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ORIGINAL RESEARCH ARTICLE

Improved Fast Mobile IPv6 Scheme with Optimized Distributed Signaling Utilizing Media Independent Handover and Efficient Link Layer Triggers

Aliyu Aminu Abdulhadi and Amina Nura
Department of Computer Science, Umaru Musa Yaradua University Katsina, Katsina State. Nigeria

ABSTRACT
Next-Generation Wireless Networks (NGWNs) are believed to create a diverse environment that presents various challenges, among which Mobility Management is most critical. The Mobile IPv6 for Fast Handovers (FMIPv6) protocol has been standardised by the IETF to address certain limitations of the baseline Mobile IPv6. However, handover latency in the FMIPv6 solution remains inadequate for active, real-time, and time-sensitive applications. In fact, this latency causes packet loss, leading to service disruption during the handover process. This study introduces a novel protocol called the Improved Fast Mobile IPv6 Scheme with Optimised Distributed Signalling Using Media Independent Handover and Efficient Link Layer Triggers, to enhance the DS-FMIPv6 handover. The simulation results demonstrate that the proposed scheme effectively reduces handoff latency, signalling costs, and power overheads, thereby supporting seamless handoffs more effectively. The average reduction in handover latency for audio is approximately 20.30%, and for video, approximately 19.02%. The average reduction in signalling costs for audio is approximately 27.14%, and for video, around 23.57%, while power consumption is reduced by 30%. This confirms that the Enhanced Distributed Signalling Fast Mobile IPv6 (EDSFMIPv6) significantly outperforms FMIPv6 by 16.67% and 18.52% under similar conditions.

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Handover latency, Mobility Management, FMIPv6, link-layer triggers, Media Independent Handover.

INTRODUCTION
The need for seamless mobility across diverse network environments has risen due to the growth of mobile devices and the rapid evolution of wireless networks. Although Mobile IPv6 (MIPv6) is a protocol designed to effectively manage IP mobility, packet loss, signalling overhead, and handover latency often hinder its performance. Modern high-mobility and latency-sensitive applications such as video streaming, augmented reality, and the Internet of Things make these limitations even more significant (Ahmed and Khalid, 2022). To reduce MIPv6 handover latency, various protocols have been proposed. FMIPv6, or Fast Handover in MIPv6, aims to minimise handover delays caused by movement detection, Care-of-Address (CoA) acquisition, and binding updates (BU) (Johan et al., 2012). This is achieved by obtaining subnet prefix information from the new Access Router (nAR) while the mobile node (MN) is still connected to its old Access Router (oAR) and using anticipation-based Layer 2 (L2) trigger information. The oAR resolves the network prefix of the nAR (Alnas, et al., 2010) based on the L2 identification reported by the MN to create a new CoA for FMIPv6. The timing issue with FMIPv6's anticipation mechanism can cause the handover process to start either earlier or later than the actual handover, making the MN's movement less predictable. Additionally, sudden wireless link degradation during the handover initiation phase may cause the MN to lose contact with the oar. In such cases, the MN may not have sufficient time to configure the new CoA (NCoA) while still connected to the oAR's link if the handover anticipation time is too long. Consequently, this can lead to extended handover durations.

Timely link-layer triggers and the Media Independent Handover (MIH) framework are employed in the Enhanced Distributed Signalling Fast Mobile IPv6 (ED-FMIPv6) method to address these challenges. The IEEE 802.21-standardised MIH provides unified interfaces and real-time link-layer condition information, supporting mobility across different network types. Prompt link-layer triggers enhance the predictability and readiness of handovers, enabling seamless transitions while reducing packet loss and delay.

Correspondence: Aliyu Aminu Abdulhadi. Department of Computer Science, Umaru Musa Yaradua University Katsina, Katsina State. Nigeria. ✉ aliyu.abddulhadi@umyu.edu.ng.

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This study presents a new protocol called Improved Fast Mobile IPv6 Scheme with Optimized Distributed Signalling Using Media Independent Handover and Efficient Link Layer Triggers. Existing MIH-based FMIPv6 schemes still face high latency and overhead due to suboptimal signalling and prediction methods. This research addresses this by combining Media Independent Handover (MIH) and Efficient Link Layer Triggers to enhance handover decision-making and execution. Distributed signalling is employed to reduce reliance on centralised entities, thereby improving scalability. It concentrates on cross-layer optimisation (Layer 2 and Layer 3) for quicker handovers. Compared to DS-FMIPv6, the proposed scheme decreases handover delay, signalling costs, and battery consumption by 20–30%, utilising Media Independent Handover (MIH) and effective Link Layer triggers to achieve cross-layer optimisation and distributed signalling. Conversely, DS-FMIPv6 is less suitable for real-time applications in next-generation networks, as it does not incorporate MIH and relies on traditional signalling, resulting in slower handovers and increased overhead.

