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RESEARCH ARTICLE

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New dynamic routing algorithm based on MANET in the LEO/MEO satellite network

Abstract The features of low earth orbit/medium earth orbit (LEO/MEO) satellite networks routing algorithm based on inter-satellite link are analyzed and the similarities between satellite networks and mobile Ad Hoc network (MANET) are pointed out. The similar parts in MANET routing protocol are used in the satellite network for reference. A new dynamic routing algorithm based on MANET in LEO/MEO satellite networks, which fits for the LEO/MEO satellite communication system, is proposed. At the same time, the model of the algorithm is simulated and features are analyzed. It is shown that the algorithm has strong adaptability. It can give the network high autonomy, perfect function, low system overhead and great compatibility.

Keywords Computer application technology, LEO/MEO satellite network, MANET, Inter-satellite link (ISL), Cluster

1 Introduction

With developments in microelectronics, telecommunication techniques and global personal-communication, the satellite communication system, owing to its particular advantage, has become a necessary and complementary ground-based transmission. LEO and MEO, due to their excellent performance, is now becoming a developmental direction in satellite communication. As the core technique of LEO/MEO satellite networks, routing technique is becoming a hotspot in the research area.

The routing technique of LEO/MEO satellite networks can be classified into two camps. One is based on the ISL (Iridium is the representation) and the other is not based on the ISL (Globalstar is the case). The property of ISL routing technique is that it does not require ground equipment, and has little dependence on the base station, so it is more reliable and more secure, which becomes the development direction of future personal communication.

In this paper, we first introduce the mechanism of dynamic routing in the satellite network then regard the LEO/MEO satellite-network as a special wireless multi-hop network to further study the dynamic routing algorithm in the ISL-based LEO/MEO satellite networks.

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2 The limit of the ISL-based LEO/MEO routing algorithm

Many LEO/MEO routing algorithms based on the ISL have been proposed [1-2], such as LEO/MEO satellite network routing policy based on ATM proposed by Markus Werner, topology design and routing algorithm of LEO satellite network proposed by the Hong Seong Chang, and the connection-oriented and simple label-switched satellite network routing algorithm proposed by Vidya Shanker VG. These algorithms reduce the amount of computation in the satellite by way of offline pre-computation to simplify the satellite function.

Compared with the traditional shortest path routing algorithm (such as Bellman-Ford algorithm, Dijkstra routing and Floyd-Warshall algorithm, offline routing algorithm), offline routing algorithm reduces the signal cost in searching the route and the computation cost of dynamic routing. However, offline routing algorithm's limitation is that it cannot overcome the following:

1) Offline routing algorithm cannot adjust routing scheme dynamically according to the characteristic of the current flow in the network. Therefore, the optimal distribution of the network resource cannot be realized, and

correspondingly it can not guarantee quality-of-service (QoS).

2) Self-adaptive of the network is not ideal. When the ISL is invalid, the offline routing algorithm cannot dynamically adjust the route according to the current network status, and the system performance becomes worse.

The similarities between the satellite network and the MANET [3-4] include node mobility, and multi-hop transmission in the wireless channel. We separate the satellite-switched network connected with ISL from the satellite communication system, including the terminals and gateways on the ground. We also make the assumption that the data transmitted from the ground to the satellite is produced by the satellite itself. This means that the satellite is the source of these data.

Based on the above assumption, we can take the satellite network as a multi-hop wireless network. However, some distinct difference between them also exist, which is detailed as follows:

1) Although the topology of satellite network also changes frequently, most of the changes can be predictable. Contrary to the random movement of mobile nodes in the MANET, the period of the satellite movement can be foreseeable.

2) The antenna that supports satellite communication is beam antenna, differing from the omni-directional antenna used by the mobile node in the MANET, which results in the difference between satellite network and the MANET. The data transmitted by the satellite communication is point-to- point through the ISL.

3) Because the distance between the satellites is much further than the distance between the mobile nodes in the MANET, in the aspect of key techniques regarding the routing scheme and the organization of network, the delay that is usually neglected in the MANET cannot be overlooked in the satellite network.

Based on the similarity between satellite network and the MANET, we propose a novel dynamic routing algorithm that is used in the LEO/MEO satellite network based on the ISL.

