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Performance Evaluation of Mobility Management Protocols in Inter-Network Wireless Mesh Networks: A Comparative Study

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ABSTRACT

This study addresses the critical challenge of mobility management in Wireless Mesh Networks (WMNs), focusing on the performance comparison of various Mobility Management Protocols (MMPs). The diverse range of MMPs, including Proxy Mobile IPv6 (PMIPv6), Fast PMIPv6 (FPMIPv6), Mobile IPv6 (MIPv6), Hierarchical MIPv6 (HMIPv6), Fast MIPv6 (FMIPv6), and Fast Hierarchical MIPv6 (FHMIPv6), present distinct advantages and limitations in terms of performance, scalability, security, and flexibility. Selecting the most suitable MMP for a given WMN application is a complex task, primarily due to the lack of comprehensive evaluation metrics that accurately reflect network efficiency. Furthermore, quantitative performance comparisons among these protocols are notably scarcen in existing research. Therefore, this research aims to contribute by categorizing MMPs applicable in Inter network WMN environments, developing a simulated WMN environment using the Network Simulator (NS-2), and conducting a thorough performance evaluation of various MMPs. Based on the result, the PMIPv6 outperform and able to provide 99.99% in packet delivery ratio, highest throughput compares to other MMPs. The outcomes of this study are expected to provide valuable insights for guiding the selection of MMPs based on specific application requirements, thereby contributing to the advancement of efficient and reliable WMN deployments.

1. Introduction

With the rapid growth in the demand of mobile subscribers, wireless device and sensors, the improvement of wireless technology receive high attention from researcher. One of the hot topics that drag their attention is seamless mobility, aim to provide seamless exchange of point of connection when user across diverse network environment. IETF standardized MIPv6 after transition to environment of IPv6 in 2002. Years by years, the protocol was studied and enhanced by researcher and produce other mobility management protocol such as PMIPv6, FMIPv6, HMIPv6 [1-4]. All the developed MMP have their own set of challenges. This paper aims to address some limitations of

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existing methods in IPv6-based MMP environments, particularly in WMN. Firstly, MIPv6 often encounters significant challenges such as handoff delay and packet loss. These issues compromise the seamless mobility experience and can result in security vulnerabilities. Although FMIPv6 was introduced to reduce handover times, it increased the complexity of the system and demanded more network resources, which may not be feasible in resource-constrained environments. Secondly, IPv6-based MMP also struggles from scalability issue. HMIPv6 attempts to reduce signaling overhead through a hierarchical structure. However, as hierarchical structure expands, it leads to bottlenecks because of heavily dependent on Mobility Access Point (MAP). Similarly, PMIPv6, which shifts mobility management responsibilities to the network infrastructure, is primarily effective within localized domains. As networks grow larger, PMIPv6's scalability is limited by the bottleneck at the Local Mobility Anchor (LMA).

Furthermore, there is underexplored on WMN context. The current body of research predominantly focuses on evaluating mobility management protocols like MIPv6, PMIPv6, and others within specific environments, such as cellular networks. WMNs have unique characteristics, such as dynamic, self-healing, and multi-hop routing capabilities, which pose distinct challenges for mobility management. Studies like those by Wei Siang *et al.,* [5] and Shah *et al.,* [6] have provided insights into the comprehensive performance that cover both host-based and network-based mobility management protocols within WMNs. Existing research has not sufficiently explored how different mobility management protocols perform under diverse metrics like latency, throughput, and packet loss in this context.

This study aims to fill these gaps by providing a comprehensive performance evaluation of both host-based and network-based mobility management protocols within WMNs. By assessing various metrics, including handoff latency, packet delivery ratio, throughput, and signaling load, the research will identify the most effective protocols for ensuring seamless mobility in WMNs. This evaluation will also support network architects, engineers, and policymakers in making informed decisions regarding protocol selection and network design to enhance the quality and reliability of WMNs.

