IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Ingénierie des Systèmes d'Information
Vol. 27, No. 4, August, 2022, pp. 557-563
Journal homepage: http://iieta.org/journals/isi

Realistic Vertical Handoff Predictive Trigger Thresholding in Heterogeneous Networks

Ganesh Rahate*, Nilkanth Chopade

Department of Electronics and Telecommunication, PCCoE, SPPU, Pune 411019, India

Corresponding Author Email: ganeshrahate.pccoe@gmail.com

https://doi.org/10.18280/isi.270405

Received: 20 April 2022
Accepted: 8 July 2022

Keywords:
vertical handover, heterogeneous networks, MIH, IEEE 802.21, NS-2

ABSTRACT

The contemporary wireless networks exhibit heterogeneity, i.e., different types of wireless networks co-exist and fulfill the user's needs. Users amongst the available networks prefer the Wi-Fi and 4G networks. Wi-Fi is a choice for homes and offices for limited coverage and high data rate. While for outdoor, 4G is a better choice due to broader coverage and reasonably better average data rates. As user mobility is high nowadays, smooth session transfer is essential amongst such heterogeneous networks to provide seamless connectivity with the best QoS. Currently, video real-time application traffic is in high demand. This paper investigates the heterogeneous /vertical handover performance for realistic traffic and terminal speeds based on the MIH framework. The MIH is IEEE 802.21 standard to maintain the service continuity amongst heterogeneous networks. The primary focus of this paper is to derive the thresholds for speeds and the link layer predictive triggers. These thresholds are helpful in the design of the algorithms to enhance the QoS and user experience. Further, to understand the limitations of the said standard for a given scenario. The packet loss ratio and handover latency are the QoS parameters. The detailed simulations are carried out in NS-2 by considering a realistic scenario of terminal speeds and application traffic (MPEG-4, H.261, and HDTV). The networks chosen for the analysis are Wi-Fi and 4G. The packet loss ratio and handover latency are considered QoS parameters. For the accuracy of results, simulation time is varied as per the user's speed. We derived predictive trigger and speed thresholds critically examined for the given application traffic.

1. INTRODUCTION

With the introduction of data-centric services at an accessible price, LTE (Long Term Evolution) customers have increased exponentially [1], with the total 4G user base of all operators reaching 1,154.62 in December 2021. Wireless subscriptions in urban areas reached 633.34 million at the end of December-21, and wireless subscriptions in rural areas reached 521.28 million during the same period. As per the Global Internet Phenomenon report 2021, amongst the top 10 application traffic, video streaming share is 48.9% downstream and 19.4% upstream, totaling 68.3% of the total internet traffic [2].

Looking at the Indian scenario, wireless subscribers greatly depend on the 4G LTE network as it covers almost the entire geographic area in the country. Wi-Fi is an IEEE 802.11 standard and is a widely acknowledged wireless network for homes and offices, especially in urban areas. The 2G network GSM and its evolutions like GPRS, EDGE as well as 3G networks UMTS have a limited market share in India [1]. The CDMA and its evolutions, such as cdma2000, 1xEV-DO, and 1xEV-DV, hold the least share in the market [3]. WiMAX (IEEE 802.16) evolved into 802.16 e/m, and other variants are also working with a small share. The resulted scenario is the heterogeneous wireless ecosystem, supporting the end-users. In this context, coexistence capabilities in such wireless networks are required to extend QoS and QoE to end subscribers. Hence for user mobility amongst these heterogeneous networks, vertical handover is essentially required for easy migration, always the best connection, QoS, and QoE requirements.

Handover is the process of keeping a session live while changing the access point. If a handover happens between different radio access technologies (RAT), it is called heterogeneous or vertical handover (VHO). The globally mobile subscriber base is exponentially increased. With the advent of smartphones and with slashed pricing of data services, the demand for data services too increased rapidly in recent years. This subscriber relies on co-existing next-generation heterogeneous networks like LTE, WiMAX, Wi-Fi, etc. Wi-Fi is limited coverage, a high data rate network, while LTE/WiMAX is a broader coverage, low data rate network compared to Wi-Fi. Today's phones are equipped with a multi-network interface. Depending on the user's choice of required Quality of Service, he/she can change the network as per the need. This change over of service happens more often amongst Wi-Fi and 4G networks like LTE/WiMAX.

