

Enhancing Handover Efficiency in PatHO-LEO Satellite Networks through Integrated Channel Optimization Techniques

Pinaki Das¹, Dr. Debabrata Sarddar², Dr. Rajat Pandit³

University of Kalyani, Department of Computer Science & Engineering, Kalyani, India,

Email: daspinaki1985@gmail.com

University of Kalyani, Department of Computer Science & Engineering, Kalyani, India,

Email: dsarddar1@gmail.com

West Bengal State University, Department of Computer Science, Barasat, India,

Email: rajatpandit123@gmail.com

Abstract

Low Earth Orbit (LEO) satellite networks have emerged as a promising solution for providing global broadband connectivity with reduced latency and extensive coverage. However, the high orbital Speed of LEO satellites causes frequent handoffs, which may adversely affect communication continuity, utilisation of resources, and the overall network performance. The efficient management of the handover in Path-Oriented Handover for LEO (PatHO-LEO) satellite networks is critical to ensure the seamless connectivity while maintaining QoS requirements. In this paper, we propose an integrated channel optimisation framework to improve the efficiency of handover by integrating adaptive channel allocation, predictive handover decision mechanisms and dynamic channel quality assessment. The proposed approach leverages real-time channel state information, satellite trajectory prediction and traffic-aware resource management to proactively detect the optimal handover opportunities and allocate communication resources efficiently. The framework anticipates link degradation and network congestion to reduce unnecessary handovers, signalling overhead and improve channel utilisation. The performance of the proposed scheme is evaluated via extensive simulations under different traffic load and mobility conditions. The results show significant improvements in handover success rate, throughput, and channel utilisation while reducing handover latency, packet loss, and end-to-end delay compared with conventional handover methods. The results show that the predictive mobility management in combination with channel-aware resource optimisation can significantly improve the reliability and efficiency of PatHO-LEO satellite networks. The proposed framework offers an efficient solution to support next generation satellite communication services such as broadband Internet access, Internet of Things (IoT) applications and real-time data transfer in highly dynamic network environments.

Keywords: Low Earth Orbit (LEO) satellites, PatHO-LEO, handover management, channel optimization, adaptive channel allocation, predictive handover, resource management, quality of service (QoS), satellite communications

I. Introduction

The cost implications of Mobile communication within wireless communication systems have been the subject of huge research studies. The primary objective of these works is to evaluate the costs associated with signalling overhead, registration processes, and transition procedures. Various optimization technique have been proposed to resolve these challenges but with the objective of reducing the overall operational cost

associated with mobility management and improving protocol efficiency [1, 2].

Here we briefly explain some cause for increasing of handover cost:

I. The 'Home Agent Handover (HH-MIP)' makes the idea of a 'Temporary Home Agent (THA)' that is closer to the mobile node that makes a more real [1]. This solution reduces latency and signalling overhead by minimizing the distance between registration and

handover. This technique improves the overall efficiency of mobility management in Mobile networks.

II. Mobile communication with Route Optimization tries to make the routing path between the Correspondent

Node (CN) and the Mobile Nodes are minimized, which makes speeds up data transmission. However, this method may cause more signalling overhead because it requires more messages to keep optimum routing paths [1].

III. The Location Manager method keeps track of the mobile node's past IP addresses, mobility location and compares them to its current address. This comparison helps figure out the location, if a location update is needed, which cuts down on unnecessary reregistration's and signalling overhead [2].

IV. The context-dependent coordination approach makes it possible to use specific coordination strategies. This means the mobility management process can change based on where the mobile node is and what it is going. This technique can make the registration process more efficient and minimized the amount of signalling needed [3].

V. In Mobile IP, the signalling overhead is mostly made up of messages sent back process and finds agent discovery, registration and handover. These signalling actions are necessary for keeping connections smooth, but they can increase the total cost of communication and uses of channel [4].

VI. To optimize the paging strategies ensuring to finding idle mobile nodes quickly and easily. Which is minimized the cost of paging operations. These technique help to make mobility management more efficient and cost-effective by reducing unused signalling and narrowing the search area [5].

