The Functional Design of a Multi-protocol Satellite Router

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Abstract. With the rapid development of Space Information Network and users' demand for communication services, interconnecting heterogeneous space networks becomes a new trend of SIN development. Networks using different protocols, such as TCP/IP, CCSDS and DTN, cannot communicate directly. In order to interconnect heterogeneous networks and face the problems brought by the challenged environment, this paper designs a multi-protocol onboard router which depends on the "store-and-forward" mechanism in DTN network protocol, as a relay with the ability of multi-protocol switching in order to support communication services among heterogeneous networks.

Keywords: Multi-protocol router · DTN protocol · Protocol switching

1 Introduction

Since the 21st century, space technology has developed rapidly and the strategic position of space has become increasingly important. Therefore, all countries are committed to the development of Space Information Network (SIN) [1]. Satellites are an indispensable part of it.

At present, the rapid development of the communication network makes the information no longer experience a simplex environment only during the transmission. Based on the evolution of terrestrial communication network technologies, satellite communication networks improve rapidly. The most obvious difference between the satellite communication network and the terrestrial one is the characteristic of links and channels. The satellite communication network has high bit error rate and asymmetric uplink and downlink bandwidth. Besides, long distance between satellites and terminals leads to long time delay of the traffic transmission. At the same time, the available time duration of links is limited so that the topology of the satellite network changes frequently. Therefore, three types of protocols for space networks are currently formed, named CCSDS (Consultative Committee for Space Data Systems) protocol [2, 3], TCP/IP (Transmission Control Protocol/Internet Protocol) [4], and the DTN (Delay Tolerant Networking) protocol [5].

Heterogeneous networks, using different protocols, bring convenience to human lives. Targeting at different channel conditions, orbital altitudes, and business requirement, different networks are designed to meet the needs of users. However, the heterogeneous network brings difficulties in compatibility and interconnection. In order

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to satisfy the requirement of multiple service patterns and complex space operation, the communication method that transmitting traffic through the heterogeneous networks cannot be avoided, which exactly the reason that we design a multi-protocol router.

In this context, we put forward the functions of an onboard router which is compatible with CCSDS protocol, TCP/IP protocol and DTN protocol by using the "store-and-forward" mechanism and "bundle layer" protocol in DTN networks, mentioned in Sect. 2. Then, the specific functions of the router are introduced in Sect. 3, including the routing algorithm and the protocol switching method. Besides, a MEO/LEO double layer satellite network model is built for simulation. And finally, the simulation results and the performance analysis are showed in Sect. 5.

2 Traffic Transmission Mechanism and Bundle Layer Protocol in DTN Networks

DTN network protocol is extremely different from other Internet protocols that DTN protocol introduces the concept of a Bundle layer between the application and the transport layer. The comparison between the DTN network architecture and the traditional one is shown in Fig. 1.

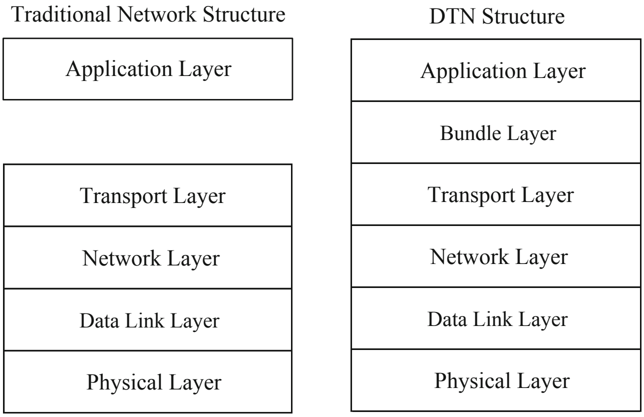

Fig. 1. The structure comparison between the traditional network and DTN.

The mainly application of DTN is the challenged networks. The main idea is to introduce "Bundle Layer" [6] as a medium of connection among different networks. In addition, traffic transmission in DTN networks is based on store-and-forward mechanism instead of end-to-end transmission paths, shown in Fig. 2.