3 Dynamic routing algorithm based on MANET technology in the satellite network

Considering the routing algorithm in MANET [5] that can be applied into the satellite network, utilizing the regularity and predictability of satellite network and being based on the offline routing algorithm, we adopt the layered network structure in the whole satellite network [6]. In other words, we carve up the whole network into clusters according to a certain algorithm. This means that we divide an entire network into subnets to reduce the broadcasting storm caused by the change of network topology in the traditional algorithm, controlling the broadcasting range in the cluster scope and therefore it can reduce the signal overhead. When message transfers among clusters, each cluster can be abstracted as a big switch node, which transfers the message in the unit of cluster. It includes three aspects: dynamical clustering, link reverse routing intra-cluster and exchange information between clusters.

When a node sends a message to another node, the source node first locates the cluster where the destination node belongs according to the initial nodes location information table. If the source node and the destination node are in the same cluster, we send data by adopting the intra-cluster routing determined by link reverse algorithm; otherwise, the cluster head selects the routing scheme, which is crossing through this cluster to its neighbor clusters for the satellites inside the clusters. The transmission of the data from the source to the destination then finally finishes.

3.1 Dynamically clustering

In order to save the signal cost of clustering and optimize the clustering scheme, we utilize the movement regularity of satellites and adopt offline algorithm to initiate the satellites clustering. First, we give some definitions as follows: the satellite clustering scheme designed during the “cluster offline initialization” is the original clustering scheme; we define the cluster in the initial clustering scheme as the original cluster and we distribute an original cluster label for each original cluster. We define the ISL which connects the satellites intra-cluster in the original cluster as the original intra-cluster ISL and define the ISL which connects the satellites inside the adjacent original clusters as the original inter-cluster ISL; we define the connectable satellites set connected by the original inter-cluster ISL as originally connectable, otherwise they are disconnectable. After the reorganization, “the new cluster” will be defined as the reorganization cluster by the contrast of original cluster.

After network initialization, we set up the following information for each node intra-cluster:

1) Original known satellite topology intra-cluster (information table of node intra-cluster).

2) All satellites know which cluster other satellites belong to (global node location information table).

3) All satellites know the connection and relative location relationship between clusters (connection information set inter-cluster).

4) All satellites know the routes to any other satellites intra-cluster (route table information intra-cluster).

After initializing the offline routing in the satellite network, if the network topology changes due to the link failure (as the division of cluster into two or more sets, or the cluster head itself fails and some nodes get away from the range of cluster, i.e., cannot receive information from cluster head), it is necessary to make dynamic reorganization of the cluster. It must obey the following principle: the original cluster and reorganized cluster can be divided further, but the combination of the cluster can only happen in case that the two reorganized clusters belong to the same original cluster. In the other words, satellites in different original clusters cannot be combined.

In order to reduce complexity of the cluster reorganization and reduce the computation overhead of satellite nodes, as well as guarantee network cluster scheme, which still obeys the design principle during the "cluster offline initialization", we carry on the reorganization process according to the following idea:

1) When there is a failure in the cluster head, satellites intra-cluster can detect this event and reelect the new cluster head.

2) As the original cluster becomes originally disconnectable due to the disconnection of some ISL inside the original cluster, the original cluster can break up. After that, the part containing the original cluster head still takes it as the new head, otherwise they will reelect new cluster head.

3) If the disconnected links reconnect, which leads the two reorganized clusters (belonging to the same original cluster) originally disconnectable to become originally connectable, we should combine the two reorganized cluster and reelect the new cluster head. In order to reduce the system overhead, we define that we can start the cluster reorganization only at the time when the satellite cannot detect a cluster head or in case the two divided parts in the same cluster get connected again.

3.2 Link reverse routing intra-cluster

In running a satellite network, each node does not send its link state information periodically if there is no change in the cluster topology, which therefore can greatly reduce the overhead caused by the topology update information. When changes in the adjacent link is detected, (non-verge satellite detect failures on non inter-cluster links, verge satellite detect failures on non inter-cluster links, verge satellite detect failures on inter-cluster links) it adjusts routes intra-cluster and broadcasts its link state information into the whole cluster so all the nodes intra-cluster can dynamically know the topology changes.

