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A Service-Efficient Proxy Mobile IPv6 Extension for IoT Domain

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Abstract: The upcoming generation of communications can provide richer mobility, high data rate, reliable security, better quality of services, and supporting mobility requirements in the Internet of Things (IoT) environment. Integrating modern communication with IoT demands more secure, scalable, and resource-efficient mobility solutions for better business opportunities. In a massive 6G-enabled IoT environment, modern mobility solutions such as proxy mobile IPv6 (PMIPv6) have the potential to provide enhanced mobility and resource efficiency. For supporting richer mobility, a cost-effective and resource-efficient mobility solution is required in a massive 6G-enabled IoT environment. The main objective of the presented study is to provide a resource-friendly mobility solution for supporting the effective integration of future communication in the massive IoT domain. In that context, a location-based, resource-efficient PMIPv6 extension protocol is proposed to provide resource efficiency in terms of required signaling, packet loss, and handover latency. To compare and analyze the proposed model's effectiveness, mathematical equations are derived for the existing as well as for the proposed solution, and such equations are implemented. Based on the comparison among existing and proposed solutions, the results show that the proposed location-based service-oriented proxy mobile IPv6 extension is resource efficient for supporting mobility in 6G-enabled IoT.

Keywords: Proxy Mobile IPv6; IoT networks; next-generation IoT; location-based PMIPv6

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1. Introduction

Rapid advancements in communication technologies are creating opportunities for various application domains due to their potential for handling massive internet traffic, richer mobility, better security, and seamless mobility [1,2]. Such potential of these technologies supports the integration of next-generation 6G-enabled IoT mobility [2–5]. As a result, various domains are motivated to embrace modern communication technologies by integrating modern mobility protocols in large-scale IoT [2,6]. Examples in such domains include information access using smart devices, processing of transactions, support for modern technologies, and mobility services. Integration of such solutions in modern mobility solutions requires optimized AI-based models, adaptive decision-based algorithms, and secure communication [7].

An effective modern solution requires the integration of 6G-enabled IoT mobility management protocol such as PMIPv6 [8] in a modern IoT environment [9,10]. PMIPv6 performs its mobility using Mobile Access Gateway (MAG) and Local Mobility Anchor (LMA) [11]. However, various problems are associated with basic PMIPv6 such as the handover delay during the handover, packet loss due to the absence of buffering mechanism, support for network mobility, additional signaling, and load on certain entities due to its involvement in overall mobility [11,12].

Furthermore, among the solutions provided for solving the aforementioned issues, predictive PMIPv6 extension protocols received much attention from experts [13,14]. One of the major reasons for its adoption is the prediction of handover occurrence in advance and making necessary arrangements before such an event [1]. Such extensions may use the Mobile Node (MN), LMA, or MAG for performing such prediction [11,12]. In the context of PMIPv6 protocol, MN is a device that moves among networks in addition to maintaining its IP address. To predict the handover moment in advance, various solutions use Received Signal Strength (RSS) [15,16].

In the following method, the RSS is used to predict the handover moment. After the timer has been set, RSS is continuously checked, and a condition is set to activate the event when RSS matches a certain threshold value. If the condition is met, it is presumed that MN is about to roam to another MAG's domain, and the relevant handover arrangements are undertaken to minimize changeover latency [16]. However, one of the major problems with such RSS-based schemes is that RSS is prone to environmental conditions and may affect the RSS measure. In such a case, the scheme may initiate the handover process even when the MN is not properly located for handover [15]. Therefore, the overall performance of the RSS-based schemes is dependent on the accuracy of the RSS measure. If the measure is accurate, these schemes will provide optimal performance. On the other hand, errors in RSS measures may lead to decreased performance of the scheme. Such an issue may lead to longer handover latency, addition signaling, and unnecessary buffering [15–17]. For solving such issues, experts use the location of the resources to enhance the decision regarding the prediction of the handover moment in addition to the identification of target MAG [18–20]. Location is integrated with other measures for improving handover prediction [21].

For supporting mobility management and enhancing the communication services in 6G-enabled IoT, the proposed scheme combines the location parameters of resources with RSS measures in an intelligent manner to improve handover moment prediction, and resource efficiency by avoiding additional signaling. Furthermore, the network resources' information is utilized more effectively for buffering efficiency too. For measuring the efficiency of different aspects, equations are derived in the context of existing schemes. The proposed scheme is compared with available schemes using the proposed equations. The overall analysis and comparisons show that the present solution is more resource efficient, resource-friendly, reliable, and accurate in predicting the handover moment. The research contributions of this study are the following:

- To provide a location-based extension for efficient utilization of resources in the IoT environment to accurately predict handover moment.
- To provide an efficient buffering mechanism for storage efficiency in the IoT domain to handle packet-loss problems.
- To achieve better signaling efficiency in the IoT environment by effectively using nMAG-ID.
- To achieve efficient handover latency for the handover process during the mobility of resources in the IoT domain.

The rest of the article is organized into the following sections. Section 2 provides details regarding the studies related to the presented problem. The proposed work, its mechanism, and its procedure are provided in Section 3. The setup for implementation and validating our extension is given in Section 4. Obtained results of the comparisons are presented in Section 5. Finally, the conclusion and future work are discussed in Section 6.

2. Related Work

Modern IoT such as 6G-enabled IoT are supported by efficient network-based mobility management protocols for resource efficiency [1,13,22,23]. For adopting IoT in a modern solution, a number of associated IoT challenges, its feasibility, security issues, and architectures are analyzed for assessing the potential adaptation of IoT [24]. Experts suggest devising scalable, resource-efficient, feature-richer, and reliable solutions for improving the services' quality in the upcoming 5G/6G communication. Furthermore, for supporting IoT, a network-based mobility protocol is devised in which the point of attachment by their respective devices is updated frequently and provides better signaling efficiency during mobility [25]. For supporting the potential domains, Ref. [25] highlights a number of functional requirements and also provided various mobility management solutions that are made on the various requirement and the modern standards of 5G/6G. To meet such functional requirements, proxy mobile IPv6 protocol extensions are one of the most feasible candidates for enhanced mobility in the IoT [26–28].

