALOHA (CSA) [8]-[10], and frameless ALOHA [11], to asynchronous alternatives [12]. These methods create time variety through replication, which may result in significant increases in transmitter complexity and power consumption as well as significant demands on the receiver's memory and processing capacity for the successive interference cancellation (SIC) processes applied for removing copies in successfully decoded.

The production of satellites technologies and rocket launch, as well as the advancement of systems communication technologies, have all contributed to the space industry's recent exponential growth [11]. The attractive result of these evolutions decreases in the cost through LEO satellites. This kind of satellite has drawn a lot of interest for potential uses due to its low latency, modular design, and comparatively low cost when it is compared with geostationary-earth orbit (GEO) satellites. LEO orbit satellites would be advantageous in this situation [13] because of their potential for worldwide coverage and lower propagation signal loss.

Massive investments from the private sector are being made for constellation of satellites [14], [15], as demonstrated by SpaceX [16] and oneweb [10] given that a single LEO is insufficient to service a vast IoT network. A promising trend for future network applications is the constellation of multiple satellites into orbit [17], [18] where IoT send their data collected via wireless media, with attempts to receive it at various satellites. In this paper, section 2 describes related works. Section 3 presents method and system model of IoT devices which want to send their collected data to a constellation of satellites, and the system constellation throughput. While section 4 discusses the simulation analysis and numerical results. Section 5 is reserved for conclusion.

2. RELATED WORKS

The number of IoT devices has been rapidly growing, and it is likely that this trend has continued. A large number of IoT devices are being deployed across various industries and sectors. Efficient and reliable communication is essential for the success of IoT applications. There are several communication protocols and technologies used in IoT to enable devices to communicate with satellites. But throughput is decreased by a high number of collisions caused by IoT connection with satellite constellations, where satellites receive a large number of packets simultaneously. Many studies and research are focused on these issues [19]-[21].

A traffic allocation technique that maximizes traffic in a multiple satellite system is presented in [17]. It is based on linear programming. Furthermore, the technique takes the visibility likelihood into account when allocating traffic to each satellite. In order to increase system capacity, the authors of [22] suggest a load-balanced satellite handover technique that involves a simultaneous handover frequency and workload optimization problem. Furthermore, a traffic load distribution approach using an adaptive power allocation algorithm for a multiple satellite connection model in order to maximize the system throughput.

In contrast to [19], where receivers use orthogonal access channel while sending data to the satellite, the authors concentrate on a scenario where relays share a slotted ALOHA channel to transmitting data, and compared with [20], [21] which proposed a system model using slotted ALOHA protocol with a collection of clustered devices which sends their messages to constellation of satellites. In fact, the channel took into consideration on-off fading model and considering equal erasure probabilities for all satellite constellations to calculate the throughput. In our case, using the model in [20] with different erasure probabilities is very likely than using the same erasure probabilities [20]. We have shown the erasure configuration when throughput takes a maximum value.

Our findings in this article indicate higher constellation satellites throughput. Furthermore, we examine how the various topologies and positions of the satellite constellation affect system throughput and stability. The proposed method in this study tended to have an inordinately higher proportion of packets successfully received compared with other papers [20] accompanied with numerical results and simulation using network simulator 2 (NS2) simulator.

3. METHOD AND SYSTEM MODEL

We take into consideration the system depicted in and Figures 1 and 2, which consists of a limited number of IoT devices willing to share a common channel with a constellation of nanosatellites in a circular LEO in order to transmit the information they have gathered. We assume that time is split up into slots for channel access. The T time-slots are independently from each other. Every frame starts with a random number of IoT devices active in each time-slot. The probability of u users transmits in time-slot following independent poisson distributions.

$$P(U = u) = \frac{(G^u)e^{-G}}{u!} \quad (1)$$

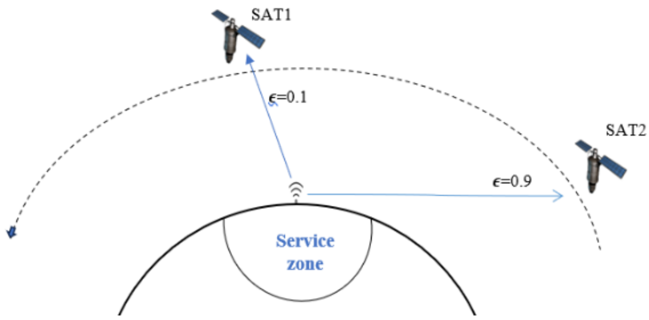

Figure 1. Constellation with 2 satellites with different erasure probabilities and spacing P=10

