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ORIGINAL RESEARCH

Performance evaluation of handover triggering condition estimation using mobility models in heterogeneous mobile networks

Asad Ali Malik[1] | **Muhammad Ali Jamshed**[2] | **Ali Nauman**[3] | **Adeel Iqbal**[1,2] | **Atif Shakeel**[1] | **Riaz Hussain**[1]

[1]Department of Electrical & Computer Engineering, COMSATS University Islamabad, Islamabad, Pakistan

[2]College of Science and Engineering, University of Glasgow, Glasgow, UK

[3]Department of Information and Communication Engineering, Yeungnam University, Gyeongsan-si, Republic of Korea

Correspondence

Muhammad Ali Jamshed and Ali Nauman.
Email: muhammadali.jamshed@glasgow.ac.uk and anauman@ynu.ac.kr

Abstract

Heterogeneous networks (HetNets) refer to the communication network, consisting of different types of nodes connected through communication networks deploying diverse radio access technologies like LTE, Wi-Fi, Zigbee, and Z-wave, and using different communication protocols and operating frequencies. Vertical handover, is the process of switching a mobile device from one network type to another, such as from a cellular network to a Wi-Fi network, and is critical for ensuring a seamless user experience and optimal network performance, within the handover process handover triggering estimation is one of the crucial step affecting the overall performance. A mathematical analysis is presented for the handover triggering estimation. The performance evaluation shows significant improvement in the probability of successful handover using the proposed handover triggering condition based on speed, distance, and different mobility models. The handover triggering condition is optimised based on the speed of the mobile node, handover completion time, and the coverage range of the current and the target networks of the HetNet node, with due consideration of the mobility model.

KEYWORDS

5G mobile communication, Internet of Things

1 | INTRODUCTION

The term Heterogeneous networks (HetNets) environment refers to a situation where diverse wireless network infrastructures are deployed in the same geographical area to serve diverse needs, such as the range of connectivity, the required data rate of communication, power limitations, the speed of the mobile node as shown in Figure 1 [1]. Small cells (femtocells) are considered one of the components of a HetNet environment, in addition to traditional macrocells. Femtocells use low power access points as they cover a limited geographical area ranging from 10 to 100 m [2]. Likewise, the satellite networks can also be part of a HetNet environment, which can provide coverage in remote or inaccessible areas where conventional terrestrial networks are difficult to install [3]. HetNet environment can be challenging to design and manage due to the need for coordination among various types of network infrastructures and the potential involvement of multiple stakeholders. However, they can provide significant benefits such as increased coverage, capacity, and service quality.

Nodes in HetNets are required to have the capability to connect to diverse networks and are consequently mandated to cater to the hardware, software, communication protocols, and network functions of the diverse networks that these nodes desire to leverage from. Such networks are commonly utilised in scenarios that require the interconnection of diverse devices or systems, such as the Internet of Things, where sensors and actuators need to interact with each other as well as other systems. Although HetNets offer greater flexibility and stronger capabilities to meet the needs of diverse applications, their

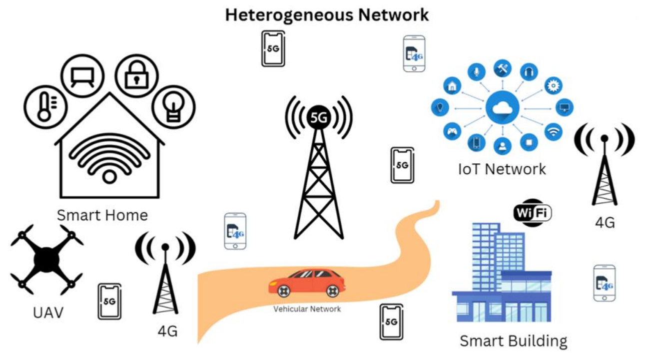

FIGURE 1 Future heterogeneous network example.

design and management can be more complex than homogeneous networks, which are composed of nodes with similar characteristics [4, 5].

To maintain connectivity across diverse networks in HetNets, a Vertical handover (VHO) is performed to transfer a device's connection from one network to another as the mobile node moves in homogeneous networks and heterogeneous networks [6, 7]. Compared to horizontal handover, where the mobile node changes its cell belonging to the same type of network that is, cellular to cellular or Wi-Fi to WiFi, vertical handovers are more complicated due to the diversity in hardware, software, and communication protocols of the nodes and networks. Therefore, a robust and flexible handover protocol that can handle the different types of nodes and connections is necessary [8, 9]. Several challenges must be considered when designing handover protocols for HetNets, such as ensuring a quick and efficient handover process to minimise connection disruption, minimising power consumption and battery life impact on low-power devices, and addressing issues, such as security, network load, and coverage [8, 10, 11].