Network-based mobility solutions such as PMIPv6 extension protocols have received much attention by avoiding the involvement of the MNs in their processes [16]. In addition, domain experts have put much effort to address and solve the aforementioned problems associated with PMIPv6 protocols [13]. As a result, a number of fast proxy mobile IPv6 extensions were proposed that minimize handover latency as low as possible [29]. The packet-loss problem is coped with the addition of a buffering mechanism to store the packets during the handover procedure. Overall signaling of the schemes is improved by eliminating the prediction of the expected resources to which the MN could roam [11]. Among the predictive schemes, there are many schemes that use the Received Signal strength (RSS) for predicting the initiating moment for handover. This scheme includes a smart buffering scheme [17], location-aware FPMIPv6, a low latency scheme [16], and FPMIPv6 [15].

An attempt made for handover efficiency and addressing the loss of packets during handover, FPMIPv6 works by predicting the next MAG (nMAG) in advance for the MN to move [15]. In this scheme, the MN identifies the target MAG when the value of RSS becomes too low. After predicting the nMAG, MN contacts the pMAG via the L2 report. Using the L2 report or L2 trigger, the MN informs the network about changing its location in the network. After receiving the information from MN, the message including handover initiation (HI) is sent from pMAG to nMAG while nMAG replies to the HI message with a Handover acknowledgment (HAck) message. For exchanging the buffered packets, a tunnel is formed between pMAG and nMAG. Furthermore, the attachment of MN is detected by nMAG and necessary signaling is performed for communicating Proxy Binding Update (PBA) and Proxy Binding Acknowledgement (PBA) between LMA and nMAG. Finally, the buffered packets and Router Advertisement (RA) are sent to the MN.

For enhancing the handover latency, the process of authentication is optimized in an RSS-based PMIPv6 protocol [16] referred to as a low latency scheme. In such a scheme, based upon the occurrence of an RSS event, De-Reg Proxy Binding Update (De-Reg PBU) is sent to LMA from pMAG. LMA immediately starts storing packets and using the Immediate Handover Request (IHR) message, it contacts its surrounding MAGs. Upon the attachment of MN, the corresponding MAG reply to the IHR message based on MN's information. LMA responds to the pMAG with De-Reg Proxy Binding Acknowledgment (De-Reg PBA). LMA then forwards any stored packets to nMAG to MN.

Another approach that directly addresses the packet-loss issue is the smart buffering scheme, which solves the problem by buffering packets during MN changeover. The smart buffering system operates by monitoring the RSS value and storing packets destined for MN when the value falls below a certain threshold [17]. MN handover process works by using Flush Request (FReq) and Flush Reply (FRep) messages. FReq message is communicated to the neighboring MAGs of nMAG when MN attachment is detected by target MAG. Using information of MN in the FReq message, the corresponding pMAG reply by using the FRep message. Furthermore, for solving packet loss, the buffered packets are transferred from pMAG to nMAG using the established tunnel.

A more efficient location-based PMIPv6 extension is devised that effectively uses the location information for enhancing the signaling efficiency, and load on network entities [1,13]. In such a scheme, the location of the MAG is shared with its corresponding MNs so that MN should only request for handover when its location is proper. Such a procedure eliminates unnecessary signaling and load on network resources.

For providing better mobility solutions based on the requirement of current as well as future communication, a resource-friendly and performance-efficient mobility solution is provided that can handle many devices in a massive IoT environment.

3. Proposed Scheme

Upcoming generation communications demand much higher mobility requirements along with efficiency in resource utilization in a massive IoT environment [30,31]. To achieve the mobility requirements in IoT, the main purpose of the presented research is to provide a resource-efficient location-based PMIPv6 extension protocol for enhanced mobility in 6G-enabled IoT. The main contributing aspects of the proposed extension include integrating RSS and the location of network entities for accurate prediction of handover initiation, optimizing the signaling efficiency, reducing handover latency, and enhancing buffering efficiency in addition to the existing RSS-based PMIPv6 protocol extensions. For signaling efficiency, RSS is integrated with location information in an effective way for avoiding unnecessary communication of networking entities. Buffering efficiency is achieved using the LMA and nMAG in an optimized way for storing the packets. Handover latency is optimized by reducing by involving MN, LMA, and nMAG-ID in the handover process. To understand the basic working of the presented protocol extension, the following are the details of the same.

3.1. Proposed PMIPv6 Protocol Extension

The proposed protocol extension is based on the foundation of RSS, location information, and profile information of the target MAG identifier. The existing RSS-based PMIPv6 protocol extensions suffer from false handover initiation, longer handover latency, additional buffering, and high signaling due to RSS errors. Furthermore, existing location-based PMIPv6 protocol extensions may enhance some of the issues; however, to provide an overall efficient protocol, extensions are required. The proposed extension improves the efficiency of RSS-based PMIPv6 extension protocols. The working of the proposed solution is the following.

To efficiently use the location information with RSS measure, the MAG will also communicate information regarding its location to the MNs attached to it. For this purpose, MAG is considered as static MAG and each MAG knows its coverage. Furthermore, MAG can communicate with its surrounding MAG and know their locations too. Therefore, after sharing its information with their corresponding MNs, MN will be able to find its distance from their MAG. Such knowledge will help the MN avoid false handover requests when RSS falls below the threshold. MN in this solution will monitor RSS in addition to the location of MAG.

The handover process is improved by monitoring not only RSS but also the effective usage of MAG's location of resources involved in mobility. It is important to mention that the MAG location will only be exploited when an RSS error occurs. Such a procedure will ensure that if the RSS measure is normal, then the MN will roam without any service disruption. However, if an RSS event or RSS error occurs, the MN will check the location of MAG to decide whether the request for handover is to be made or not. In case of an RSS error, the location will not be appropriate, and MN will not request for handover initiation. Such decision-making will also eliminate false handover initiation problems. Furthermore, MN will only request for handover whenever handover is mandatory.

For simplifying the handover process and to optimize the signaling efficiency by avoiding unnecessary communication among network resources, the MN will communicate information associated with its location using an L2 report when an RSS event occurs. It is important to mention that an RSS event is when the MN is properly located for handover, and an RSS error is when RSS becomes too low due to surroundings.