VII. 1.7. The adaptive handover approaches change the handover method in real time based on how the network is working and when the nodes are moving. This adaptive method cuts down maximum signalling and makes handovers more efficient to keeps service going [6].

And to reach everyone in the world, different types of satellite networks are designed to cooperate with

terrestrial networks. A LEO satellite orbits the earth approximately every 100 minutes so ground based equipment can only view a satellite for a couple of minutes at a time [7]. That means if a conversation goes on too long, the system has to switch from one satellite to another to keep the connection going.

1.1. LEO satellite Pros and Cons

a) Pros

I. Low Latency: The LEO satellites orbit closer to the Earth for these cause there is very low latency when they sending data or receiving data. This makes them very useful to necessitate real-time communication for video calls, voice calls and online games [8].

II. High-Speed Connectivity: The LEO satellite are closer to customers, they can provide stronger signals and faster data communication rates, which makes broadband connection more reliable [8].

b) Cons

I. Short Visibility Time: Each satellite can stable to one place for a few minutes, hence the satellite to satellite handovers are needed often to keep the link stable [9].

II. Limited Coverage Area per Satellite: Each LEO satellite only covers a tiny part of the Earth at a time because of smaller foot print, so more satellites are needed to keep coverage going all the time [9].

PatHO-LEO means "Satellite Mobility Pattern Based Handover Management in LEO" Satellite. This is a method of handover management that was developed specifically for low Earth orbit (LEO) satellite communication systems which of its unique characteristics. The mobility patterns of both satellites and user terminals or Mobile Node (MN), it intends to minimize the amount of traffic that is associated with handovers. One of the most important parts of this strategy is the Billboard Manager, which is a centralized server that is responsible for maintaining and updating the position information of MN and satellites. Through the dynamic position data, PatHO-LEO is able to facilitate handover decisions that are both more efficient and adaptable, hence contributing to the preservation of seamless connectivity in highly mobile situations [10].

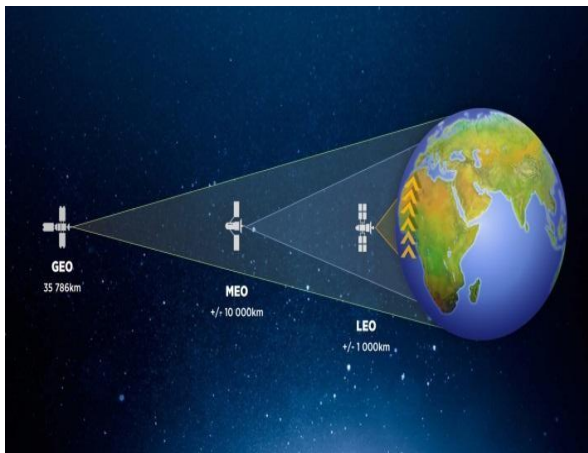


Fig 1: Orbital altitude and coverage areas.

2. Related work:

At the initiation of a handover, the Mobile Node (MN) registers itself with the help of Foreign Agent (FA) and waits for a channel to be assigned. It also updates its position in the Home

Agent (HA) directory at the same time. The Home Agent (HA) received incoming data packets and sends them to the Foreign Agent (FA) for delivery. The FA takes the packages and decapsulate it and then sends them to the MN.

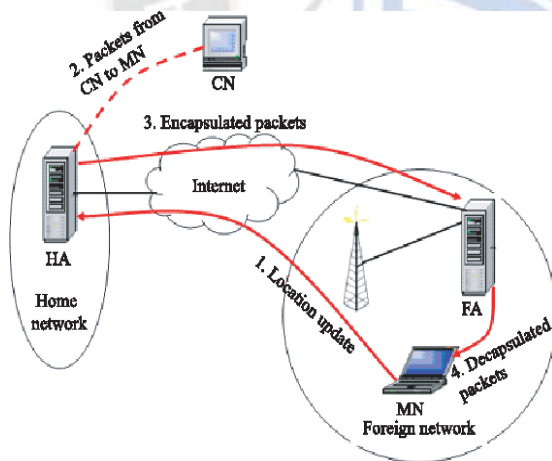


Fig 2: Handover Flow of Mobile IP

Pattern-based handover management is a grate technique for cut down too many messages. In this method, satellites first sign up with the Base Manager (BM). The Mobile Node (MN) then signs up with the BM and ready to construct a table of Satellite and

