Research on Handover Technology for 5G LEO Satellite Network Based on ns-3

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Abstract. The 5G Low Earth Orbit (LEO) satellite network offers several advantages, including wide coverage, stable communication, and strong flexibility, making it an ideal solution for high-quality communications. Due to the fast movement of satellites, research on handover technology for LEO satellite networks is crucial. This paper uses the network simulator (ns-3) to build a 5G LEO satellite network and introduces delay for each handover process. We propose a handover algorithm based on distance difference threshold, taking into account spectrum allocation. In order to evaluate quality of service (QoS) of the network, we explore the influence of handover delay and threshold selection by setting multiple groups of handover delay and distance difference thresholds. Simulation results indicate that as handover delay increases, the impact of handover events on the network also increases gradually. Moreover, an appropriate threshold based on the actual situation can reduce the number of handovers and minimize communication delay. In particular, when the handover delay is 6ms, the communication delay can be reduced by about 2ms with an appropriate distance difference threshold.

Keywords: ns-3 · 5G LEO satellite network · handover delay · distance difference threshold

1 Introduction

The 5th Generation Mobile Communication Technology (5G) boasts superior network speed and lower latency, with advanced features such as ultra-high frequency band and large-scale multiple-input multiple-output (MIMO) technology. This enables a greater number of devices to connect to the network simultaneously and also supports an increased number of smart device connections. The International Telecommunications Union (ITU) has classified 5G services into three primary categories [1], namely Enhanced Mobile Broadband (eMBB), Ultra Reliable Low Latency Communication (URLLC), and Massive Machine Type Communication (mMTC). As a hot research topic worldwide,

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5G has been widely adopted across various fields, including industrial control, autonomous driving, smart home, and many more.

Compared to 5G ground communication network, satellite communication offers significant advantages, such as wide coverage and stable communication. In remote areas such as deserts and oceans, ground network may not provide coverage or may be too costly [2], while satellite network can offer low-cost and efficient network access services. Additionally, satellite communication is not affected by weather or terrain, and the probability of signal interruption and other failures is low, which make it suitable for emergency communication. The Low Earth Orbit (LEO) satellite network, in particular, offers lower communication delay, lower link loss, and higher transmission rate compared to High Earth Orbit satellite network, and can achieve super-large system capacity through giant constellations [3,4]. Combining LEO satellites as the Next Generation Base Station (gNB) with 5G ground networks [5] can make up for the shortcomings of 5G ground networks in transportation, maritime communication, telemedicine for remote areas, and other fields, with broad development prospects. Figure 1 shows the application scenario of 5G LEO satellite network. However, due to the fast movement of LEO satellites, when only one satellite gNB is servicing User Equipment (UE), it is easy to lose connection between UE and the satellite. To address this issue, it is necessary to construct LEO satellite clusters and handover the connection relationship between UEs and satellite gNBs.

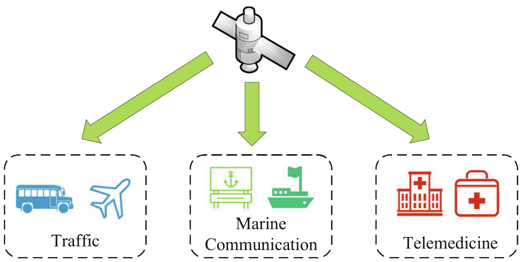

Fig. 1. Application scenario of 5G LEO satellite network.

Recent years have witnessed a growing number of works on handover in satellite networks. Related researches have been carried out from multiple perspectives. Some scholars study handover algorithms from the perspective of load balancing [6–8]. Based on the minimum handover frequency algorithm, Liu et al. [6] outlined a load balanced satellite handover strategy, which can optimize the power allocation of the satellite and improve the system capacity. Shi et al. [7] designed a handover algorithm named as Load Balancing and Remaining Visible Time based Handover (LBRVTH) in LEO satellite network. Simulation results show that the algorithm can effectively ensure better quality of service (QoS). Dai et al. [8] proposed a multi-objective intelligent handover (MIHO) algorithm to increase balance load. This algorithm has good performance in both throughput and load balancing. With the vigorous development of artificial intelligence, relevant technologies have also been applied in the research of satellite network handover algorithms [9,10]. Considering the signal strength, the remaining service time and the number of idle channels of the candidate satellite, Miao et al. [9] described a handover algorithm for LEO mobile satellite networks based on multi-attribute decision. He et al. [10] proposed a novel satellite handover strategy based on multi-agent reinforcement learning that aims to minimize average satellite handovers. Simulation results show that the above two algorithms have outstanding performance in reducing the blocking rate of UEs. The current LEO satellite handover algorithms focus on considering satellite network parameters, and some scholars have developed a new approach based on preferences of UEs [11,12]. Wu et al. [11] proposed a handover algorithm to maximize the benefits of mobile terminals of UEs based on their preferences, which can greatly improve the call quality. Similarly, according to the known dynamic preference information, Lei et al. [12] adopted dividing the time period of different services to screen out candidate handover satellites, and used the decision matrix to select the satellite for UEs to handover to meet their requirements. In addition, for the satellite handover of massive User Terminals (UTs) in mega constellation, Zhang et al. [13] proposed an improved handover algorithm based on the existing net-work-flows (HSNF) algorithm to enhance the algorithm performance by preventing infinite loop.