We adopt link reverse algorithm to set up routes inside cluster. Link reverse algorithm is a distributed algorithm and it will run at every satellite intra-cluster. Besides, this algorithm is also declinational satellite-oriented. In other words, the algorithm always has an independent instance to handle for each declinational satellite. We name the destination satellite as DEST.

The process that sets up a route from a given satellite to DEST is equal to the one that sets up a series of directional orders from this node to the DEST. We first introduce some conceptions for convince.

In the standard glossary, if a digraph does not contain directed loop, this graph is called acyclic directed graph (ADG). If all the nodes in a ADG can find a path from this node to the destination node, then we call this ADG as destination oriented and it can be marked as destination oriented ADG (DOADG); otherwise we call the ADG as destination disoriented ADG and it can be noted as destination disoriented ADG (DDADG). Apparently, an ADG is destination disoriented if and only if other nodes having no outgoing borders except for the destination node.

The basic idea of this algorithm is that if we maintain a DOADG for every destination satellite intra-cluster, all nodes in the network will locate in this DOADG and we can make the ADG destination oriented by reconstructing it when some links fail. In detail, the process of routing consists of two modules: routing initialization and routing maintenance.

3.2.1 Routing initialization

Assuming a DOADG solution, which takes DEST as the root is not exclusive. Considering that the movement of a satellite is regular and predictive, this process can be accomplished by using offline method and it can filter these DOADG according to some special standards to select the best solution. The standard that DOADG selects and optimizes should synthetically consider the following elements:

1) The summation of distance from all source nodes to DEST should be as short as possible.

2) The load on the different ISLs should be kept balanced as much as possible.

3) Because of the mobility of the satellites, some connection-broken changes will occur in certain ISLs. In order to decrease the jitter during communication, selecting a path that can be maintained for a long time and decreasing the switch between ISLs is important. The routing initialization inside the cluster is indicated in Fig.1.

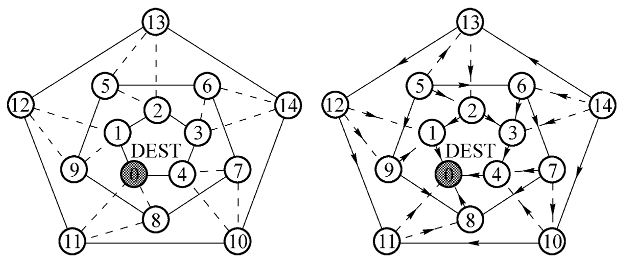


Fig. 1 Initialization chart inside cluster

3.2.2 Routing maintenance

There exists multiple routes from the source satellite to the destination satellites and the mechanism of multiple routes provide error-tolerant scheme for route selecting. If the failure of ISLs is not sufficient to change the original DOADG into DDADG and the entire network is still all connected, then the claim that there exists at least one path from any satellite to DEST is true. Therefore, the adjustment to the routes is not need at all. As demonstrated in Fig. 2, the three ISLs connecting with satellite 8 fail and topology changes but the topology after changing is still a DOADG, so the communication among other satellites will not be affected. However, if the ISL between satellite 1 and 0 (DEST) fails at this time demonstrated in Fig. 3, then the topology changes from DOADG to DDADG because satellite 1 does not have any outgoing border. In this circumstance, the routes must be adjusted because any path from satellite 1 to DEST is not known in satellite 1.

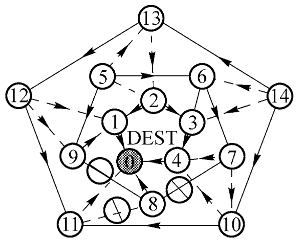


Fig. 2 Part ISL routes failing need not be amended

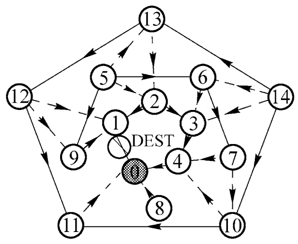


Fig. 3 ISL<1, 0>fails and DOADG change into DDADG

In order to transform DDADG to DOADG and decrease the routing signal cost as much as possible, we adopt proportion reverse algorithm as the topology switch method in the route maintenance process. The proportion reverse algorithm flow chart is shown in Fig. 4.