Fast Mobile IPv6

Fast Mobile Ipv6 was recommended as a solution to reduce service disruptions and handover delay caused by Mipv6. According to Sabelo et al., (2010), Fast Mobile IPv6's most exciting feature is its reliance on link-layer information to quickly anticipate handover events. An MN uses an L2 Trigger to exchange Router Solicitation for Proxy Advertisement (RtSolPr) and Proxy Router Advertisement (PrRtAdv) messages with the Previous Access Router (PAR) to set a new Care-of Address (nCoA) when it detects movement towards the NAR. To link its old CoA with the new CoA, the MN transmits an FBU to the PAR. Handover Initiate (HI) and Handover Acknowledgement (HAck) messages are used to create a bidirectional tunnel between the PAR and NAR to avoid routing failure (YI and Wang, 2014). After notifying the PAR of the FBU, the MN proceeds through L2 handoff procedures. Once the L2 handoff is successful, the MN uses an Unsolicited Neighbor Advertisement (UNA) message to announce its presence on the new link. Packets are then delivered to the MN by the NAR. The process for Binding Updates to the Home Agent and the Correspondent Node is the same as that for MIPv6 (Vahid, 2016). Figure 1 demonstrates the signalling of FMIPV6.

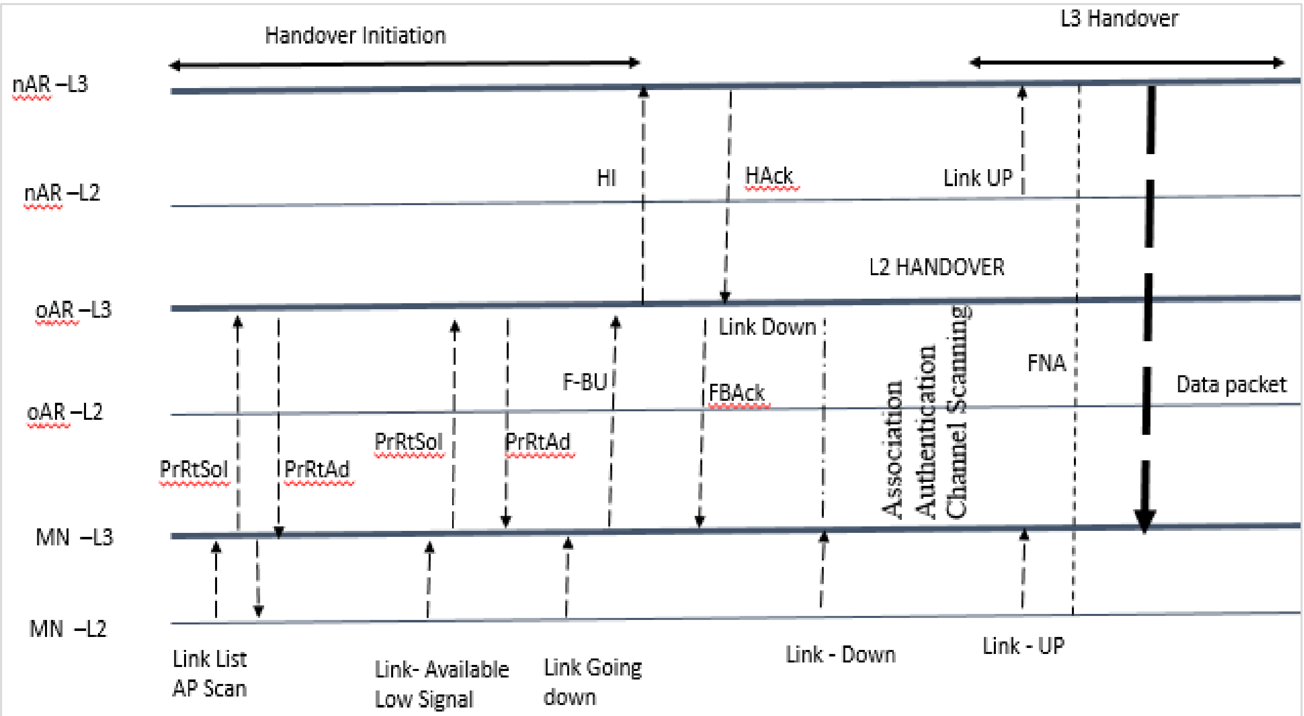

Figure 1: The FMIPv6 procedure using MIH primitive

Literature Review

To address the challenges of seamless mobility in heterogeneous networks, recent research has focused on integrating Media Independent Handover (MIH) with Fast Mobile IPv6 (FMIPv6). In these systems, handover decisions must be made quickly. Many methods have been proposed to reduce handover delays; however, issues still remain. Joe and Shin (2010) used the MIH Information Service to gather data that helps predict the target cell for the MN, enabling preparation for handover in advance. They do not consider the time impact that can lead to early handover after triggering Link Going Down. The technique also employs GPS-based data, which can be beneficial to Minnesota. Furthermore, Sabelo and Dlodlo (2010) proposed enhancing Fmipv6 performance during handover. Their technique performs significantly better than the current FMIPv6 protocol, as demonstrated by ns-2 simulation results. It significantly reduces packet loss, end-to-end delay, and handover latency. The impact of TCP retransmission, packet buffering, reordering, and redirection during or after handover has been effectively minimised by this method. Additionally, Kim (2009) introduced the pseudo-binding FMIPv6 (pFMIPv6) technique to address the challenges faced by fast-moving MNS. The mobile node receives information from the access router about nearby networks. In response, the MN generates multiple CoAs and begins pseudo Fast Binding Update (pFBU) with all neighbouring networks, even before detecting the signal of the next network. This approach greatly reduces the time deficit involved in various handover processes for a fast-moving MN.