In the Bundle layer, the part closest to the application layer is called Bundle API [7], which is the application agent of the bundle layer and the interface between the bundle and the application layer, configuring bundle layer according to the services provided by the application layer. In addition, the interface between the bundle layer

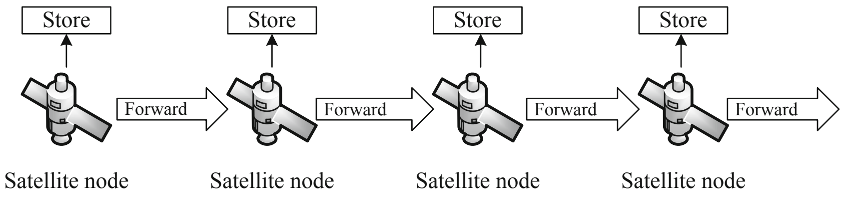

Fig. 2. "Store-and-forward" mechanism of DTN

and the transport layer is the Bundle adaptor, achieving the interconnection and the coordination of various protocols in different networks.

DTN is kind of challenged network with high time delay, which leads to the importance of "store-and-forward" mechanism to ensure the traffic transmission in the communication network with unstable links and long delay. If a DTN node can find out the next hop address of the current data packet, the packet will be transmitted, or else, the packet will be stored in the node and deleted when the packet is successfully sent to the destination. Therefore, a DTN node has permanent storage space to face the challenge of long-time unavailable links, which is one of the differences with the traditional networks.

Two assumptions are required to achieve all the process mentioned above:

1. The storage space of nodes is available and evenly distributed in the network;
2. The space of the storage queue can guarantee certain durability and robustness of the DTN network, in order to support the establishment of the next reliable path.

3 The Functional Design of the Multi-protocol Router

In order to achieve interconnection of heterogeneous satellite networks, the function of the router should include two parts, namely the routing and the gateway function. This section will give the specific routing algorithm and protocol switching procedure of the router based on the DTN protocol.

3.1 Routing Algorithm

Earliest-Delivery (ED) routing algorithm is widely used in DTN networks, details mentioned in [9]. However, ED algorithm is not the optimal routing algorithm for satellite DTN networks. The changing of the topology makes data packets fail to be transmitted according to the originally calculated path. As mentioned above, the topology of the satellite network has uncertain time delay and is interrupted frequently, bringing routing calculation difficulties.

As we all know, the motion of the satellite is cyclical so that the network topology can be obtained by the ephemeris approximately. Therefore, in order to simplify the dynamic topology of the satellite network, the concept of the virtual topology is introduced.

Virtual topology strategy is an efficient way to predigest high-changing-frequency topology [8], which transfers dynamic topology into large amount of static topologies by dividing one period time into several time pieces (or slots), based on the periodicity and predictability of the satellite motion. Concerned that the overhead of ED algorithm is time-varying, the way of time division will directly affect the performance of the ED algorithm. Therefore, the time pieces are divided as follows:

- Take the time that satellite links on/off as the route update time.
- Set a time threshold and when the update interval is less than the threshold, the update time will be merged with the previous one in order to reduce the number of time slice snapshots.

In summary, the specific process of the route calculation strategy is shown in the Fig. 3.

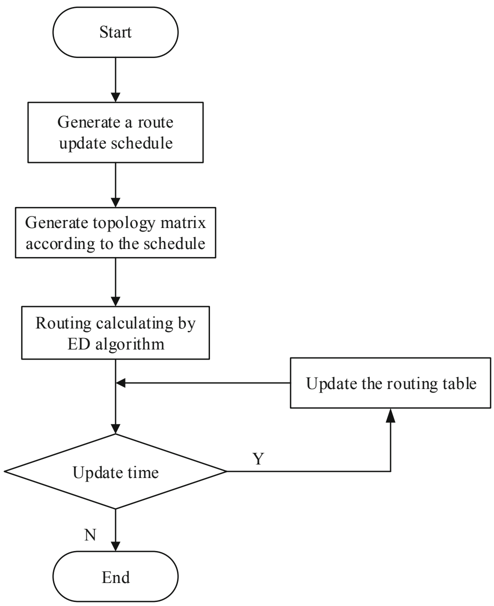

Fig. 3. Route calculation strategy

3.2 Protocol Switching

Another key function of the multi-protocol router is protocol switching. Currently, the commonly used protocols in satellite networks are TCP/IP, DTN, and CCSDS protocol. Therefore, the router designed in this paper will be mainly compatible with these three protocols.