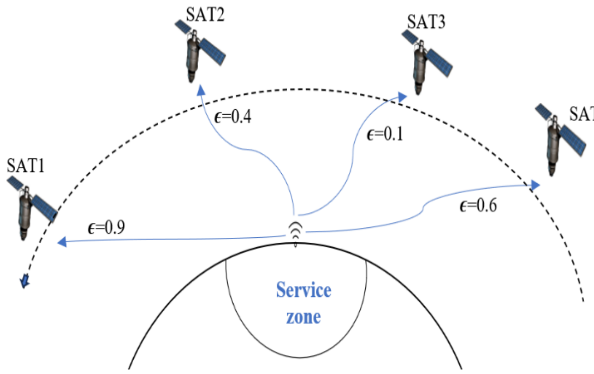

Figure 2. Constellation with 4 satellites with different erasure probabilities and spacing P=5

The time to move from one location to another by satellite is referred to as an iteration [23]. Additionally, each time the constellation of satellites crosses over the IoT [24], it is referred to as a lap. Every iteration takes the same amount of time [25]. The (instantaneous) coverage area of the nanosatellite is determined by the half-angle measured at earth's center. In (2) gives the half-angle [26].

$$\theta = \left[\mathrm{Ar}\cos\left[\frac{R_T}{R_T+h}\cos(E_{min})\right] - E_{min}\right] \tag{2}$$

Where: E_{min}: the elevation angle, $E_{min} = 10°$
h: the Picosatellite altitude
The effective earth radius, or R_T, is equal to 6378.137 km
For $E_{min} = 10°$ and h=650 km, we get:

$$\theta = 16{,}650°$$

In this case, for an orbit over the equator with an inclination angle of zero, the total number of separate and concatenated service zone on Earth is equivalent to $\frac{360}{2\theta}$=11,25. For the rest of the paper, we consider that every service zone is divided into 20 positions of satellites with on-off fading channel modeling [20], [27]. The erasure probabilities $\alpha_1, \alpha_2, \ldots\ldots \alpha_k$ depending on the satellite's location and IoT devices. Observe from Figure 1 that the erasing chance is lowest at the place closest to the zenith, while positions near the horizon have the highest erasure probabilities. in order for the satellites to detect a specific erasure probability α_k, $k\epsilon\{1,2,\ldots\ldots K\}$.

Scenario 1. Table 1 explains the erasure probabilities and the positions of satellites with K=2, and spacing of P=10. In this case, both satellites are separated by 10 positions. In the next step, the second satellite take the position of the first satellite). Additionally, we examine a collection of 10 distinct erasure probabilities, denoted by $\alpha_k\epsilon\{0.01; 0.1; 0.2; 0.3; 0.4; 0.5; 0.6; 0.7; 0.8; 0.9\}$. These may be directly correlated with the satellite's elevation angle relative to the IoT devices, ranging from 90° at the zenith to nearly 0° at the horizon. We have 20 positions. We therefore need approximately 20 satellites to cover the service area at all times where all IoT devices are positioned in this area [28].

Table 1. Erasure probabilities at each location with P=10 satellite spacing, when taking K=2 satellites

P	SAT	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
	SAT1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	-	-	-	-	-	-	-	-	-	-	-
10	SAT2	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.01	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	-
	SAT3	-	-	-	-	-	-	-	-	-	-	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.01

Scenario 2. Table 2 explains the erasure probabilities and the positions of satellites with K=4 and spacing of P=5. In this case, both satellites are separated by 5 positions. The second satellite moves into the first satellite's current location in the following iteration.