Previous literature have analyzed the handover algorithm of satellite networks from multiple perspectives, but the simulation tools used cannot simulate the network in the physical world well and the evaluation indicators of network quality focus only on throughput and blocking rate of UEs. Therefore, in [14], the author built a satellite-ground integrated network using network simulator (ns-3) which performs better than other simulators. Moreover, UEs are attached to the nearest satellite and communication delay is used as the performance indicator. Simulation results show that the delay of the satellite network is larger than that of the ground network due to the longer communication link. However, this analysis is based on an ideal scenario where the occurrence of handover events will not bring additional effects such as delay, which is limited in practice.

To overcome the shortcomings of [14], this paper adopts ns-3 to build a 5G LEO satellite network, introduces handover delay for each handover event, and proposes a handover algorithm based on distance difference threshold. By setting multiple groups of handover delay and distance difference thresholds and comparing them with the minimum distance handover algorithm in [14], we explore the influence of handover delay and threshold selection on network performance.

The rest of this paper is organized as follows. Section 2 describes the model of the 5G LEO satellite network, including the role of each functional module, the description of visibility between UEs and satellite gNBs, spectrum resource allocation. Section 3 introduces the handover algorithm based on distance difference threshold in detail. Section 4 uses ns-3 to conduct network simulation, introduces the simulation platform as well as parameter configuration, and analyzes the simulation results. Finally, Sect. 5 summarizes the work of the full paper and puts forward the future work plan.

2 5G LEO Satellite Network Model

2.1 Model Description

The 5G LEO satellite network model is shown in Fig. 2.

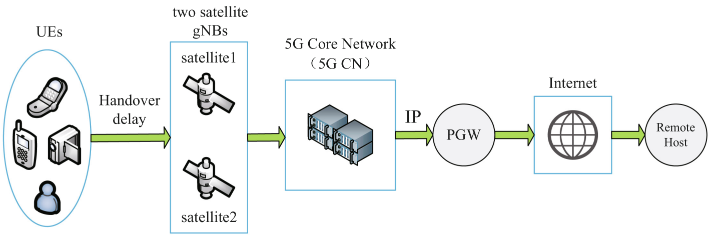

Fig. 2. 5G LEO satellite network model.

The core components are listed as follows.

- *UEs*: User devices on the ground that can access the Internet through 5G New Radio (NR) to send and receive data. In ns-3, UEs are abstracted as ground nodes.
- *gNBs*: Two satellite base stations, both of which can provide direct access to UEs. Usually, a satellite gNB receives access from many UEs. Therefore, gNBs are responsible for managing UEs, including resource allocation, scheduling and access policy management.
- *5G Core Network (CN)*: Manages all functions related to the establishment and maintenance of a 5G communications network, which may consist of one or more physical or virtual nodes connected to each other.
- *PGW*: Packet Data Network Gateway (PGW) connects the architecture to the Internet. If a UE wants to access the Internet, it must pass through the PGW entity. PGW allocates IP addresses for UEs and provides IP routing and forwarding functions. In addition, PGW has other functions, such as different billing and different policies based on users and services.

2.2 Guarantee of Visibility Between UEs and Satellites

When a UE located on the ground communicates with a satellite gNB, the visibility should be taken into account, that is, the elevation angle should not be less than a certain threshold. When the elevation angle is too small, there will be a large communication delay. Figure 3 visually shows the elevation angle between UE and satellite.

