A Handover Strategy in the LEO Satellite-Based Constellation Networks with ISLs

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Abstract *A new handover strategy named minimal-hops handover(MHH) strategy for the low earth orbit(LEO) satellite constellations networks equipped with inter-satellite links(ISLs) is proposed. MHH strategy, which is based on the hops of the end-to-end connection paths and makes good use of the regularity of the constellation network topology, can appropriately combine the handover procedure with routing and efficiently solve the inter-satellite handover issue. Moreover, MHH strategy can provide quality of services(QoS) guarantees to some extent. The system performances of the MHH strategy, such as time propagation delay and handover frequency, are evaluated and compared with that of other previous strategies. The simulation results show that MHH strategy performs better than other previous handover strategies.*

Key words *low earth orbit(LEO) satellite-based constellation networks; time propagation delay; quality of services (QoS); inter-satellite link (ISL); inter-satellite handover*

Due to various economic and technical constraints, terrestrial mobile networks can only provide communication services with a limited coverage. Recently, in response to increasing demand of real-time multimedia services and the truly global coverage required by personal communication services (PCS), there is a vast research on non-geostationary orbit (NGSO) satellites systems, especially on low earth orbit (LEO) satellite constellations with an altitude between 700 km and 1 500 km. LEO satellite constellations equipped with inter-satellite links (ISLs), such as Iridium, Teledesic, Courier and so on, usually have onboard switching (OBS) and onboard routing (OBR) facilities and form an independent network in space. Direct connectivity between any pair of satellite mobile users can be achieved through the satellites and ISLs without any essential usage of the terrestrial core network. For the wide application prospect, they have already been the focus of the research on the satellite communication systems[1-4].

Because of the LEO satellite's rotation around the earth and the mobility of end-users, the connection requires frequent handover and rerouting decisions. Therefore, handover strategy can be considered as the most important issue that greatly affects the system performance. There are several handover strategies for intra- and inter-satellite handovers in Refs.[5～15]. Handovers between different spotbeams are discussed in Refs.[13～15]. The mainly object in Refs.[5,9～12] is the analysis of the impact of handover strategies on the system performances, such as time propagation delay, handover frequency, call dropping probability (CDP) and elevation angle. Using some predictive characteristics in mobile satellites systems, a strategy based on user terminal position and signal strength measurement is proposed in Ref.[6], and a reliable handover rerouting protocol is proposed in Ref.[7], and the system performance metrics including the number of handover and the routing delay are discussed in Ref.[8]. Furthermore, there are also some other handover strategies that are the combination of handover and connection admission control or radio resource management or channel allocation.

In the LEO constellations, although handover procedure is closely correlated with rerouting, almost all the existing strategies pay more attention to the handovers themselves and ignore the rerouting. In this way, this paper proposes a new strategy named

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minimal-hops handover (MHH) strategy for LEO satellite constellation networks with ISLs. Based on the hops of the end-to-end connection path, MHH strategy appropriately combines handover procedure with routing.

1 LEO Satellite Constellations

In the satellite constellation network, the essential system framework is made up of constellation including satellites and ISLs and earth stations. There exist two typical LEO satellite constellations with global coverage, which are the rosette constellation and the polar orbit constellation[16~18].

1.1 Constellation Design

The polar orbit satellite constellations usually cover either the global area or the polar and high latitudinal areas. R. David Luder firstly proposed a constellation design method utilizing polar orbit satellites, but he did not take the phasing offset between satellites into account. Other scholars proposed an optimized method for polar orbit constellation design after lots of research. For example, Iridium system uses a polar orbit constellation with 66 satellites at an altitude of 780 km, whose satellites are placed in six orbital planes of eleven satellites each, inclined at 86.4° to provide global services with elevation angle above 8.2°. The phrasing between orbits is 16.36°. As shown in Tab.1, the orbit altitude is improved to 1 400 km and the modified constellation is called Iridium-like.

