

Integration of Channel Enhancement Techniques for Cost-Optimized Handover in PatHO-LEO Satellite Networks

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Abstract— This paper presents an enhanced handover management strategy for Low Earth Orbit (LEO) satellite networks using the PatHO-LEO protocol integrated with channel enhancement techniques. The goal is to cut handover costs and optimize mobility management. The proposed method incorporates the concept of dynamic channel allocation by increasing the number of available channels and reducing guard bands, ensuring optimal bandwidth utilization without compromising safety margins. Additionally, a pattern-based handover approach using a Satellite is employed to minimize signalling overhead. Simulation results validate the performance benefits of the proposed method, showing significant reductions in handover delay and cost, confirming its scalability and applicability for future satellite communication systems.

Index Terms— LEO satellite, PatHO-LEO, Channel Enhancement, Handover Management, Mobility Pattern, Signalling Cost, Mobile IP, Satellite Communication.

I. INTRODUCTION

Numerous research studies have investigated the cost implications of Mobile IP within wireless communication systems. These works primarily focus on analysing the expenses related to handover procedures, registration processes, and signalling overhead. To address these challenges, various optimization strategies have been proposed, aiming to enhance protocol efficiency and minimize the overall operational cost associated with mobility management [1][2]

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

- The Home Agent Handover (HH-MIP) make the concept of a Temporary Home Agent (THA) located in closer proximity to the mobile node [1]. By reducing the registration and handover distance, this method effectively minimizes latency and signalling overhead, thereby enhancing the overall efficiency of mobility management in Mobile IP networks.
- Mobile IP with Route Optimization seeks to shorten the routing path between the Correspondent Node and the Mobile Node, thereby improving data transmission efficiency. However, this approach may lead to an increase in signalling overhead due to the additional messages required to maintain optimized routing paths [1].

- The Location Manager approach maintains a record of the mobile node's previous IP addresses and compares them with its current address. This comparison helps determine whether a location update is necessary, thereby reducing redundant registrations and minimizing signalling overhead [2].
- The Context-dependent coordination approach enables the application of site-specific coordination policies, allowing the mobility management process to adapt based on the mobile node's location and operational context. This flexibility can lead to more efficient registration procedures and reduced signalling overhead [3].
- In Mobile IP, signalling overhead primarily consists of messages exchanged during agent discovery, registration, and handover processes. These signalling activities are essential for maintaining seamless connectivity but can contribute significantly to the overall communication cost [4].
- Optimized paging techniques focus on efficiently locating idle mobile nodes, thereby reducing the cost associated with paging operations. By minimizing unnecessary signalling and limiting the search area, these methods contribute to more effective and resource-efficient mobility management [5].
- Adaptive handover techniques dynamically adjust handover parameters in response to real-time network conditions and the mobility patterns of nodes. This adaptive approach helps to reduce unnecessary signalling, enhance handover efficiency, and maintain service continuity [6].

To achieve global coverage, heterogeneous satellite communication networks are designed to operate alongside terrestrial networks. A typical LEO satellite completes an orbit around the Earth in approximately 100 minutes, which results in any given satellite being visible to ground-based equipment for only a few minutes at a time [7]. Consequently, if a communication session exceeds this brief window, the system must perform a handover from one satellite to another to maintain continuous transmission.

A. LEO satellite Pros and Cons

Pros

Low Latency: LEO satellites orbit close to the Earth, which significantly reduces the delay in data transmission. This makes them well-suited for applications that need real-time communication, such as video calls and online gaming [8].

High-Speed Connectivity: Their shorter distance from users allows for stronger signals and faster data rates, enabling reliable broadband access [8].

Cons

Short Visibility Time: Each satellite is only in view of a specific location for a few minutes, requiring frequent handovers to maintain a stable connection [9].

Limited Coverage Area per Satellite: Each LEO satellite covers a small portion of the Earth at any time, so more satellites are needed to ensure continuous coverage [9].

PatHO-LEO, or Satellite Mobility Pattern-Based Handover Management in LEO Satellites, is a handover management technique designed specifically for low Earth orbit (LEO) satellite communication systems. It aims to reduce handover-related traffic by taking into account the mobility patterns of both satellites and user terminals. At the core of this approach is the Billboard Manager, a centralized server that maintains and updates the location information of satellites and users. By leveraging this dynamic location data, PatHO-LEO enables more efficient and flexible handover decisions, helping to maintain seamless connectivity in highly mobile environments [10].