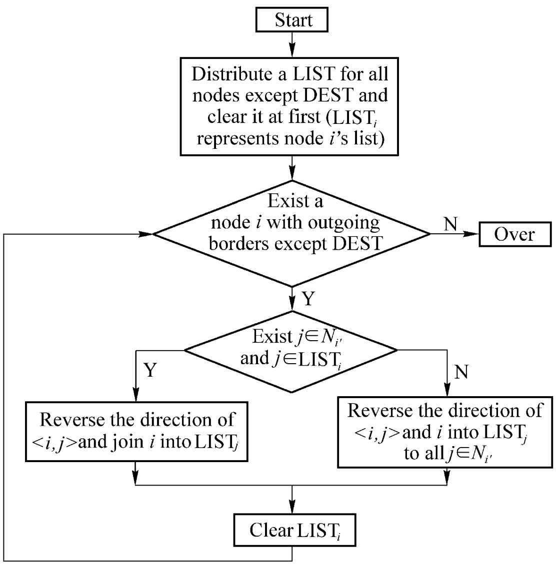


Fig. 4 Proportion reverse algorithm flow chart

Link reverse algorithm can adjust routes automatically according to the change of network topology. It can steer clear of the fault link at the time proportion links fail. All of this solves the problem of mass link breaking and performance decline caused by the lack of an automatically adjusting routing scheme when some ISLs fail. Compared with the traditional shortest path algorithm, this algorithm can benefit low signal overhead and much quicker convergence.

3.3 Information exchanging inter-cluster

While transferring information intra-cluster, it requires network topology information exchange among clusters. As a result, it can set up a route with the use of affluent information. When the topology state intra-cluster changes, it requires informing other clusters under the following conditions:

1) When some nodes intra-cluster is unreachable, the head must inform other clusters that the unreachable nodes are not available. It can prevent data from being sent to this cluster when other clusters send data to those nodes.

2) When the cluster is divided, the proportion which reelects the cluster head need to inform other clusters of its existence and its controlling range.

3) When clusters combine, the head of the combined cluster broadcasts the notification that some clusters are no longer available because they have been combined. The new cluster head notifies other cluster heads its expanded controlling range.

4) When the connection counts of the verge satellite intra-cluster with the adjacent clusters decline to zero or decline by 1, the cluster head should inform other cluster heads that there is no connection of this cluster with certain adjacent clusters or the count of connection has changed and they should update inter-cluster connection information matrix.

5) When the verge satellites of the cluster recover the connectivity with adjacent clusters or connection count increases by 1, the cluster head should inform other cluster heads that this cluster has recovered connectivity with certain adjacent clusters (and they should update inter-cluster connection information matrix).

When we abstract the cluster as a node, the whole network topology represents another logical topology $T=(P,V)$, in which P is the set of the nodes. Each node here corresponds to a cluster, and V is the set of unidirectional borders inter-cluster. Each border of V represents the ISL between two adjacent clusters and it also holds a weight which represents the connecting condition between adjacent clusters. The weight takes inverse proportion to the count of ISLs between clusters. If all of the ISLs between clusters break, the weight will be infinite.

Because each node in the cluster need to maintain a DOADG which takes all the other nodes as the destination, we can obtain the information of cluster members and their initial link state. When the inter-cluster ISLs have connection-broken changes, the cluster members detecting the changes inform the cluster head of these changes. The cluster head broadcasts the message to all the other cluster heads and updates T (weight of border in V). The head sends the satellite intra-cluster the optimal routing scheme of crossing through this cluster to all its adjacent clusters (it is called crossing through route). For example, if satellite S want to send data to satellite D, S first sends a route request to the cluster head, then the cluster head selects the optimal route to D (the route discussed here is merely the route in T, we name it as cluster source route, and it consists of all the labels of cluster it arrives at from S to D) according to the cluster which D belongs to and the topology information of T (the cluster that have more links with other clusters is foremost selected as the transfer cluster), after that the cluster head sends the cluster source route to S. Then, S will cross through the clusters one by one to get to the destination cluster according to the information of cluster source route and the crossing through route configured intra-cluster, and finally arrives at D. When the cluster is divided into two disconnected parts, the reverse cannot form a new DOADG, so it reconstructs to a new cluster.