2. Literature Review

Siang *et al.,* [5] investigated “A Comprehensive Performance Evaluation of MIPv6 and PMIPv6 Mobility Management Protocols in Wireless Mesh Network”. The researchers conducted a comprehensive performance evaluation of IPv6-based mobility management protocol. The research access network focused on wireless mesh network. They completed the performance comparison for MIPv6 and PMIPv6 based on performance metrics include Packet Delivery Ratio, throughput and latency. Their simulation result shows that PMIPv6 have better performance than MIPv6 in term of better throughput, lower latency, and higher Packet Delivery Ratio. Shah *et al.,* [6] investigated “A Route Optimized Distributed IP-Based Mobility Management Protocol for Seamless Handoff across Wireless Mesh Networks”. The researchers investigated the challenges of mobility management in WMNs and propose a Distributed IP-based Mobility Management Protocol (DIMMP). They quantitatively illustrate the relative strengths and weaknesses of existing solutions in mobility management with details. The protocols that involve in this research are MIPv6, IMeX, and DIMMP. Their result shows that DIMMP increase the overall performance for handoff execution in WMNs. From the study, DIMMP distributed the mobility anchors, used MARs to fix the issue of broadcast and delay when discovering route.

Hoh *et al.,* [7] investigate “Consolidation of Host-Based Mobility Management Protocols with Wireless Mesh Network”. The researchers investigate and the performance of Host-Based mobility management protocols within WMN in terms of latency, throughput and packet loss ratio. In the paper, they state the characteristic and mobility management method of each MMP The researchers used network simulator ns-2 as simulation tool and compare each protocol by Packet Delivery Ratio, throughput and latency. Their results demonstrate that the performance of the developed FHMIPv6 with WMN performs better as compared to other Host-based protocols. Rui *et al.,* [8] aimed to investigates "IP Mobility Enhancements for MIPv6 and PMIPv6". He simulates a single mobile network and compares the performance obtained by the proposewebd enhancements (HIMPv6, FMIPv6 and FHMIPv6). The researchers used network simulator ns-2 as simulation tool. The performance metrics for the study are handoff latency, packet loss, signalling load and bandwidth per station. The simulation setup a micro-mobility domain. Multiple mobile nodes move around randomly inside the environment and a mobile node is observed. It simulates the extreme cases and considering different traffic sources. The study analysis the different overall performance of the various protocol and their causes was acquired.

Hsieh *et al.,* [9] investigated "Performance analysis on Hierarchical Mobile IPv6 with Fast-handoff over End-to-End TCP". The researchers present a detailed performance analysis of the HMIPv6 architecture with fast-handoff mechanism. They quantitatively illustrate the relative strengths and weaknesses of using fast-handoff and hierarchical structure in managing address resolution and registration processes. The protocols that involve in this research are MIPv6, FMIPv6, HMIPv6, and FHMIPv6. Their result shows that FHMIPv6 achieves drastic performance than MIPv6. From the study, they suggest three key design criteria for better seamless handoff architecture, which is forwarding mechanism should locate as close to MN, additional packet duplication for forwarding to new AR from the MAP and ability of identify the packet sequence. Li *et al.,* [10] investigate "A Comprehensive Performance Evaluation of PMIPv6 over IP-based Cellular Networks". The researchers analyze comprehensive performance metrics, including signalling cost, handover delay and packet loss, in a realistic IP-based cellular networks model. Their results demonstrate that the performance of PMIPv6 is the best compared with host-based mobility management such as MIPv6, FMIPv6 and HMIPv6.

Pérez-Costa *et al.,* [11] aimed to investigates "A Performance Comparison of Mobile IPv6, Hierarchical Mobile IPv6, Fast Handovers for Mobile IPv6 and their Combination". He simulates a single mobile network and compares the performance obtained by the proposed enhancements (HIMPv6, FMIPv6 and FHMIPv6). The researchers used network simulator ns-2 as simulation tool. The performance metrics for the study are handoff latency, packet loss, signalling load and bandwidth per station. The simulation setup a micro-mobility domain. Multiple mobile nodes move around randomly inside the environment and a mobile node is observed. It simulates the extreme cases and considering different traffic sources. The study analysis the different overall performance of the various protocol and their causes was acquired. The MobileIPv6 Protocol is an anchor-based solution [12] using Home Agent (HA), an anchor node to complete mobility management works. It keeps track of position information of relocated mobile nodes. There are multiple types of enhancements on the protocol as it faces limitation on high handover latency and signaling overhead. The most popular enhancements are FHMIPv6 and PMIPv6 which introduce new node to support HA to increase the efficiency of consuming network resources. Table 1 shows the comparison of all IPv6-based MMP.