In addition, DSFMIPv6, a novel protocol presented by Mohtasim et al., (2012), efficiently reduces handoff latency, signaling costs, and power overheads to improve support for frequent and flawless vertical handoffs. Cho et al., (2013) proposed EMIPv6 as an improved fast IP mobility management system that uses several Care-of-Addresses (CoAs) and the IEEE 802.21 Media Independent Handover (MIH) information service to lower packet loss and handover delay in vehicle networks. By expanding the IETF FMIPv6 and the MIH information service, several CoAs are prepared beforehand to lower the movement prediction error of FMIPv6, significantly lowering packet loss and handover latency. This is the key characteristic of EMIPv6. Simulation and mathematical analysis have both been used to assess performance. According to the simulation results, EMIPv6 performs better than FMIPv6 in terms of packet loss and handover delay.

The study of Pirovano et al., (2025) suggests a different strategy that integrates delay-tolerant features directly at Layer 3 by utilizing advancements in IP version 6 (IPv6) and Internet Control Message Protocol version 6 (ICMPv6). The suggested IP-compliant method improves interoperability by integrating these features into the current IPv6 framework, allowing DTN nodes to easily communicate with compliant IPv6 nodes across terrestrial networks. The capabilities of BP version 7 and IPv6 are thoroughly compared in this study, with opportunities and shortcomings highlighted. On the basis of this research, a node architecture is created to carry out the DTN functionalities, opening the door for a smoother integration of terrestrial and deep-space networks while lowering complexity and enhancing scalability.

To improve the quality of service (QoS) in vehicular networks, Banda et al., (2013) suggest a network layer handover strategy called Vehicular Fast Handovers for Mobile IPv6 (VFMIPv6). This scheme aims to reduce overhead cost impacts, packet loss issues, and handover delay. An analytical model is presented together with the system description of the suggested solution. Our suggested method performs better than the traditional solutions, according to numerical performance evaluations.

The relevant literatures reviewed necessitate the need for Enhanced Distributed Signaling Fast Mobile IPv6 (EDSFMIPv6) by utilizing 802.21 protocol with predictive link layer triggers in order to enhance handover performance in terms of signaling overhead, packet loss, and handover delay to enable a better smooth handoff.

Media Independent Handover Services

A new IEEE standard called Media Independent changeover (MIH) facilitates smooth handover between heterogeneous and homogeneous networks. Instead of implementing network handover on its own, 802.21 offers the data necessary to allow for handover in both directions across multiple network environments, such as cellular, GSM, GPRS, WiFi, and Bluetooth. Radhwan et al., (2015) use the MIH function to create the protocol's network handover enabling function. Generally, MIES is used to identify when handovers are necessary. And its offers services to the upper layer by reporting event organization and event reporting corresponding to lively variations in link features, link position, and link class. The standard specifies a number of common events, including "Link Up," "Link Down," "Link Parameters Report," "Link Going Down," and "Link Detected." Higher layers can govern the physical, data link, and logical link layers locally or remotely thanks to Media Independent Command Services (MICS). Through a series of handover commands, the higher levels manage the reconfiguration or the choice of a suitable link. The lower levels receive the decisions made at the top layer through the commands. For instance, a mobile node may be asked to switch between links using the command service. MIH_Switch, MIH_Get_Status, and other commands are defined (Sivaradje, 2014). To facilitate handovers, media independent information service (MIIS) offers an environment-associated mechanism that aid a media independent handover function (MIHF)
unit to locate and retrieve network information that is present in geographical range.

MATERIALS AND METHODS

In order to quickly forecast the potential serving network, we provide an enhanced distributed signaling Fast Mobile IPv6 (EDSFMIPv6) that makes use of predictive link layer triggers.

Descriptions of Methods

The following actions should be taken in order to implement Enhanced Distributed Signaling Fast Mobile IPv6 (EDSFMIPv6) more effectively considering reduction of signaling cost, handover latency and power consumption against Distributed Signaling Fast Mobile IPv6 (DSFMIPv6).

- The Neighbor Discovery part gathers and stores both lively and fixed network layer information.
- The Handover Trigger part acquires information from the Neighbor Discovery part and processes it based on clear prediction algorithms and inceptions that confirm suitable triggering of the handover process.

- The RSS Monitoring and Prediction, focuses on gaining lively link layer information that has an influence on handover results.
- Handover effecting part, accomplishes the command it receives from the Handover Trigger part.

Fast binding acknowledgement message (FBAck) is dropped in favor of a new message called Binding update start (BUs) for able protocol implementation. Without implementing the entire 802.21 protocol, the solution uses MIIS functionalities to discover and choose the possible network before vertical handover actually occurs. Using the MN information from the eRtSolPr message and the nearby network information from the router's stock, choosing possible network will also assist the OAR in assessing the handoff determination algorithm (HDA). After evaluating the possible new MN network, a new Care-of-Address (nCoA) is generated utilizing the link local address and network start.