In this paper, we address the performance analysis of the VHO between Wi-Fi and 4G networks for a realistic scenario of mobile networks. We consider video streams H.261, MPEG-4, and HDTV for analysis. As per the need of applications, the speed and link quality thresholds are derived through experimentation. Section 2 gives an overview of various solutions for VHO related to high data rate traffic. Section 3 briefly reviews the MIH and related triggers. In section 4, the realistic simulation parameters are presented. Section 5 and 6 are the simulation results and conclusion, respectively.

2. RELATED WORK

There are various proposals available in the literature to optimize vertical handovers.

Duraimurugan et al. [4] presented a novel architecture for heterogeneous networks in which they advise improving functions at the server-side to boost QoS. In terms of QoS criteria such as latency, delivery ratio, and throughput for various data rates and buffer sizes, the suggested design is compared to the current architecture. The findings show that end-to-end latency is decreased by 10%, the delivery ratio is improved by 12%, and throughput is raised by 17% when compared to the previous design. However, realistic terminal speeds need to be considered for QoS parameters. Moreover, the major focus is on the video streaming traffic.

In their study, Ferlin et al. [5] investigated the loss recovery mechanism of TCP and MPTCP in order to enhance the performance in high latency and lossy networks. Due to the fact that TCP recovery mechanisms in multipath impede head-of-line blocking, this methodology is extended to multipath TCP (MPTCP), with a special focus on heterogeneous situations. The authors evaluate the proposed framework's performance and show that it can significantly enhance latency-sensitive real-world traffic like video streaming and online services when compared to regular TCP and MPTCP. However, the major focus is on real-time traffic only and reducing latency by integration of FEC and TCP.

In their paper, Medeiros et al. [6] propose a QoS/QoE and Radio-aware SER handover management strategy for heterogeneous networks in order to facilitate video dissemination with QoS/QoE. The SER algorithm employs the analytic hierarchy process (AHP) to change the priority of each criterion in order to choose the best radio base station for the mobile node to connect to, allowing for quick video transmission decisions and a great user experience. Due to the SER approach, much higher-quality videos are obtained than earlier handover techniques. But the terminal speed is equally important while the transfer of a call from one access point to other and should be considered when proposing the various algorithms.

Mohamed Lahby et al. [7] proposed a novel technique based on a k-partite graph. To represent the vertical handover problem, the authors first propose the k-partite graph theory. Second, a robust and lightweight technique based on the cost function and Dijkstra's algorithm is used to choose the optimum path. The experimental findings suggest that the proposed technique can provide superior QoS performance for FTP traffic and video streaming than existing algorithms. In this paper, the major focus is on video streaming traffic only, and terminal speed needs to be considered.

In their paper, Marques et al. [8] give a quick rundown of the 802.21 standards that are used in a WiMAX-to-Wi-Fi handoff. The paper also evaluates ns-2's scalability and reliability when simulating 802.21 scenarios with several nodes and proposes a novel and very simple method for calculating the predicted number of handovers in an ns-2 simulation. The proposal majorly focuses on procedural aspects of the MIH process and the CBR traffic.

According to Jain and Tokekar [9] the vertical handoff decision is influenced by the network coverage region and Mobile Node speed. Real-time applications such as HDTV, MPEG-4, and H.261 are studied. For various network traffic loads, application types, and Mobile Node speeds, vertical handoff latency is explored. They have shown that the speed of the Mobile Node has an influence on packet loss. However, they have considered an integrated heterogeneous network that includes UMTS and WLAN.

Sinky et al. [10], in their work, proposed their results on transport layer handoff difficulties in currently deployed networks. The usage of MPTCP as a viable solution to alleviate handoff- and mobility-related service continuity challenges is then discussed. Finally, they suggest cross-layer strategies to consider while creating a handoff-aware MPTCP protocol. However, the terminal speed is set at a standstill, and pedestrian-only and high-definition traffic need to be considered [8].

Jayasheela and Gowrishankar [11] proposed a new VHO approach to solve the reliability and robustness issues related to vertical handover decisions. They suggested a vertical handover method based on LSTM. Formal approaches for analyzing wireless network reliability and flexibility in relation to handoff choices were given. The suggested vertical handover approach was compared to a current technique in simulated research, and the new vertical handover technique demonstrated its relative strengths by producing trustworthy and robust handoff judgments. However, in this proposal, formal methods are used to find the reliability and robustness of vertical handoff.