1.1 | Vertical handover

VHO refers to the process of transferring a wireless device's connection from one network type to another. For example, a smartphone may switch from a cellular network to a WiFi network as the user moves around [12, 13]. The objective of optimisation in this scenario is to ensure that the handover process is as seamless as possible, minimising disruption to the device's connection. Several techniques can be used to accomplish this goal [14], including measurement-based handover, which involves gathering information about the connection quality on different networks at regular intervals and using that data to determine the optimal time for performing a handover [15, 16].

1.2 | Types of handover

Predictive handover is a technique that utilises the historical data of a device's movements and network usage patterns to predict when a handover may be needed and initiate the process beforehand [17]. Cooperative handover is another technique that involves multiple devices or networks cooperating to coordinate the handover process, resulting in a more seamless transition between networks [18]. Context-aware handover is a method that considers additional information about the device's environment, such as its location and network availability, to make more informed decisions about when to perform a handover [19]. The authors in ref. [20] proposed energy-efficient VHO techniques by incorporating two functions one for scanning and optimal network and other function for taking handover decision based on network conditions.

The act of handover involves transferring authority or control from one entity to another. In order to execute a handover, it is necessary to determine the need for a handover, select the appropriate target for the handover, the timing of the handover, and define the conditions that will trigger the handover process [21–23]. Handover necessity estimation (HNE) is the process of determining whether a handover is necessary based on various factors, such as resource availability, the complexity of the task, and potential risks [24, 25]. Handover target selection (HTS) involves selecting the most suitable target channel for the handover, considering factors such as the target channel capacity and capabilities [26, 27].

The process of determining the conditions that will initiate the handover, such as the availability of resources, and completion of a task, is known as handover triggering condition estimation (HTCE). Once the decisions about HNE, Handover target selection, and HTCE have been made, the handover process can commence. It is crucial to make these decisions thoughtfully as they can significantly affect the efficiency of the handover process.

2 | HANDOVER TRIGGERING CONDITION ESTIMATION

HTCE is a crucial step in the handover process as it involves transferring control for a task or network to another. It is vital that the handover is triggered at the appropriate time, neither too soon nor too late, to ensure a smooth and efficient transfer [28]. HTCE is important as it helps to minimise the risk of errors or delays by carefully establishing the triggering conditions for the handover. This, in turn, can improve the overall efficiency of the handover process. Various approaches are used to determine the triggering conditions for HTCE and handover. Some of the current HTCE schemes are discussed in Table 1.

To trigger a handover at a specific time, such as the end of a shift or the completion of a particular task, is known as the time-based triggering approach. This method can be effective when the delegated tasks or activities are well-defined and have a predictable duration [29]. Event-based triggering is a method of triggering a handover when a specific event occurs, such as the arrival of a critical component or the completion of a maintenance procedure. This method can be useful when the

TABLE 1 Comparison of handover triggering schemes.

Approach	Reference	Advantages	Disadvantages
Time-based triggering	[29]	Useful for tasks with predictable duration	Unsuitable for unpredictable tasks where handover should be triggered based on network conditions or user requirements.
Event-based triggering	[30]	Useful for complex or unpredictable tasks	Not effective for predictable tasks as it may lead to unnecessary handovers. Can be more responsive to sudden changes in the environment.
Performance-based triggering	[31]	Useful for high-quality task completion	Difficult to assess performance accurately, May lead to frequent handovers if the performance metric threshold is not appropriately set.
Resource-based triggering	[32]	Useful for resource-intensive tasks	May overlook other important factors such as application performance or time sensitivity & can lead to unnecessary handovers.
Hybrid-based triggering	[33, 34]	Can take into account multiple factors	Complex to implement and maintain. Finding the right combination of factors for triggering can be challenging.

tasks or activities being delegated are more complex or unpredictable [30].

The method of triggering a handover based on the performance of the entity that is currently performing the task or activity is called performance-based handover triggering. The performance of the entity can be measured based on various factors such as their rate of progress, quality of work, or level of fatigue. This method is particularly useful when it is crucial to complete tasks or activities to a high standard. Several studies have explored different aspects of performance-based triggering, such as the use of weighted criteria to measure performance [31] and the integration of cooperative techniques to improve performance [18]. Resource-based triggering is a handover approach that triggers the handover based on the availability of resources. This method is particularly helpful when the tasks require a significant amount of resources to complete effectively [32]. Additionally, several hybrid approaches combine various elements of the above schemes to trigger the handover at the most appropriate time [33, 34].

