Advances in Engineering Research (AER), volume 61
International Conference on Mechanical, Electronic, Control and Automation Engineering (MECAE 2017)

A Satellite Network Based on Distributed SDN

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Keywords: SDN, Satellite network, Consistency of cluster.

Abstract. According to the characteristics of satellite network and based on the idea of distributed SDN, a distributed software defined satellite network architecture is proposed in this paper. And the consistency of controller cluster is achieved based on the Raft algorithm. Theoretical analysis and simulation show that, this architecture has higher throughput and lower delay and more suitable for the complex satellite network.

1. Introduction

With the rapid development of space information technology, countries generally realized: Satellite network plays an increasingly important role in the aspects of e global communications, navigation, weather forecasting, environment and disaster monitoring, resource exploration and military applications etc. Satellite network as the core of the space network platform has increasingly become an enduring strategic research and development projects.

The characteristics of satellite network brought network performance a lot challenges. For example, the dynamic topological properties led to more instability routing algorithm, long distance between the satellite and earth and one-on-one between satellite and ground station control result in the waste of time to the update of the global network [1]. Literature [1] proposed a new type of satellite network architecture based on single controller SDN, software defined satellite network (SDSN).

However, the single controller SDSN architecture can't satisfy satellite network characteristics such as long time delay, large spatial scale, and dynamic topology [2]. Aimed at the characteristics of satellite network a distributed SDSN is proposed in this paper. This architecture set up the multiple controllers in the air, which reduced the transmission delay and enhanced the anti-destroying ability and extensibility of the entire network at the same time.

2. Satellite Network Based on Distributed SDN

2.1 SDN Introduction

Software Defined Network is a brand-new Network system. SDN separates the control plane from data plane in network equipment, obtains the global information from the network resources from whole, and deploys integrally in real time according to the dynamic change of network nodes and business requirements logically. Through the overall control of the controller, you can realize the function of network like link found, topology management, etc [3, 4].

As the network size becomes larger and larger, the single controller SDN has been unable to deal with the multi-level and multi area network communication problems which leads to the decline of the quality of the whole network communication and even result in paralysis. The hot spots about the current research are in the distributed SDN networks, using the SDN controller to form a distributed cluster and hierarchically controlling the regional network nodes, which not only alleviate the carrying capacity of the single network, but can also solve the problem of the network such as reliability, scalability and other issues [5, 6].

There are two types of distributed systems, fully distributed and hierarchical distributed [7]. In the fully distributed, SDN network is generally divided into multiple disjoint regions and one or more controllers manage a disjoint SDN switch set. This structure helps to reduce the delay between the switch and the controller. In the hierarchical control structure, the function of the controller is vertical, the upper controller usually knows the state information of the whole network and is responsible for the load balance and the consistency of the lower controller [8].

2.2 Architecture Analysis

In this article, the completely distributed SDN architecture is applied to satellite network. We put forward a new satellite network architecture, distributed SDSN. Its system structure is shown in figure 1.

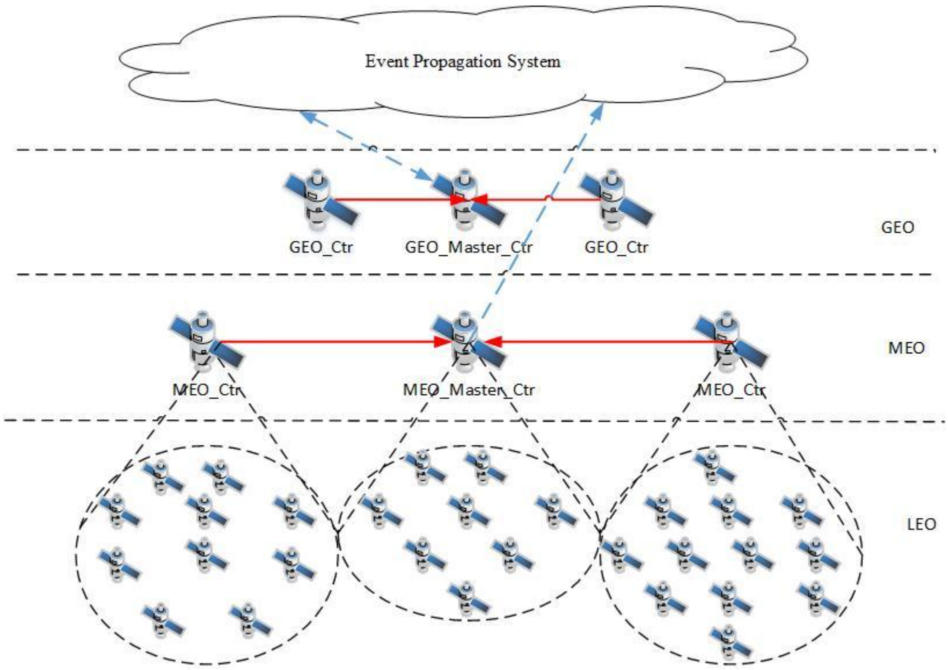

Fig 1. Distributed SDSN architecture diagram

According to the three layers satellite constellation satellite network space-based network can be divided into three layers, they are low orbit satellite layer, medium orbit satellite and high orbit satellite. Leo satellite as infrastructure layer are only responsible for simple data forwarding. Medium orbit layer and high orbit layer contains satellite as controller and satellite as switch. Controllers distributed in each layer achieve the control layer centralized logically and distributed physically. All the controllers run the same control software and application according to the standard network level view.