Zang et al. [12] in their proposal, they present a novel, efficient handover decision technique for mmWave HetNets based on a Markov Decision Process (MDP) to improve the overall service experience of consumers. The suggested approach eliminates unnecessary handovers and successfully addresses beam forming misalignments and signal blockages in mmWave small cells by exploiting the user's mobility information. The authors proposed the numerical results of reduction in the computational complexity.

Chatting et al. [13] present a network selection method based on the Fuzzy technique for order preference with similarity to the ideal solution (FTOPSIS) algorithm, which is used to categorize the available networks. After that, the weights of the criteria were calculated using the Fuzzy analytic hierarchy process (FAHP) approach. To assess our suggested strategy, we show implementation and simulation studies. Our FE-TOPSIS method beats the standard FTOPSIS algorithms, according to the results. However, the authors majorly focus on easing the network selection process by considering all types of traffic classes for a given terminal speed.

In their paper, Abdullah and Zukarnain presented a better vertical handover determination approach for heterogeneous wireless networks based on a number of criteria. The algorithm is made up of three different technical interfaces: LTE, WiMAX, and WLAN. Vertical handover determination methods are divided into three categories: equal priority, mobile priority, and network priority. The simulation findings demonstrate that the three types of decision algorithms outperform the typical network decision algorithm [14] in terms of handover number probability and handover failure probability. The authors have focused on 4960 bytes of video and 320 bytes of audio traffic for a given terminal speed.

For better understanding of the heterogeneous networks and handoff few more proposals of different technologies [15] and [16] are also referred. The realistic terminal speed, the class of the traffic, vertical handoff latency, and packet loss are essential factors in selecting the vertical handoff option and assuring seamless mobility. In the reviewed papers, realistic terminal speeds and one or the other traffic class are considered for experimentation. In light of this, the current study proposes deriving an impact of real terminal speeds and almost all popular video traffic classes on vertical handover using the MIH framework. An application-specific Mobile Node cut-off speed for optimal VHO performance is derived. Also, predictive trigger thresholds for a given scenario are determined. This paper investigates the impact of Mobile Node speed on vertical handoff delay performance for various applications. The effect of packet loss on the Mobile Node's speed is also explored.

3. MIH (MEDIA INDEPENDENT HANDOVER)

The Media Independent Handovers (MIH), commonly known as the IEEE 802.2l standard, is an IEEE solution for handoff. The IEEE 802.21 standard has provided a framework for improving and optimizing intra-system and inter-system handoffs. The handoff is accomplished by passing information from the lowest layer (Link layer) to the upper levels [3, 17]. The IEEE 802.21 standard enables MNs to find and pick the best network in their area. The kind of link, quality, and identifier are examples of typical information flow between a neighborhood network and an MN. MN will be able to connect to the best network available due to this. It is critical to preserve adequate security relationships between communication end-points while the mobile switches Points of Attachment (PoA). Lower and higher-layer approaches can be used to achieve these security linkages. The MIH Function (MIHF), which is positioned between the MIH User (MIHU) and the device interface as depicted in Figure 1, is the heart of MIH [3].

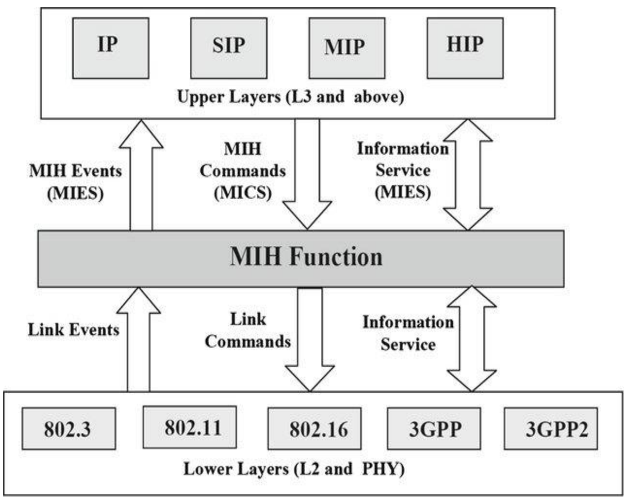


Figure 1. MIH architecture [17]

MIH has the support of various events and triggers shown in Table 1.