After receiving the location information of MN, then pMAG will identify the target or next MAG that is expected to be the next MAG for MN. pMAG will send a De-Reg PBU message along with nMAG-ID to LMA. Upon receiving De-Reg PBU, LMA will start buffering packets and will keep sending the packets to pMAG. At the same time, LMA also sends an IHR message to the nMAG using the nMAG-ID. In a low latency scheme, LMA multicast the IHR message to surrounding MAGs. However, in the proposed location-based protocol extension, the LMA only sends the IHR message to the corresponding nMAG instead of surrounding MAGs. Such enhancement significantly reduces the signaling required. For forwarding the buffered packets, a tunnel is established between LMA and nMAG.

When MN is detached from pMAG, then the LMA forward all the buffered packets to nMAG and, at the same time, LMA sends a De-Reg PBA message to pMAG. When the MN attachment is detected by nMAG, then it immediately provides services to the MN by sending the buffered packets received from the LMA. In the meantime, nMAG communicates with LMA via PBU message in order to inform the LMA regarding MN's arrival while LMA replies with a PBA message. Upon receiving the PBA message, nMAG communicates with MN by forwarding the Router Advertisement (RA). LMA forwards the packets destined for MN towards nMAG that are further provided to MN via nMAG in a regular fashion.

The proposed solution will always ensure that MN will only request when a handover is necessary. In the case of existing RSS-based extensions, RSS errors had a major effect on performance efficiency. Additional signaling and unnecessary information communication during RSS errors are avoided in the proposed solution. Furthermore, information communication regarding target MAG-ID provides an accurate measure for LMA to know in advance the MN's expected MAG. In addition, such information also helps LMA to effectively manage the load on entities. However, such a problem is not in the scope of this paper. Target MAG-ID avoids the multi-casting of IHR messages to the surrounding MAGs of LMA. The overall working flow of messages and entities involved in the proposed protocol extension is shown in Figure 1.

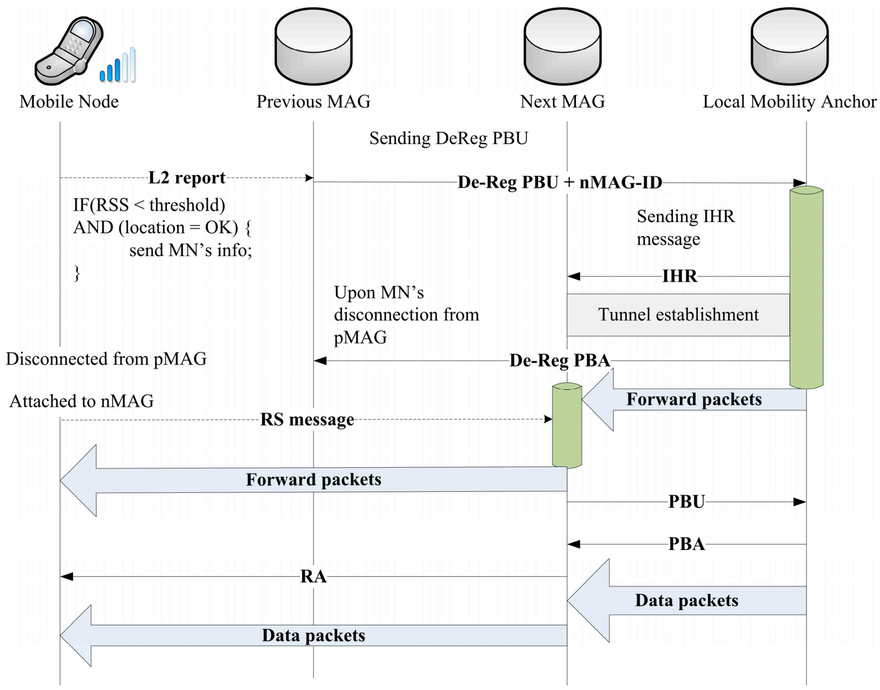

Figure 1. Working and signaling procedure of Loc-PMIPv6.

3.2. Signaling Required for Proposed PMIPv6 Extension

The main aim of the provided scheme is to achieve the low signaling requirement, handover efficiency and required buffering in a single solution. For this purpose, the scheme is based on location information to eliminate the additional signaling during RSS error and the multi-casting of IHR messages by sharing the target MAG-ID with LMA. As aforementioned, the MAG shares its location information with its MNs. Therefore, the signaling requirement for handover is the location sharing of MAG with MNs. Furthermore, in the case of the RSS event, MN shares its information with pMAG using the L2 report. Finally, the signaling completed with LMA communicated the IHR message with nMAG.

Based on the working of the proposed scheme (Loc_PMIPv6), MN will share its location information with its current MAG (pMAG) if an RSS event occurs. Subsequently, pMAG identifies target MAG and informs LMA regarding target MAG by sending a message that contains De-Reg PBU and nMAG-ID. With the help of nMAG-ID, LMA communicates with the target MAG using an IHR message. The signaling required for proposed Loc_PMIPv6 extensions is computed using Equation (1), where N is the number of MNs, the cost for sharing MAGs information with MN is represented by C_{loc_MAG}.

$$C_{LH\text{-}PMIPv6} = N \cdot C_{loc\_MAG} + \mu_c \cdot T \cdot \delta . \left\{ C_{L2report} + \left(C_{IHR} \cdot C_{LMA\_MAG} \right) \right\} \quad (1)$$

In Equation (1), the cost of the L2 report is represented by $C_{L2report}$, δ is the number of MNs attached to its associated MAG. C_{IHR} is showing the cost of IHR messages, C_{LMA_MAG} is the number of hope between LMA and MAG. M_c is the cell crossing rate and it is calculated by using Equation (2). In Equation (2), cell radius, and velocity is represented by R and v, respectively.

$$\mu_c = \frac{2\,\upsilon}{\pi\,R} \quad (2)$$

3.3. Handover Latency in Non-Location-Based RSS Extensions

Handover latency is the amount of time the MN is not receiving the services during handover. Such services become unavailable when MN is disconnected from pMAG until it receives the first packet from nMAG. Handover latency is affected by RSS error as the handover moment is predicted early. Such a problem is referred to as false handover initiation. In an RSS-based scheme, such additional added latency is identified by Equation (3).

$$t_{error} = \sum_{k=1}^{\frac{T_R}{f}} (1 - p_e)^{k-1} . p_e . \{ T_R - (k-1) f \} \quad (3)$$

Equation (3), T_R shows the time during which the MN reaches within nMAG's domain. f and p_e are the frequency for RSS checking and the probability of RSS error. Furthermore, the probability of MN to reach to the MN is shown using $(1 - p_e)^{k-1} * p_e$. Furthermore, the RSS error is the event when the MN threshold is lower than its defined value.