Method Operation

Handover procedures in proposed improved scheme begin when MN receives an L2 signal from one of the neighboring networks. The MN then sends an enhanced proxy router solicitation message (eRtSolPr) to the pAR, describing new route field that contains information about the quality level and bandwidth available for new subnets. After receiving the eRtSolPr, the pAR evaluates the potential new network of MN and formulates a new Care-of Address (nCoA) using the new network's L2 ID. The pAR then starts the Duplicate Address Detection (DAD) to check the uniqueness of the CoA by exchanging pHI (pseudo HI) and pHAck (pseudo HAck) messages with NAR. By communicating its new CoA to MN, pAR sends ePrRtAdv message to inform MN of its apt network; once obtaining ncare of address, MN sends fast binding update message to notify old access router that it is ready to handoverto new network. Through the creation of an initially inactivated passageway between pAR and NAR, packet loss during handovers may also be minimized. Therefore, the old access router ceases sending traffic to it and starts sending packets to the NAR over the already formed passageway. The old access router also sends a Binding Update start (BsI) message to the NAR, piggybacking Context Transfer Data message to notify it new MN is nearby to joint, and initiates to start Binding Update procedure with corresponding node and home agent. The MN, temporarily, performs a scan new network and starts Layer 2 (L2) handoff, It then sends a UNA message to the NAR to indicate its existence. The Context Transfer Activate Request message is also piggybacked on the NAR, carrying permission token to validate Context Transfer's reliability. The protocol operation connecting MN is now complete and MN able to accept data packet from NAR routed through pAR. The Binding update process on NAR starts when the pHOTI message piggyback on pBUHA sent to Home agent. This enables beginning of pBU process to HA and Return routability to occur simultaneously. The Home agent forward pHOTI to CN, and the NAR responds with pBAHA message. NAR at that moment sends the pCoTI message,t responds with pHoT or pCoT message to NAR. This marks the end of the RR process. The pseudo Binding update can now be sent by NAR to Correspondent node following the completion of RR.

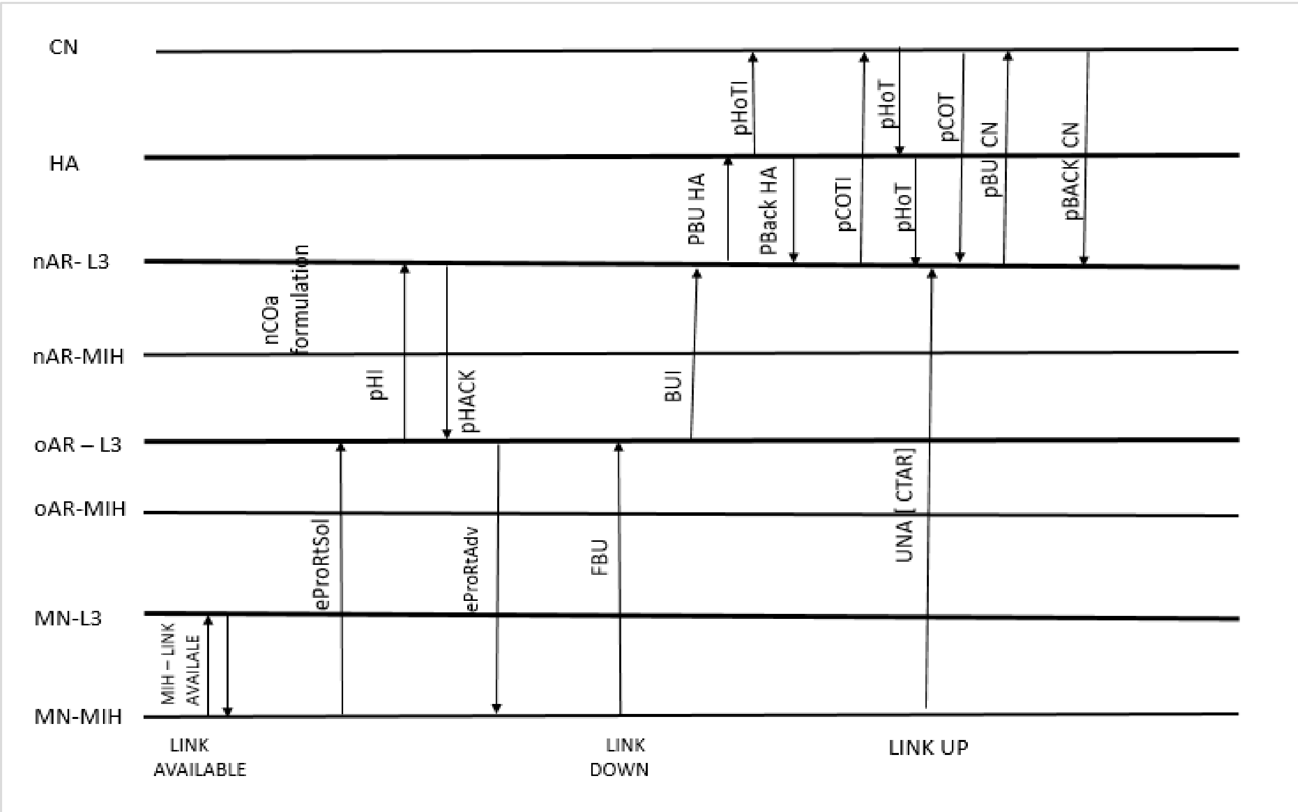

Figure 2: Signaling flow of the Proposed ED-FMIPV6

Simulation and Results

The simulation setup, which is located in a 3000 x 3000m area on the simulator platform, is made up of one WLAN and one WiMAX cell. The WiMAX and WLAN cells partially overlap. Using a data packet size of 4960/320 bytes for video and audio correspondingly, and interval between packets fixed at 0.004 s, video and audio traffic was communicated via UDP from a CN to the MN. The simulation time is set at 400 s, and MN speeds are set between 3 and 30 ms.