Table 1. MIH predictive and events triggers [8]

Sr. No.	Event triggers	Predictive triggers
1	Link Up	Link Going Down
2	Link Down	Link Going UP
3	Link Detected	
4	Link Roll Back	
5	Link Parameters Report	
6	Link Handover Imminent	
7	Link Handover Complete	

Predictive and event triggers are the two forms of Layer 2 triggers. Predictive triggers indicate the likelihood of a future change in system attributes. Because they are attempting to forecast the future, they may be inaccurate; therefore, being able to withdraw a predictive trigger is advantageous. The term "event trigger" refers to a specific event that has occurred. An example of an event trigger is Link Up, Link Down, Link Detected, etc. An example of a predictive trigger is Link Going Down [8, 18]. The various L2 triggers that have been found to aid in the handoff process are depicted in Figure 2. We are using the predictive trigger LGD for experimentation.

The Link Detected trigger is the indication of target network availability, and handover to the target network can be initiated. The Link-Up and Link Down trigger is an indication of the readiness of Layer 3 to send or not the packets over the link. An LGD trigger is an indication that a Link Down is expected soon, and the handoff process can be initiated. If the link starts going up, then a Link Roll Back trigger sent to the triggered destination [18].

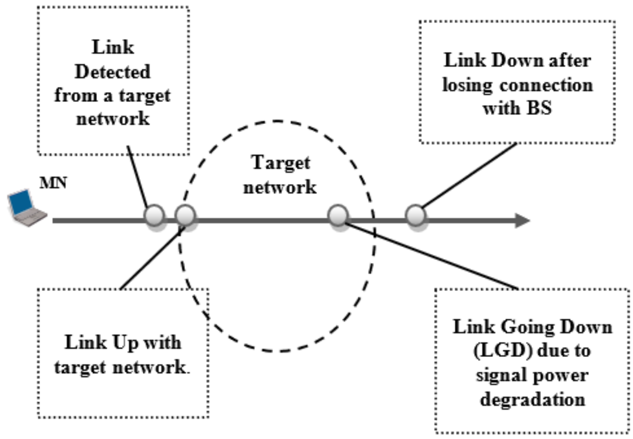


Figure 2. Event and predictive triggers [17]

4. SIMULATION PARAMETERS

This section describes the simulation parameters of experimentation. We used ns-2.29 with the NIST add-on patch for simulating an overlapping scenario shown in Figure 3.

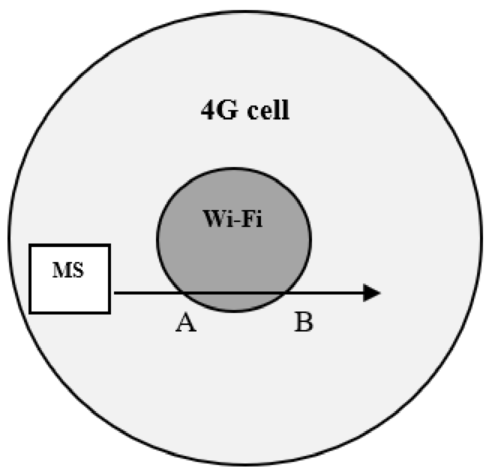


Figure 3. Simulation Scenario

An overlapping coverage of 4G and Wi-Fi networks is shown in Figure 3. MS starts its journey in a rectilinear path and crosses the Wi-Fi cell twice, causing vertical handoff around points A and B. The MS is a multi-interfaced node equipped with Wi-Fi and a 4G interface. At the beginning of the simulation, it is connected to a 4G network, senses a better network (Link Detected trigger) while moving, and selects Wi-Fi. The first VHO takes place between 4G to Wi-Fi at point A. It leaves Wi-Fi coverage depending upon its speed and the second VHO begins on a generation of LGD triggered by Wi-Fi around point B.

4.1 Network parameters

Table 2 shows the network-related parameters used in the simulation.

Table 2. Network Simulation parameters

Sr. No.	Parameters	Value
1	Application Traffic	UDP (CBR) 200Kbps, 396.8Kbps, 1Mbps, 4Mbps
2	4G network coverage	1000m
3	Wi-Fi coverage	20m
4	4G Parameters	RX Threshold= 1.26562e-13, CS Threshold= 80% of RX Threshold, dcd_interval= 5sec, ucd_interval=5sec, modulation= OFDM_16QAM_3_4,
5	Wi-Fi Parameters	RX Threshold=6.12277e-09, CS Threshold=90% of RX Threshold
6	pr_limit	1 to 5 for prediction trigger Link Going Down (LGD)
7	Propagation channel	Two-Ray Ground model
8	Antenna	Omnidirectional
9	Mobile Station Velocity	1,1.3,3 and 4.7m/s
10	Simulation duration	Speed specific

4.2 Realistic MS velocities

For experimentation, realistic speeds of MS [19] are considered, which are given in the following Table 3.