Table 2. Erasure probabilities at each position with spacing P=5 and LEO satellites number K=4

P	SAT	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
	SAT1	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SAT2	0.4	0.5	0.6	0.7	0.8	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SAT3	0.1	0.01	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	-	-	-	-	-	-	-	-	-
5	SAT4	0.6	0.5	0.4	0.3	0.2	0.1	0.01	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	-	-	-	-
	SAT5	-	-	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.01	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
	SAT6	-	-	-	-	-	-	-	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.01	0.1	0.2	0.3
	SAT7	-	-	-	-	-	-	-	-	-	-	-	-	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2

In Table 3 we explain the variation of number satellites in orbit according to the number of positions between two satellites. Where if the number of positions between to satellite is 1 the number of satellites in the zone of service is 20 and the erasure probability Epsilon equal 0.1. We also notice that the number of satellites decreases as the number of position increases.

Table 3. Number of satellites in orbit according to the number of positions between two satellites

Position between two satellites	Sat/Zone	Epsilon	Sat/Orbit
1(position)	20	0.1	220
2	10	0.2	110
3	7	0.3	74
4	5	0.4	55
5	**4**	**0.5**	**44**
6	3	0.6	37
7	3	0.7	32
8	3	0.8	27
9	3	0.9	24
10	**2**	**1**	**22**

Moreover, we consider a fixed erasure probability. These erasure probabilities may be associated with the satellite's elevation angle relative to the IoT [29]. The minimum elevation angle E_{min} is necessary to achieve a reliable communication and determines the satellite visibility time in service area [30]. The time taken by the satellite to do one orbit around the Earth is:

$$T_v = 2\pi.\left(\frac{(R_T+h)^3}{\mu}\right)^{\frac{1}{2}} \tag{3}$$

$$T\_v = 5860\ s = 97{,}66\ min$$

With the gravitational Earth constant $\mu=3.986\times10^{14}\ m^3s^{-2}$, the satellite altitude h=650 km, and the Earth radius is R_T=6378 km, the satellite speed is:

$$V_T = \sqrt{\frac{\mu}{R_T+h}} \tag{4}$$

The speed of satellite around the Earth at the altitude of 650 km, is equal to V_T=7.531 km/s [26] where each IoT keeps the same visibility time. The shape of the earth and obstructions like mountains make it impossible for a satellite to see any place on Earth with an elevation angle lower than E_{min}. The amount of time that a single satellite is visible at any given location on Earth depends on the radius and gravitational constant. From (3) calculates the nanosatellite visibility time for each IoT, which is 5860 seconds during the Nanosatellite pass [31]. If a packethasn't been erased by the channel and if no packets have collided with it. The packet will be successfully received at the satellite [32]-[34].

A receiver does not take into account the capture effect or multi-user detection [35]. According to the fading channel method that was first introduced in [27], we consider a data unit to be either fully shadowed with probability (1-α). Based on these suppositions, a binomial distribution of parameters $(u;\ 1-\alpha)$ governs the quantity of non-erased packets that reach a constellation when u simultaneous transmissions occur over a single slot. The probability P(k) of a successful reception is:

$$P(k) = \binom{u}{k} p^k\, q^{u-k} \tag{5}$$

So, (5) becomes:

$$P(k) = \frac{u!}{(u-k)!\,k!}\, p^k\, q^{u-k}$$

And for k=1 becomes:

$$P(k=1) = u(1-\alpha)(\alpha)^{u-1}$$

where: P(k=1): probability of successful reception when numbers of success among (u) trials k=1
u: numbers of trials
k: numbers of success among (u) trials
$\frac{(u)!}{(u-k)!k!}$: numbers of outcomes with exactly k success among (u) trials
$(1-\alpha)(\alpha)^{u-1}$: probability of 1 success among (u) trials

The amounts of successfully received packets during a time slot at the k^{th} satellite [36], or the average throughput, is then:

$$Th_{SA} = \sum_{u=0}^{\infty} \left[P(k=1) * P(U=u)\right] \tag{6}$$

$$Th_{SA} = \sum_{u=0}^{\infty} \left[\frac{(G^u)e^{-G}}{u!} u(1-\alpha)\alpha^{u-1}\right]$$

$$Th_{SA} = G(1-\alpha)e^{-G(1-\alpha)}$$

The packets successfully received at one satellite per time slot is known as the system throughput (Th_{SA}).