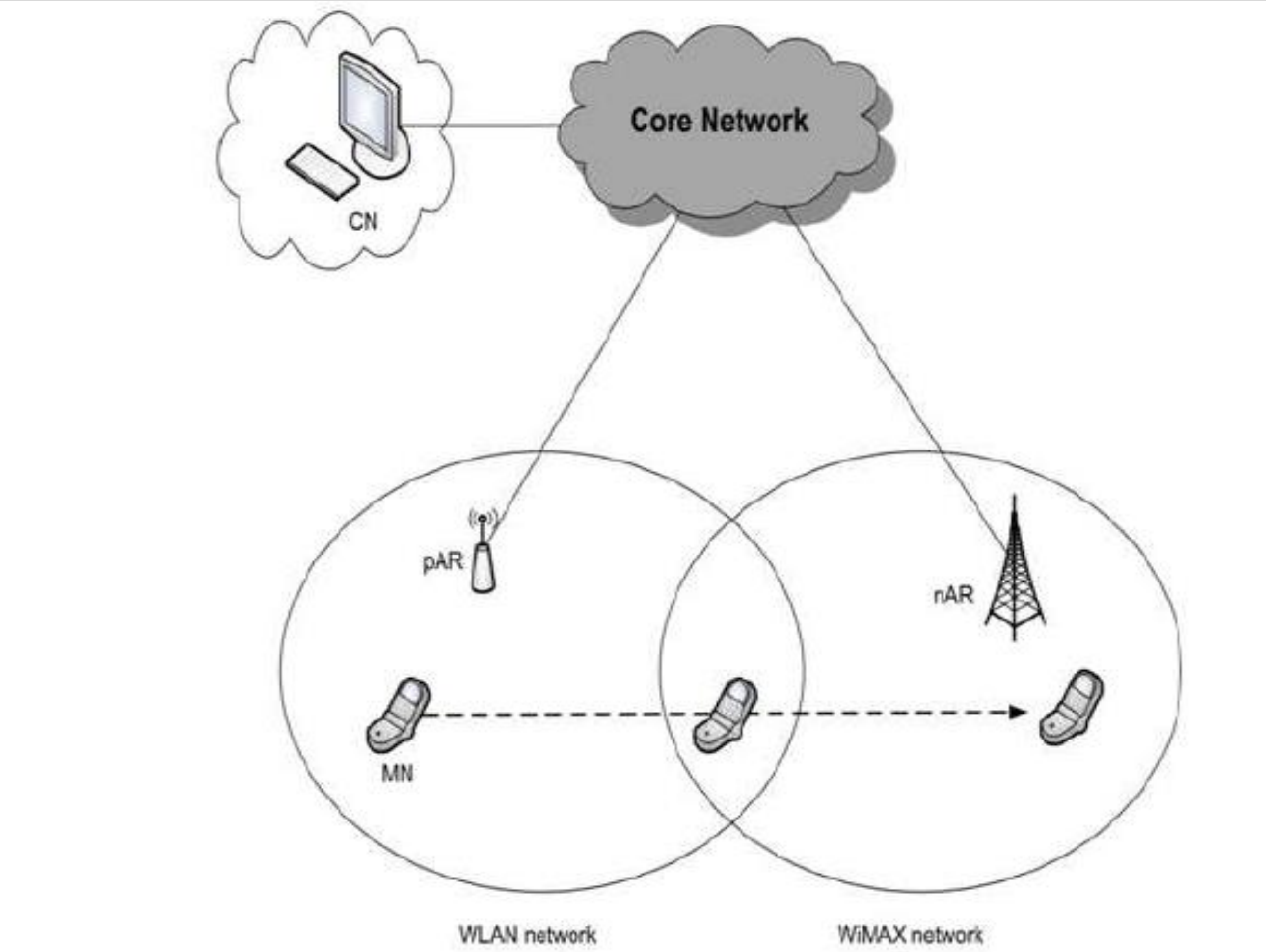

Figure 3: Network Scenario Radhwan et al., (2015).