According to the law of cosines

$$(R+h)^2 = d^2 + R^2 - 2 \cdot d \cdot R \cdot \cos(90^\circ + \varepsilon), \tag{1}$$

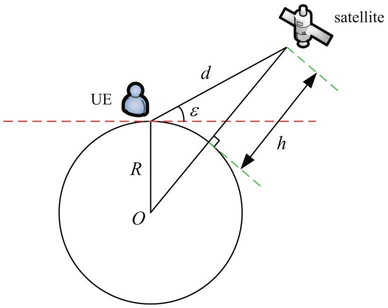

Fig. 3. Elevation diagram between UE and satellite.

where, ε is the elevation angle, R=6378km is the earth radius, h is the orbital altitude of the satellite, and d is the distance between UE and the satellite. The distance can be obtained as

$$d = -R \cdot \sin(\varepsilon) + \sqrt{R^2 \cdot \sin^2(\varepsilon) + h^2 + 2 \cdot R \cdot h}. \quad (2)$$

In the 5G LEO satellite network, the minimum elevation angle and orbital altitude are constrained, and the distance range can be calculated by Eq. (2), which can ensure the visibility between UE and satellite during simulation time.

2.3 Spectrum Resource Allocation

Band Width Part (BWP) and Component Carrier (CC) configurations are also implemented. Services of each UE may have different requirements on communication performance, and the 5G LEO satellite network can support a variety of applications with different requirements. In this paper, UE services are divided into two groups according to communication performance requirements, namely TF_0 and TF_1, and available spectrum resources are allocated to them. The available frequency band is divided into two segments for the transmission of the above two services. Both segments of spectrum are set as Time Division Duplexing (TDD) mode, and each segment only has one CC and BWP. In addition, each satellite gNB can support access to two services. Figure 4 shows the TDD based spectrum resource allocation diagram.

3 Handover Algorithm Based on Distance Difference Threshold

In non-terrestrial network with LEO satellite as gNBs, the distance between UE and satellite is changing rapidly, so UEs should handover the connection relationship with satellite gNBs effectively. The traditional handover algorithm requires each UE to be attached to the nearest satellite gNB. However, the occurrence of handover events will inevitably bring delay effects. Therefore, we

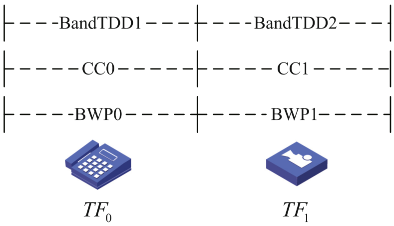

Fig. 4. Spectrum resource allocation diagram.

introduce handover delay and proposes a handover algorithm based on distance difference threshold, which replaces minimum distance handover algorithm.

The coordinates of UEs and the satellite gNBs are set in Earth-Centered Earth-Fixed (ECEF) coordinate system. The number of UEs is N, and the coordinate of UEi is (x_{ui}, y_{ui}, z_{ui}), $i = 1, 2, \cdots, N$. The number of satellites gNBs is two and the coordinate of gNBj is (x_{sj}, y_{sj}, z_{sj}), $j = 1, 2$. The positions of UEs are fixed, and the positions of satellite gNBs change with orbit. The distance from UEs to satellite gNBs can be calculated as

$$d_{ij} = \sqrt{(x_{ui} - x_{sj})^2 + (y_{ui} - y_{sj})^2 + (z_{ui} - z_{sj})^2}. \tag{3}$$

Set the simulation time as T and set the inquiry period as T_0, where $T = MT_0$. This means that handover decisions are made every T_0 for a total of M times. The moment of every decision is $t_k = kT_0$, $k = 0, 1, \cdots, M-1$.

The specific process of the algorithm is presented in Algorithm 1. At the initial time (at time t_0), each UE is attached to the nearest satellite gNB, which is also the initial condition of the algorithm. At the moment $t_k (k \neq 0)$ when the handover decision needs to be made, follow steps in Algorithm 1.

Algorithm 1: Handover algorithm at time t_k

Input: Coordinates of UEs (x_{ui}, y_{ui}, z_{ui}), Coordinates of satellite gNBs (x_{sj}, y_{sj}, z_{sj}), Distance difference threshold *thre*
Output: Connection relationship between UEs and satellite gNBs at time t_k
for i *in* $1, 2, \cdots, N$ **do**
  Calculate the distance between UEi and gNB1, which is defined as d_{i1};
  Calculate the distance between UEi and gNB2, which is defined as d_{i2};
  if UEi *is attached to* gNB1 *after the last decision (at time* t_{k-1}*)* **then**
    if $d_{i1} - d_{i2} < thre$ **then** attach UEi to gNB1**else** attach UEi to gNB2
  else
    if $d_{i2} - d_{i1} < thre$ **then** attach UEi to gNB2**else** attach UEi to gNB1
  end
end

4 Simulation and Performance Evaluation

4.1 Introduction of Simulation Platform

The work carried out in this paper is based on the ns-3 environment, which requires the use of 5G-LENA module and Satellite module. Here is a brief introduction of simulation environment and core modules.