4 Validation and performance evaluation

In this section, we first build up a satellite simulation platform using NS-2 to simulate the routing algorithm.

4.1 Parameter set

The simulation employs the Iridium satellite network topology, and the initial cluster partition scheme shown in Fig. 5 is indicated as follows: there are 6 clusters, and the corresponding cluster heads are 11, 46, 54, 15, 18, 50. The bandwidth of ISL is 1 Mbit/s, the link transmission delay is 10 ms. Each satellite sends data at constant bit rate (CBR), the data packet is 200 bytes, and the time-interval between sending packets is 100 ms. The period that the cluster head sends a message representing the cluster head to cluster member is 5 ms. The signal packet is uniformly set as 200 B.

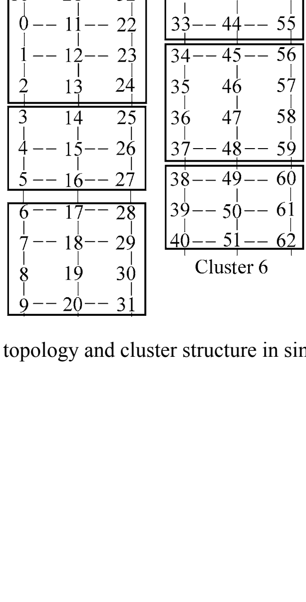


Fig. 5 The network topology and cluster structure in simulation

The simulation can be categorized into two instances. One is the cost of link reverse algorithm in a network that does not have any failure. The other is the signal overhead under the condition that the network ISL faces the trouble. We compare the results of these two cases with open shortest path first (OSPF), respectively. The upgrade period of the link state information in the OSPF is set as 60 s in the simulation.

4.2 The network without failure

Figure 6 compares the cost between link reverse algorithm and OSPF algorithm when the time for simulation is 100 s in a network that does not have any failure. In the OSPF algorithm, nodes must broadcast their link state information to the whole network. While in the link reverse algorithm, the whole satellite network is divided into several clusters. Cluster members only need to report their link state information to the cluster head periodically and the cluster head only sends a reply package, which attests its existence to the cluster members periodically. Therefore, the signal cost is less than that of OSPF algorithm.

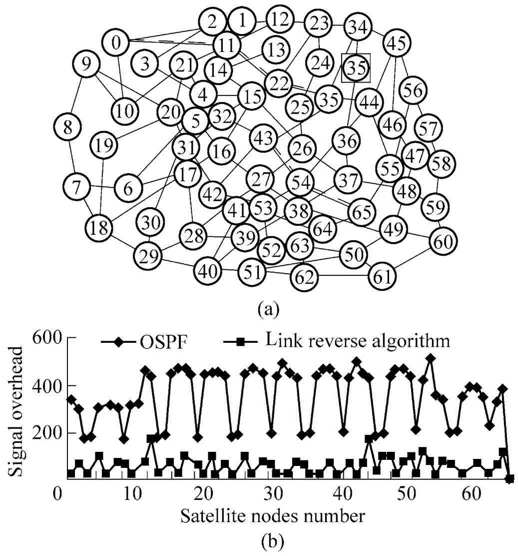
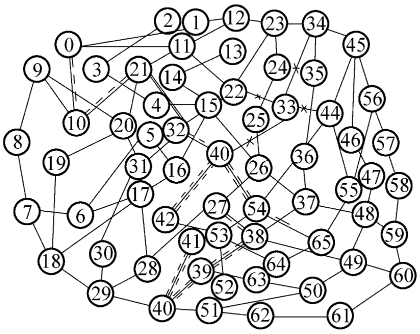


Fig. 6 The overhead comparison of link reverse algorithm and OSPF algorithm in network without failure; (a) Topology of network without failure; (b) Comparison of signal overhead

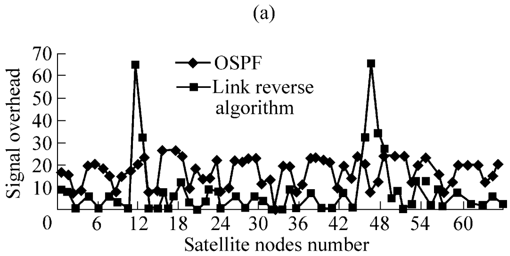
4.3 The network with some ISLs broken-down

A node which is broken-down causes all the connected links to be broken down.