Handover latency in FPMIPv6 is started when the RSS event or RSS error occurs. After the falling of the RSS value to the defined threshold, the pMAG requests handover initiation by sending an HI message to nMAG. Handover acknowledgment is responded to through a HAck message from nMAG to pMAG. Handover latency is calculated when MN receives its packets from nMAG from the disconnection ϕ of MN from pMAG. As a result, handover latency is the function of the L2 report, the cost of the HI message, and the HAck message. Furthermore, if the tunnel is established after the L2 down then MN does not receive its packets from pMAG, even if MN roams inside the domain of pMAG. In addition, FPMIPv6 is suffering from additional latency due to RSS error t_{error} too. Equation (4) represents the handover latency in FPMIPv6.

$$t_{FPMIPv6} = max\left\{ t_{error} + \varnothing - \left(t_{HI} + t_{scan} + t_{HAck} + t_{report} \right), 0 \right\} + t_{L2} + t_{WRS} + t_{RS} + t_{w-data} \quad (4)$$

Handover latency is initiated after the disconnection of MN from pMAG and stopped when LMA and target MAG share PBU and PBA messages in the smart buffering scheme. RSS error does not affect the RSS error as the packets are delivered to MN if it is inside the pMAG domain. PBU and PBA messages are exchanged when MN is detected by nMAG. In the meantime, FReq and FRep messages are also communicated between pMAG and LMA.

After the nMAG receives these messages, the process for handover ends. The required handover in a smart buffering scheme can be calculated using Equation (5).

$$t_{\text{Smart-buff}} = t_{L2} + t_{RS} + t_{WRS} + t_{RA} + \max\{(t_{PUB} + t_{PBA}), (t_{FRep} + t_{FReq})\} \quad (5)$$

Handover starts in low latency scheme when DeReg-PBU is received by LMA in low latency scheme. After the nMAG detects the MN then PBU messages are forwarded to LMA and LMA responds with PBA to nMAG. LMA then provides the buffered packets to nMAG that is further delivered to MN. The low latency scheme is also affected by the RSS error. In such cases, the handover starts early, which also adds additional latency to the scheme. Overall handover latency in a low latency scheme is computed using Equation (6).

$$t_{\text{Low-latency}} = t_{\text{error}} + \varnothing + t_{WRS} + t_{L2} + t_{RS} + t_{PBA} + t_{RA} \quad (6)$$

3.3.1. Handover Latency in Location-Based RSS Extensions

Compare to the other schemes, the location-aware scheme provides much better handover performance due to the effective utilization of location information for handover prediction. In addition, the MN receives the services as long as it is in the pMAG domain. Furthermore, the forwarded buffered packets to nMAG from pMAG are also delivered to MN as soon as the MN attaches to nMAG. Overall, the location-aware scheme provides efficient handover latency and can be calculated using Equation (7).

$$t_{\text{Location-aware}} = t_{WRS} + t_{L2} + t_{RS} + t_{\text{w-data}} \quad (7)$$

LH-PMIPv6 scheme is also based on location information and is not affected by RSS error, so no additional latency is added to the scheme. Handover starts when DeReg-PBU is received by LMA from the pMAG. The handover process ends when MN is attached to nMAG. Next, MAG and LMA exchange PBU and PBA messages. RA is communicated to and buffered packets are provided to nMAG by LMA for MN. Equation (8) describes the measuring of handover latency in LH-PMIPv6.

$$t_{\text{LH-PMIPv6}} = t_{WRS} + t_{L2} + t_{RS} + t_{PBA} + t_{RA} \quad (8)$$

3.3.2. Handover Latency of the Proposed Loc-PMIPv6

The proposed Loc-PMIPv6 protocol extension utilizes the location information for eliminating early handoff, and additional latency in addition to communicating to target MAG using nMAG-ID. Regarding handover performance, the proposed scheme keeps sending packets to MN when MN is inside the pMAG domain. LMA-stored packets are provided to nMAG when MN is disconnected from pMAG. Based on the connection of MN with target MAG, the target MAG immediately sends the buffered packets by minimizing the handover latency. Therefore, the handover latency for the proposed Loc-PMIPv6 is calculated using Equation (9).

$$t_{\text{Loc-PMIPv6}} = t_{WRS} + t_{L2} + t_{RS} + t_{\text{w-data}} \quad (9)$$

3.3.3. Buffering Cost

Buffering is required for the packet-loss problem because, during the handover process, the MN is disconnected and the packets may be lost. For such a problem's solution, the incoming packets are stored until the MN is connected to the target MAG. However, long handover latency and the additional latency due to RSS error incur additional buffering. Although, handover efficiency contributes to the efficiency of buffering. However, several schemes keep multiple copies of the packets to ensure that the packet loss that consumes additional resources is required. Therefore, an efficient PMIPv6 extension avoids unnecessary buffering during MN's handover. The following is the detail of the buffering mechanism in the existing and proposed scheme.