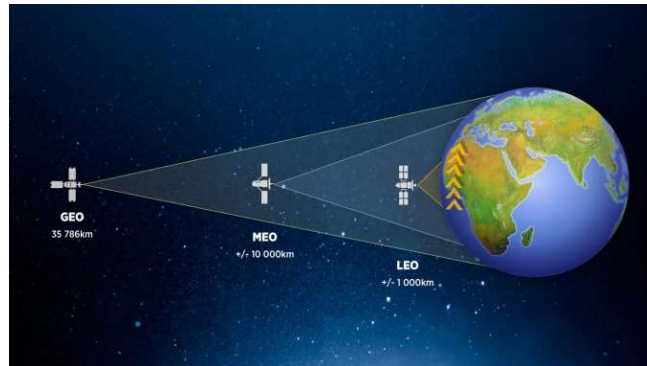


Fig 1: Orbital altitude and coverage areas.

II. LITERATURE REVIEW

When a handover begins, the Mobile Node (MN) registers itself with the Foreign Agent (FA) and waits for channel allocation. At the same time, it updates its location in the Home Agent (HA) directory. The Home Agent (HA) encapsulates incoming data packets and forwards them to the Foreign Agent (FA) for delivery. The FA encapsulates these packets and delivers them to the MN.

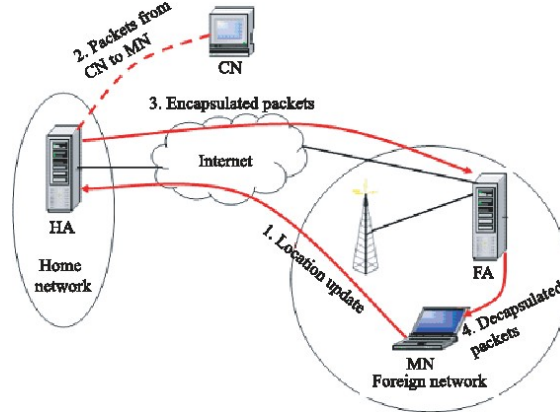


Fig 2: Handover Flow of Mobile IP

Pattern-based handover management is a useful way to reduce excessive messaging traffic. In this approach, satellites first register with the Base Manager (BM). The Mobile Node (MN) then registers with the BM and assists in creating a Satellite and User Mobility Pattern (SMUP) table. Once the SMUP table is established, the Correspondent Node (CN) connects to the BM, which then facilitates the delivery of data packets from the CN to the MN.

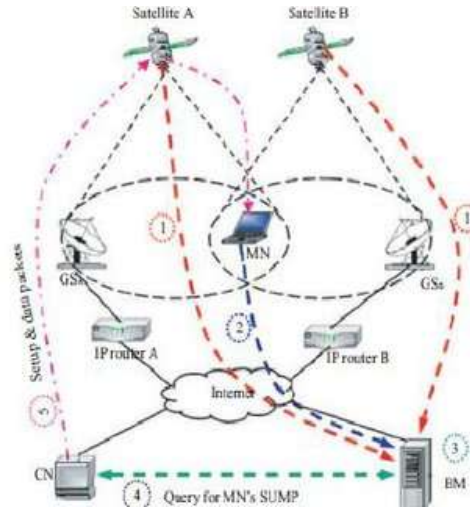


Fig 3: Handover scenario in PatHO-LEO

Satellites first register with the Base Manager (BM). After that, the Mobile Node (MN) registers with the BM and helps create the Satellite and User Mobility Pattern (SMUP) table. Once this is set up, the Correspondent Node (CN) connects to the BM, and data packets are then sent from the CN to the MN.

In paper [11], the handover management cost of the PatHO-LEO protocol is analyzed and compared with that of Mobile IP. A more detailed set of simulation results is presented in [12], providing further insights into the performance of PatHO-LEO. The handover management cost primarily includes the cost of binding updates and data delivery during the handover process. This cost is calculated by multiplying the size of the control message, denoted as M , by the number of hops, H , required to deliver the message across the network. The cost evaluation is formally defined by Equation (1).

$$\text{Cost} = M.H \quad (1)$$

The Cost of MIP is

$$C_{MIP}(t) = M.H_{MN,LD}.R_{HO}(t) \quad (2)$$

The Cost of PatHO-LEO is

$$C_{PatHO-LEO}(t) = [M.H_{MN,LD} + (H_{AR,AR}.R_{HO}(t).\alpha)] + [(M.H_{AR,AR}.(S-1) + M.S).n(t).(1-\alpha).\lambda] \quad (3)$$

$n(t)$ = the total number of MNs per coverage area at time t

α = the ratio active MNs to the total number of MNs.