As a result, multiplicities need to be eliminated. The throughput is not the total throughput that satellite experiences. In order to account for the intersections, inclusion-exclusion [37] can be applied to the cardinality of sets of packets that satellite has successfully received. For example, using the inclusion-exclusion principle, the distinct received successfully packets for the three sets D1, D2, D3, and D4 is:

$$|D1 \cup D2 \cup D3 \cup D4| = |D1| + |D2| + |D3| + |D4| - |D1 \cap D2| - |D1 \cap D3| - |D1 \cap D4| - |D2 \cap D3| - |D2 \cap D4| - |D3 \cap D4| + |D1 \cap D2 \cap D3 \cap D4|.$$

The double-counted elements in the D1, D2, D3, and D4 sets are eliminated. This is applicable to K sets in general [37].

The quantity of packets gathered by the group of relays inside a slot is uniformly distributed over various time intervals and is independent. Now that we have seen how the uplink channel behaved for consecutive slots, let D_k represent the collection of data units that satellite k decoded over the duration of the observation. As a result, the total set of packets gathered can be written as $\cup_{k\epsilon K} Dk$. By the weak law of large numbers [37], we have:

$$\left|\cup_{k=1}^{K} D_k\right| = \sum_{\beta\neq\emptyset} (-1)^{|\beta|+1} \left|\cap_{j\epsilon\beta} D_j\right| \tag{7}$$

where β is a set that contains the subsets indexes that need to be evaluated at their intersection. The satellite ordering matters in our scenario because the erasure probabilities are different. After that, it is essential to understand $\bigcap_{j\epsilon\beta} D_j$, which is the intersection cardinality of sets that a subset $\beta \subseteq \{1, \dots, K\}$ of satellites with cardinality $|\beta|$ successfully received. Taking into account the traffic model previously described, the probability of same packet being received by $|\beta|$ satellites is given by the fact u packets simultaneously transmitted in time slot [17].

$$q_\beta = u \prod_{k\epsilon\beta}(1-\alpha_k)(\alpha_k)^{u-1} \quad (8)$$

The average packets received by $|\beta|$ satellites [38], for all u, after the realization of many time-slots is $\left|\bigcap_{j\epsilon\beta} D_j\right| = \sum_{u=0}^{\infty}\left[q_\beta * P(U=u)\right]$. Consequently, given varying erasure probabilities [33], the system throughput Th_T is:

$$Th_T = \sum_{\beta\neq\emptyset,\beta\subseteq\{1,\dots,K\}}(-1)^{|\beta|+1}\left|\bigcap_{j\epsilon\beta} D_j\right| \quad (9)$$

$$Th_T = \sum_{\beta\neq\emptyset,\beta\subseteq\{1,\dots,K\}}(-1)^{|\beta|+1}\sum_{u=0}^{\infty}\left[q_\beta * P(U=u)\right]$$

$$Th_T = \sum_{\beta\neq\emptyset,\beta\subseteq\{1,\dots,K\}}(-1)^{|\beta|+1}\sum_{u=0}^{\infty}\left[u\prod_{k\epsilon\beta}(1-\alpha_k)(\alpha_k)^{u-1} * \frac{(G^u)e^{-G}}{u!}\right]$$

$$Th_T = \sum_{\beta\neq\emptyset,\beta\subseteq\{1,\dots,K\}}(-1)^{|\beta|+1}\, G\prod_{k\epsilon\beta}(1-\alpha_k)\; e^{-G(1-\prod_{k\epsilon\beta}\alpha_k)}$$