The decision to trigger a handover in a VHO process often takes into account the received signal strength level and quality of service (QoS) metrics [35]. In a QoS-based VHO algorithm, when the current bandwidth falls below that of the serving network, the user's connectivity is switched to a candidate network with higher bandwidth, enhancing the user's perceived quality of the connection. However, in a vehicular environment, where the mobile node moves at high speeds and spends limited time in a new coverage area, this approach may not always be practical [36]. In a highly mobile and dynamic environment, relying solely on QoS requirements may not be sufficient for accurate and effective handover decisions. Hence, it is crucial to also consider other factors such as the movement pattern and locality information of the mobile node [35, 36]. Considering these factors can help improve the accuracy and effectiveness of handover decisions in such environments.

The rest of the paper is divided into four sections, that is, Section 3 discusses mobility models, Section 4 discusses HTCE, and Section 4.1 discusses Urban Environment Scenarios. Section 4.2 covers handover prediction based on average speed, Section 4.3 covers handover conditions, and Section 5 presents simulation results. Finally, the conclusion is in Section 6.

3 | MOBILITY MODELS FOR URBAN ENVIRONMENTS

Mobility models refer to mathematical representations of the movement patterns of individuals or groups in a given area. These models are utilised to simulate the movement of mobile nodes in a city. Based on the factors that influence a mobile node's movement, mobility models are classified into different categories as follows. Temporal dependency models consider the node's previous movement, whereas spatial dependency models account for the correlation of movement among various nodes. Bounded mobility models consider geographical constraints, such as streets, freeways, and obstacles. The study of the impact of different factors such as transportation on the movement of people, vehicles, or other mobile nodes in a particular area can be facilitated by these models [37].

3.1 | Random waypoint model

The Random waypoint model (RWM) is a widely used model for simulating the movement of mobile nodes in wireless networks. It is a simple model that randomly selects a destination for a mobile node and then moves that node to the destination at a constant speed. The RWM is often used to simulate the movement of mobile users in wireless networks, such as those in mobile Adhoc networks (MANETs) or cellular networks.

Despite the RWM's ease of implementation lack some important mobility characteristics that limit its applicability in real-world scenarios. One limitation is the lack of spatial and temporal dependence on velocity, as well as the lack of geographical restrictions. The velocity of a mobile node in an RWM model is considered a memoryless independent process, which means that the velocity at the current location is independent of the velocity at the previous location. This ignores the extreme mobility cases such as sudden stops, sharp turns, and sudden acceleration, which can occur in the RWM traces. However, in real-world scenarios, the speed of vehicles increases gradually. Additionally, the movement of a mobile node may be limited by obstructions such as buildings, streets, freeways, or blind spots, which are not accounted for in the

RWM. The RWM suffers from two issues, that is, (i) sharp turns and abrupt stops, where a sharp turn occurs when the direction changes between 900 and 1800 and (ii) a sudden stop occurs when there is a change in speed that is unrelated to the previous speed [38].

3.2 | Freeway mobility model

The Freeway Mobility Model (FMM) is a vehicle movement model that can simulate the movement of vehicles on a highway or freeway based on the assumption that vehicles move in a straight line at a constant speed and stay within predefined lanes [39]. The FMM has been widely used in vehicular ad hoc networks and cellular networks to simulate vehicle movement. The model's parameters include the distance travelled on the freeway, the number of lanes, the maximum speed of vehicles, the number of vehicles on the freeway, the traffic flow direction, the separation between vehicles, and the time required for a vehicle to change lanes. Using the FMM, the impact of factors such as traffic congestion, traffic flow, and communication infrastructure deployment on wireless network performance in vehicular environments can be investigated.

3.3 | Manhattan mobility model

The Manhattan Mobility Model (MMM) is a mobility model used to simulate the movement of mobile nodes in a grid-like environment, such as a city [40]. This model requires that the node movement is restricted by the street layout of the city. The mobile node can travel horizontally or vertically along the grid of the city streets and make turns at intersections. Unlike the FMM, the mobile node in the MMM can change direction, with a 0.5 probability of continuing straight and a 0.25 probability of turning left or right at each intersection. The MMM is heavily dependent on both time and space. This model is commonly used to simulate mobile user movement in urban environments, such as those found in MANETs or cellular networks. Parameters such as the grid size, the number of nodes in the grid, the maximum node speed, the interval between movements, and the probability of changing course can be used to define the MMM. The MMM can be utilised to investigate the impact of various factors on the performance of wireless networks in urban environments, such as urban planning, traffic congestion, and the deployment of communication infrastructure. Several papers have proposed advanced versions or variations of the MMM, including the Correlated Manhattan Mobility Model and Group Mobility Model.