The rosette satellite constellation proposed by A. H. Ballard is popularly used to provide services with global coverage or between certain latitude by inclined satellites. The system performance of rosette constellation is similar to that of Walker constellation. According to the customary symbol and usage, rosette constellation can be expressed as (N, P, m). N is the number of satellites and P is the number of planes, while m is the harmonic factor and takes on integer values from 0 to $N-1$. For example, Celestri-like system adopts a rosette constellation with 63 satellites at an altitude of 1 400 km, which can be expressed as (63, 7, 5). As shown in Tab. 1, all the satellites are deployed in seven planes of nine satellites each and incline at 48° and the phasing between orbits is 28.57°.

Tab. 1 Constellation parameters

LEO Constellation	Constellation Type	Orbit Altitude /(Km)	Inclination /(°)	Number of satellites	Number of Orbits	Phasing between orbit planes /(°)
Iridium-like	Polar	1 400.00	86.40	66.00	6.00	16.36
Celestri-like	Rosette	1 400.00	48.00	63.00	7.00	28.57

1.2 Inter-Satellites Links

The connectivity of a LEO constellation substantially depends on the presence of ISLs. There are two types of ISLs: intraplane (Intra-) ISLs connecting satellites within the same orbit and interplane (Inter-) ISLs connecting satellites in adjacent orbits.

For the Iridium-like constellation, it is assumed that the intra-ISLs are permanently maintained and the inter-ISLs closest to the equator are maintained for each time. The oldest ISLs that are beyond the latitude bounds are switched off while the new ISLs that are within the latitude bounds are switched on. The bounds are assumed at north and south latitude 60°. Because of the rapid relative movements between the satellites in the oppositely directed orbit planes, there are no ISLs between them.

For the celestri-like constellation, intra-ISLs and permanently maintainable inter-ISLs are considered. Each satellite has been equipped with four bidirectional ISLs.

1.3 Redundant Coverage

A LEO satellite at the altitude between 700 km and 1 500 km can cover only about 3%～5% of the earth’s surface. LEO constellation with global coverage usually consists of several dozens, even several hundreds satellites. There exist vast areas even the whole globe that are redundantly covered. For a satellite user in the redundant coverage area, there are more than one satellite available to communicate with. In order to evaluate their redundant coverage, Iridium-like and Celestri-like are simulated, which have similar number of satellites at the same altitude. Assuming that the end-user is located at Beijing (north latitude of 39.91°, east longitude of 116.39°), the total simulation time is 24 h, and there are 8 640 points sampled by every 10 s. The multiplicities of coverage are shown in Fig.1 and Fig.2. User can be usually covered by three or four satellites in Celestri-like at a time while two or three in Iridium-like. It is obvious that the satellites in the Rosette constellation are deployed more evenly than that in the Polar Orbit constellation.

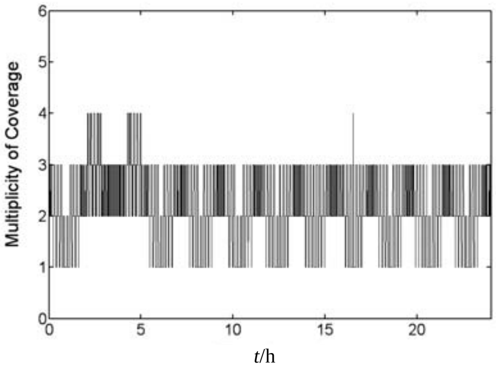


Fig. 1 Iridium-like: multiplicity of coverage

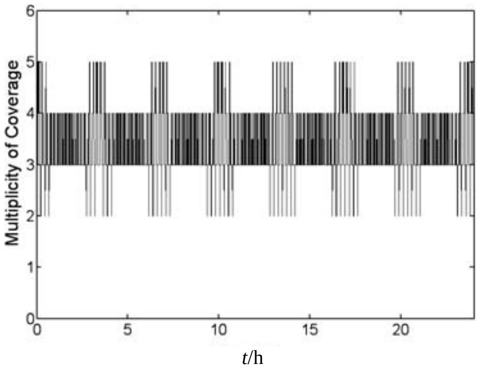


Fig.2 Celestri-like: multiplicity of coverage

2 Minimal Hops Handover Strategy

Due to the LEO satellite's rotation around the earth and the mobility of end-users, satellite users must frequently handover from one satellite to another during a connection. On the other hand, in order to achieve better performance, an appropriate handover strategy must be carefully selected. After a handover, rerouting is usually needed, so handover procedure is closely combined with routing. In this section, several previous handover strategies are firstly introduced and then the MHH strategy is proposed.

