# Satellite IoT services Using Multichord Peer to Peer Networking

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***Abstract*— Internet of Things (IoT) is becoming a fundamental component of future networks and is expected to be the underlying infrastructure of mobile and ubiquitous applications. However, IoT networks are highly dynamic environments and challenges arise for developing scalable, self-organizing and self-configuring topologies. In this paper, we focus on the problem of discovering, connecting and organizing IoT devices that facilitate mechanisms to collect, aggregate, filter, process, store and retrieve data. In particular, we propose a novel peer to peer multichord-based protocol for IoT over LEO satellite networks. We show that our proposal provides the capability of data storage, lookup and retrieval in a timely manner. Preliminary simulation results show that multichord IoT satellite networks can provide the required high-speed connectivity with low latency and high robustness to failure.**

***Keywords—Satellite Internet of Things, MultiChord peer to peer networks, Starlink LEO constellation.***

## I. Introduction

Internet of Things (IoT) is a new paradigm in the field of networking that consists of massive number of sensors and computing devices with capability of interacting with one another autonomously. This will require new concepts in the network structure as well as new techniques to manipulating data. Consequently, in this paper we present a two-fold contribution. First, we propose the Chord concept for logical networking to provide IoT services and modify its standard operation to work in a multi-chord architecture. We show that our proposal allows for scalability, differentiability and robustness to failure. Second, we propose an overly network for IoT services based on multi-chord for LEO-based satellite networks. For our simulations, we choose as a reference the Starlink LEO constellation.

### *A. Chord peer to peer network*

Nowadays, data we produce through our devices are processed and stored by centralized Internet service providers in a cloud computing structure. Although data is distributed among different servers, there is a single point of control and access to them. This approach of entrusting people's data to centralized Internet service providers may challenge the implementation of mechanisms to preserve people's privacy. This is even more certain in the context of the IoT, whereby billions of devices will continuously collect fine-grained personal information. Consequently, we propose distributed hashing in a chord peer to peer network for data storage and manipulation in a decentralized manner. Specifically, we focus on designing an overlay management architecture based on the chord protocol, i.e.: given a key (data item), it maps the key onto a node (peer) using consistent hashing [1] to assign keys to chord nodes.

Our proposal is an extension of the successful chord technology to cope with the dynamism of IoT networks given the physical orbital constraint of an IoT network over satellite.

The advantages of using the chord protocol as a distributed peer-to-peer lookup system are:

- Load balancing: due to the usage of distributed hash function, keys are spread evenly over nodes.
- Decentralization: chord is fully distributed; no node is more important than other thus improving robustness.
- Scalability: logarithmic growth of lookup costs with number of nodes in network, even very large systems are feasible
- Availability: chord automatically adjusts its internal tables to ensure that the node responsible for a key can always be found.

However, chord networks have the limitations of not being able to distinguish type of data stored, no control on process of modifying data that is stored, lookup delay increases significantly with the growth of nodes in chord and finally robustness may be jeopardized in case of simultaneous failure and/or add-join of nodes.

To overcome such limitations, our proposed solution consists of multi-chord networking as an extension to the existing chord peer to peer network. Each chord represents a type of data collected from sensors that provide this kind of data. The architecture of proposed multi-chord consists of a main chord network of edge devices that branch from them sub-chords of specialized nodes. We also bring new commands (operations) to the standard chord network commands such as: remove shared node, merge shared chords, split shared chords, leave from shared node to single node, join shared chord, sleep single node, sleep shared node, awake single node and awake shared node.

Our proposal differs from existing solutions as follows. In [2], the authors focused on designing an overlay management architecture based on Chord algorithm. The architecture is a collection of multiple peer Chord rings, and thus each of these rings is considered as a smart context. The proposed architecture is simulated and evaluated. Their architecture is evaluated by simulating a large scale environment with a large number of nodes and sensors to evaluate performance and operation costs of the entire system with various topologies and properties. The achieved results prove that our proposal has the operability and feasibility to apply to practice as will be shown in the results sections. On the other hand, the proposal in [4] is a direct extension to chord concept where there is no interconnection clear between the chords. On the contrary, our proposal developed the concept of shared nodes that will facilitate the operations between the chords.