In practical case for K=4, we have:
β={{1},{2},{3},{4},{1,2},{1,3},{1,4},{2,3},{2,4},{3,4},{1,2,3},{1,2,4},{1,3,4},{2,3,4}}
So:
$Th_T = G(1-\alpha_1)e^{-G(1-\alpha_1)} + G(1-\alpha_2)e^{-G(1-\alpha_2)} + G(1-\alpha_3)e^{-G(1-\alpha_3)} + G(1-\alpha_4)e^{-G(1-\alpha_4)} - G(1-\alpha_1)(1-\alpha_2)e^{-G(1-\alpha_1\alpha_2)} - G(1-\alpha_1)(1-\alpha_3)e^{-G(1-\alpha_1\alpha_3)} - G(1-\alpha_1)(1-\alpha_4)e^{-G(1-\alpha_1\alpha_4)} - G(1-\alpha_2)(1-\alpha_3)e^{-G(1-\alpha_2\alpha_3)} - G(1-\alpha_3)(1-\alpha_4)e^{-G(1-\alpha_3\alpha_4)} + G(1-\alpha_1)(1-\alpha_2)(1-\alpha_3)e^{-G(1-\alpha_1\alpha_2\alpha_3)} + G(1-\alpha_1)(1-\alpha_2)(1-\alpha_4)e^{-G(1-\alpha_1\alpha_2\alpha_4)} + G(1-\alpha_1)(1-\alpha_3)(1-\alpha_4)e^{-G(1-\alpha_1\alpha_3\alpha_4)} + G(1-\alpha_2)(1-\alpha_3)(1-\alpha_4)e^{-G(1-\alpha_2\alpha_3\alpha_4)} - G(1-\alpha_1)(1-\alpha_2)(1-\alpha_3)(1-\alpha_4)e^{-G(1-\alpha_1\alpha_2\alpha_3\alpha_4)}$
but when $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha$ the system throughput for k=4 becomes $Th_T = 4G(1-\alpha)e^{-G(1-\alpha)} - 6G(1-\alpha)^2e^{-G(1-\alpha^2)} + 4G(1-\alpha)^3e^{-G(1-\alpha^3)} - G(1-\alpha)^4e^{-G(1-\alpha^4)}$, [20], (6)). In equal erasure probabilities, $\alpha_k = \alpha$ the cardinality becomes $\left|\bigcup_{k=1}^{K} D_k\right| = \sum_{j=1}^{K}\binom{K}{J}(-1)^{J-1}\left|\bigcap_{j\epsilon\beta} D_j\right|$ as in ([20], (5)).

4. RESULTS ANALYSIS AND DISCUSSION

We evaluate the constellation satellites throughput in this article. Furthermore, we examine how the various topologies and positions of the satellite constellation affect system throughput and stability. Assuming a constellation with K=2 and K=4 satellites, with different erasure probability at different positions. Figure 3 shows the throughput achieved as a function of the traffic load per position. The satellite constellation traveling with adjacent positions with a space between the satellites equal to P=10, while k=2 is the size of the satellites number that are visible for the IoT devices with different erasure probabilities see Figure 3.

The curve of throughput varies according to the erasure probability that the satellites 1 and 2 takes in its position and we notice that certain curves are identical. The different erasure probability which can take the two satellites in constellation are (α_1, α_2) ϵ {{0.1,0.9}, {0.3,0.7}, {0.5,0.5}, {0.2,0.8}, {- ,0.01}}. The maximum value of throughput achieved when the erasure probability of satellite 1 and 2 are (α_1, α_2)={0.6,0.4}, (α_1, α_2)={0.5,0.5}, and the channel load G=2, and begins to decrease when the value of the load reaches G=3. On the other hand, the minimum value of throughput achieved when the erasure probability of satellite 1 and 2 are (α_1, α_2)={-,0.01} it means that the second satellite is out of visibility in relation to IoT in service area and the channel load G=2, and begins to decrease when the value of the traffic load reaches G=1.6.