Table 1: **Simulation setup for Handover Latency**

Parameter	Configuration
Protocols Compared	- DS-FMIPv6 (Audio & Video) - Proposed DS-FMIPv6 (Audio & Video)
Mobility Model	Mobile Node (MN) speed range: **5–30 m/s** (5, 10, 15, 20, 25, 30 m/s)
Performance Metric	Handover Delay (ms) during MN movement at varying speeds.
Traffic Types	- **Audio**: Low-latency traffic (e.g., VoIP) - **Video**: High-bandwidth traffic (e.g., streaming)

Handover latency for DS-FMIPv6 and proposed EDS-FMIPV6 is shown in Figure 4, where it is clear that employing EDS-FMIPV6 can significantly improve the handover operation. Audio and video traffic had average handover latencies of 46.29 and 41.66 seconds for DS-FMIPv6 and the proposed EDS-FMIPv6 approach, respectively, while the latter had average handover latencies of 38.57 and 33.94 seconds. The handover latency in the DS-FMIPv6 and EDS-FMIPV6 techniques will similarly grow when the MN increases the speed, even though the maximum latency at a speed of 28 ms is 70 ms / 61.6 ms and 84 ms / 75.6 s for audio and video, respectively, average reduction of handover delayfor Audio is ≈ 20.30% and that of Video is ≈ 19.02%.. The suggested EDS-FMIPv6 approach yielded superior outcomes by 16.67% and 18.52 under the identical circumstances.

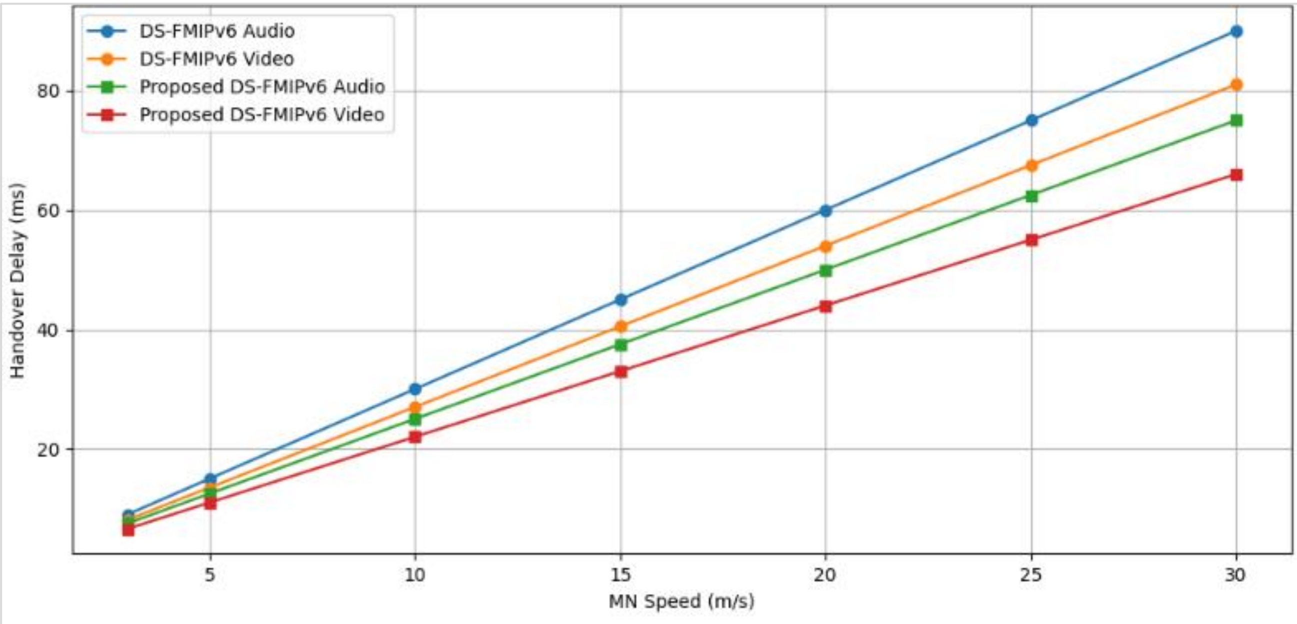

Figure 4 shows the handover latency for DS-FMIPv6 compared to the proposed EDS-FMIPV6

Table 2: **Simulation setup for packet loss**

Parameter	Configuration Details
Protocols Compared	- DS-FMIPv6 (Audio & Video) - Enhanced DS-FMIPv6 (Audio & Video)
Mobility Conditions	Mobile Node speeds: 5-30 m/s (5,10,15,20,25,30)
Performance Metric	Packet Loss Percentage (%)
Traffic Types	- Audio (VoIP-like, latency-sensitive) - Video (streaming, bandwidth-sensitive)
Measurement Range	2-12% packet loss

The DS-FMIPv6 and EDS-FMIPV6 packet loss is shown in Figure 5. A packet loss occurs when a certain number of data packets are sent from the sourc e (CN) but are not received by the destination (MN) with in a specified period of time. As demonstrated, packet loss with DS-FMIPV6 - begins at 0.4 packets at a speed of 1 ms for audio traffic a nd surpasses 10 at a speed of 25 ms for video traffic. In c ontrast, the EDS- FMIPV6 value hits 6.25 packet loss in the worst scenario. In comparison to the DS-FMIPv6, the EDS-FMIPV6 loses less packets when the MN speed rises.