### B. Starlink

SpaceX filed plans with the US Federal Communications Committee (FCC) to build a constellation of 4,425 low Earth orbit communication satellites. It will use phased array antennas for up and downlinks and laser communication between satellites to provide global low-latency high bandwidth coverage [3]. These filings provide a great deal of detail about the RF links between the satellites and the ground, including how phased-array antennas can steer narrow transmission beams for both uplink and downlink. The filings do not discuss in detail satellite to satellite communications. No radio spectrum for satellite-to-satellite communication is requested, so lasers must be the primary communication link between satellites. Starlink represents a new category of wide-area backbone, where thousands of satellites move and connect in a predictable pattern, but due to orbital constraints the network is far from a simple static mesh. We ground our study on the basic properties of the Starlink deployment and proceed by overlying multi-chord approach on such a network. In Starlink's initial phase, 1,600 satellites in 1,150 km altitude orbits will provide connectivity to all except far north and south regions of the world. A second phase adds another 2,825 satellites in orbits ranging from 1,100 km altitude to 1325 km, increasing density of coverage at lower latitudes and providing coverage at least as far as 70 degrees North [4] as shown in Fig. 1 [5]. In contrast, we are mostly concerned with satellite to satellite communication. A good working assumption is that each satellite will have five free-space laser links to connect to other Starlink satellites. The orbital data for the LEO constellation is:

| | Initial phase |
|---|---|
| Number of satellites | 1600 |
| Orbital planes | 32 |
| Satellites per plane | 50 |
| Altitude (km) | 1150 |
| Inclination | 53 |

Table 1. specification of Starlink system

Given five laser links per satellite – four permanent links and one transient link and knowledge of orbits, questions can now be addressed about building a scalable, self-configuring and self-organizing logical network, and how to allocate and lookup data on that network.

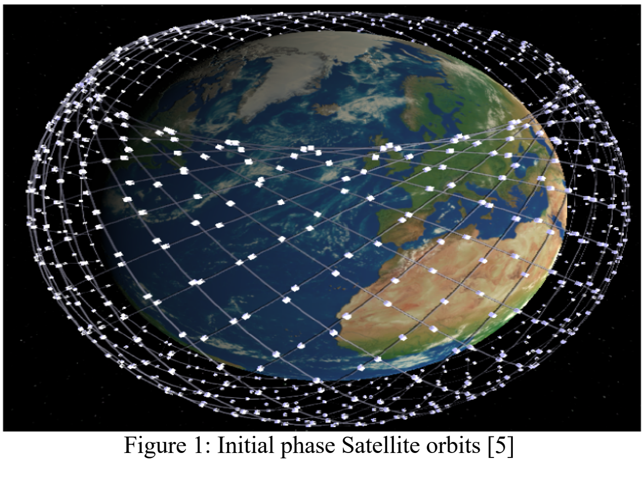


Figure 1: Initial phase Satellite orbits [5]

The paper is structured as follows. Section II introduces the proposed multichord IoT satellite network and its projection over the starlink satellite constellation. Section III includes our model analysis and simulation results are presented. In section IV we conclude the paper also outlining future work in section V.

## II. MULTICHORD IOT SATELLITE NETWORKIG

The authors in [6] focus on the use of satellite communication systems for the support of IoT. The authors highlight the enabling factors of IoT through satellites: 1) the interoperability between satellite systems and sensors/actuators and 2) the support of IPv6 over satellite. They also provide an integrated solution among MAC protocols for satellite routed sensor networks, efficient IPv6 support, heterogeneous networks interoperability, quality of service (QoS) management, and group-based communications.

Authors in [7] used a constellation of five Molniya satellites and one-dimension electronic scanning phased array ground terminals. The result is a baseline concept that meets customer needs for internet of things (IoT) data connectivity and for consumer high data rate Internet access. Molniya orbit satellites provide the benefits of available bandwidth, lack of interference with other satellite links, and less crowded orbital paths. A drawback is that they are not geostationary since they have highly elliptical orbits.

Authors in [8] focus on low earth orbit (LEO) satellite constellation-based IoT services for their irreplaceable functions. They provide an overview of the architecture of the LEO satellite constellation-based IoT including the following topics: LEO satellite constellation structure, efficient spectrum allocation, heterogeneous networks compatibility, and access and routing protocols.

To the best of our knowledge, proposed satellites IoT networks in the literature have not yet considered peer to peer connectivity based on the chord concept, which has the advantage of being distributed, scalable and robust to failure.