4 | PROPOSED HTCE MODEL

To ensure a seamless transition between wireless access networks, the timing of handover triggering is crucial. This handover triggering point is determined by various factors such as the speed and direction of the mobile device, network density, type of mobility model, and environment. Different techniques, including signal strength-based, time-based, hybrid, and location-based handover, can be used for this prediction as discussed in the following section.

4.1 | Urban environment scenario for handover triggering estimation

The scenario involves a mobile node moving within a vehicular environment at speeds ranging from 10 to 40 km/h. The network infrastructure is comprised of multiple heterogeneous wireless access networks that partially cover the road, with the trajectory of the mobile node constrained by main roads, side roads, and streets. The straight road is assumed to have full Wi-Fi coverage, while the side streets have cellular coverage.

In Monika et al. [41], when a mobile node reaches a junction in the urban scenario, it has a 50% probability of proceeding straight and a 25% probability of turning left or right. If the node decides to turn left, it needs to perform a handover to another 3G cellular network to maintain an ongoing call. Typically, if the mobile node maintains its speed at the junction, it is assumed that it intends to proceed straight. However, if the speed decreases below a certain limit, it indicates that the mobile node is turning left or right. Accurately predicting the handover trigger point based on speed can help prevent call drops and other network service issues.

The depicted scenario in Figure 2 illustrates a junction and coverage scenario with mobile nodes represented by orange dots and their speeds indicated by arrows. The mobile node travelling straight is indicated by a black and bold arrow, representing its direction and higher speed compared to the mobile nodes turning left or right. On the other hand, the mobile nodes intending to turn at the junction have their speed represented by a blue arrow, accompanied by a thin blue line indicating their slower speed compared to the nodes going straight.

4.2 | Handover prediction based on the average speed

The technique for predicting handover for a mobile node turning at a junction involves the average speed before the junction. Figure 3 shows a depiction of the technique with similar junction and coverage details to the actual scenario. Speed checkpoints are represented by orange dots, while blue dots represent the final speed at the time of the turn. The respective speed observed at each checkpoint is used to calculate the average speed. Although the average speed should ideally be calculated at the time of turning, speed samples are taken before the junction to assess the technique's adaptability.

Figure 3 also shows the handover triggering area, which refers to the region where the proposed technique is expected to accurately predict the handover decision. This triggering area is not fixed and varies based on the system's capacity to

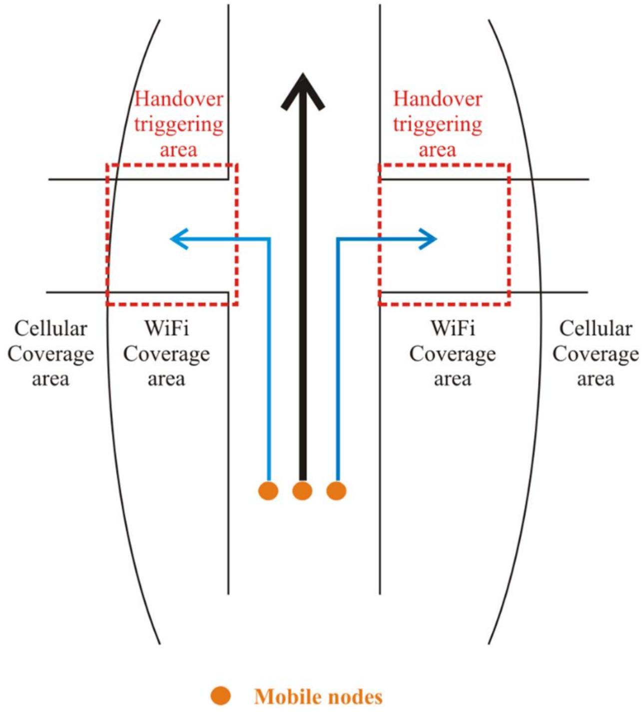

FIGURE 2 Urban environment scenario for handover triggering estimation.