- *ns-3*: ns-3 is a discrete network simulator that can abstract a continuous process in the physical world into a series of discrete events in the virtual world. This technology enables ns-3 to simulate various network protocols in the physical world very realistically.
- *5G-LENA module*: This module is a pluggable module of ns-3 that supports configurable Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD) modes. It can also accurately model the numerology-dependent slot and OFDM symbol granularity [15]. With the 5G-LENA module, the construction and simulation of 5G communication networks can be completed effectively.
- *Satellite module*: It is developed based on the mathematical model SGP4 [16]. By inputting the Two-Line Element (TLE) data, it can output the speed and position of satellites in ECEF coordinate system and realize the node movement according to TLE data, which can be used to simulate the satellite gNBs.

4.2 Simulation Parameter Configuration

In this network, each communication link is set as Down Link (DL), meaning that the information transmission direction is from remote Host to UEs. Considering the general value of handover delay and the orbital characteristics of satellites

Table 1. Simulation Parameter Configuration.

Simulation Parameter	Value
Number of satellite gNBs	2
Number of UEs	from 1 to 6
Satellites altitude	800 km
Orbital planes eccentricity	0
Orbital planes inclination	80°
Right ascension of ascending intersection	100°
Perigee argument	90°
Minimum elevation angle	25°
Total number of transmitted packets	1800
Packet size	1280 Byte
Simulation duration	3 s
Handover delay	2 ms; 4 ms; 6 ms
Distance difference threshold	9000 m; 11000 m; 13000 m

in this paper, we set three groups of handover delay and distance difference thresholds. Table 1 shows the simulation parameter configuration.

4.3 Results and Analysis

In order to present the superior performance of the proposed algorithm, we compare our work with the minimum distance handover algorithm in [14], which can represent the state-of-the-art.

Figure 5 shows the change of communication delay when the handover delay is 2 ms. In this case, the delay corresponding to the minimum distance handover algorithm is always the minimum. This indicates when the handover delay is small, setting a threshold can reduce the number of handovers and the extra time cost caused by handovers. However, the effect of the increasing distance between UEs and the satellite gNBs (without using the minimum distance handover algorithm) is more significant. Therefore, the handovers will not have a great impact on the network, so it is more appropriate to attach UEs to nearest satellite gNBs or set a small threshold.

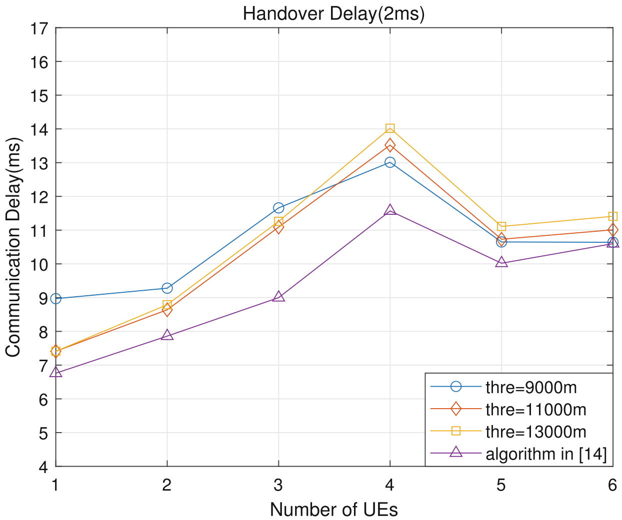

Fig. 5. Communication delay (handover delay is 2ms).

Figure 6 illustrates the change of communication delay when handover delay is 4ms. It can be observed that when the number of UEs is 1, 2, 4, and 5, the delay corresponding to the minimum distance algorithm is not the minimum. By selecting an appropriate threshold, the delay of the network can be minimized. As the handover delay increases, the occurrence of handovers will bring a more significant delay effect to the network. In contrast, the impact of the increase of communication distance will decrease. Therefore, an appropriate handover threshold should be set to reduce the number of handovers, thereby reducing the communication delay.