Here, we propose the Multichord IoT satellite network, which is divided into three components as shown in figure 2, namely ring (orbit), node (satellite), and sensor, which are defined as follows:

- Ring: it is the logical topology for a single IoT network. It uses Chord as a base method to organize and discover IoT devices. As a first approach, we assume the ring will represent the orbit when all satellites are of the same type.
- Node: it is a peer object located on the ring. Nodes correspond to gateway devices in the terrestrial chord network and satellites in a satellite network. We divide nodes into two types, *single node* which is a node that is participating in only one ring and *shared node* which is a node that is simultaneously participating in at least two rings. In satellite constellation the shared node will be a satellite in an orbit that transiently will have a connection with another satellite in another orbit. Thus, acting as a shared node in the two orbits.
- Sensor: is an object representing terrestrial or aerial sensors in practice. In our multi-ring architecture, sensors cannot join directly on rings like nodes (i.e. gateway)

because they manifest characteristics of real devices, which are limited by capabilities of communication, computing and storage. Therefore, sensors must connect to a certain gateway.

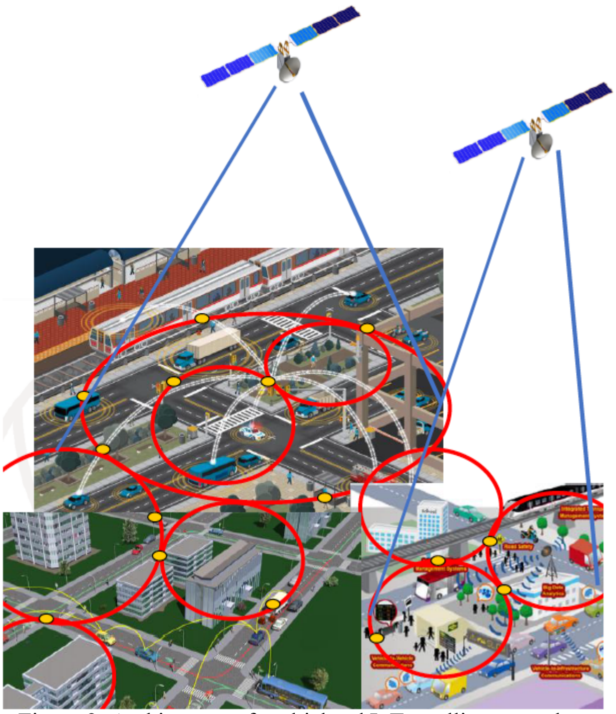


Figure 2: Architecture of multichord IoT satellite network.

## III. Model Analysis

The basic idea behind Chord is to assign a unique identifier to each node in the network as well as a unique key for every data to be manipulated in the network. This is achieved using consistent hash function. SHA-1 is used as a base hash function.
A node's identifier is defined by hashing the node's IP address and port number to define its value in a subchord.ID (node) = hash (IP, Port)

Similarly, to store data in a node, we first hash the type of data to be stored and retrieved in this subchord and then hash the data itself to decide the node that will store this data.

ID (type)=hash (Type)

In addition, every orbit in the satellite constellation will have and ID which we will call the orbit ID (OID).

In terrestrial networks, the ID is obtained by hashing the IP of the node to be a unique ID. However, in satellite networks we are proposing the hashing of the argument of inclination angle of that orbit as there is no IP for an orbit.

A satellite orbit is called subchord ring in our model. A Key (k) that represent a hashed data is assigned to the first node whose identifier is equal to or follows (the identifier of) k in the identifier space. This node is the successor node of key k, denoted by successor (k) as shown in Fig. 3.

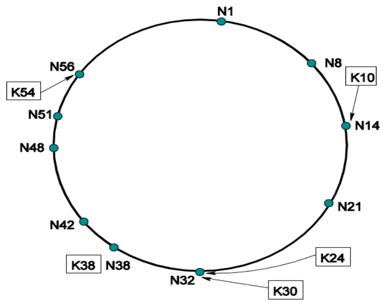



Figure 3: Satellite on a given orbit along keys assigned to them.