3.3.4. Buffering Required in Non-Location-Based RSS Extensions

The FPMIPv6 is an RSS-based scheme and does not use the location for accurate prediction of the handover moment. Therefore, due to RSS error, the scheme incurs additional buffering when the prediction of the scheme is wrong. Buffering costs in this scheme include the packets stored at nMAG from the pMAG using the established tunnel until the MN reaches to nMAG domain and is attached to nMAG. Buffering required in the FPMIPv6 scheme is calculated using Equation (10) where session length and session rate are represented by $E(s)$ and λs.

$$B_{\text{FPMIPv6}} = \lambda s \cdot E(s) \cdot \{ t_{\text{error}} + \varnothing - (t_{\text{scan}} + t_{\text{report}} + t_{\text{mag}} + t_{\text{HI}} + t_{\text{HAck}}) + t_{\text{L2}} + t_{\text{RS}} + t_{\text{WRS}} \} \quad (10)$$

The smart buffering scheme is also affected by the RSS error due to the environment. In such cases, the handover moment is detected as incorrect and, due to early handover initiation, the packets are buffered. pMAG buffers the packet in a smart buffering scheme until the FReq message is received by nMAG. Furthermore, the buffered packets are forwarded to nMAG from the duration when nMAG achieves FRep and PBA messages. In a situation, where the PBA is received by nMAG from LMA earlier than FRep, the packets are buffered from LMA so that it receives all the packets from pMAG. Buffering can be calculated by using Equation (11).

$$B_{\text{smart-buff}} = \lambda s \cdot E(s) \{ t_{\text{error}} + t_{\text{L2}} + t_{\text{WRS}} + t_{\text{RS}} + t_{\text{FReq}} + \text{abs}\,(t_{\text{PBU}} + t_{\text{PBA}} - t_{\text{FReq}} - t_{\text{Frep}}) \} \quad (11)$$

Buffering in low latency extension starts when the DeReg-PBU message is received by LMA. Buffering is continued up to the moment when LMA receives the PBU message from nMAG after the MN's attachment is detected. Having the dependency of the procedure of low latency scheme over RSS measure, the scheme is affected by the RSS error, and additional buffering is performed when RSS error occurs. In response to the PBU, LMA replies with PBA, and the stored packets are provided to nMAG which is further delivered to MN. Buffering in a low latency scheme is computed using Equation (12).

$$B_{\text{Low-latency}} = \lambda s \cdot E(s) (t_{\text{error}} + \varnothing + t_{\text{L2}} + t_{\text{WRS}} + t_{\text{RS}}) \quad (12)$$

3.3.5. Buffering Required in Location-Based RSS Extensions

Contrary to the schemes that only depend on the RSS measure, the location-aware scheme is based on the location of resources and is not affected by RSS error; hence, the additional buffering is avoided by predicting the accurate handover. The starting point of buffering is when the RSS and location are proper for handover. The pMAG keeps buffering the packets until MN moves from the pMAG domain. Upon disconnection of MN, the buffered packets are transferred to nMAG using the bi-directional tunnel. When MN is attached to nMAG, the buffered packets are delivered to MN. The buffering uses Equation (13) in a location-aware scheme.

$$B_{\text{Location-aware}} = \lambda s \cdot E(s) (\varnothing - t_{\text{report}} + t_{\text{L2}} - t_{\text{mag}} + t_{\text{WRS}} + t_{\text{RS}}) \quad (13)$$

Buffering in LH-PMIPv6 begins when DeReg-PBU is received from pMAG to LMA. Based on the location of network entities, the RSS error is not affecting the performance of this scheme. Buffering begins after DeReg-PBU and ends when LMA receives the PBU message from nMAG after MN is attached to nMAG. Buffering cost in the LH-PMIPv6 is calculated using Equation (14).

$$B_{\text{LH-PMIPv6 (v1)}} = \lambda s \cdot E(s) (\varnothing - t_{\text{report}} + t_{\text{L2}} - t_{\text{mag}} + t_{\text{WRS}} + t_{\text{RS}} + t_{\text{PBA}}) \quad (14)$$

3.3.6. Buffering Required in Proposed Loc-PMIPv6

The proposed Loc-PMIPv6 extension is based on location information in addition to the RSS measure. As a result, the proposed extension protocol is not prone to RSS error.

Buffering in this scheme starts when the DeReg-PBU is received by LMA from pMAG. The packets are buffered in LMA until the MN is disconnected from pMAG. Buffered packets are forwarded to nMAG so that the packets are immediately delivered as soon as the MN becomes attached to nMAG. Upon the connection of MN with nMAG, buffered packets are provided. Equation (15) is used for measuring the buffering cost of LH-PMIPv6 extension.

$$B_{LH\text{-}PMIPv6(v2)} = \lambda s \cdot E(s) \big(\varnothing - t_{report} + t_{L2} - t_{mag} + t_{WRS} + t_{RS} \big) \tag{15}$$

4. Implementation and Evaluation Measures

For assessment and comparison of the proposed PMIP6 protocol extension with the existing RSS-based PMIPv6 extensions, mathematical equations are derived for comparing the efficiency. For measuring the potential integration of the proposed scheme in IoT, equations are implemented by developing an application. The main purpose of the application is to provide an easy means for the user to provide input parameters and generate output results and assess the performance for fulfilling the requirements of 6G adopted IoT. Users can easily set different parameters and their values such as RSS checking, the velocity of nodes, etc., along with the customization of output file generation. The details of the parameters, their default values, and their description are shown in Table 1. The application measures handover latency, signaling required, and the required buffering and stores these results in an Excel file. Excel can be used for meaningful interpretations for incorporating more features and functionality, and the application will be updated and refined in future installments.

Table 1. Parameters and variables used for analysis.

Parameters Taken	Symbol	Default Values
The radius of the cell	R	100 m
Number of MNs	δ	20
Cost of HI message	C_{HI}	52 bytes
Cell crossing rate	μ_c	Equation (2)
The delay occurs from L2 down to L2 up	t_{L2}	0.02 s
Hopes between two MAGs	H_{MAGs}	04
Cost of L2report	$C_{L2report}$	40 bytes
The velocity of the nodes	υ	{5,. . ., 50}
No of hope between MAG and LMA	H_{LMA_MAG}	06
Cost of IHR message	C_{IHR}	52 bytes
Measuring time	T	30 s
HI message transmission time	t_{HI}	0.03 s
Number of MAGs around a MAG	N	20
Cost of HAck message	C_{HAck}	52 bytes
PBU message transmission time	t_{PBA}	0.06 s
Delay before sending RS message	t_{w-data}	0.001 s
Delay before sending RS message	t_{WRS}	0.01 s
Time for scanning nMAG	t_{scan}	0.02 s
HI message transmission time	t_{Hack}	0.03 s
Cost of sending MAG's location information	C_{loc_MAG}	40 bytes
FReq message transmission time	t_{FReq}	0.03 s
Session length	$\lambda s \cdot E(s)$	20 bytes
PBA message transmission time	t_{PBU}	0.06 s
Session rate	$\lambda s \cdot E(s)$	0.01/s
Delay for L2 down since MAG or MN detects that RSS is below the threshold	∅	0.02
The probability of RSS error	p_e	Rate of RSS error
FRep message transmission time	t_{FRep}	0.03
RS transmission time	t_{RS}	0.01 s