The approach that implemented in IPv6-based MMP is Locator/Identifier Split-based Mobility Approach (LISMA) [13]. The HA responsible to maintain the locator and identifier information of mobile node. Locator information indicates the location of mobile node, and the identifier information indicates the information to maintain mobile node's communication while changing point of attachment over the network to provide seamless mobility. Mobility management consists of two types of services, location management and handover management to support seamless connectivity and efficient communication for mobile clients that move between different network access points. Its primary goal is to enable users and devices to transition smoothly between different network environment while minimizing disruption to ongoing communication and maintaining a consistent QoS.

Table 1
Comparison of IPv6-based mobility management protocols

Feature	MIPv6	FMIPv6	HMIPv6	FHMIPv6	PMIPv6
Types of mobility	Host-based	Host-based	Host-based	Host-based	Network-based
Operating layer	Network layer	Access layer, Network layer	Network layer	Access Layer, Network layer	Network layer
Handover type	Reactive	Reactive/ proactive	Reactive	Reactive/ proactive	Reactive
Mobility scope	Global	Global/Local	Local	Global	Local
Functionally correspondent entity	HA	HA	HA	HA	LMA
Topological correspondent entity	AR	Enhanced AR	MAP	MAP, AR	MAG
Mobility support	IPv6	IPv6	IPv6	IPv6	IPv4, IPv6
Involvement of MN	Yes	Yes	Yes	Yes	No
Handover latency	Long	Moderate	Moderate	Low	Moderate
Signalling overhead	High	High	Low	Moderate	Moderate

Location management is a service that often keep trace of the location of mobile devices to anticipate and facilitate handovers [14]. Location management can be separate into 2 stage, location registration and call delivery [15]. The first stage (location registration) deal with new devices' location updating on the access link periodically. This allows the network to authenticate the mobile client location profile and update the mobile client's location profile. The second stage (call delivery) is the ability of the network to find current mobile node's location in the access network.

The aim of handover management is allowing the network to maintain the mobile clients' communications while moving and change their point of attachment over the network [16]. The handover process has three stages include initiation, which either user, network agent identifies the need to switch to new network. Second stage is new connection establish, where mobile client needs to choose a network to operate, depending on network load, available bandwidth, QoS. The final stage is data-flow control, where the delivery of the data from the old connection path to the new connection path is maintained. There will be two conditions in handover management, vertical and horizontal handover [17]. Table 2 show the different between both types of handovers.

Table 2
Characteristics between horizontal and vertical handover

Feature	Horizontal handover	Vertical handover
Event	MN move to new point of attachment within homogenous access network.	MN move to new point of attachment within heterogenous access network
Mobility types	Local mobility	Global mobility.
IP address	MN no IP address changed.	Network interface changed, MN changed its IP address.
Example	WLAN to WLAN.	GSM to WiMAX.

There are two handover strategies while performing handover, soft handover and hard handover [16]. Hard Handover happens when the Mobile Client no longer connected to current access link then establishes a new connection with a new access link in the network. High handover latency and packet loss occurred in this type of handover caused an interruption to the Mobile Client's communication session. Soft Handover happens when the mobile client establishes a new access link connection while retain the connection to the previous access link in the network. In this way, the mobile client may be connected with two or more access points at a given moment.

2.1 Host-Based Mobility Management Protocol

MIPv6 established by IETF intended to enable IPv6 mobile client to move from one IP subnet to another. The mechanism of MIPv6 allow Mobile client to be reachable and maintain on going connection with Mobile Client's position keeps on changing within the topology. During entire mobility process, Mobile Client maintains using the same allocated IP address [1]. Second mode for communication is "Route Optimization". MN need to register its current binding at CN. This enable all packets can be routed directly using shortest communication path. This allows CN routed packets directly to MN without involvement of HA. This optimization avoids congestion at MN's HA and Home Link, improve network reliability and security. Figure 1 show the signalling flow of MIPv6.

Although MIPv6 protocol is able to support IPv6 mobility, it also has its drawbacks such as high handover latency, high packet loss and signalling overheads that cause it slow to deploy in real world. These weaknesses lead to the investigation to enhance MIPv6 performance [18]. FMIPv6 was proposed by IETF to reduce handover latency and bring improvement for the application of real-time traffic during handover process occurred. Fast Handover is previously performing the movement detection and IP address configuration before the MN moves from its attachment point to a new attachment point [3]. Figure 2 show the signalling flow of FMIPv6.