User Mobility Patterns (SMUP). After that SMUP table set up is completed, the Correspondent Node (CN) connects to the BM. Then BM helps to CN for sending data packets to the MN.

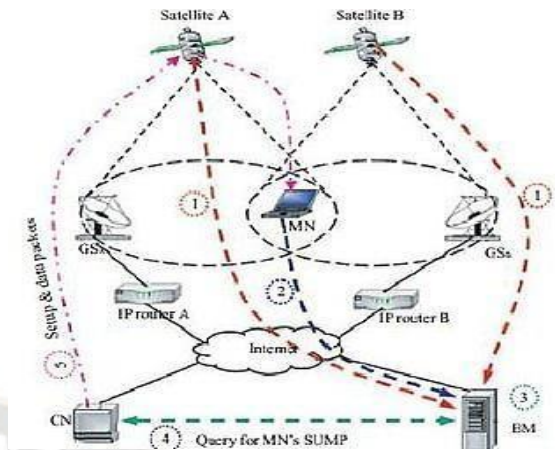


Fig 3: Handover scenario in PatHO-LEO

The Base Manager (BM) is the first place satellites go to register. After that, the Mobile Node (MN) sign up with the BM and helps create the Satellite and “User Mobility Pattern (SMUP) table”. After this is set up, the Correspondent Node (CN) connects to the BM, and data packets are transferred from the CN to the MN. The cost of managing handovers for the PatHO-LEO protocol is looked at and compared to the cost of managing handovers for Mobile IP in paper [11]. In [12], you can see a more complete set of simulation results that provide you more information about how well PatHO-LEO works. The total overhead of handover management primarily comprises the expenses incurred from binding updates and data transmission throughout the process. This cost is calculated as the product of the size of the control message (M) and the number of hops (H) it traversed in the network. This cost assessment is given in a formal mathematical form in Equation (1)..

The Cost of MIP is

$$\text{Cost} = M \cdot H$$

(1)

$$C_{MIP}(t) = M \cdot H_{MN,LD} \cdot R_{HO}(t)$$

..... (2)

The Cost of PatHO-LEO is

$$C_{PatHO-LEO}(t) = [M \cdot H_{MN,LD} + (H_{AR,AR} \cdot R_{HO}(t) \cdot \alpha)] +$$

$$[(M \cdot H_{AR,AR} \cdot (S - 1) + M \cdot S) \cdot n(t) \cdot (1 - \alpha) \cdot \lambda]$$

..... (3) The population of mobile nodes (MNs) within a given coverage area at any specific time ‘t’ is denoted by ‘n(t)’.

The parameter α represents the proportion of active mobile nodes (MNs) relative to the total MN population. Number of hops between two neighbor satellites = $H_{AR,AR}$

Single-beam satellites serving a single paging area = S
Rate of new connections to an MN = λ

$$R_{HO}(t) = V_{sat} \cdot L_{sat} \cdot \int_{V_{sat}(t-\Delta t)}^{V_{sat}} D V_{sat}(t) dt$$

..... (4)

Let V_{sat} and L_{sat} signify the satellite ground speed.