2.1 Previous Handover Strategies

In recent years, a number of handover strategies used in the satellite systems have been proposed or discussed, such as the nearest satellite, the strongest signal, the longest remaining visibility time, the least loaded satellite and the shortest path.

Nearest satellite handover (NSH) strategy: it uses the nearest satellite criterion, which believes that the best satellite for QoS should be the nearest satellite, i.e. the satellite with the highest elevation angle. The handover procedure can be determined by the analysis of the geometric elevation angle based.

Strongest signal handover (SSH) Strategy: the permanent provision of sufficient power that is required to establish or to maintain a connection is a primary condition of the radio communication. Strongest signal can provide better QoS, so the strength of the signal power from a plot signal is a suitable paramount handover initiation criterion.

Longest remaining visibility time handover (LRVTH) strategy: when a handover takes place, end-users handover to the satellites which can provide the longest remaining visibility time for the current connection and be kept communicating with until their elevation angle is blow the given threshold $E_{\min}$.

Less loaded satellite handover (LLSH) strategy: selecting the less loaded satellite can balance the generated traffic load among all covering satellites. It must know the real-time traffic load which is distributed in the network, so it is very complicated to implement in real systems.

Shortest path handover (SPH) Strategy: at any time, end-users of a connection select the satellites that provide the shortest distance of the communication path. It can get shorter propagation delay than other handover strategies.

2.2 Minimal Hops Handover Strategy

Although handover procedure is closely correlated with rerouting procedure, almost all the previous strategies focus on the handover procedures themselves but ignore the rerouting procedures after handover. So they cannot make full use of the characteristics and regularity of constellation topology. This paper proposes a new handover strategy named MHH strategy, which combines handover procedure with routing. It utilizes the minimal hops handover criterion to determine when and which satellites to handover.

MHH criterion: both end-users of a connection concertedly select satellites to communicate with, which make the connection have the minimal number of hops. When MHH strategy is applied to a LEO satellite constellation network with ISLs, both end-users of the connection periodically detect which satellites are covering them and whether there is a path with less number of hops available for them. If one end-user is out of the coverage of its current satellite, it must select new satellites for the current connection. Otherwise, end-users keep communication with their current satellites. It is assumed that a static routing algorithm is adopted to calculate onboard routing table and the routing items include the number of hops between satellites in the constellation network. The onboard routing table is automatically refreshed by system and there is no further discussion about routing.

The detailed steps of realizing the MHH strategy in a LEO constellation network are shown as follows.

Initialization: when the system is initialized, onboard routing tables are calculated and their routing items include routing paths and the number of hops (Hop_{ij}) between satellites (S_i, S_j, where i and j are the serial numbers of the satellites). Routing tables are automatically refreshed with the change of network topology.

Establish connection: it is assumed that there are m satellites covering the source user of a connection and n satellites covering the destination user. According to MHH criterion, two satellites are selected from the pairs (S_{SRCi}, S_{DESTj}, i=1 ~ m, j=1 ~ n) respectively communicate with the end-users and m is the number of satellites covering the source user and n is that of the destination user. The number of hops between the selected ones is minimal among the pairs and the elevation angles of them are the maximal among the pairs whose hops number is minimal.

Handover and holding on the connection: during a communication connection, each end of the connection periodically detects which satellites cover itself and determine whether it need to handover. If the current satellite is out of coverage or a less hops path becomes available, two satellites are reselected from the pairs (S_{SRCi}, S_{DESTj}, i=1～m, j=1～n) according to MHH criterion, and they are respectively communicated with end-users.

In a word, the key criterion of MHH strategy is that when and which satellites to handover are determined by the hop numbers of the communication path and the elevation angles. It reduces the handover frequency to some extent and makes the handovers interval as longer as possible.

3 Performance Evaluation

The performance of MHH strategy is evaluated under different LEO constellations including rosette and polar orbit constellation. The system performances of MHH strategy, such as time propagation delay, mean elevation angles and handover frequency, are simulated and compared with that of other previous strategies.