*Key Insert and Remove*

Two operations are needed for a key to be inserted or removed from the multichord IoT satellite network. The first operation is to lookup the subchord (orbit) responsible for this kind of data type. The second operation is to find the node (satellite) in such subchord that will store in ior remove the data from it.
The first operation is performed using the Orbit ID table which is very similar to the finger table concept in chord protocol [9] except that the entries in the table are the heads of each subchord implemented in the system.
The second operation is performed using the finger tables of the nodes in the subchord that have been chosen from the first operation. This is a standard operation similar to the one used in single chord model. The two operations are illustrated in Fig. 4.

A satellite will be defined by two IDs: Orbit ID and Satellite ID (OID, SID)

SID = hash (satellite IP) in n bits
OID = hash (point of perigee node) in m bits

*Node Join and Leave*

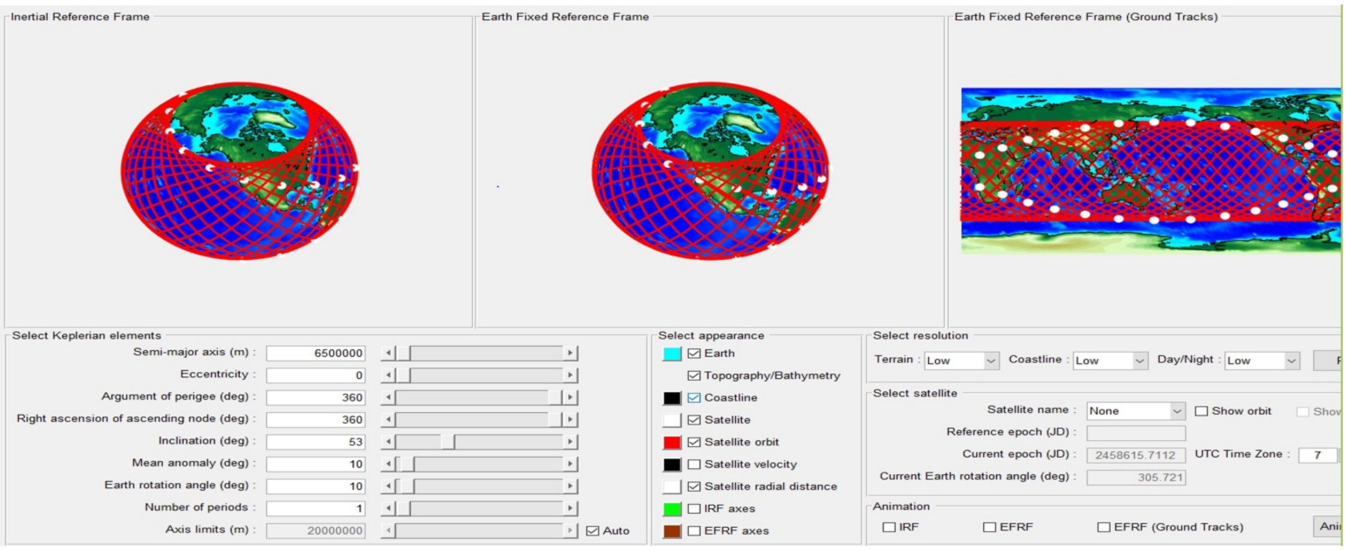



Figure 5: The orbits parameters and constellation.

Another task that is required in a multichord IoT satellite network is the joining of new satellites in an orbit or leaving of existing nodes from an orbit. The two operations require first to adjust the keys stored in the nodes of a subchord and to update the figure and subchord tables accordingly. The two operations are similar to the standard join/leave operations in a single chord model but with the addition of updating the subchord tables of the head nodes in the multidimensional chord network.

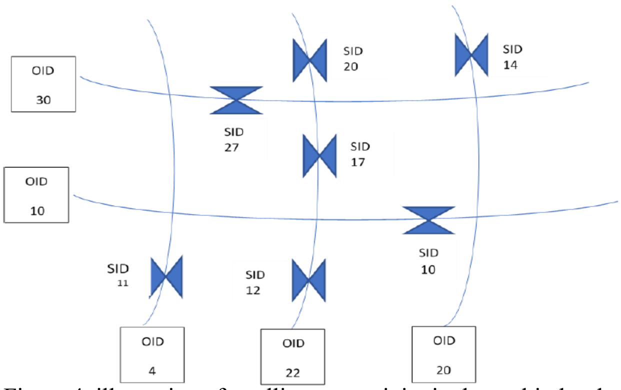


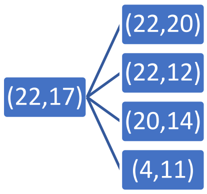

Figure 4: illustration of satellite connectivity in the multi-chord approach

*Satellite connectivity*

Every satellite in the constellation has four permanent connections:

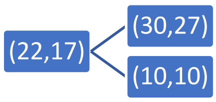
- Successor Satellite in same orbit
- Predecessor satellite in same orbit
- Successor Satellite in next orbit
- Predecessor Satellite in pervious orbit

By next orbit we mean the orbit that directly follows orbit in consideration while the previous orbit is the orbit that was directly before the orbit in consideration.
For example, from Fig. 4 satellite #17 in orbit #22 will have those satellites in direct connection with them.




In addition, every satellite has two temporary connections:

- Successor Satellite that will be in the crossing orbit above it.
- Predecessor Satellite that will be in crossing orbit below it.




## IV. SIMULATION RESULTS

We have carried out preliminary simulations of our proposed peer to peer IoT network using a discrete event simulator to evaluate its performance.

Figure 5 shows the simulation result assuming the Starlink orbits with the different parameters specified for the 32 orbits from inclination and eccentricity as well as the semi-major axis. We then modelled and simulated the process in one of the 32 orbits that includes 64 satellite nodes.

Fig. 6 shows the constellation comprised of 64 satellites and the virtual connectivity between the satellites using the chord peer to peer networks. Each satellite node can reach six other satellites as proposed by the concept of finger table in the chord networks. This will guarantee that all satellites in a given orbit will be reachable in a nearly mesh-like topology. For example, the satellite with ID=7 will have the finger table shown in the figure.

We then started simulating the response time the satellite will take to respond to request for data stored in the IoT network.

For this paper, we investigated the response time within a single orbit and we intend to study the response between different orbits in coming papers. The response time in the following figure is measured without taking the propagation time into consideration as this will be function to the orbit distance from the Earth. Thus the represented results are the processing and queuing time within satellites or between satellites within same orbit.

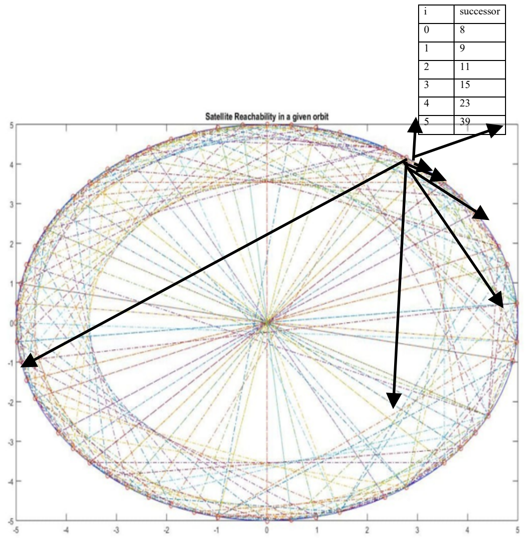



Figure 6: Virtual connectivity between satellites in a given orbit.

Fig. 7 shows the mean time of satellite response to IoT data requests as a function of the number of satellites in an orbit.

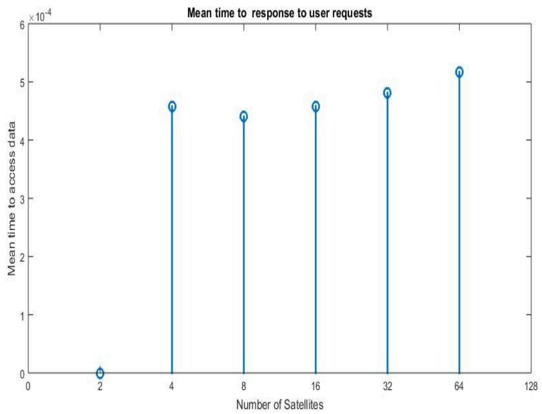



Figure 7: Mean time in sec to access data within an orbit.

The figure shows that the average response in around 0.5 ms which is considered very adequate to high speed for all variations of satellite numbers per orbit. This is contributed to the fact that mean time to access data will follow a complexity in order of log (n).