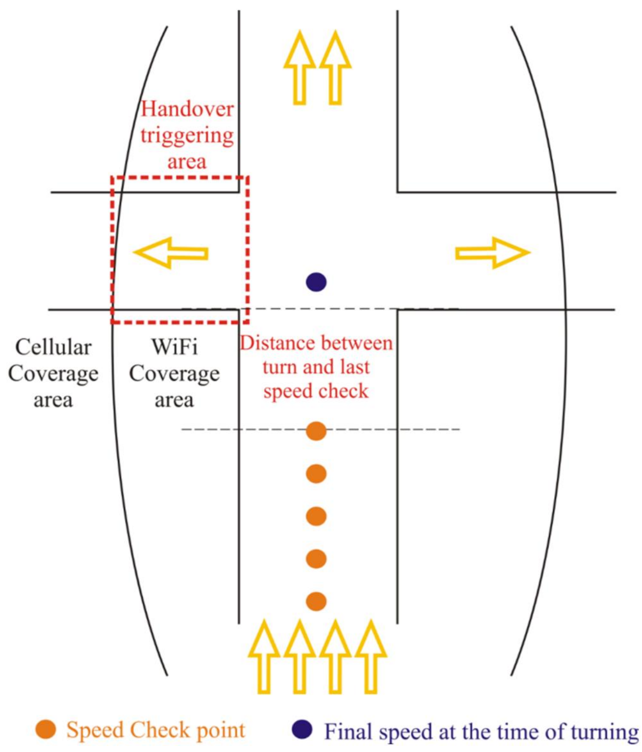

FIGURE 3 Representation of handover prediction technique.

perform handover within a specific region. The proposed technique's effectiveness is evaluated by testing its performance within different triggering areas, and the results are compared to determine its adaptability and reliability. By analysing the performance of the proposed technique within various triggering areas, better insights into its ability to accurately predict handover decisions can be gained.

The flow chart depicted in Figure 4 provides a detailed explanation of the proposed technique's functionality. The technique starts by collecting speed data at the speed checkpoints and calculating the average speed. The assumption about the mobile node's turning is made based on this average speed. If the average speed falls below a certain limit, the node is assumed to be turning, and the handover process is initiated. This approach is justified as a decrease in speed is expected when a mobile node turns at a junction.

To validate the assumption, another check is performed based on the final speed, that is, the actual speed at the time of turning. This step ensures that the prediction is accurate and avoids unnecessary handovers. Furthermore, the handover latency time is also considered to ensure that the handover process is completed within a certain time frame. If the speed is higher than the mobile node will not be able to complete the handover for the given handover latency and will lead to handover failure. This is important as an unsuccessful handover may result in call drop and QoS degradation. Overall, this technique ensures that handover is initiated at the right time and in the right manner, resulting in a smooth handover process for the mobile node.

4.3 | Handover condition

Handover-triggering conditions are specific criteria or events that signal the need for a handover to occur in a wireless network. These conditions are used to determine when a mobile device should switch its connection from one base station (or access point) to another to maintain continuous and seamless communication.

In this work, the handover process is triggered based on an assumption that can be represented by the following equation:

$$\frac{1}{N}\sum_{n=1}^{N} V(n) < V_{\lim} \quad (1)$$

Here, N is the number of speed samples, V is the speed vector, and $V_{\lim}$ is the speed limit for triggering the handover. If the average speed calculated from the speed samples falls below the predefined speed limit, the assumption is made that the mobile node is turning, and the handover process is initiated.

Similarly, the success of the handover process is determined by the following equation:

$$\text{latency} < \frac{D_b}{V_{final}} \quad (2)$$

Here, D_b is the block distance, and V_{final} is the final speed of the mobile node in metres per second at the time of turning. If the time taken by the mobile node to cover the block distance is less than the handover latency, the handover is considered

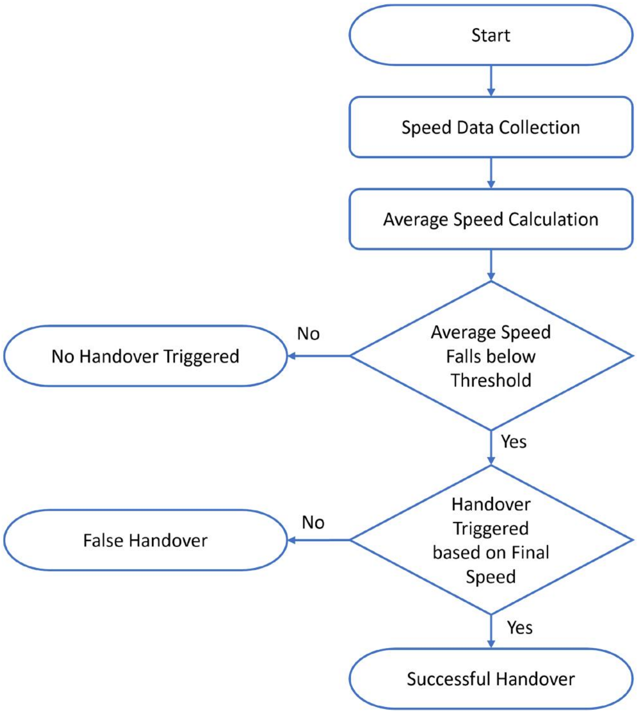

FIGURE 4 Flow chart of the proposed technique.

successful, for example, real-time application has a very stringent requirement on latency.