Measures for Evaluation

The proposed equations regarding the optimized protocol extension are Equations (1), (14) and (15). Equations are also implemented in the Java application to measure the cost of associated issues for parameters. However, to assess the effectiveness of the proposed protocol extension, criteria are defined for evaluating the performance of the existing PMIPv6 protocol extensions. For this purpose, a number of quality assessment criteria are defined to assess the effectiveness of the proposed solution in addition to the factors that are affecting the performance of such protocol extensions. Such aspects include the number of nodes, variation in the velocity of MNs, and the effect of RSS on the performance of handover latency, required buffering, and the signaling cost. Based on such aspects, the effectiveness of the existing and proposed scheme is compared. The details of the comparison and obtained results are discussed in detail in the subsequent sections.

5. Results and Analysis

Using the aforementioned criteria for comparing the proposed and existing PMIPv6 extensions, the schemes are compared and results are analyzed for their effective performance efficiency in the context of the IoT domain. Performance efficiency is obtained in the context of the buffering of each scheme, the handover latency, and the signaling required for initiating the handover process. Furthermore, along with the above performance criteria, other aspects during mobility of MN are also considered to have direct or indirect effects on the performance. These include the variations in the velocity of MNs that directly affect the signaling cost. In addition, the number of MNs has a direct relationship with the signaling required. Furthermore, RSS error probability has a severe effect on signaling efficiency due to early handoff. Early handoff also increases the additional buffering and the handover latency. The results are analyzed in the presence of RSS error, velocity, and number of MNs. Detail of such analysis is provided as follows:

5.1. Signaling Efficiency (A1)

Initially, the effect of the RSS error on the signaling cost is assessed. For this purpose, the velocity of the MN is taken constant, such as (v = 20 m/s), and the signaling cost is assessed for variations in RSS error (0.0–0.5). It is important to mention that the velocity has a direct relationship with signaling cost, in the context of increasing velocity when the signaling cost becomes high. For meaningful representation, signaling cost is plotted on the y-axis while variation in RSS error is recorded on the x-axis. The comparison is shown in two parts. First of all, the proposed extension is evaluated in comparison with non-location RSS extensions as shown in Figure 2. Furthermore, a comparison among location-based available and presented schemes is represented in Figure 3.

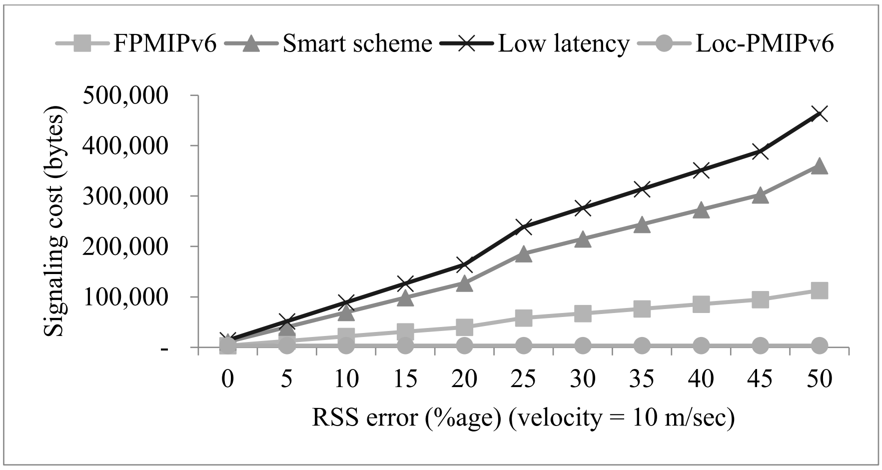

Figure 2. Comparing signaling among proposed and non-location-based extensions.

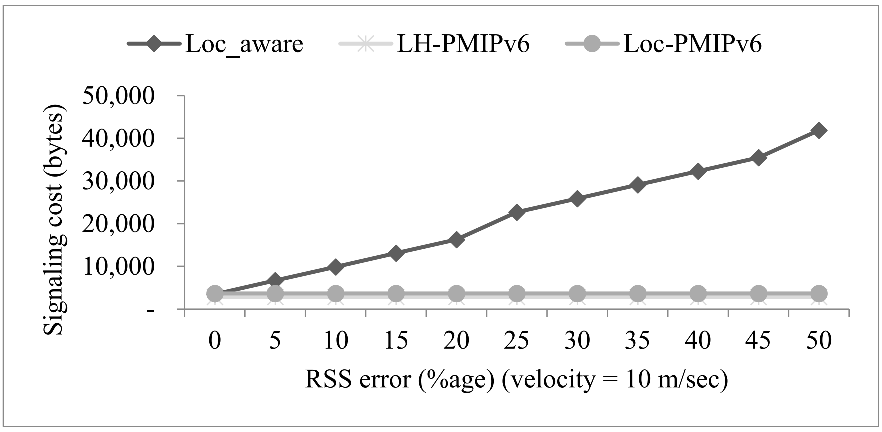

Figure 3. Signaling comparison among proposed and location-based extensions.

From the statistics, it is shown that RSS-based existing schemes including low latency scheme, FPMIPv6, and smart buffering, incur high signaling for different levels of RSS error. One of the main reasons for their worst performance is that these schemes are only based on the RSS measure. Therefore, when the RSS is affected by the environment, then these schemes are affected by wrong handover moment prediction, which ultimately leads to high signaling costs. In the case of location-based PMIPv6 extensions, the signaling cost is much lower than the aforementioned schemes. Among these schemes, proposed Loc-PMIPv6, and LH-PMIPv6 protocol extensions have high signaling efficiency compared to location-aware PMIPv6 extensions.