To quantify the results in figure 7, we measured the variance in such time as function of number of satellites as shown in figure 8. Although the average time to access data within an orbit is nearly the same as the number of satellites increases in the orbit, the variance of such time is linearly dependent on the number of satellites as seen in figure 8. This is can be contributed to the fact that data will be distributed on larger number of satellites and thus expected to take more time for lookup and retrieval in some cases. One interesting result is the variance in 4 satellites per orbit which is nearly equal to 64 satellites and our argument here is that the time consumed in lookup within as satellite is the main contributor than the time to lookup as satellite as in case of 64 satellites.

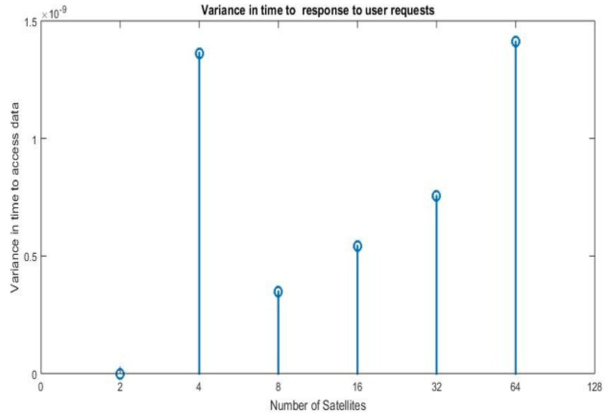



Figure 8: Variance in time to access data within an orbit

On the other hand, figure 9. shows the time taken to stabilize on orbit from point of data storage and retrieval when a satellite or group of satellites are failed. The figure shows the effect of satellite failures on the time needed to stabilize the network when amount of traffic data is varied.

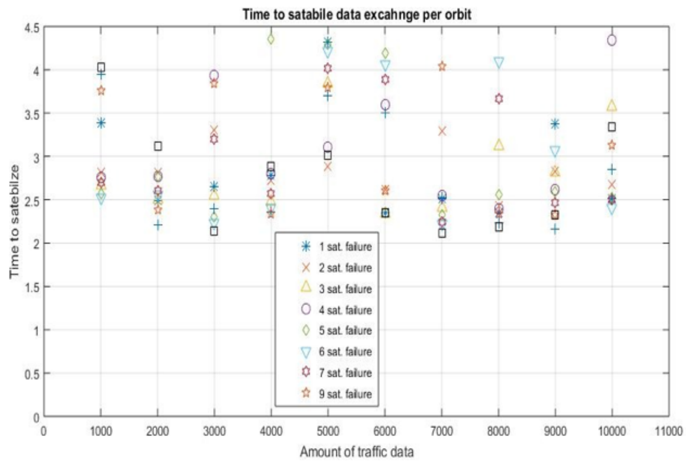



Figure 9: Network stabilization time in sec vs number of satellite failures.

The figure shows that a time of nearly 4 to 5 seconds is needed to stabilize the network after satellite failures, this time is also considered adequate in high speed IoT networks. However, statistics shown in Fig. 6 proves that 90% of the time required to stabilize a network will not exceed 4 seconds in the most vulnerable situation of 10 satellites in failure. The figure also shows that the difference between the 10 percentile and 90 percentile is within acceptable values which is nearly showing a uniform distribution.

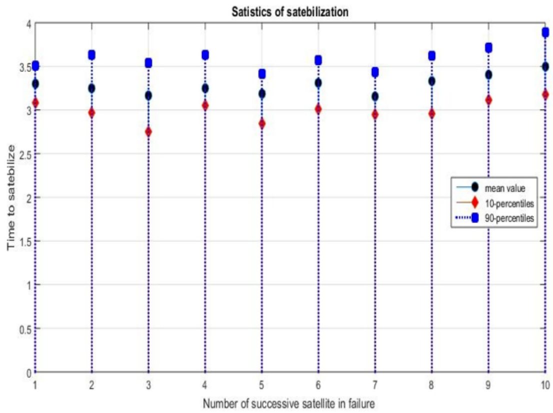


Figure 10: Statistical values of network stabilization time in sec.

## V. Conclusion and Future Work

In this paper we presented a peer-peer IoT satellite network based on the well known chord concept. It has the advantage of being distributed and scalable. We have shown that the response to users requests within the same orbit can be achieved in a timely manner. Future work will investigate the inter-orbit communication and the robustness to cascaded satellites failure in one and multiple orbits.

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