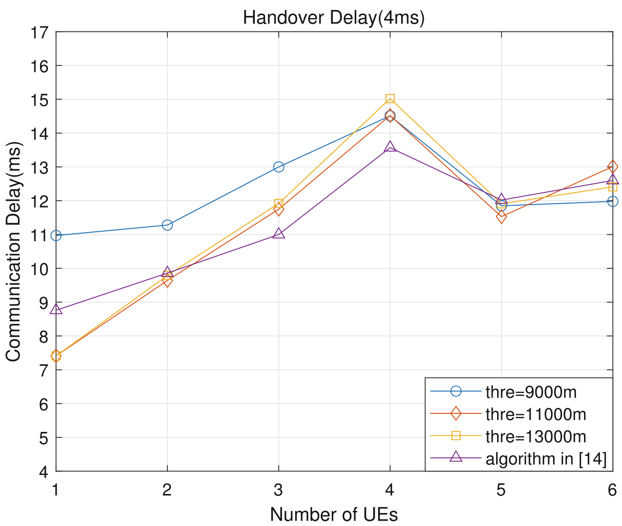

Fig. 6. Communication delay (handover delay is 4 ms).

Figure 7 presents the change of communication delay when handover delay is 6ms. For each number of UEs from 1 to 6, the delay obtained by using the mini-mum distance handover algorithm is no longer the minimum. For example, when the number of UEs is 5, the minimum delay can be obtained by setting a threshold as 11000m, which is about 2ms less than that using the minimum distance handover algorithm. In this case, the delay caused by the handovers has a more significant impact on the performance of network, while the impact of the increasing communication distance is further weakened. In extreme cases, we can even let the number of handovers approach zero to reduce the large effect on the satellite network.

Table 2 shows the number of handovers for different numbers of UEs under the set thresholds. It can be observed that the number of handovers can be

Table 2. Number of handovers for different thresholds.

Threshold	Number of Handovers					
	1UE	2UEs	3UEs	4UEs	5UEs	6UEs
9000m	1	2	2	3	3	4
11000m	0	1	1	2	2	4
13000m	0	1	1	2	2	3
Algorithm in [14]	1	2	3	4	5	6

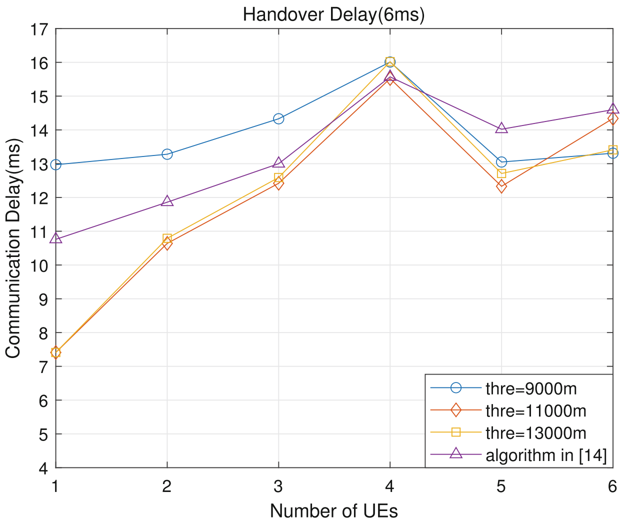

Fig. 7. Communication delay (handover delay is 6 ms).

reduced by setting a threshold and decreases with the increase of threshold, which also validates the conclusions obtained from Fig. 5, Fig. 6 and Fig. 7 well.

5 Conclusion and Future Work

In order to make the simulation more suitable for the actual scenario, this paper constructs 5G LEO satellite network based on ns-3, introduces handover delay and proposes a handover algorithm based on distance difference threshold. In addition, we consider visibility between UEs and satellite gNBs, as well as spectrum resource allocation. Simulation results indicate that when the handover delay is small, the lower distance difference threshold should be selected or the minimum distance algorithm can still be used. With the increase of handover delay, the impact caused by handover gradually increases, and the impact caused by the change of communication link distance is further weakened. In this case, the distance difference threshold should be increased to reduce the number of handover. The handover threshold should be determined based on the actual scenario and prior knowledge, which can reduce the number of handover events while ensuring that the communication distance is not too long, thereby minimizing the delay of the network.

Our future work plan is as follows. Considering the handover delay, the algorithm based only on the distance difference threshold is still not comprehensive enough. In the future, machine learning and intelligent decision-making technology will be used to optimize the handover strategy and network performance. Additionally, we will increase the number of UEs and satellite gNBs, and deploy the handover algorithm based on distance difference threshold to a larger scale 5G LEO satellite network.

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