The mathematical expression for the paging frequency is ' $n(t)(1 - \alpha)\lambda$ '. In this process the initiating satellite sends a paging query to the (S-1) neighbouring satellites. This distribution. This is either the cost to compute or send this distribution ' $M \cdot H_{AR,AR}(S$

$- 1)$ '. Where ' M ' represents the control packet size and ' $H_{AR,AR}$ ' is the number of hop between two close satellites. Each neighbouring satellite receives the question and sends the paging message to all mobile nodes (MNs) in its coverage area. In this

In our proposed work, we introduce a novel channel enhancement technique for LEO satellite systems. Let N_{prev} represent the number of existing (previous) channels, and N_{new}

So the new cost is after enhancing the channel is

$$N_{incr} = \frac{((N + 1) \cdot W \cdot N)}{2A}$$

..... (5)

way, the paging message can reach the destination node regardless of its location.

3. Proposed Work:

In another work, the number of channels was increased and the guard bands between them were reduced with the same safety ratio [13]. Here " A " is the area covered by the satellite. " W " is the total bandwidth. " N " is the number of useful channels that can be used in that bandwidth.

$$N_{New} = N_{prev} + \frac{((N_{prev} + 1) \cdot W \cdot N_{prev})}{2A}$$

..... (6)

denote the number of newly added enhanced channels. Accordingly, the total number of available channels in the enhanced system can be expressed as:

$$C_{PatHO-LEO-New}(t) = \frac{C_{PatHO-LEO} \cdot N_{prev}}{N_{New}}$$

..... (7)

The Cost of PatHO-LEO is

$$C_{PatHO-LEO}(t) = [M \cdot H_{MN,LD} + (H_{AR,AR} \cdot R_{HO}(t) \cdot \alpha)] + [(M \cdot H_{AR,AR} \cdot (S - 1) + M \cdot S) \cdot n(t) \cdot (1 - \alpha) \cdot \lambda]$$

..... (8)

When more channels are available, the total handover cost can be reduced by a large margin. The greater the channel capacity the better the distribution of resources and the less the handover time and less the risk of dropping a call or interrupting a service. This leads to better performance of the system and a great reduction in the cost of operating the system.

4. Result:

The integration of the proposed channel enhancement technique leads to a substantial reduction in handover management costs within the PatHO-LEO protocol. These improvements in performance and cost efficiency were validated through simulations carried out using MATLAB 2018.

4.1. Handover Cost vs. Number of Mobile Node

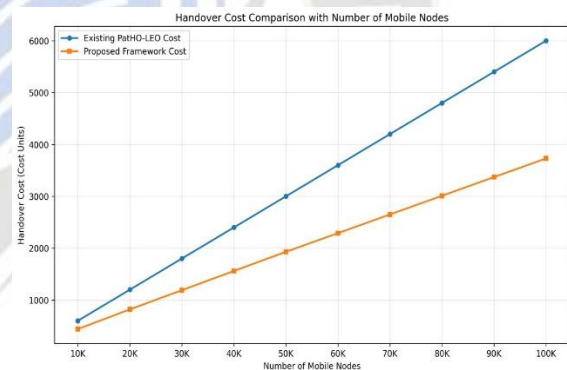


Fig 4: Handover Cost of existing and New PatHO-LEO vs. Number of Mobile Nodes

The comparison performance analysis of Handover Cost for different number of mobile nodes (10K to 100K) shows (Figure 4) that the overhead for both approaches increases linearly as the scale of network grows. However, the Proposed Framework outperforms the Existing PatHO-LEO model at all tested densities. However, for a lower density of 10K nodes, the proposed solution achieves a handover cost of 450 units compared to 600 units for PatHO-LEO. As the network scales to 50K nodes, the proposed framework cost is much lower than the existing approach (under 2000 units vs 3000 units). The gain is even more pronounced at 100,000 nodes, where the proposed model reaches a maximum of around 3,750 units and PatHO-LEO jumps to 6,000 units. The performance gap has widened which shows that the

proposed framework is efficient in reducing the signalling overhead and improving the scalability and efficiency. Hence, it is suitable for high-density mobile satellite communication networks for these reasons.