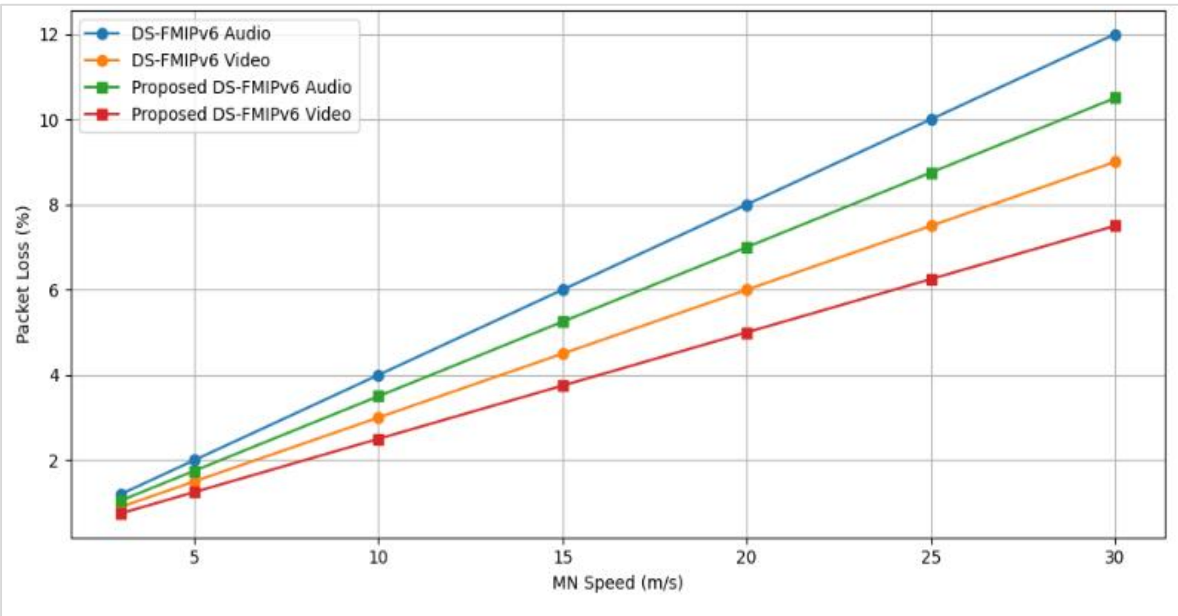

Figure 5: Packet loss for the DS-FMIPv6 and EDS-FMIPV6

Table 3 : Simulation Signaling Overhead

Parameter	Configuration Details
Protocols Tested	- DS-FMIPv6 (Audio & Video) - Enhanced DS-FMIPv6 (Audio & Video)
Mobility Conditions	Mobile Node speeds: 20, 25, 30 m/s (high mobility)
Performance Metric	Signaling Overhead (measured in Kilobytes)
Traffic Types	- Audio (VoIP-like traffic) - Video (Streaming traffic)
Measurement Range	2-10 KB signaling overhead

The average signaling overhead (in KB) at the network la yer and higher levels during handover operations is show n in Figure 6 under the overall messages signaling overhe ad. When compared to DS-FMIPv6 in the vertical mode, the proposed IDS-FMIPV6 improves DS-FMIPV6 by low signaling overhead of audio is ≈ 27.14.0% while an average reduction in video is ≈ 23.57% of traffic.

The DS-FMIPv6 and IDS-FMIPV6 power consumption is shown in Figure 7. The result shows that The **Proposed Algorithm consistently reduces power consumption by 30%** compared to DS-FMIPv6 across all handover counts in the network.