Table 3. Realistic MS velocities [19].

Sr. No.	User velocity type	Velocity m/s
1	Mobile users with PDAs.	1
2	Pedestrian	1.3
3	Public bus during peak traffic time.	3
4	Public bus during peak-off traffic time.	4.7

4.3 Simulation time

The simulation time is kept variable depending upon the velocity of MS specified in Table 4. MS starts at 470 m in the scenario and stops at 540m. It covers 70m of distance during its journey. Simulation time is manually evaluated and adjusted around the Wi-Fi cell boundaries given in Table 4. Variable simulation time enables the accuracy of measurement of handover latency and packet loss as QoS parameters.

Table 4. Velocity-specific simulation time

Sr. No.	Simulation time(sec)	Velocity m/s
1	70	1
2	54	1.3
3	23	3
4	15	4.7

4.4 Application traffic

Table 5 gives the real-time application traffic [9] considered for experimentation. The CBR video is the high demand traffic is purposely considered to retrieve the MIH performance for high bandwidth traffic optimally.

Table 5. Real-time application traffic [9]

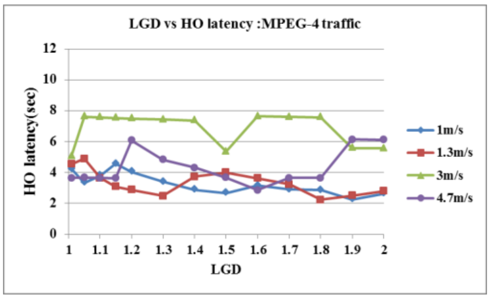
Sr. No	Application Traffic	Interval(ms)	Packet Size	Data Rate
1	HDTV	2	1024	4Mbps
2	MPEG-4	6	800	1Mbps
3	Video Streaming	100	4960	396.8Kbps
4	H.261	26	660	200Kbps

5. SIMULATION RESULTS AND DISCUSSION

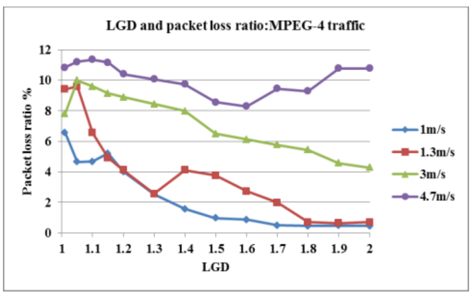
This section analyzes the impact of predictive trigger LGD for various MN speeds and application traffic. We propose fair LGD values and speed thresholds for real-time video traffic.

5.1 QoS parameters

Figures 4-7 show the impact of the LGD trigger on QoS parameters (handoff latency and percent packet loss ratio) for the specified CBR traffic.