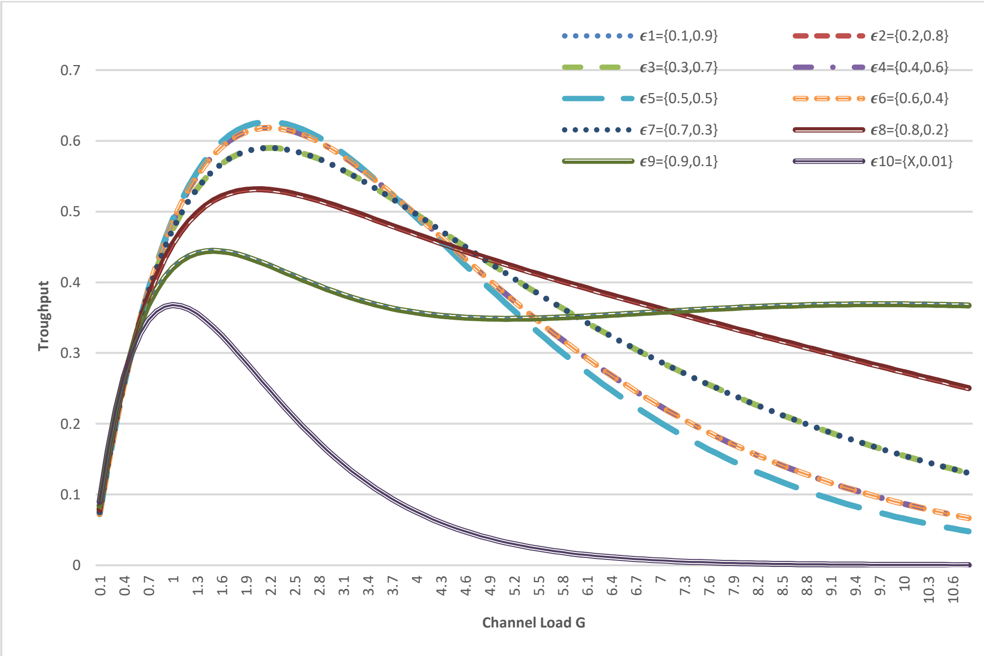

Figure 3. Throughput according to channel load G with k=2 at different positions of satellite constellation

In the case where number of satellites is K=4 in Figure 4 the positions space between satellites are equal to P=5, with different erasure probabilities $(\alpha_1, \alpha_2, \alpha_3, \alpha_4)$ ϵ {{0.9,0.4,0.1,0.6}, {0.5,00.1,0.5}, {0.7,0.2,0.3,0.8}}. In the Figure 4, the throughput reaches its highest value $\text{Th}_\text{T} = 0.9$ when the average load equal G=2.9 and the value of erasure probability of the Sat1, Sat2, Sat3, Sat4 is $(\alpha_1, \alpha_2, \alpha_3, \alpha_4)$= {0.7,0.2,0.3,0.8}, and begins to decrease when the value of the load reaches G=4. Figure 5 shows the average throughput based on channel load for K=2 and K=4 satellites. The throughput value for K=4 satellites is greater than the contribution to two satellites. Where the throughput reached the maximum at $\text{Th}_\text{T} = 0.82$ and the average load equal G=2.6. While the throughput of K=2 reached the maximum at $\text{Th}_\text{T} = 0.52$ and the average load equal G=1.9.

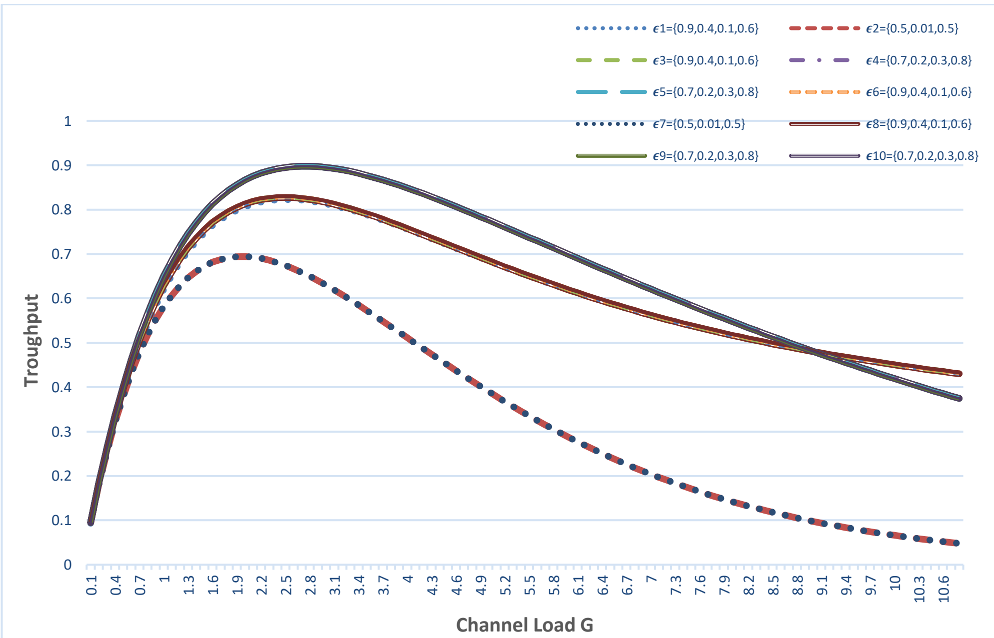

Figure 4. Throughput according to channel load G with k=4 at different positions of satellite constellation