$H_{AR,AR}$ = the number of hops between two adjacent satellites

S = the number of single-beam satellites that cover a single paging area.

λ = The rate of new connections to a MN.

$$R_{HO}(t) = V_{sat}.L_{sat} \cdot \int_{V_{sat}(t-\Delta t)}^{V_{sat}} DIV_{sat}(t)dt \quad (4)$$

Where V_{sat} and L_{sat} denote the ground speed of satellite

The expression $n(t)(1-\alpha)\lambda$ represents the rate at which paging occurs. In this process, a satellite must send a paging request to its $(S-1)$ neighboring satellites. The associated cost of sending these requests is given by $M.H_{AR,AR}(S-1)$, where M is the size of the control message and $H_{AR,AR}$ is the number of hops between adjacent satellites. Once the request is received, each satellite broadcasts the paging message to all mobile nodes (MNs) located within its coverage area, ensuring that the intended recipient can be reached regardless of its exact position within that region.

III. METHODOLOGY

In another study, the number of channels was increased while the guard bands between them were reduced; ensuring that the safety ratio was still maintained [13]. In this context, ‘A’ represents the area covered by the satellite footprint, ‘W’ denotes the total bandwidth, and ‘N’ refers to the number of effective channels available within that bandwidth

$$N_{incr} = \frac{((N+1).W.N)}{2A} \quad (5)$$

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

$$N_{New} = N_{prev} + \frac{((N_{prev}+1).W.N_{prev})}{2A} \quad (6)$$

So the new cost is after enhancing the channel is

$$C_{PatHO-LEO-New}(t) = \frac{C_{PatHO-LEO}.N_{prev}}{N_{New}} \quad (7)$$

The Cost of PatHO-LEO is

$$C_{PatHO-LEO}(t) = [M.H_{MN,LD} + (H_{AR,AR}.R_{HO}(t).\alpha)] + [(M.H_{AR,AR}.(S-1) + M.S).n(t).(1-\alpha).\lambda] \quad (8)$$

The overall handover management cost is significantly reduced by increasing the number of available channels. The enhanced channel capacity enables more efficient allocation of resources, reduces handover delays, and lowers the likelihood of call drops or service interruptions. As a result, the system achieves improved performance and a notable reduction in operational costs.

IV. 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

A. PatHO-LEO New cost

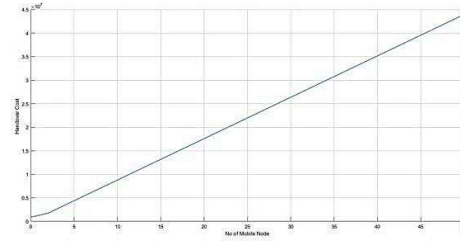


Fig 4: Handover Management Cost Vs. Mobile node when increase the no of channel

Fig 4 illustrates the handover management cost in the PatHO-LEO protocol. The results indicate that as the number of mobile nodes increases, the cost rises gradually. This trend highlights potential scalability challenges, particularly in terms of channel availability and efficient resource allocation under high-traffic conditions

B. Handover cost reduction of PatHO-LEO Cost with increase the no of channel

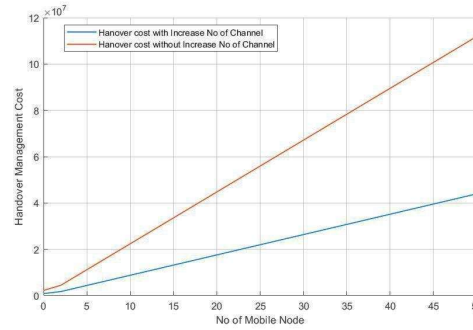


Fig 5: Handover Cost between old PatHO-LEO vs. Increased Channel PatHO-LEO.

Fig 5 shows that the handover management cost in the original PatHO-LEO protocol is significantly higher than in the scenario where the number of channels is increased. This comparison clearly highlights the effectiveness of the channel enhancement technique in reducing overall handover costs within the same protocol framework

V. CONCLUSION

This study demonstrates that enhancing channel capacity within the PatHO-LEO protocol significantly improves handover efficiency in LEO satellite networks. By increasing the number of available channels and optimizing resource allocation, the proposed approach effectively reduces handover delays, signalling overhead and overall management costs. Simulation results validate the performance gains, confirming the approach as a scalable and cost-efficient solution for future satellite communication systems

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