3.1 Simulation Scenario

Four handover strategies are carefully selected to evaluate, such as the longest remaining visibility time, the nearest satellite (maximal elevation angle), the shortest propagation path and our proposed minimal hops. In order to reduce the complexity of realization and simulation, LRVTH strategy is slightly modified. When a connection is set up or handover, end-users select the nearest satellites and keep in touch with them until one of them is out of sight by the threshold $E_{\min}$. Furthermore, because of satellites' rapid rotation around the earth and the mobility of end-users, both the distance of ISLs and that between satellites and users varied continuously. SPH strategy is too complicated to implement in a real system, but still a useful reference for more elaborated ones.

Two selected LEO satellite constellations are iridium-like (polar orbit) and celestri-like (rosette). In addition, it is also assumed that the onboard routing table is automatically refreshed and its items include the number of hops between satellites in the constellation network.

Provided that the end-user locates at Beijing (north latitude of 39.91°, east longitude of 116.39°) and Sydney (south latitude of 33.89°, east longitude of 151.03°) and the elevation angle threshold $E_{\min}$ is 15°, the source user at Beijing sends a packet every 5 s. The number of the delay sampling point for each strategy is 17 280. The simulation results also include the number of handover.

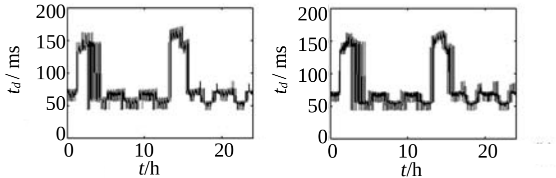
Under the same conditions, when the end-users locate at Guangzhou (north latitude of 23.10°, east longitude of 113.29°) and New York (north latitude of 39.91°, east longitude of 116.39°), the propagation delay and handover frequency of different strategies are simulated, too.

3.2 Simulation Result

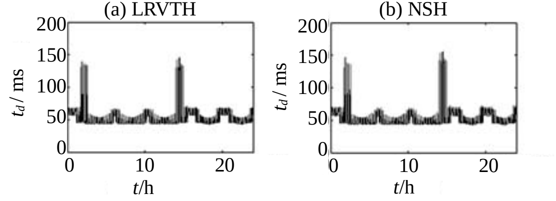
The propagation delay results for different handover strategies are shown in Fig.3 (Iridium) and Fig.4 (Celestri). It is clearly that the propagation delay of MHH strategy is much less than that of the LRVTH strategy and the NSH strategy and close to that of the SPH strategy. In order to make it clear that the affect to the propagation delay of different strategies, the probability density functions (PDF) of different strategies and constellations are shown in Fig.5 and Fig.6. The cumulative distribution functions (CDF) of different strategies and constellations are shown in Fig.7 and Fig.8. Fig.5～Fig.8 also show that the propagation delay of MHH strategy is close to that of the SPH strategy and much better than that of other two strategies.

QoS can be usually measured by delay, jitter and bandwidth. For a real-time service, delay is especially important. The better delay performance of MHH strategy can provide a better QoS guarantee.

The mean propagation delay and total number of handover under different conditions are shown in Tab.2. These statistical results show that the performance of the MHH strategy is much better than others. Its delay is close to that of the SPH strategy, but much less than that of the other two. Its handover frequency is higher than that of the LRVTH strategy, and lower than that of the other two.