Firstly, use clustering management methods to realize MEO satellite partition management of LEO satellite. Controllers of the MEO/GEO layer constitute the cluster to share the information of topology change. Thus the transmission delay between each node is highly demanded. The master controller that named Master Ctrl is set up in each layer of controller cluster, and Master_Ctrl in each layer shares the information of each layer through the event propagation system.

3. Consistency of the Cluster Controller

In the distributed SDSN architecture the proposed in this paper, controllers of the MEO/GEO layer constitute the cluster. In the cluster we need to guarantee the controller data consistency. I this section the consistency of controller is realized based on the Raft algorithm.

3.1 Selection of the Controller

(1) The role of controller

Controller in the cluster are divided into three states: Leader, Follower, Candidate. Each state is responsible for different tasks. The state transition is shown in figure 2.

Leader: Responsible for log management of synchronization, process a request from the other controller and keep Heartbeats contact with followers;

Follower: All controller are followers at the beginning. Response to the Leader of the log synchronous request, respond to the request of the Candidate and forward the transaction of followers that requested to the Leader.

Candidate: Responsible for the vote. A control node changes from Follower to Candidate and initiate the election. It changes to Leader state after it selected as Leader.

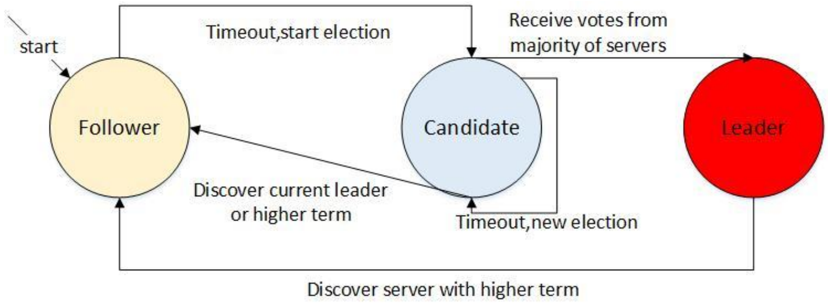

Fig 2. State transition

(2)Term

Satellite networks are highly dynamic, so the whole election process need to be divided into many Terms according to the time slice of satellite network topology change in controller cluster. The time slice is divided as follows:

Definition 1 Graph $G(t)=(V,E(t)),0\le t\le T$ represent the network structure of the satellite network with controller cluster at t moment. Among them, $V=\{v_1,v_2,...,v_s\}$ represent satellite nodes set in the system, $E(t)$ is the interstellar link set at t moment, T is satellite system cycle.

Suppose Γ is the set that consist of a series of descending order, and don't repeat time point. Each time point at least has one inter satellite link switching (open or close).That is:

$$\Gamma=\{t_i|G(t_i+\varepsilon)\ne G(t_i),\varepsilon\to 0,0\le i\le n,t_{i-1}<t_i,t_0=0,t_n=T\} \tag{1}$$

Time slice Δ of Network G defined as the difference set of adjacent time point, as shown below:

$$\Delta=\{\delta_i|\delta_i=t_i-t_{i-1},t_i\in\Gamma,0<i\le n\} \tag{2}$$

Among them n is the degrees of set Δ, $n=|\Delta|$, it reflects the extent of the network topology changes.

Dividing the election process Term according to the time slice Δ.Each Term at least has on Leader and each Follower can only vote once. As shown in figure 3:

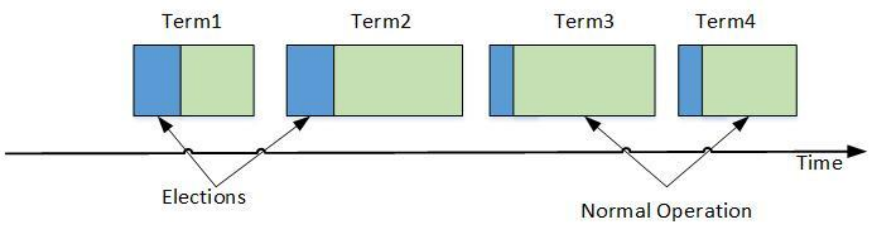

Fig 3. Term

(2) Role Election

Firstly, filtrate controllers which can be the Leader in the future according to the Multi-objective optimization algorithm.