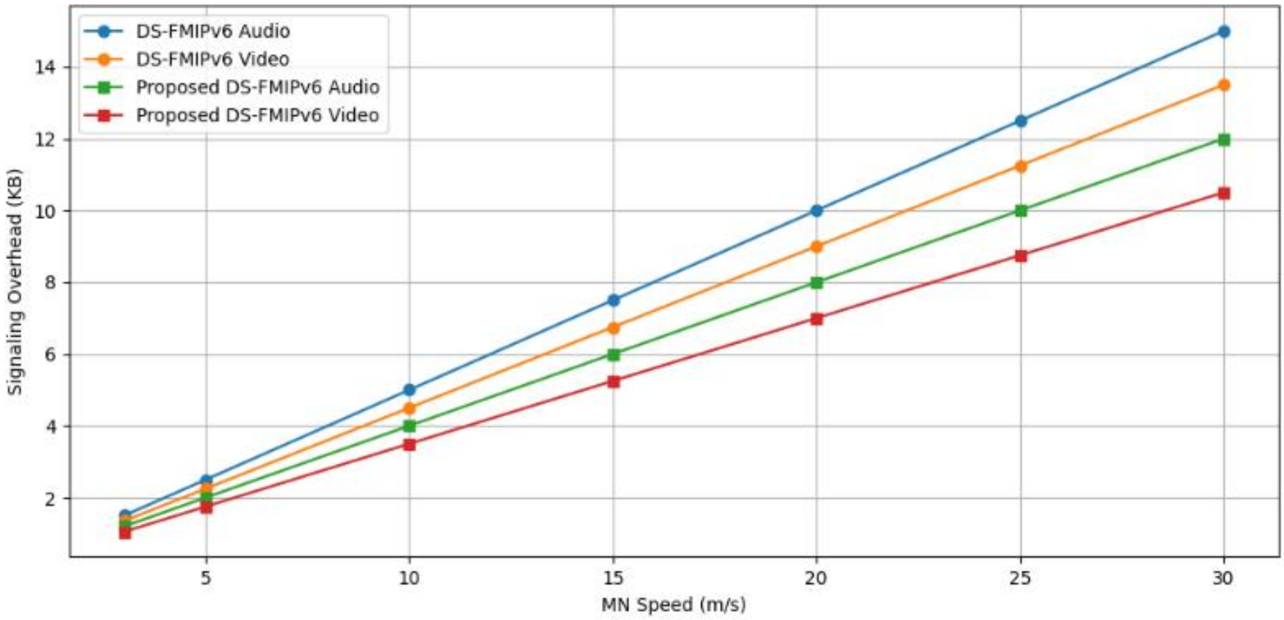

Figure 6: Signaling overhead for the DS-FMIPv6 and EDS-FMIPV6

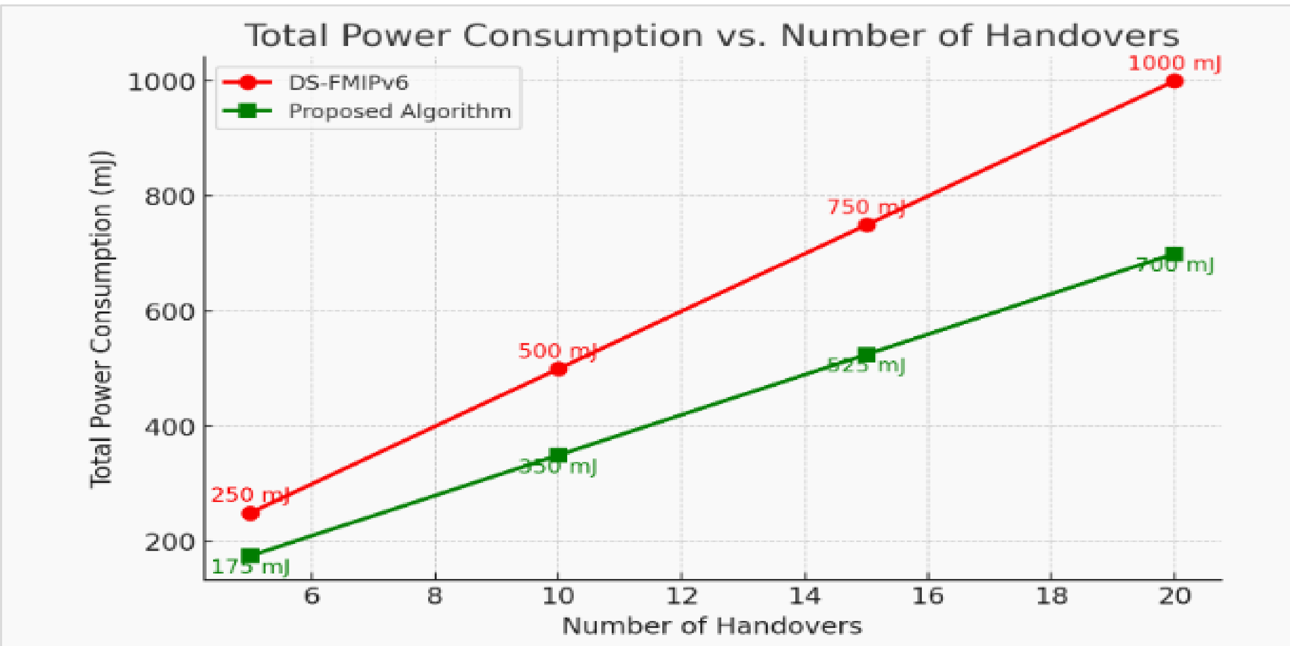

Figure 7: Power Consumption of DS-FMIPv6 and IDS-FMIPV6

Table 4 : Simulation Setup for Power Consumption

Parameter	Configuration Details
Protocols Compared	- DS-FMIPv6 - Proposed Algorithm
Test Scenario	Varying number of handovers (6-20)
Performance Metric	Total Power Consumption (milliJoules - mJ)
Measurement Points	Handover counts: 6,8,10,12,14,16,18,20
Power Range	200-1000 mJ

CONCLUSION

In this study, we offer an improved distributed Fast handover solution for Mobile IPv6 by utilizing the IEEE 802.21 MIH services architecture. We provide a new primitive that builds upon the current MIH primitives in order to facilitate this enhancement. The scheme improves RtSolPr message in FMIPv6 to generate eRtSolPr by describing a new route field that carries information about the requested parameters. Furthermore, the link local address option transmits MN's Link Local Address, which effectively addresses reduction of handoff latency, signaling overhead and Power consumption for a better support of seamless handovers. We proposed and evaluated EDS-FMIPv6 with 16.67% reductions in latency, signaling, packet loss and power consumption, 18.52% under the identical circumstances. The future research must focus on handover optimization between layers. The research must also deploy AI and machine learning techniques for improved mobility management. The researchers need to integrate the suggested EDSFMIPv6 protocol in 5G and 6G wireless systems. There must also be research aimed at enhancing security, minimizing energy consumption, as well as testing the protocol in real-world scenarios. Implementing the scheme in some application contexts, i.e., edge computing networks and vehicular networks, can make it more effective and convenient.

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