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Research of multi-path routing based on network coding in space information networks

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Abstract A multi-path routing algorithm based on network coding is proposed for combating long propagation delay and high bit error rate of space information networks. On the basis of traditional multi-path routing, the algorithm uses a random linear network coding strategy to code data packets. Code number is determined by the next hop link status and the number of current received packets sent by the upstream node together. The algorithm improves retransmission and cache mechanisms through using redundancy caused by network coding. Meanwhile, the algorithm also adopts the flow distribution strategy based on time delay to balance network load. Simulation results show that the proposed routing algorithm can effectively improve packet delivery rate, reduce packet delay, and enhance network performance.

1. Introduction

A space information network[1–3] is composed of spacecrafts and ground stations which have the ability of space communication. It is an interconnected network information system in which spacecrafts and ground stations complete communication by forwarding or reflecting functions. A space information network has the following characteristics: wide coverage, networking flexibility, quick network building, and few limitations from geography. It can provide integrated communication for a variety of space missions such as meteorology, environment and disaster monitoring, resource survey, topographic mapping, reconnaissance, communication broadcast, and scientific exploration.

Subjected to the space environment, the error rate in a space information network is high. In addition, it is easy to lead to loss packets, long link delay, and serious delay jitter. Using the traditional packet retransmission mechanism greatly increases the network transmission cost. Therefore, the routing algorithm in the space information environment has been a hot topic. Currently, the routing technology for space information networks is mostly suitable for satellite networks. Research has focused on the following three categories. The first category is the QoS routing technology,[4,5] in which QoS routing is put forward to satisfy multimedia, VoIP, and other services, and the main research includes reducing the switching probability of star and ground or the interstellar link. The second category is the load balancing routing technology,[6,7] in which the load is reasonably allocated to multi-path to improve network throughput. A variety of load balancing routing strategies for satellite networks have already been proposed. They can

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be divided into four categories: source routing, centralized, distributed, and hierarchical routing. The third category is the multi-service routing technology.[8] In order to provide a variety of services with different routings, network traffic can be divided into three types: delay-sensitive type, bandwidth-sensitive type, and best effort to deliver type. We can look for a routing which meets the requirements according to different traffic. However, these algorithms are not effective solutions for long delay and high error rate in space information networks. Thus, a space information network multi-path routing based on network coding (SMNC) is proposed, which can provide efficient and reliable routing transmission for space information networks.

2. The basic idea based on the network coding transmission

The main idea of network coding[9–12] is that the received and relative information on each node should have a linear or non-linear process and then be retransmitted. At last, the destination node decodes to recover the original data packets. Compared with the traditional transmission, network coding can improve the efficiency of transmission, save transmission energy, and increase the reliability and safety of transmission.

Due to the high bit error rate channel in a space information network, communication failures often occur. Meanwhile, the long link delay (for example, the round-trip propagation delay between a geostationary satellite and a ground station can be more than two hundred milliseconds) makes the traditional network retransmission method decrease space network performance seriously. Thus, a multi-path routing algorithm[13,14] based on network coding is proposed, in which intermediary nodes encode and add redundancy. When the destination node receives a sufficient number of linear irrelevant data packets, communication is ended. Thereby, this method can reduce retransmission and delay. The algorithm is suitable for larger space information networks (more than 30 nodes). On the basis of the traditional multi-path routing, data packets are randomly linearly coded in the multi-path routing algorithm. Therefore, in order to ensure the next hop node to receive enough data packets, each node determines the number of encoded packets according to the received data packets and the link status, and ensures successful packet transmission by adding redundancy. Figs. 1 and 2 show the coding idea.

Fig. 1 shows the traditional multi-path routing strategy and Fig. 2 shows the multi-path routing strategy based on network coding. As shown in Fig. 1, the source node S sends packets A, B, C to the destination node D. There are three paths between the source node and the destination node. Each path has a bit

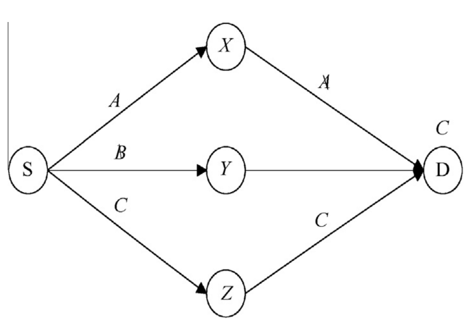

Fig. 1 Traditional multi-path routing transmission strategy.

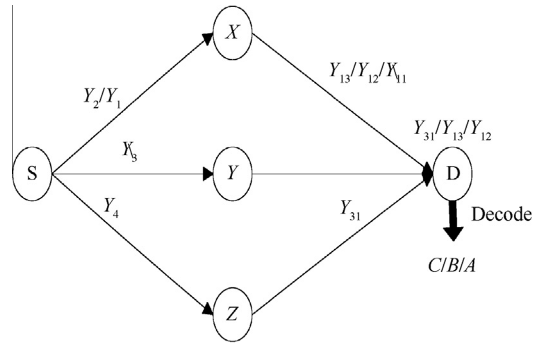

Fig. 2 Multi-path routing transmission strategy based on network coding.

error rate. In Fig. 1, the bit error rates of the links lead to the loss of data packets ~~A~~ and ~~B~~, so the source node has to retransmit packets, resulting in increasing the delay of data transmission. In Fig. 2, the source node and the intermediate nodes increase the actual number of transmitted packets according to the bit error rates of the links by encoding. The source node S send encoded packets $Y_1\backslash Y_2$, Y_3 and Y_4 to the intermediate node X, Y, Z, and the packet ~~Y_3~~ is lost during transmission. The intermediate node X, Y, Z send the recoded packets $Y_{11}\backslash Y_{12}\backslash Y_{13}$ and Y_{31} to the destination node D, the packet Y_{11} is lost during transmission. Finally, the destination node can decode out of the original data packets A, B, and C according to the three received packets.

It can be seen that the multi-path routing algorithm based on network coding can ensure successful packets transmission and reduce the number of retransmissions by adding redundancy.[15,16] Meanwhile, a new retransmission mechanism is proposed which retransmits data packets through intermediate nodes. It can reduce long delay and high cost caused by retransmission. At the same time, the algorithm optimizes the node caching mechanism, and a flow distribution algorithm based on delay is proposed. They balance network load and improve throughput of a network.

3. Multi-path transmission based on network coding

3.1. Data transmission with network coding

3.1.1. Source node coding

The source node establishes many paths, and then the original data are coded.[17,18] First of all, the source node divides N packets (X_1, X_2,..., X_N) into a group, and give the same group identification (the group identification increases from 0) to them. After grouping, it determines the number of encoding according to the link status. To solve packet loss caused by the high bit error rate, we add redundancy in the space information network. $M(s)$ represents the actual number of packets sent by the source node, and the formula is as follows:

$$M(s) = \left\lceil \frac{N}{\min\{P[s,i]\}} \right\rceil \; i \in D(s) \tag{1}$$

where N represents the number of packets in this group, $P[s, i]$ represents the link status between the source node and the next hop node (namely successful data transmission rate, expressed as a percentage), which can be achieved by periodically sending probe packets to the neighbors; $D(s)$ represents the next hop