To achieve protocol switching, three steps are required:

1. Identify the protocol used by the received packets.
2. Unpack the data packets.
3. Repack the data according to the protocol of the destination network.

In order to carry out the first step, which is the key point of protocol switching, we put forward a new frame format here, adding an 8-bit frame information part at the beginning of the frame, shows in Fig. 4.

In the 8-bit frame information part, the first 4 bits represent the protocol used in the source network protocol and the last 4 bits represent the destination one. Only when the source and the destination protocol are different will the data packets be repacked.

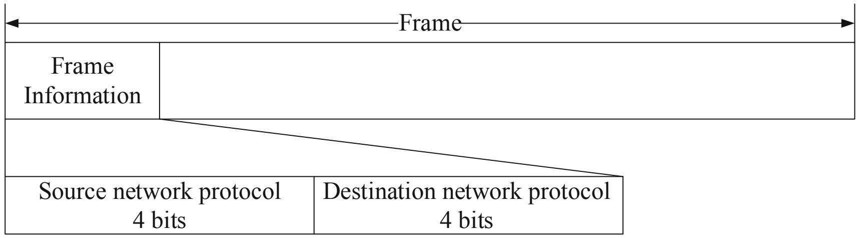

Fig. 4. Frame format

3.3 Summary

The function of the multi-protocol onboard router should include the following points:

- For services in the same subnetwork, the satellite with the router can work as a relay node, in other words, it can forward data packets in each subnetwork under TCP/IP, DTN, and CCSDS protocols respectively.
- To prevent collisions of data packets at the receiver, each satellite networks operates in different frequency, which means 3 different receivers are used in the MEO satellite.
- The router can simultaneously support TCP/IP, DTN, and CCSDS protocol to achieve inter-network transmission, which means the protocol switching.
- As the satellite with router is visible to three different systems, routing tables that this satellite updates are about the whole network, requiring routing tables of three networks. However, networks are not visible to the one using different protocol and their routing calculation is separated from other networks.
- Because of the large business pressure and high time propagation delay, the "storage and forwarding" function of the DTN system is added to ensure packet transmission and low packet loss rate in the satellite communication network.

In this context, we design the operation procedure of the on-board router and divide the procedure into three different parts, as shown in Fig. 5. When the router receives a packet, the protocol of its source and destination should be identified firstly. If the protocols are same, which means two nodes are in the same network, the router will only act as a relay. Or else, the router will repack the data packet according to the protocol used by the destination network and transmit it.

According to the function division in the Fig. 5, we design the router model in OPNET as shown in Fig. 6.