Definition 2 $w_{c,f}$ represents possible node pair of Candidate and Follower in the controller cluster. $Q(w_{c,f})=\{E_1,E_2,...,E_k\}$ represents the link connection between Candidate and Follower, that is Candidate reach Follower through $k-1$ jump.

In order to show the traffic of the single link, the link inclusion function is defined as:

$$\theta_{E_k}^{Q(w_{s,d})} = \begin{cases} 1, E_k \in Q(w_{s,d}) \\ 0, E_k \notin Q(w_{s,d}) \end{cases} \tag{3}$$

In the formula, if the path through the link E_k then $\theta_{E_k}^{Q(w_{s,d})}$ take 1 and instead take 0.

Use d_{E_k} to indicate the time delay on the link E_k and c_{E_k} to indicate link connection length on the link E_k.

Definition 3 Using m to represent m class resources in controller system that composed of satellite node set $V = \{v_1, v_2, ..., v_s\}$, each satellite has number of resources.

Present multi-objective optimization design of the link connecting length c, link overall delay d and satellite resources R_j, the optimization function and constraint conditions are as follows:

$$\begin{cases} \max c = c_{E_i} . \theta_{E_i}^{Q(w_{c,f})} \\ \min d = \sum_{i=1}^{k} (d_{E_i} . \theta_{E_i}^{Q(w_{c,f})}) \\ \max R_j = (R_{j1}, R_{j2}, ..., R_{jn}) \end{cases} \tag{4}$$

$$s.t.$$

$$i \in k, k < 5, j \in V, \frac{m+1}{2} \le n \le m$$

Transform the multi-objective optimization into a single objective optimization task with weighted coefficient, the formula is as follows:

$$\max f = \omega_1 c - \omega_2 d + \omega_3 R_j \tag{5}$$

In the formula, ω_1, ω_2 and ω_3 represents the weighted value of link connecting length c, link overall delay d and satellite resources R_j respectively $(\omega_1 + \omega_2 + \omega_3 = 1)$.

Chose Candidate according to the optimized f and start the election, controller role election process of each Term is shown in Figure 4.

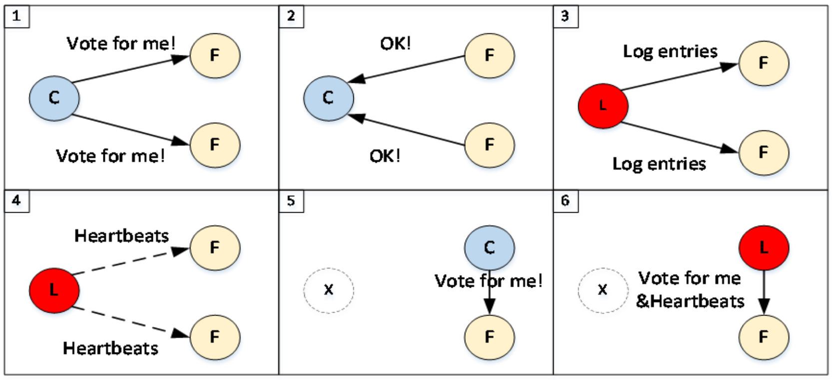

Fig 4. Role election

① Candidate sends a request to the other Follower for elect themselves;

②Other controllers agree and send OK. In this process, if one Follower do not receive the requirement of election because of the fault, then the candidates can select themselves. The candidate can be Leader as long as the votes greater than N/2+1.

③ Candidate becomes Leader and it can issue instructions to voters (Followers), such log copy;

④ After then, Leader notice the log copy through Heartbeats;

⑤ If this Leader collapses, then Followers that satisfied the optimization.

⑥ That Follower becomes Leader after it agrees and continue to bear the instruction work such as log copy.

3.2 Log Replication

The main function of log replication is to ensure the consistency of nodes. When Leader is elected, it begins to be responsible for requests from other nodes. All transactions (update operations) requests must first be processed by Leader.

Log copy operation procedure is as follows:

(1)Other nodes send logs (transaction requests) to Leader;

(2)Leader append this log to local log;

(3)Leader sync the Entry to other Follower via Heartbeats;

(4)Follower logs the log after receiving the log and sends ACK to Leader;

(5)Leader receives the majority (n/2+1) of the Follower ACK information and sets the log to be submitted to the local disk;

(6)Leader returns the result to the sending node and notifies all Follower to store the log in its own local disk in the next Heartbeats.

4. Simulation and Performance Analysis

4.1 Simulation Parameter

The proposed architecture was simulated through Matlab. The simulation was carried on in satellite network model of GEO/MEO/LEO, the simulation parameters of constellation orbit are shown in table1. GEO satellite layer is consist of three geosynchronous satellites; MEO satellite layer adopt ICO constellation; LEO satellite layer use Iridum constellation with adjusted orbital plane and inclination. Each satellite layer provides global coverage.