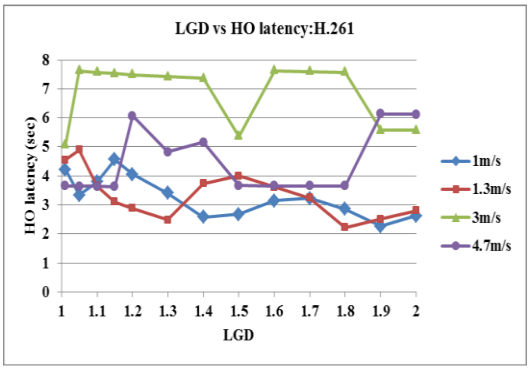


(a) Handoff latency for MPEG-4

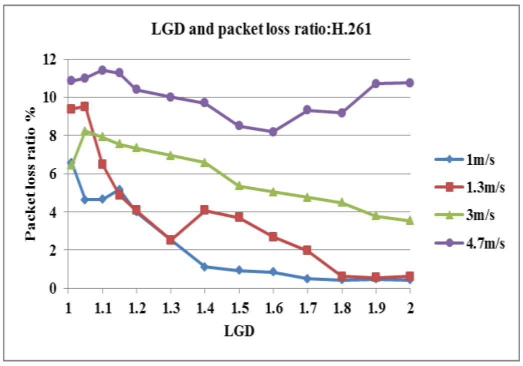


(b) Packet loss ratio for MPEG-4

Figure 4. QoS parameters for MPEG-4 traffic

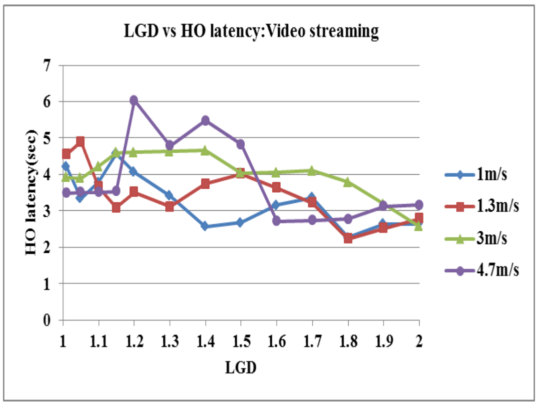


(a) Handoff latency for H.261

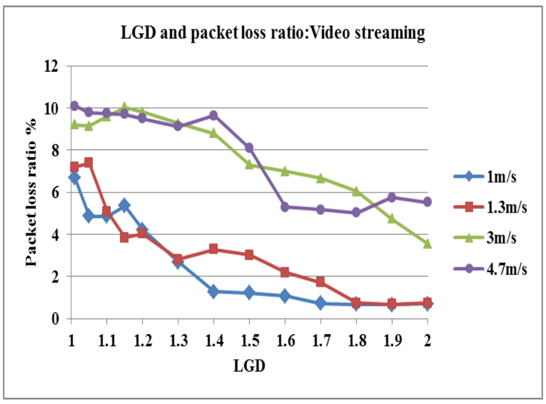


(b) The packet loss ratio for H.261

Figure 5. QoS parameters for H.261 traffic

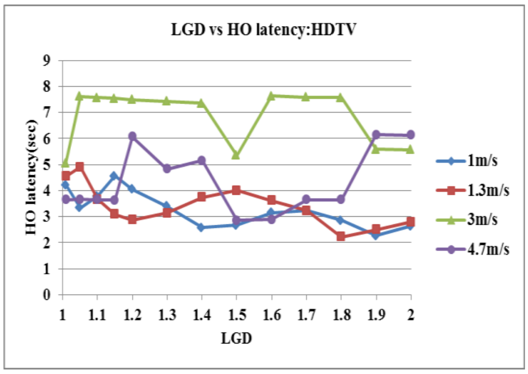


(a) Handoff latency for video streaming

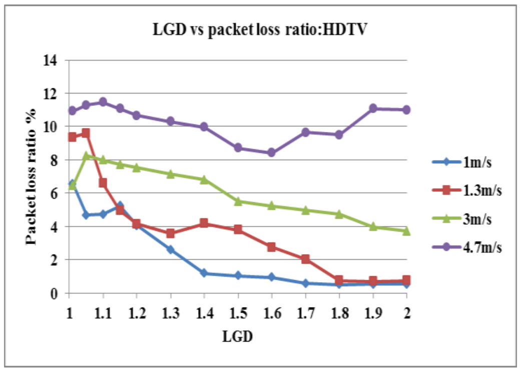


(b) Packet loss ratio for video streaming

Figure 6. QoS parameters for video stream traffic



(a) Handoff latency for HDTV



(b) Packet loss ratio for HDTV

Figure 7. QoS parameters for HDTV traffic

For MN velocity of 1 m/s, if the LGD value is 1.1, the average trigger generation happens at 54.97 sec (4.97 m away from cell boundary), resulting in the latency of 3.786 sec. For the LGD value of 1.5, the average trigger time is 52.24 sec (2.24 m away from the cell boundary), resulting in a latency of 2.67 sec. Table 6 shows the LGD values and handover latency. The negative distance shows the trigger within the cell, while the positive distance is the trigger instance out of Wi-Fi coverage. It is evident that with an increase in the LGD, percent packet loss is reduced for all speeds of MN. This is due to the HO process beginning well within the Wi-Fi cell and getting enough time for HO process completion.