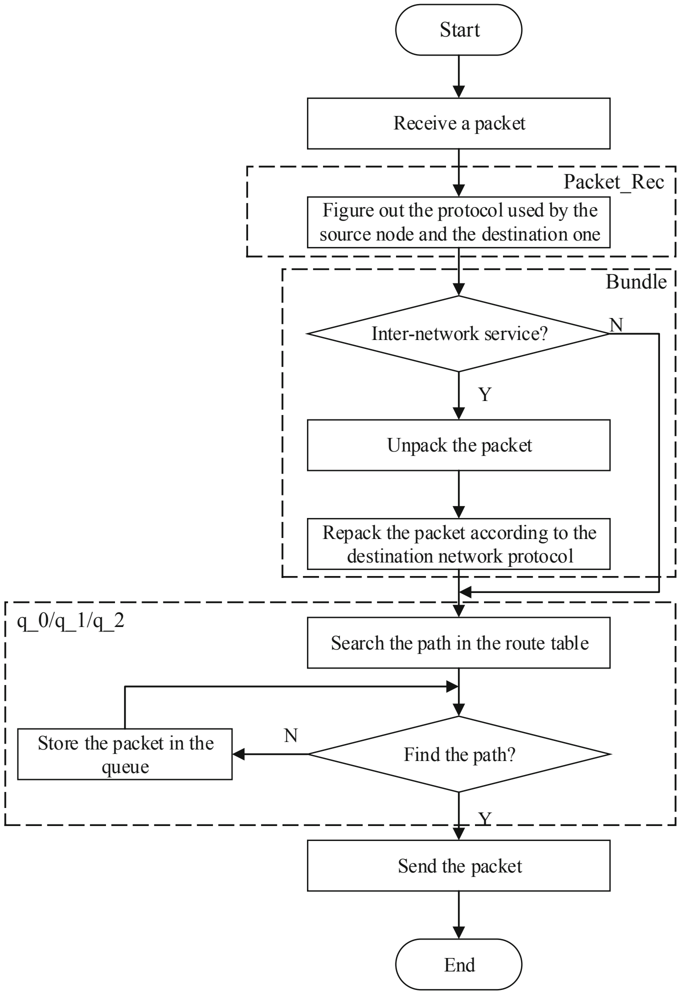

Fig. 5. The operation procedure and function division of the on-board router

The router has 3 independent storage space as queues, corresponding to 3 different networks, saving packets and finding their routes. The router has 3 route searching modules, which are used to find the routes of 3 different networks. The work of these three routing lookup modules is separated from each other and can operate in parallel.

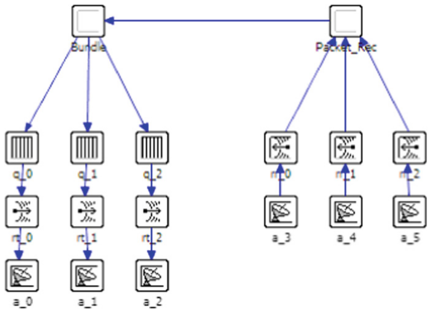

Fig. 6. The on-board router model in OPNET

4 A MEO/LEO Double Layer Satellite Network Model

In order to measure the performance of the router, we establish a MEO/LEO double-layer satellite network as the application scenario of the router, including 3 different LEO satellites network, composed of 3 LEO satellites each, using TCP/IP, DTN and CCSDS protocol respectively and a MEO satellite with the router we designed above on-board.

The satellite constellation we used is shown in Fig. 7, composed of 9 LEO satellites and 1 MEO satellite. All orbits are circular. The specific parameters of the MEO/LEO double layer satellite network model are listed in Table 1.

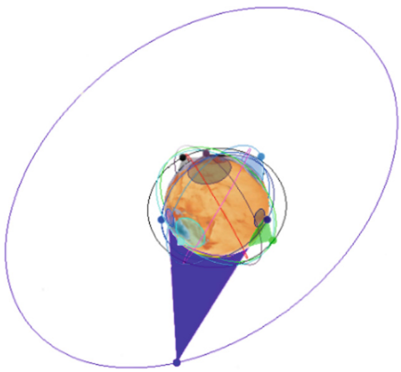

Fig. 7. The MEO/LEO double layer satellite network model

5 Results and Analysis

According to the satellite network mentioned in Sect. 4, we build the MEO/LEO double layer satellite network model in OPNET as the simulation scenario. The performance of the router is simulated by using the storage capacity of the MEO satellite router and the load of the network as variables.

Table 1. Parameters of the network model

Satellite-Protocol	Altitude/km	Inclination/°	RAAN/°
LEO-TCP/IP	1680.8	60	60/180/300
LEO-DTN	2000	60	30/150/270
LEO-CCSDS	1000	60	0/120/240
MEO-ROUTER	20000	55	0

For the routing method, we take the successful packets arrival ratio as a measurement of the performance. As shown in Fig. 8, compared with the traditional ED algorithm, the one using virtual topology strategy has a higher successful transmission ratio. When the storage capacity is not enough, a certain number of packets are dropped due to insufficient storage space. Larger storage capacity brings a better performance.