The simulation runs for 100 s. At 5 s, node 33 is randomly picked out and is set to be broken-down (the four ISL that connected to node 33 are all down) and the routes complete reconstruction at 5.063 s. The link reverse algorithm carries out link reconstruction for the broken link automatically. Take the route from node 0 to node 65 as an example. In a network without any failure, the route from node 0 to node 65 starts from node 0, through node 11, node 12, node 33, node 43, node 54, and ends at node 65, as shown in Fig. 6(a). After the breakdown of node 33, the route from node 0 to node 65 is reconstructed to be from node 0, through node 10, node 21, node 32, node 43 and node 54 to node 65, as shown in Fig. 7(a). We can see from Fig. 7(b) that only the signal cost of node 11 and node 43 increases, the cost of all other nodes is the same as the cost when the network does not fail. This is mainly because node 33 is a member of cluster 3, as shown in Fig. 5. When all the links connected to node 33 break down, cluster 3 will be unable to connect with its neighbors: cluster 1 and cluster 2 through ISL frome node 33 to node 22 and ISL from node 33 to node 34. Node 22 and node 34 will report the breakdown respectively to their local cluster heads: node 11 and node 46. Thereupon these two cluster heads recompute the boundary satellites that lead to cluster 3, and report the result to all the members in the cluster. The signal cost of the two nodes increase in that way. But this kind of adjustment merely occurs in such neighbor clusters that link breakdown affects, so the cost of other nodes does not change dramatically. Therefore, the total cost is still small. That also shows that the link reverse algorithm has good expandability, and the cost will not increase dramatically along with the network scale growth.



(a)



(b)

Fig. 7 The overhead comparison of link reverse algorithm and OSPF algorithm when node 33 fails. (a) Topology when node 33 fails; (b) Comparison of signal overhead

5 Features of dynamic routing algorithm based on MANET technology in the LEO/MEO satellite network

1) When some of the satellite links break down, they can be dynamically renewed and the broken link will be bypassed. The system's haleness and error-tolerant ability are greatly enhanced.

2) Adopting the link reverse algorithm, it supports multi-path route and completes load balance among different links. Compared with traditional DV and LS routing algorithm, the link reverse algorithm has less routing signal cost.

3) The entire network is divided into several clusters (small network), and the renewal information broadcasting storm in traditional routing algorithm is constrained in clusters, and information exchanges among clusters only occur when necessary. Also, many topology changes inside a cluster are transparent to other clusters. These transparent changes do not need to be informed to the whole network, so the signal cost is reduced greatly. The self-adaptability is also enhanced. That is to say, if some of the links are broken down, the routing problem can be solved locally (only this cluster or its neighboring clusters are affected).

4) A cluster head which carries out supervision and management is chosen for each cluster. Cluster heads control information exchange among clusters, and guarantee the topology of the whole network to be coherent. But the data transmission of each node does not completely rely on the cluster head.

5) Clusters can be dynamically reorganized. After the topology of a cluster is broken, the fission can be carried out. When the broken links are restored, the mergence can be carried out under certain conditions.

6 Conclusions

We analyze the common property of the MANET and LEO/MEO satellite network connected with ISL, and take the part of routing algorithm in the MANET that can be applied into the satellite network for reference, and fully make use of the regularity and foreseeability of satellite networks. Based on the offline routing algorithm, we adopt a hierarchical network routing structure on the satellite network. The broadcasting storm is reduced when the topology changes in the network, so the signal cost is reduced exponentially. When it needs to exchange information in the unit of cluster among clusters, each cluster abstractly becomes a big switching node. The self-adaptability and autonomy of the satellite network are enhanced, which enables the network to have more self-adaptability, comprehensive function, little system cost and extensive applicable scope.

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