Table 6. LGD and handover latency for 1 m/s speed

Sr. No.	LGD value	1.1	1.5	2	3	10
1	Distance from Wi-Fi cell (m)	4.98	2.24	00.04	-2.55	-7.77
2	Handover Delay (s)	3.786	2.671	2.632	2.273	2.414

As the LGD values increase, the handover latency decreases. It is the indication of the early beginning of handover when it is disconnected from the Wi-Fi hotspot. According to the result shown in the curves, the higher the LGD, the sooner the event will be generated even though the MN is well within the Wi-Fi cell. Note that if an LGD value is at the lower side, we have a handover latency of around 3.786 s, which signifies that the handover is processed too late. In contrast, higher values of LGD anticipate the handover before the MN leaves the Access Point boundary. It will be interesting to decide the LGD thresholds for various traffic types.

5.2 LGD thresholding

The applications are categorized as interactive or non-interactive video applications to determine the LGD thresholds. Video teleconferencing is one type of interactive video. The QoS requirements for interactive video might vary dramatically depending on the picture's quality, degree of interactivity, amount of motion, and size. As a result, the network latency goal is either 100 or 400 milliseconds, depending on how interactive it is. The packet loss ratio should be less than 0.1 percent. The IEEE 802.20 Working Group on Mobile Broadband Wireless Access recommends 560 milliseconds latency and a packet loss ratio of less than 1% for non-interactive video such as video streaming on mobile devices [20, 21]. The latency and packet loss requirements are application-specific; hence we considered 1% and 5% tolerable packet loss in the interactive and non-interactive video. Table 7 shows the experimentally derived LGD for different speeds. It is evident that the speed of MS affects the LGD value. For MPEG-4 and H.261 applications, 1% or less packet loss ratio is possible with one and 1.3 m/s speed, while video streaming is possible for all stated speeds with an increased value of LGD factor. For HDTV, the speed of 4.7 m/s resulted in a packet loss of more than 5%.

Table 7. Experimental values of LGD thresholds

Sr. No.	Speed (m/s)	MPEG-4	H.261	Video streaming	HDTV
1	1	1.5	1.5	1.2	1.2
2	1.3	1.8	1.8	1.15	1.15
3	3	-	-	1.9	1.7
4	4.7	-	-	1.8	-

5.3 Speed thresholding

Speed of the MS has a significant impact on handover latency and packet loss. Figure 4 to 7 shows the impact of MS speed on QoS parameters. Table 8 shows the average handover latency for various speeds, while Table 9 shows the packet loss for different traffics based on derived LGD thresholds. It is evident that the speed of MS significantly decides handoff latency, while the packet loss ratio depends on application type and speed. As speed increases, the handoff latency also increases.

Table 8. Handoff latency for MS movement

Sr. No.	Speed (m/s)	4G-WiFi HO latency (sec)	WiFi-4G latency (sec)
1	1	0.3636	2.9566
2	1.3	0.3838	3.0732
3	3	0.3665	7.4227
4	4.7	1.1320	4.9018

Table 9. The packet loss ratio for various application traffic

Sr. No.	Speed (m/s)	MPEG-4	H.261	Video streaming	HDTV
1	1	0.969	0.937	4.223	4.064
2	1.3	0.711	0.632	3.855	4.947
3	3	-	-	4.739	4.964
4	4.7	-	-	5.029	-

It is evident from Table 9 that video streaming application is well supported by MIH for all MS speeds. MPEG-4 and H.261 have support for 1 and 1.3 m/s terminal speeds, while HDTV traffic is supported for 1 to 3 m/s terminal speed. In the case of HDTV traffic, the packet loss ratio is beyond the 5% threshold for 4.7 m/s.

6. CONCLUSIONS

In this experimentation, our major focus is on impact analysis of realistic terminal speeds and application traffic such as HDTV, MPEG-4, and H.261 on VHO. The terminal speeds greatly impact the QoS for the video traffic during VHO. The handover latency and packet loss ratio are considered as QoS parameters in the experimentation. The simulation findings demonstrate that for interactive video services, vertical handoff to WLAN is beneficial for users traveling at a pedestrian pace; however, for non-interactive services, the vertical handoff is beneficial even though the user is traveling at high speed. We could determine the speed thresholds for a variety of traffic. Moreover, the application-specific predictive trigger (LGD) levels for optimum video traffic QoS are derived by extensive simulations. Such LGD thresholds and cut-off speed are very much useful for designing the VHO algorithms. In the future, the speed and LGD thresholds will be used in designing vertical handover decision algorithms to improve the QoS in heterogeneous networks.

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