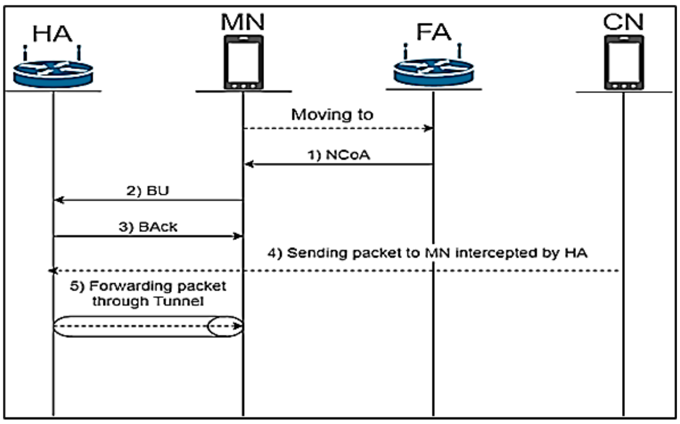

Fig. 1. Signalling flow of MIPv6

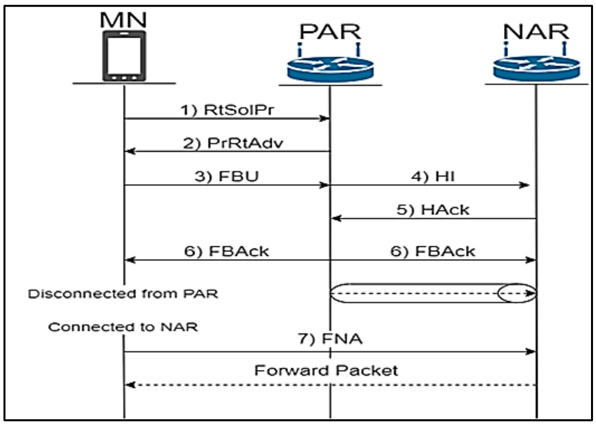

Fig. 2. Signalling flow of FMIPv6

The handover latency is defined as duration of a process to terminating existing connectivity and obtaining new IP connectivity. This handover latency results from MIPv6 several processes as movement detection, new CoA configuration, and location update and these procedures are time consuming tasks. FMIPv6 enable MN to initiate Layer 3 handover process with new AR while MN is still connected to old AR before Layer 2 handover is completed [19]. The solution of FMIPv6 have reduce the handover latency but the early L2 triggers will causes inaccurate prediction and negatively affect seamlessness of mobility. As MN frequently change point of attachment caused handover latency and high signalling overheads, IETF introduced HMIPv6, a local mobility management protocol for improvement of MIPv6. The introduction of MAP in HMIPv6 acts as the proxy HA for mobile node within the local domain. This reduced handover latency and the amount of signalling between the MN, its CN, and its HA [20]. Figure 3 show the signalling flow of HMIPv6.

FHMIPv6 is an idea of experts aim to improve FMIPv6 and HMIPv6 which combine both schemes based on their advantages [21]. It reduces movement detection latency and new CoA configuration delay during handover by using FMIPv6 procedures. Moreover, the signalling overhead and BU delay during handover are reduced by utilizing HMIPv6 processes. Figure 4 show the signalling flow of FHMIPv6. However, FHMIPv6 also suffers from some limitations. Communication performance of the network is not optimal as it does not appropriately consider reusing the information acquired from previous handover process and the delay of allocating new CoA and BU [22]. The handover process is not intelligent as it does not judge the network status and the motion pattern of MN during handover process [23].