In addition, the signaling required is directly affected by the attached number of MNs to a corresponding MAG. For this purpose, experiments are run for different numbers of MN, and the respective required signaling is assessed. The statistics of the same are represented in Figures 4 and 5, where MNs are horizontally plotted with variations in the range (20–100) in addition to the RSS error due to environment (RSS = 0.20). It is observed that the signaling cost is directly affected by the number of MN. Among the existing schemes, the schemes that do not use location information for handover moment perform much worst in comparison to the location-based extensions. Such a scheme includes a low latency scheme, FPMIPv6, and smart buffering. Among the location-based extension protocols, the proposed LH-PMIPv6 performs better compared to the location-aware PMIPv6 protocol extension. Based on the relative comparison, the proposed scheme provides promising signaling efficiency with respect to the existing location-aware and RSS-based PMIPv6 protocol extensions.

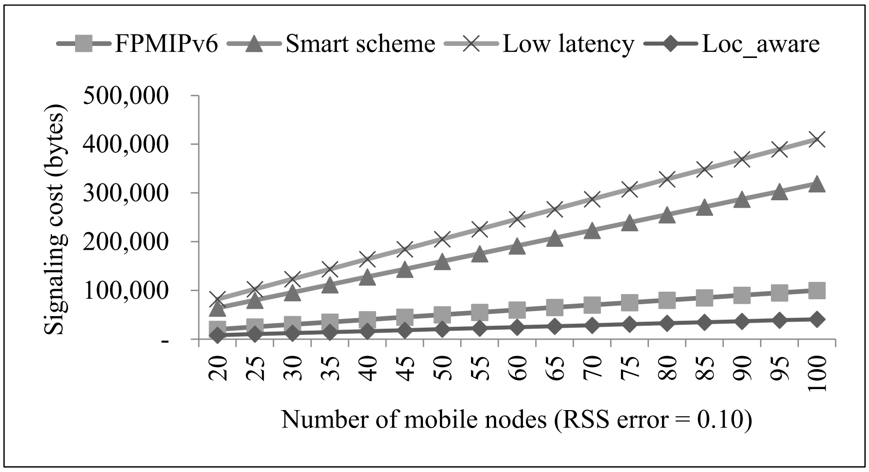

Figure 4. Signaling comparison among proposed and non-location-based schemes.

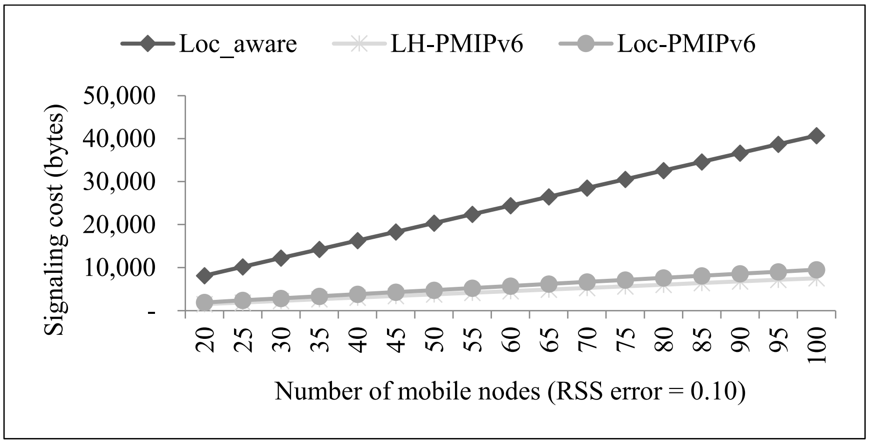

Figure 5. Signaling comparison among proposed and location-based schemes.

By analyzing the results obtained from the comparison, it is observed that the proposed scheme requires less signaling by avoiding any additional communication that takes place between MNs and MAG in the presence of RSS error. Furthermore, by accurately predicting the target MAG-ID, the LMA avoids multi-casting IHR messages to the surrounding MAGs. Such enhancements significantly reduce the signaling required.

5.2. Handover Latency (A2)

The handover latency of the schemes is compared based on the variations of RSS error. For analysis, the variations of RSS error are taken between the range (0.0–0.5), and the respective handover latency is evaluated. The statistics of the comparison among non-location-based schemes and extensions are provided in Figure 6. While the statistics of comparison among location-based existing schemes and the proposed one are shown in Figure 7. In the comparison graphs, the horizontal axis depicts the error probability, and the y-axis represents the handover latency. RSS error probability affects the handover latency and by comparison, it is observed that location-based PMIPv6 extensions provide much less handover latency. With the existing extensions including FPMIPv6, low latency, and smart buffering, the handover latency becomes much too high for high RSS error probability.

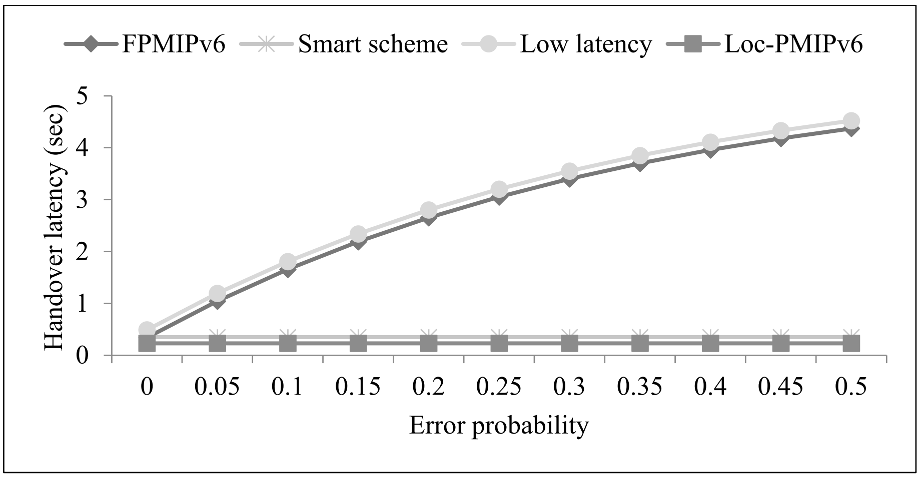

Figure 6. Comparing handover latency among processed and non-location-based schemes.