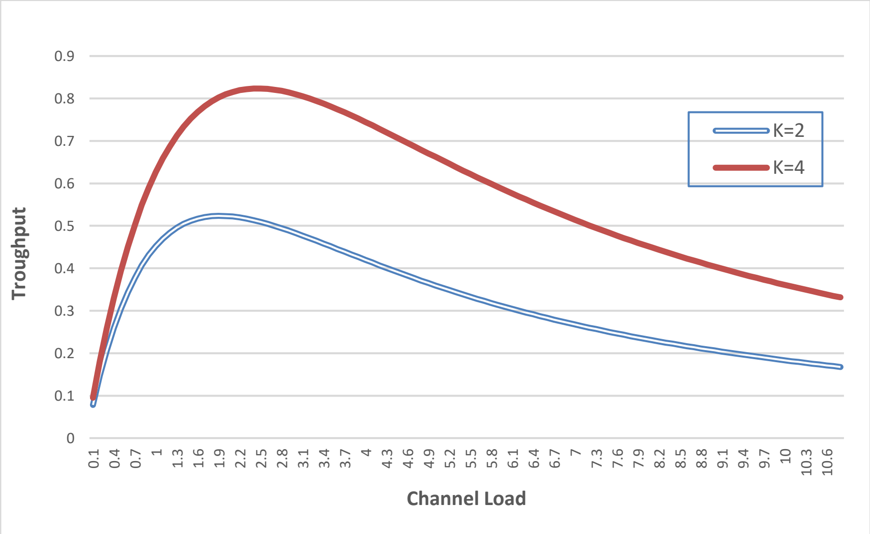

Figure 5. Average throughput according to channel load for k=2 and K=4

Figure 6 show the results for K=1 and K=2 satellites validating the analysis of the packet successfully received according to the time of retransmission, for 50 Terminals and K=1 is less than K=2, where for K=1 the packet successfully received with stability of system is 98 and for two satellites is 154. For a long retransmission duration, the number of successfully received packets decreases for both curves because the packets become out of system. In Figure 7, for the case of 100 terminals in the service zone, the packet successfully received according to the time of retransmission for K=1 is less than K=2, whereas for K=1, the packet successfully received with the stability of the system is 151, and for two satellites, it is 262. For a long retransmission duration, the number of successfully received packets decreases for both curves because the packets become out of system. The results indicate that the constellation of satellites with K=2 satellites can increase the number of successful received packets and reduce collisions despite the large number of IoT devices. The constellation of satellites simulation when we use two satellites in Figures 6 and 7 increases the throughput, as discussed in the theoretical results analysis in Figures 3 and 4.