Table 1. Simulation parameters

	GEO	MEO	LEO
altitude of satellite orbit (km)	35786	10390	896
number of orbital plane	1	2	8
number of satellites in each orbit	3	5	6
inclination of satellite orbit(°)	0	45	90
angular speed(°/min)	0.25	1.0	3.6
minimum elevation(°)	8	10	8

Based on this network model, we establish the traditional satellite network architecture, distributed SDSN architecture in this paper and SDSN architecture in literature [1] respectively. From the two aspects of throughput and delay, the performance of these three architectures is verified by simulation.

4.2 Simulation Results Analysis

(1) Throughput

The relationship between the network throughput and the traffic load under the three architectures is shown in Figure 5. Before the network is not saturated, the network throughput increases linearly with the increase of traffic. With the increase of business load, the network throughput of traditional architecture and SDSN architecture will reach saturation. However, the throughput of distributed SDSN architecture will still increase. It shows that the distributed SDSN architecture of satellite network has higher throughput and can carry more traffic.

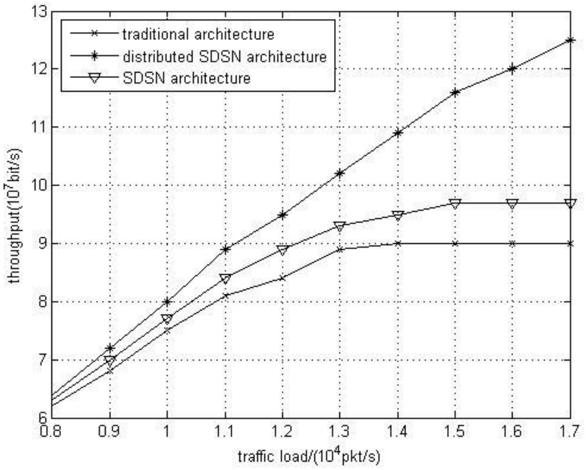

Fig 5. Throughput simulation diagram

(2) Delay

The relationship between end to end transmission delay and traffic load is shown in Figure 6. The end-to-end delay of the traditional architecture is much larger than that of the distributed SDSN architecture and the SDSN architecture, and it increases sharply with the increase of the load. This is because the SDN controller has the whole network topology information, it can do the global optimization of the routing and the entire network can be convenient and flexible mobilization of resources. Thereby the performance of the entire network is enhanced. However, the end-to-end delay of SDSN architecture is larger than that of distributed SDSN architecture. This is due to the distributed controller cluster of the distributed SDSN architecture can better adapt to the satellite network's long delay, dynamic topology and other characteristics. It has better performance.

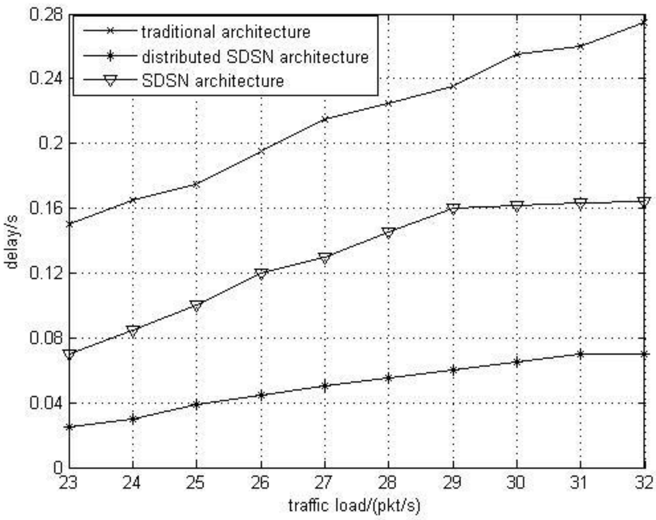

Fig 6. Time delay simulation

5. Summary

In view of the shortcomings of the traditional satellite network architecture and based on the distributed SDN, a new architecture of distributed software defined satellite network is proposed this paper. In this architecture, the LEO satellite as the infrastructure layer is only responsible for simple data forwarding, the control layer is composed of GEO/MEO satellites. The controller clustering technology is used to improve the resource utilization and network reliability of the system, and the consistency of the controller cluster is realized based on the Raft algorithm. This architecture greatly reduces the transmission delay, and has better scalability and survivability.

The performance of the proposed architecture is verified by simulation. The simulation results show that compared with the traditional satellite network architecture and SDSN architecture, the proposed architecture has high throughput and low delay. Therefore, the distributed SDSN architecture proposed in this paper is more suitable for complex satellite networks and has superior performance.

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