Offloading in CubeSats Communication via Inter-Satellite Links

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Abstract
CubeSats (Cube Satellites) have been used in academic and industrial communities in the last few decades because they can be deployed cost-efficiently when compared to traditional large satellites. Since they have limited contact time with the ground station, each satellite cannot download all the data within this time period. In this paper, we consider the offloading among satellites via inter-satellite links. A satellite which has a large amount of data but has a small contact time with the ground station can offload its data to its neighbor satellites that have little amount of data but excess contact time with the ground station. We propose a Rivest algorithm to show that the number of collisions increases with the increasing number of estimated offloaded packets when two or more satellites offload their data packets.

1. Introduction
CubeSats are member of nano-satellites and their sizes vary from 1 U (one unit) with the dimensions of 10 cm × 10 cm × 10 cm and a mass of 1 kg, 2U with the dimensions of 10 cm × 10 cm × 20 cm with a mass of 2 kg and up to 12U. They operate in LEO (Low Earth Orbit) which is at the altitude of about 500 km – 2000 km from the ground. They have many advantages of better signal quality and shorter propagation latency, compared with MEO (Medium Earth Orbit) and GEO (Geostationary Earth Orbit) satellite systems [1]. Although their dimensions are fixed for uniformity during launch and deployment, many utilize folding solar arrays which extend and provide the satellite with extended power generation capabilities for the duration of its mission.

Since CubeSats are moving in their own orbits at high speed, they may not download all the data to the ground station within their limited contact time with the ground station in the case that they have a very large amount of data but small contact time. In that case, they need to offload their data to others which have spare time with the ground station. If there is a need to have continuous global coverage, we have to rely on ISL between CubeSats to provide a seamless communication channel in the space segment [2]. In one scenario, when the data is offloaded to one satellite by two or more nearby satellites, it can cause collision and packet loss. We want to reduce the collision and increase the number of packets offloaded.

We assume that the time when there is interconnection with one satellite and others is divided into slots [3]. One packet is transmitted in one time slot. We also assume that all satellites have the same data rate and same packet size. The amount of data that a satellite carries is represented as the number of packets. When a time slot starts, each satellite has to decide deterministically whether or not to transmit the packet. Therefore, there are three possible outcomes:

1. a hole: if no neighbor transmits on the slot
2. a success: if one neighbor transmits on the slot
3. a collision: if more than one neighbor transmit on the slot

2. System Model and Problem Formulation

Fig.1. System Mode
In our system model, there are “n” number of satellites that form a constellation. They follow their own orbits predictability and precisely. Each satellite has its neighbors and they want to offload their data. At each time slot, each satellite estimates the probability that “n” satellites are ready to offload the data for each n and the observed history of holes, successful transmissions and collisions.

According to the Rivest Algorithm, the uniform probability of transmission rate \( r_t \) for all satellites is determined by the estimated number of packets “\( \phi \)”. We approximate the distribution of the number of packets in the system during the current time slot as Poisson distribution with mean “\( \phi \)”. So the distribution of the number of packets \( N \) offloaded is:

\[
P(n) = \frac{\phi^n e^{-\phi}}{n!}
\]  

(1)

The probability of each packet offloaded on the current slot is \( r_t = \frac{1}{\phi} \). The probability that the current time slot is empty (hole) is:

\[
P_h(n) = (1 - r_t)^n
\]  

(2)

The probability of successful transmission is:

\[
P_s(n) = nr_t(1 - r_t)^{n-1}
\]  

(3)

The probability of collision occurs is:

\[
P_c(n) = 1 - P_s(n) - P_h(n)
\]  

(4)

Moreover, we set the value of \( \phi \):

\[
\phi = \max(\phi + \tau, 1)
\]  

(5)

where \( \tau \) is the arrival rate of packets. We can calculate the expectation of the final distribution of \( N \) given that a collision occurs \( E[N|C] \) by using (1) through (4).

\[
P(n)P_s(n) = P(n)(1 - P_s(n) - P_h(n))
\]  

(6)

\[
P_{N|C}(n) = \frac{P(n)(1 - P_s(n) - P_h(n))}{1 - e^{-\phi r_t} - \phi r_t e^{-\phi r_t}}
\]  

(7)

By taking the expectation of (7), \([3]\).

\[
E[N|C] = \frac{\phi^2 r_t + \phi r_t - 2 e^{\phi r_t - 1} - \phi r_t}{e^{\phi r_t - 1} - \phi r_t}
\]  

(8)

Simplifying (8).

\[
E[N|C] = \phi + \frac{1}{e - 2}
\]  

(9)

If the arrival rate of packets \( \tau \) becomes higher, the expected number of packets that can cause collision will be greater. The collision can be reduced by minimizing the estimated number of packets offloaded.

3. Simulation Result

In Fig (2), we observe that the probability decreases with the fix value of \( \phi \) when the number of packets increases because of collisions. To reduce the collision, the estimated value of \( \phi \) should be mitigated as in Fig (3).

![Fig.2. Distribution of number of packets N](image)

![Fig.3. Expected number of collisions](image)

4. Conclusion

In this paper, we proposed the Rivest Algorithm to prove that the number of collisions increases when more than one satellite offload their data packets within the contact time window. For our future work, we will extend how to schedule for offloading data among satellites using inter–satellite links as well as maximizing the throughput of the system.
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