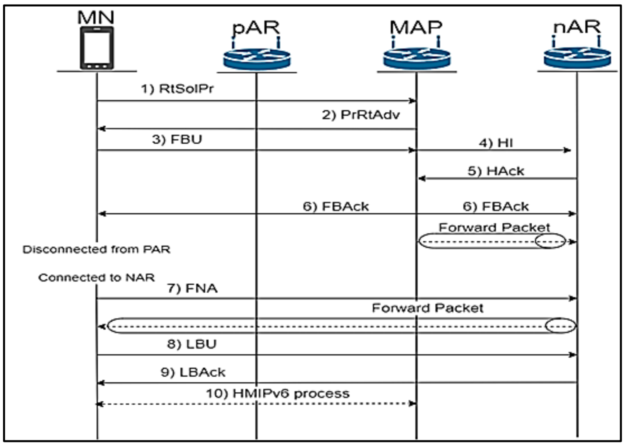

Fig. 3. Signalling flow of HMIPv6

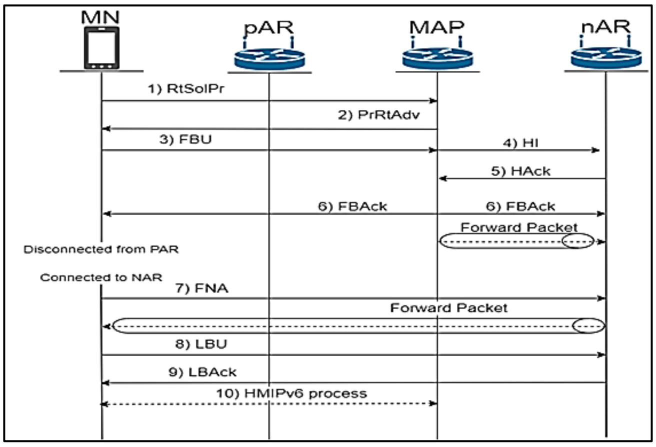

Fig. 4. Signalling flow of FHMIPv6

2.2 Network-Based Mobility Management Protocol

PMIPv6 is introduced and standardized by IETF is to provide mobility management support to a network-based mobile node (Figure 5). It consists of a PMIPv6-domain which is a localized mobility management domain that handles mobile node's mobility management. It does not require the mobile node to participate in IP mobility related signalling.

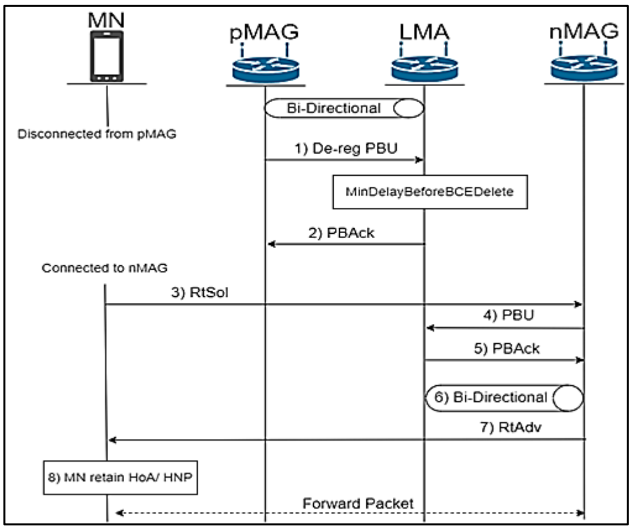

Fig. 5. Signalling flow of HMIPv6

The proxy mobility agent will track the mobile node's movements and will does the mobility management on behalf of the MN attached to the network [24]. PMIPv6 consists of two entities, LMA and MAG. MAG responsible for tracking MN's movements and initiating mobility-related signalling while LMA works like HA in MIPv6 for maintaining reachability to the MN's CoA [10].

2.3 Wireless Mesh Network

WMN is combination of mesh routers and mobile mesh clients which have the characteristic of having multiple path and multiple hops in wireless local area network and wide area network. WMN has applicated in various of communication needs such as smart home devices, communications satellite constellations, network coverage at rural area [25]. Mesh network linked nodes together and expanding the network by branching its connection with other nodes as shown in Figure 6. The characteristic of mesh enables the network form in centrally managed or decentralized. This type of network has high reliability and flexibility as each node only needs to transmit packet to its neighbour node. The WMN also form a multiple hop and path for the source to send its packet successfully to destination. When the path is down, the protocol will reroute the packet and choose the best path to the destination [22].