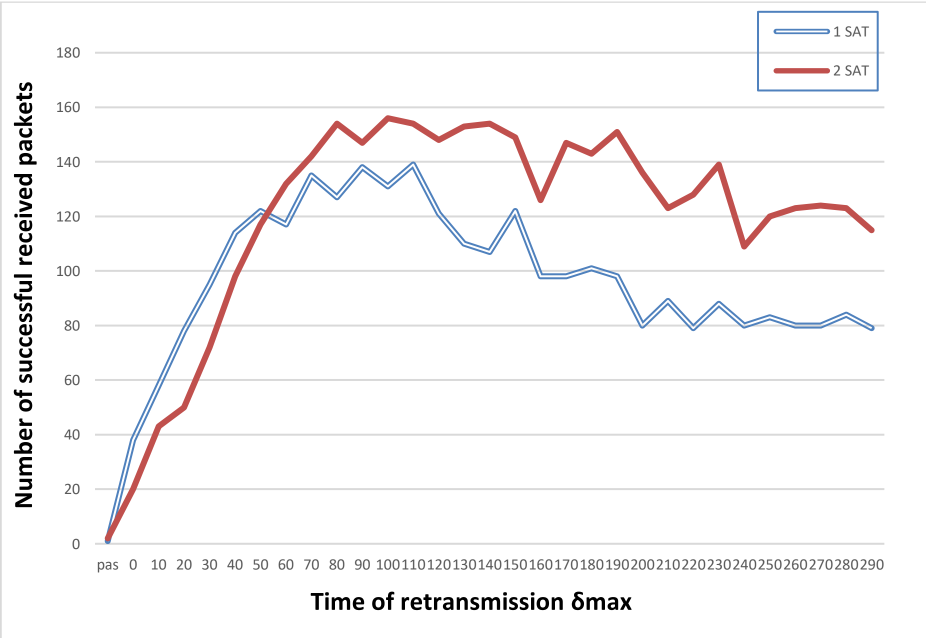

Figure 6. Packet successfully received by constellation according to the time of retransmission for 50 terminals with k=1 and k=2

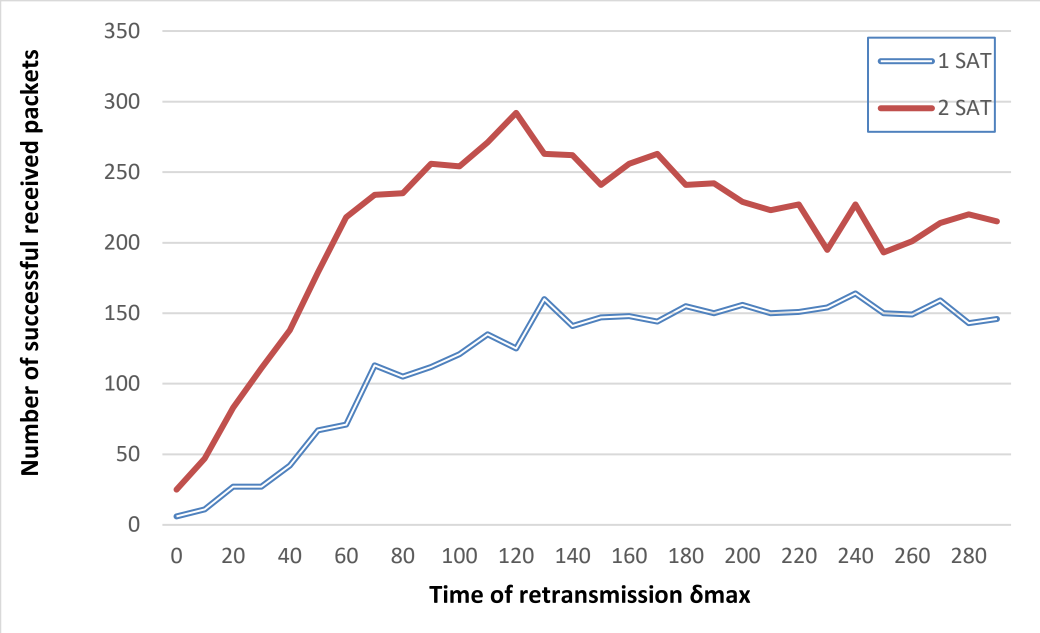

Figure 7. Packet successfully received of constellation according to time of retransmission for 100 terminals with K=1 and K=2

5. CONCLUSION

In this paper, we have examined the throughput and stability performances of slotted ALOHA protocol where IoT devices transmits towards a constellation of non-cooperative satellites with a different erasure probability for each satellite. Considering an on-off fading model, we offered exact analytical expressions for the uplink channel for a number of LEO satellites in visibility with a service zone containing a set of IoT devices. The numerical results have showed an improvement in terms of throughput and stability of slotted ALOHA protocol as much as the number of satellites in visibility increases and inter-satellite spacing decreases. The simulation of the same system using NS2 simulator is conducted and shows a good correlation with the theorical study.

The proposed method in this study tended to have a higher proportion of packets successfully received. Our findings offer definitive proof that this method help to use more IoT devices per service area, and reduce collisions. Future research may look into simulate and evaluate slotted ALOHA protocol with cooperative constellation satellites.

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