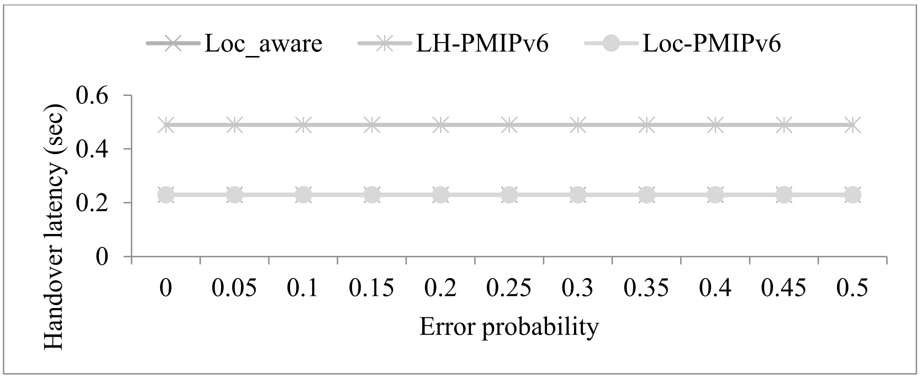

Figure 7. Comparing handover latency among processed and location-based schemes.

Among the location-based scheme, the proposed scheme provides much more promising handover latency compared to the existing LH-PMIPv6 protocol extensions and provides the lowest level of latency equivalent to the location-aware PMIPv6 extension protocol. By exploiting the location information of network entities, the proposed scheme provides a more resource-efficient solution. One of the optimizing factors behind the location-based scheme is the prediction accuracy of the handover moment, whereas other schemes start the handover process earlier than the actual time. Furthermore, the proposed solution eliminates such problems in addition to the additional communication among network entities.

5.3. Buffering Cost (A3)

Buffering required for solving the packet-loss problem is assessed between the existing scheme and the proposed one. Buffering required is evaluated in the context of an error-free environment and when the RSS error probability varies. In reality, the RSS, due to the environment, affects a number of existing schemes including low latency scheme, FPMIPv6, and smart buffering. For representing such phenomena, these extensions are compared with RSS error variations in the range (0.0–0.5) while keeping the session rate value (0.05). A more meaningful representation of the comparison is shown in Figures 8 and 9. Statistics show that buffering cost is directly proportional to the session rate. The schemes including low latency, smart buffering, and FPMIPv6 suffered from additional buffering due to RSS error. On the other hand, location-based PMIPv6 approaches are not affected by RSS errors. Among the location-based scheme, the proposed scheme performs relatively better than the LH-PMIPv6 scheme while providing the same level of buffering efficiency as the location-aware PMIPv6 extension.

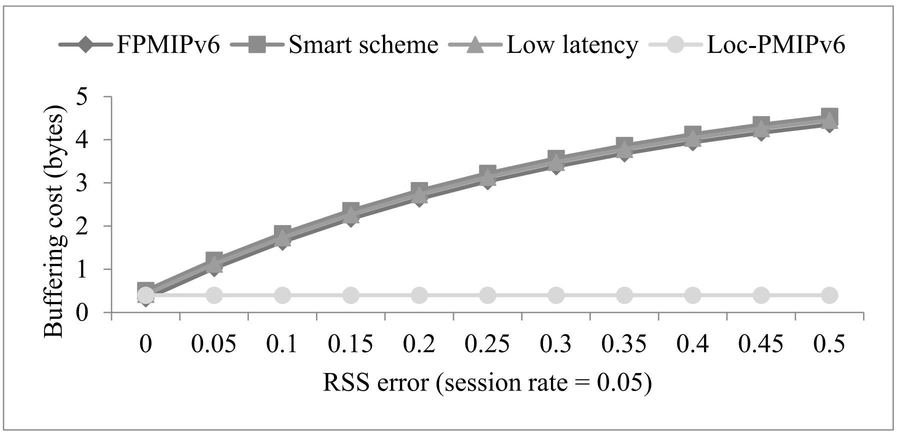

Figure 8. Buffering comparison among processed and non-location-based schemes.

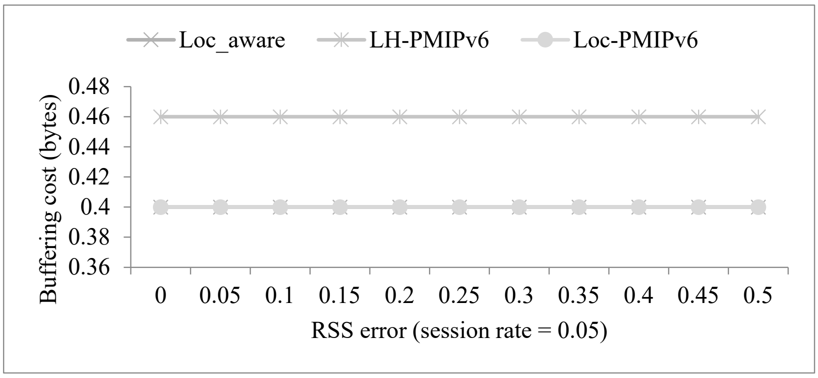

Figure 9. Comparing buffering among processed and location-based schemes.

From the comparison, the proposed solution provides higher signaling efficiency, low handover latency, and efficient buffering performance by predicting the handover moment accurately. Furthermore, the presented scheme eliminates the multi-casting of IHR by LMA due to the utilization of target MAG-ID. As a result, the proposed solution is more reliable and has the potential for its adaptation for mobility management in upcoming future-generation communications.

6. Conclusions and Future Work

Integration of future communications in IoT has the capability to provide many effective business opportunities to meet the requirement of current as well as future needs. Future 6G-enabled IoT requires resource-efficient mobility solutions in addition to a better quality of services requirement. For supporting mobility in industrial IoT, a location-oriented network-based IPv6 solution is provided to optimize the performance of PMIPv6 protocol by effectively using the location information of network resources in the domain of industrial IoT in addition to integration with RSS measure. By avoiding additional communication, and unnecessary messages due to RSS errors, the proposed extension provides resource efficiency by accurately predicting the handover moment and avoiding additional signaling and buffering. The presented extension is evaluated in comparison with available related RSS protocol extensions and, based on the results obtained, it is observed that the proposed solution optimizes the performance by reducing handover latency, eliminating additional signaling, and requiring buffering. This research has the potential to be adapted for supporting mobility requirements in industrial IoT. Furthermore, the proposed extension can be enhanced by the inclusion of a number of aspects such as speed, direction, and mobility history for intelligent decision-making regarding resource efficiency and load distribution among network resources.

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