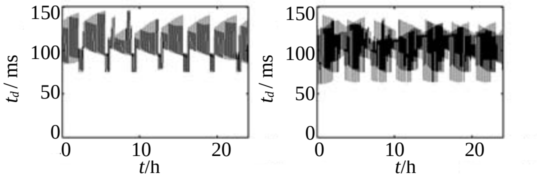


(a) LRVTH (b) NSH

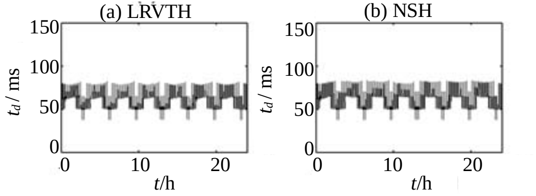


(c) SPH (d) MHH

Fig.3 Iridium-like: propagation delay

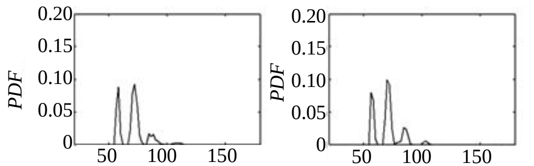


(a) LRVTH (b) NSH

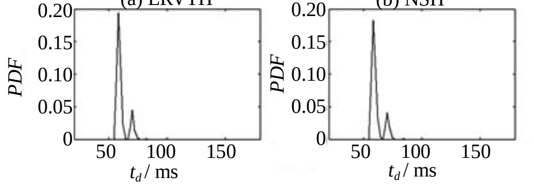


(c) SPH (d) MHH

Fig.4 Celestri-like: propagation delay

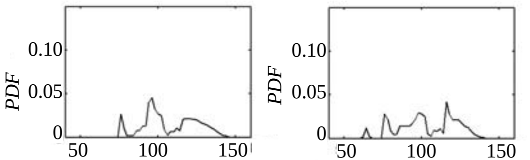


(a) LRVTH (b) NSH

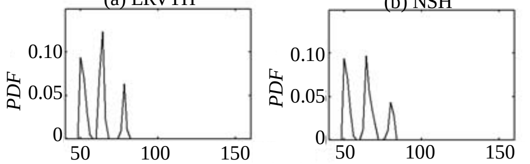


(c) SPH (d) MHH

Fig.5 Iridium-like: PDF of delay



(a) LRVTH (b) NSH



(c) SRH (d) MHH

Fig.6 Celestri-like: PDF of delay

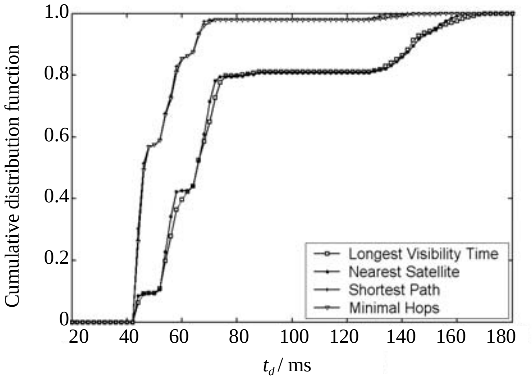


Fig.7 Iridium-like: PDF of delay

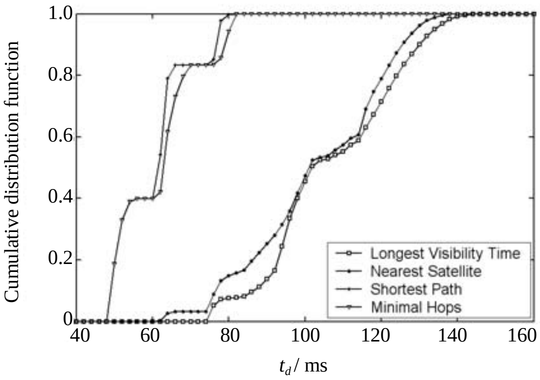


Fig.8 Celestri-like: PDF of delay

Tab.2 Statistics of performance parameters for considered handover strategies and constellations

constellation		Iridium-like				Celestri-like			
handover Strategy		LRVTH	NSH	SPH	MHH	LRVTH	NSH	SPH	MHH
Beijing to Sydney	mean Delay	77.92	77.34	52.77	53.14	107.76	103.91	61.17	62.39
	number of handover	269.00	404.00	410.00	326.00	216.00	553.00	304.00	300.00
Guangzhou to New York	mean Delay	69.83	69.46	60.33	60.46	80.84	78.69	64.01	68.00
	number of handover	274.00	404.00	401.00	362.00	245.00	511.00	574.00	483.00

4 Conclusions

LEO satellites constellation networks are expected to support real-time multimedia traffic and to provide their users with the appropriate QoS guarantee. This paper proposes the MHH strategy based on combination of the rerouting and handover. Compared to the previous handover strategies, it has better system performances, such as propagation delay and handover frequency. Furthermore, MHH strategy is suitable to both LEO and MEO satellites constellations with ISLs.

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