4.2. Handover Delay vs Number of Channels

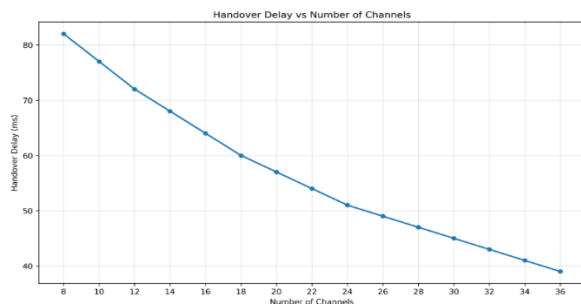


Fig 5: Variation of handover delay with the number of available channels in the proposed framework.

The number of available channel resources has a clear negative correlation with the time taken by the system to switch over (Figure 5). The handover delay decreases from ~ 82 ms to 39 ms when the number of channels increases from 8 to 36. This is a significant improvement of ~ 52%. With only 8 channels, there's a lot of competition for resources, and long wait times. More channels quickly clears up this congestion. The largest latency reduction is between 8 and 20 channels, after which the rate of reduction slows down more gradually after 24 channels. Ultimately, reaching the maximum capacity of 36 channels provides optimal resource availability and minimal signaling backlogs to ensure fast, efficient handovers.

4.3. Throughput vs Traffic Load

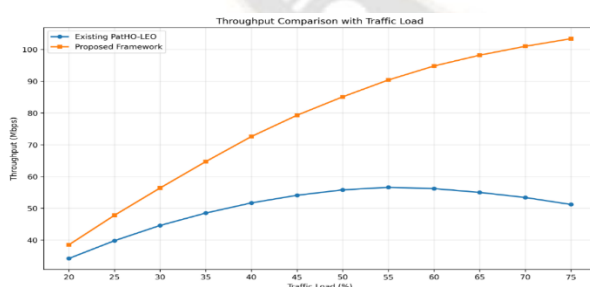


Fig 6: Comparison of existing and proposed throughput under varying traffic load conditions.

The graph (Figure 6) shows that the proposed framework always outperforms the existing PatHO-LEO method in terms of throughput for all traffic-load levels. The proposed throughput increases from 38.5 Mbps at 20% to 103.4 Mbps at 75% with

increasing traffic load. Whereas, the existing method reaches only about 56.7 Mbps at 55% and then decreases gradually. The better performance means the channels are being used better, and traffic is being handled better, when there is a lot of traffic. The proposed framework achieves much higher throughput and better network scalability than the existing work.

4.4. Handover Success Rate vs Mobility

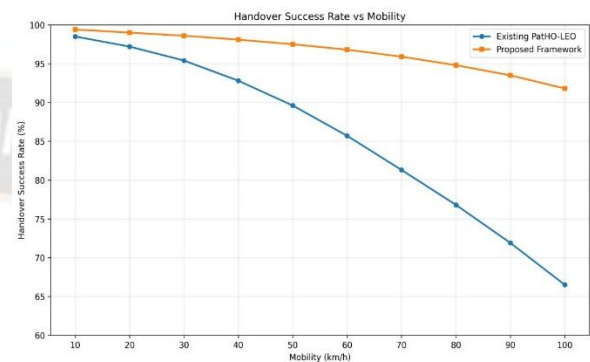


Fig 7: Comparison of handover success rate under varying mobile-node mobility.

The graph (Figure 7) shows a decrease in the success rate of handover with the increase of mobility in both approaches. The success rate of the proposed framework is higher with the range of 99.4% to 91.8% at 10 km/h and 100 km/h respectively. While the success rate of the existing PatHO-LEO is 98.5% and 66.5%. The performance gap increases with the mobility level, which means that the system can better support fast mobile-node movement. From the results, the proposed framework achieves a 25.3% higher handover success rate than the current method at 100 km/h. The outcomes show that the new framework provides more credible handoffs in the presence of a lot of movement.