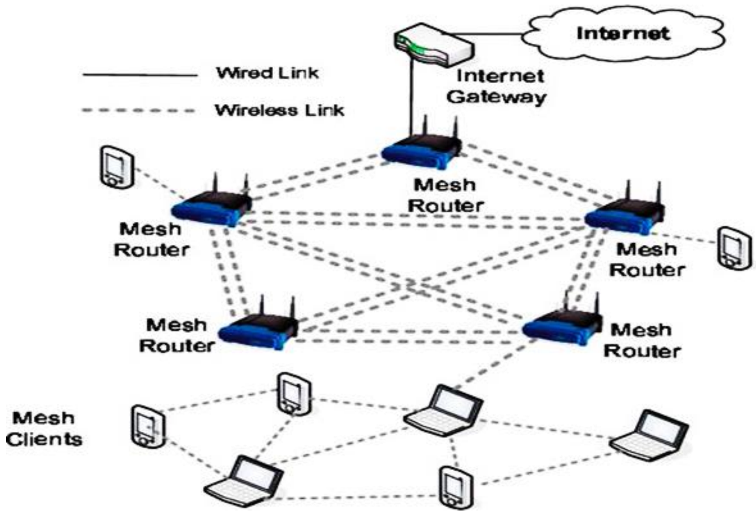

Fig. 6. Wireless mesh network

3. Methodology

3.1 Simulation Setup

Simulation of mobility management protocol under WMN is done through Network Simulator 2 (NS-2) using Linux based-computer. FHMIPv6 protocol is selected as it performs better among the Host-based Mobility Management Protocol [7,26]. PMIPv6 and FHMIPv6 protocols were designed, developed and simulated in NS-2. Both MMPs are simulated under WMN environment for comparison and analysis. Some parameters and configurations had been set to be constant value to obtain an optimum result for both MMPs. Mac 802.11 is set up for network environment for both MMPs. The data rate is fixed to 100 Mb and interface queue types is drop tail mode [27]. Next, the topology of MMPs need to be built up. 8 nodes are set up and link together and all the unique nodes are installed in the topology. For PMIPv6, the unique nodes will be HA, CN, LMA and two MAGs. The unique nodes for FHMIPv6 will be HA, CN, MAP, and two ARs. The details of the parameter and its values for setting up both MMPs is shown in Table 3.

Table 3
Simulation parameter

Parameter	Value
Link delay	2ms
Data rate for Mac 802.11	100Mb
Window size byte	32
Duration	100s
Transport Protocol	TCP

3.2 Performance Metrics

The performance metrics are throughput, packet delivery ratio and handover latency. Throughput is the total of packet successfully send from correspondent node to mobile node. Packet Delivery Ratio is ratio of received packets over sent packets between sender and receiver. Handover latency in this research is defined as the overall latency experienced by the mobile node throughout the handover process [27,28]. It is the period of mobile node down connection with previous access router and establish connection and receive packets from new access router.

4. Results and Discussion

Simulation results are presented with detailed discussion. Table 4 and Table 5 shows below showed the performance of each MMPs. All the performance metrics result for MMPs are presented in detail. The packet size starts from 128 bytes and increase to 256 bytes, 512 bytes, 1024 bytes, 2048 bytes and 4096 bytes.

Table 4
PMIPv6 with WMN

Proxy mobile internet protocol version 6 (PMIPv6)						
Packet Size (bytes)	128	256	512	1024	2048	4096
Throughput (Mbps)	5.515	7.912	12.005	14.954	25.986	32.422
Packet delivery ratio (%)	99.99	99.99	99.99	99.99	100	99.99
Handover latency (ms)	684	692	761	835	1112	1540

Table 5
FHMIPv6 with WMN

Fast hierarchical mobile internet protocol version 6 (FHMIPv6						
Packet size(bytes)	128	256	512	1024	2048	4096
Throughput (Mbps)	1.856	2.362	3.040	3.624	4.107	4.410
Packet delivery ratio (%)	90.46	86.00	86.10	86.32	87.12	88.05
Handover latency(ms)	276	307	489	720	828	1097

Figure 7 show throughput PMIPv6 and FHMIPv6. As the packet size increased from 128bytes to 4096bytes, throughput of PMIPv6 increase from 5.515 Mbps at 128 bytes, 7.912 Mbps at 256 bytes to 12.005 Mbps at 512 bytes, 14.954 Mbps at 1024 bytes, 325.986 Mbps at 2048 bytes and reaches 32.422 Mbps at 4096 bytes. For FHMIPv6, throughput also increase gradually from 1.856 Mbps at 128 bytes, 2.362 Mbps at 256 bytes, 3.040M bps at 512 bytes, 3.624 Mbps at 1024 bytes 4.107 Mbps at 2048 bytes and reaches 4.410 Mbps at 4096 bytes. In conclusion, PMIPv6 performs better than FHMIPv6 in term of throughput.