4.4 | Probability of successful handover

Considering the relationships 1 and 2, we obtain the probability of successful handover ($P_{handover}$) as follows:

$$P_{handover} = P\left(\frac{D_b}{V_{final}} < \text{latency}\right) \tag{3}$$

where $P\left(\frac{D_b}{V_{final}} < \text{latency}\right)$ is the probability that the time taken by the mobile node to cover the block distance is less than the handover latency time.

We can calculate $P_{handover}$ for different values of speed and latency, block distance, averaging samples, and decision distance using the above equation. Equations (2) and (3) combined together to get the probability of successful handover in terms of speed, latency, and block size as follows:

$$P_{handover} = P(V < V_{\text{lim}}) \cdot P\left(\frac{D_b}{V_{final}} < latency\right) \tag{4}$$

Where $P(V < V_{\text{lim}})$ is the probability that the average speed falls below the predefined speed limit and $P\left(\frac{D_b}{V_{final}} < latency\right)$ is the probability that the time taken by the mobile node to cover the block distance is less than the handover latency time, given that the mobile node is turning.

Assuming that the speed of the mobile node follows a Gaussian distribution with mean μ and standard deviation σ, we can calculate $P(V < V_{\text{lim}})$ as follows:

$$P(V < V_{\text{lim}}) = \int_0^{V_{\text{lim}}} \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(v-\mu)^2}{2\sigma^2}\right) dv \tag{5}$$

Similarly, assuming that the time taken by the mobile node to cover the block distance follows a Gaussian distribution with mean μ_t and standard deviation σ_t, we can calculate $P\left(\frac{D_b}{V_{final}} < latency\right)$ as follows:

$$P\left(\frac{D_b}{V_{final}} < latency\right) = \int_0^{\frac{D_b}{latency \cdot V_{final}}} \frac{1}{\sigma_t\sqrt{2\pi}} \exp\left(-\frac{(t-\mu_t)^2}{2\sigma_t^2}\right) dt \tag{6}$$

Combining the two equations, we get the final expression for the handover success probability:

$$P_{handover} = \int_0^{V_{lim}} \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(v-\mu)^2}{2\sigma^2}\right) dv \cdot \int_0^{\frac{D_b}{latency \cdot V_{final}}} \frac{1}{\sigma_t\sqrt{2\pi}} \exp\left(-\frac{(t-\mu_t)^2}{2\sigma_t^2}\right) dt \tag{7}$$

To calculate the values of $P_{handover}$ for different values of speed and latency, we need to specify the values of V_{lim}, D_b, V_{final}, μ, σ, μ_t, and σ_t. We can then use numerical integration techniques to evaluate the above integral.

4.5 | Block distance and decision distance

As block distance and decision distance have a direct impact on the probability of successful handover, the Equation (7) can be extended to incorporate these parameters yielding the following equation:

$$P_{handover} = \begin{cases} 1, \& \quad \text{if} \\ \frac{D_d}{V} \geq T_{lat} \; \frac{D_d}{V \cdot T_{lat}} \left(\frac{D_b}{D_d} - \frac{D_b}{V \cdot T_{lat}}\right), \\ \& \quad \text{otherwise} \end{cases} \tag{8}$$

Note that if the decision distance D_d is greater than the block distance D_b, then the probability of successful handover is always 1, as the mobile node will have enough time to complete the handover process before reaching the decision point.

To incorporate the impact of speed on handover success probability, we can introduce a speed factor f_s as follows:

$$P_{handover}(V) = \begin{cases} 1, & \text{if} \\ \frac{D_d}{V} \geq T_{lat} \ \frac{D_d}{V \cdot T_{lat}} \\ \times \left(\frac{D_b}{D_d} - \frac{D_b}{V \cdot T_{lat}} \right) f_s(V), \\ & \text{otherwise} \end{cases} \tag{9}$$

where $f_s(V)$ is a function that maps the speed V to a value between 0 and 1, representing the impact of speed on handover success probability.