5. Comparison Dataset for New PatHO-LEO Framework

Mobile Nodes	PatHO-LEO Channels	New Channels	Existing Handoff Cost	New Handoff Cost	Existing Delay (ms)	New Delay (ms)	New Success (%)
20	8	12	168	126	58	42	100.0
40	8	14	336	238	65	48	97.2
60	8	16	360	278	73	53	98.1
80	8	20	480	326	82	58	98.6

100	8	24	600	389	94	64	96.7
120	8	28	720	446	107	72	95.4
140	8	32	840	502	121	81	94.8
160	8	36	960	558	135	89	93.8

6. Conclusion:

The results indicate that the PatHO-LEO protocol with the increased channel capacity results in much more efficient handovers in LEO satellite networks. The proposed method improves channel availability and optimises resource use, which reduces handover delays, signalling overheads and overall management costs. The simulation results demonstrate the efficiency of the approach and thereby verify it as a cost-effective and scalable option for future satellite communication systems.

Reference:

1. Jeng-Yueng Chen, Chun-Chuan Yang & Li-Sheng Yu, "HH-MIP: An Enhancement of Mobile IP by Home Agent Handover", Article number: 653838 (2010), Published: 26 April 2010.
2. Debabrata sarddar, Dipsikha Ganguly, Soumya Das, Suman Kumar Sikdar, Sougata Chakraborty, Kunal Hui, Shabnam Bandyopadhyay, Kalyan Kumar Das, Sujoy Palit, "Cost Analysis of Mobile IP for the Repetitive IP Stations during a Short Period of Time", International Journal of Computer Applications, ISSN: 0975 – 8887, Volume 45– No.19, May 2012
3. Ning Zhang, "Study Of Mobile Technology in Wireless Communication System.", January, 2008, <https://doi.org/10.1049/cp:20080925>
4. Mohammad Al mojamad, "Integrating IP Mobility Management Protocols and MANET: A Survey", future internet, 3 September 2020, <https://doi.org/10.3390/fi12090150>
5. Xiaowei Zhang, Javier Gomez Castellanos, Andrew T Campbell, "P-MIP: paging extensions for mobile IP.", Mobile Networks and Applications, Volume 7, Issue 2, Pages 127–141, <https://doi.org/10.1023/A:1013774805067>, 0 April 2002
6. Tin-Yu Wu, Ching-Yang Huang, Han-Chieh Chao, "A Network environments", Ad Hoc Networks, Volume 3, Issue 3, May 2005, Pages 351-370, <https://doi.org/10.1016/j.adhoc.2003.09.011>
7. J. T. Malinen and C.Williams, "Micromobility taxonomy", Internet Draft, IETF, Nov. 2001
8. P. Bhagwat, C. Perkins, and S. Tripathi, "Network layer mobility: An architecture and survey", IEEE Pers. Commun., vol. 3, no. 3, pp. 54–64, June1996.
9. Endler, M., Nagamuta, V. "General approaches for implementing seamless handover", Proceedings of the second ACM international workshop on Principles of mobile computing, p.17-24, 2002.
10. Aysegül Tiysiiz; Fatih Alagöz, "Satellite mobility pattern scheme for central and seamless handover management in LEO satellite networks", Journal of Communications and Networks., Volume: 8, Issue: 4, December 2006, pp. 451 – 460, DOI:10.1109/JCN.2006.6182793, ISSN: 1229-2370
11. T"uys"uz and F. Alag"oz, "Satellite mobility pattern based handover management algorithm in LEO satellites", in Proc. IEEE ICC 2006, Istanbul,Turkey, June 2006.
12. Ays,eg"ul T"uys"uz and Fatih Alag"oz, "Satellite Mobility Pattern Scheme for central and Seamless Handover Management in LEO Satellite Networks", JOURNAL OF COMMUNICATIONS AND NETWORKS, VOL. 8, NO. 4, DECEMBER 2006.
13. Dr. Debabrata Sarddar, Utpal Ghosh, Rajat Pandit, "Increasing The Number of Channel of cell by reducing Bandwidth of Guard Band", Journal of Emerging Technologies and Innovative Research (JETIR) www.jetir.org, volume-6, issue-3, pp. 801-812, ISSN NO: 2349-5162, March 2019