This is the reasons PMIPv6 is a network-based MMP, it does not involve Mobile Node in handover procedure. MAG act as a proxy and communicate with Mobile node and help MN to send Proxy

Binding Update (PBU) to LMA to update Mobile Node Profile. This will reduce the signalling overhead and decrease packet loss. Therefore, throughput of PMIPv6 is high because it highly utilized the bandwidth.

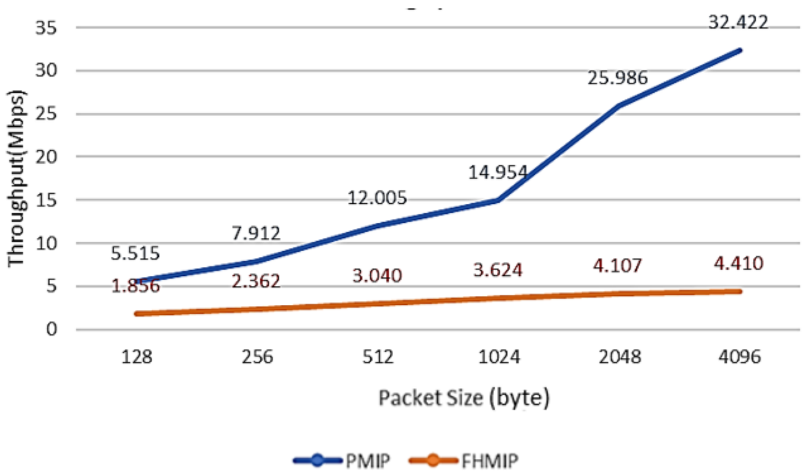

Fig. 7. Throughput

Figure 8 showed the packet delivery ratio of PMIPv6 and FHMIPv6. As the packet size increased from 128bytes to 4096bytes, packet delivery ratio of PMIPv6 records 99.99% at 128 bytes, 256 bytes, 512 bytes, 1024 bytes, 4096 bytes and 100% at 2048 bytes. For FHMIPv6, packet delivery ratio records 90.46%at 128 bytes, 86.00% at 256bytes, 86.10% at 512 bytes, 86.032% at 1024 bytes, 87.12% at 2048 bytes and 88.05% at 4096 bytes. In conclusion, PMIPv6 performs better than FHMIPv6 in term of packet delivery ratio.