To incorporate the impact of decision distance on handover success probability, we can introduce a decision distance factor f_d as follows:

$$P_{handover}(V, D_d) = \begin{cases} 1, & \text{if} \\ \frac{D_d}{V} \geq T_{lat} \ \frac{D_d}{V \cdot T_{lat}} \\ \times \left(\frac{D_b}{D_d} - \frac{D_b}{V \cdot T_{lat}} \right) f_s(V) f_d(D_d), \\ & \text{otherwise} \end{cases} \tag{10}$$

where $f_d(D_d)$ is a function that maps the decision distance D_d to a value between 0 and 1, representing the impact of decision distance on handover success probability.

4.6 | Data transfer rate

To calculate the data transfer rate in Mbps, we can use the following equation:

$$\text{Data Transfer Rate} = \frac{\text{Packet Size} \times \text{Number of Packets}}{\text{Total Transfer Time}} \tag{11}$$

Here, the packet size and number of packets are assumed to be fixed. The total transfer time can be calculated using the following equation:

$$\text{Total Transfer Time} = \frac{\text{Decision Distance}}{V_{avg}} \tag{12}$$

where V_{avg} is the average speed of the mobile node. We can calculate the data transfer rate for different values of speed and decision distance using the above equation.

5 | SIMULATION AND RESULTS

The performance evaluation of the proposed handover triggering condition based on different factors is performed using Monte Carlo simulation in MATLAB. The simulations were performed over one million repetitions to obtain an average. The first step of the simulation involved generating the mobile node's speed profile using a random process. The speed profile was then used to select speed samples along the path. The number of speed samples was varied to determine the effectiveness of the proposed handover technique. Figure 5 depicts a representative mobile node's speed profile, where the blue line represents the actual speed along the path, and the red lines represent the selected speed samples. The average speed, depicted by the dotted green line, was calculated using these speed samples to initiate the handover process. The distance between the junction and the point where the average speed is calculated was also varied in the simulation. The handover triggering area, which is the block distance required to complete the handover process, was also changed to evaluate the proposed technique's effectiveness. Finally, the latency time, which is critical in determining the system's efficiency in performing the handover, was also varied in the simulations.

5.1 | Results and discussions

To evaluate the performance of the proposed technique, simulations were conducted for the scenario and parameters discussed earlier. The simulation results, as shown in Figure 6, were obtained by varying the handover latency, and it can be observed that as the handover latency increases, the successful handover probability decreases. This is due to the fact that at the given speed and latency the mobile node exits the coverage of the current access point before it is connected to the target access point. As mentioned earlier, handover latency is an indicator of the system's efficiency in performing handover; a lower latency indicates a more efficient system that can perform handover in less time.

The handover probability is evaluated by varying the block distance, which is a measure of service coverage, and determines the distance at which handover should be triggered. The results depicted in Figure 7 clearly indicate that increasing the block distance leads to a higher handover probability. This result is expected since increasing the block distance provides more time for the handover process to be completed successfully. The block distance is a critical parameter that affects the handover process's performance, and it must be carefully selected to balance service coverage with HSP.

The next result shows the impact of the number of speed samples on handover probability, as depicted in Figure 8. As the number of speed samples increases, the handover probability also increases. This is because more speed samples provide a more accurate representation of the mobile node's speed profile, allowing for better decision-making in terms of handover. However, it is important to note that increasing the

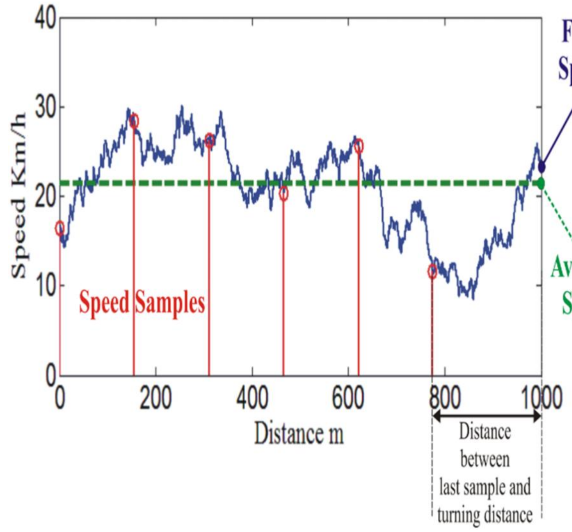

FIGURE 5 Speed profile of the mobile node.