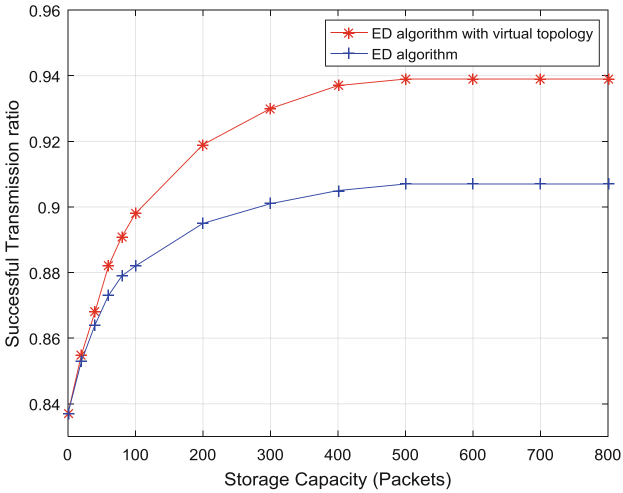

Fig. 8. The performance of the improved ED algorithm

As for the protocol switching part, we take the ratio of packet that the router processes successfully and the end-to-end time delay as the measurements of its capacity. In this context, we consider both of the storage capacity and the network load as variables.

In Fig. 9, we conclude that higher storage capacity allows the router to handle more protocol switching packets correctly. However, the performance of the router does not continue to increase as storage space increases. Network load is another impact factor of the router. The higher the network load, the greater the processing pressure of the router, which causes the decrease of the processing performance.

As shown in Fig. 10, the end-to-end time delay has the same tendency as the performance of the routing processing. Thanks to the improved ED algorithm, the end-to-end time delay of the network is controlled to within 70 ms. What must be

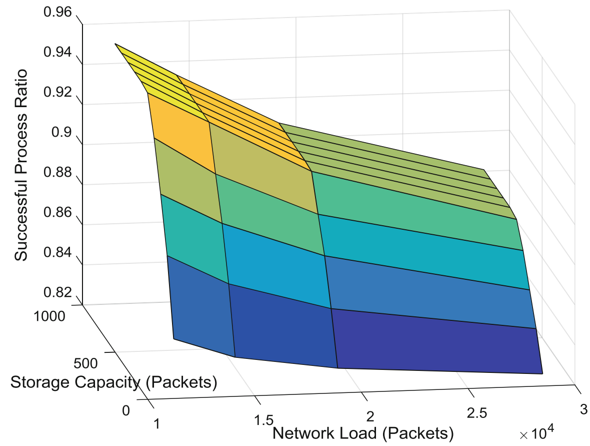

Fig. 9. The simulation result of the successful process ratio

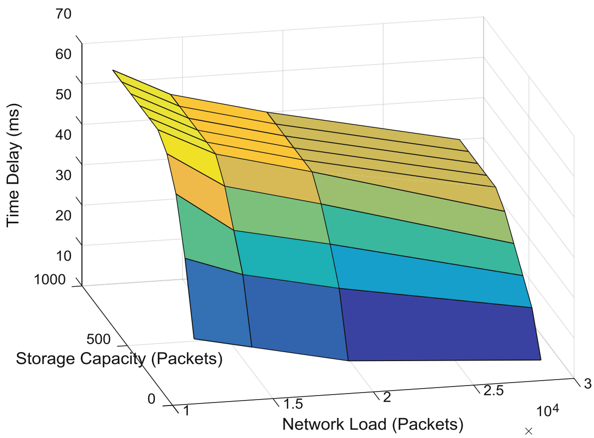

Fig. 10. Average end-to-end time delay

emphasized is that the lower time delay in high network load does not mean a better performance, which is exactly caused by the discarding of a certain number of packets.

6 Conclusion

In this paper, we design a multi-protocol onboard satellite router based on "store-and-forward" mechanism and the bundle layer protocol in DTN network to support TCP/IP, CCSDS and DTN protocol traffic at the same time. In order to simplify the dynamic topology of the satellite network, we apply the virtual topology strategy to improve the ED algorithm. Finally, according to the simulation result in OPNET, we find out the performance of the router is related to its storage space and the network load in a way. However, to realize a further improvement of the performance, a corresponding retransmission method is required, which will be our future work.

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