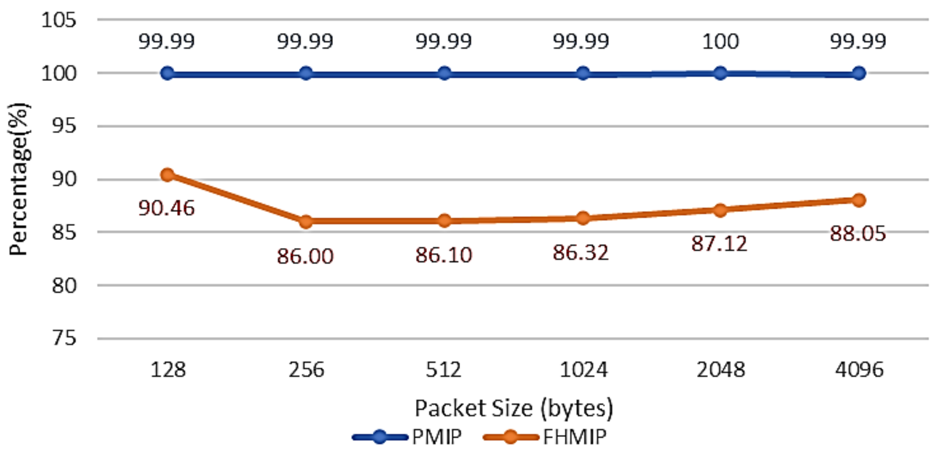

Fig. 8. Packet delivery ratio

Figure 9 showed the handover latency of PMIPv6 and FHMIPv6. As the packet size increased from 128bytes to 4096bytes, handover latency of PMIPv6 records 684 ms at 128 bytes, 692 ms at 256 bytes, 761 ms at 512 bytes, 835 ms at 1024 bytes, 1112 ms at 2048 bytes and 1540 ms at 4096 bytes. While FHMIPv6, handover latency records 276 ms at 128 bytes, 307 ms at 256 bytes, 489 ms at 512 bytes, 720 ms at 1024 bytes, 828 ms at 2048 bytes and 1097 ms at 4096 bytes. In conclusion, FHMIPv6 performs better than PMIPv6 in term of handover latency.

The reason is FHMIPv6 utilize the handover process by reducing movement detection delay, Care of Address (CoA) configuration delay and signalling overhead process. FHMIPv6 forms by integrating

FMIPv6 and HMIPv6. It contains function of FMIP which is signalling message anticipation. It reduces movement detection delay, CoA configuration delay through Router Solicitation Proxy (RtSolPr), Proxy Router Advertisement (PrRtAdv) and Fast Binding Update (FBU). It also reduced signalling overhead process by having MAP to act as the proxy for mobile node to communicate with Home Agent.

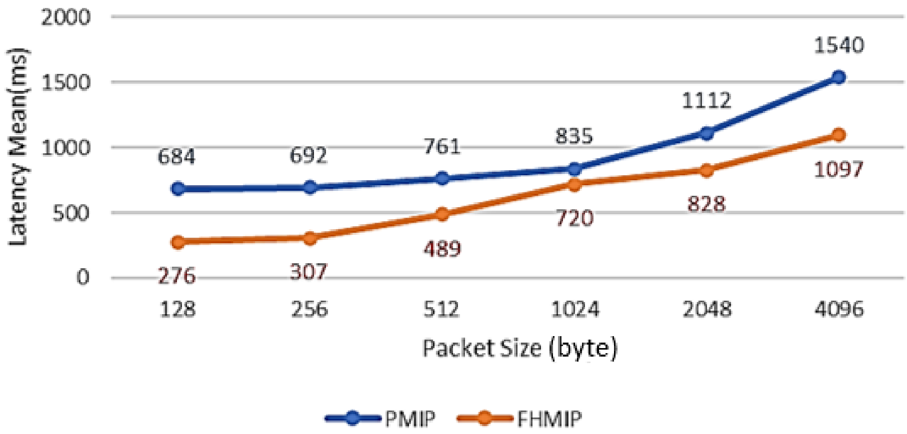

Fig. 9. Handover latency

5. Conclusions

The comparative analysis of PMIPv6 and FHMIPv6 within a Wireless Mesh Network (WMN) environment reveals distinct advantages and trade-offs associated with each mobility management protocol. The findings indicate that PMIPv6 demonstrates significantly higher throughput and packet delivery ratios in comparison to FHMIPv6, with an impressive throughput improvement of up to 735,192% at a packet size of 4096 bytes and an average enhancement of 114.48% across all packet sizes. This notable performance can be attributed to the network-based mobility management capabilities of PMIPv6, wherein the Mobile Access Gateway (MAG) efficiently handles handover processes without requiring involvement from the Mobile Node (MN), thereby minimizing signaling overhead and optimizing bandwidth utilization.

Conversely, FHMIPv6 offers lower handover latency and exhibits up to a 40.35% better performance than PMIPv6 when dealing with smaller packet sizes of 128 bytes. This reduction in latency is largely due to the effective integration of FMIPv6 and HMIPv6 mechanisms, including Signal Message anticipation, Router Solicitation Proxy, Proxy Router Advertisement, and Fast Binding Update, all of which collectively decrease Movement Detection Delay and Signaling Overhead. These results underscore the importance of selecting the mobility management protocol that aligns with the specific performance requirements of the WMN environment. PMIPv6 is more suitable for scenarios prioritizing high throughput and packet delivery ratios, whereas FHMIPv6 is preferable in situations where minimizing handover latency is critical. This study not only addresses initial problem statements but also lays the groundwork for future research into enhanced mobility management protocols in WMNs, potentially leading to the development of hybrid solutions or optimized schemes that leverage the strengths of both PMIPv6 and FHMIPv6.

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