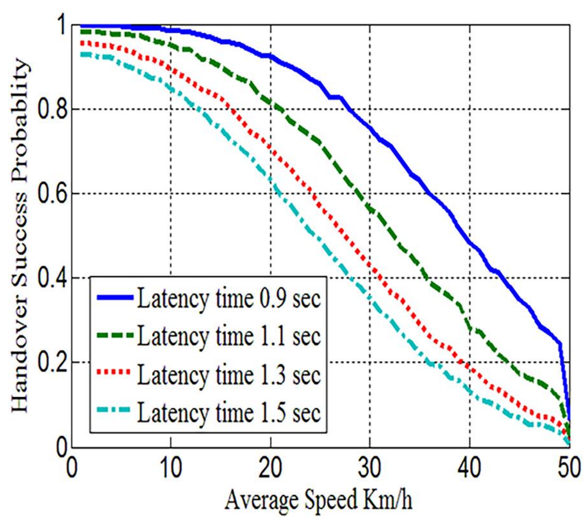

FIGURE 6 Handover probability for different values of handover latency.

number of speed samples also increases the computational complexity of the technique.

The variation of the decision distance is a crucial parameter in evaluating the proposed technique's performance. The decision distance refers to the distance from the last averaging point to the turning junction. As the decision distance increases, the last sample is chosen farther away from the junction, which can affect the difference between the average and final speed. The impact of the decision distance on handover probability is depicted in Figure 9, where it can be seen that increasing the decision distance leads to a decrease in the handover probability. This is because the longer the decision distance, the more likely it is for the mobile node's actual speed to differ significantly from the average speed, making it more difficult to predict the handover time accurately. Therefore, the decision distance is a critical parameter to consider in optimising the proposed handover technique's performance.

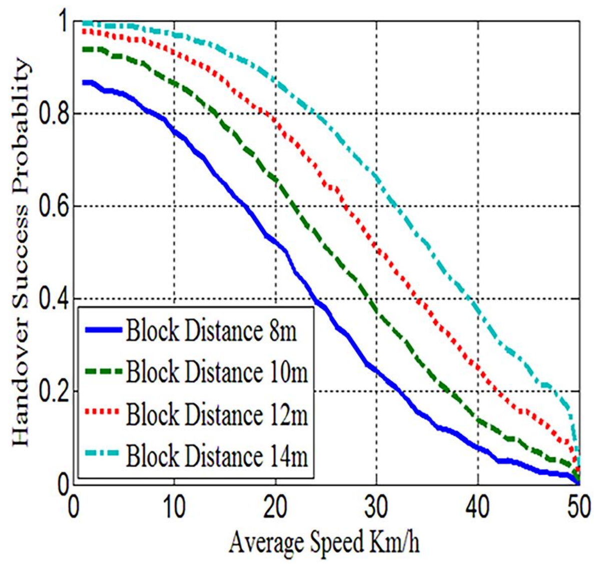

FIGURE 7 Handover probability for different values of block distance.

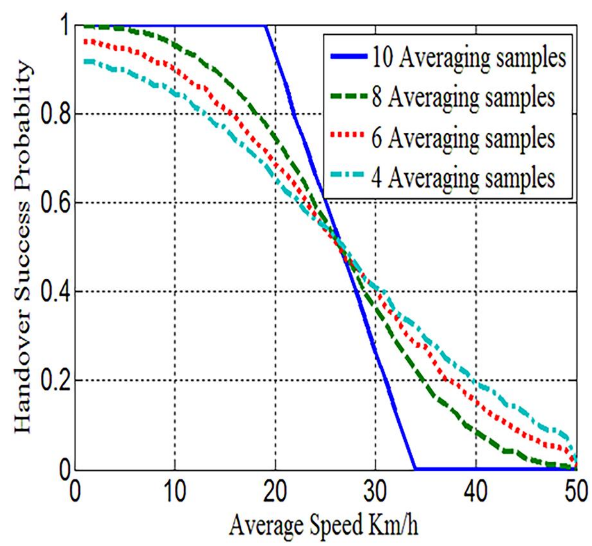

FIGURE 8 Handover probability as the number of averaging points is varied.

$$\text{data}_t \approx \left[\frac{d_o - d_d}{\frac{1}{N}\sum_{n=1}^{N} V(n)}\right] \times D_{WiFi} + \left[\frac{d_d}{\frac{1}{N}\sum_{n=1}^{N} V(n)}\right] \times D_{cellular} \tag{13}$$

The system parameters used in the simulation scenario include the distance of observation (d_o), decision distance

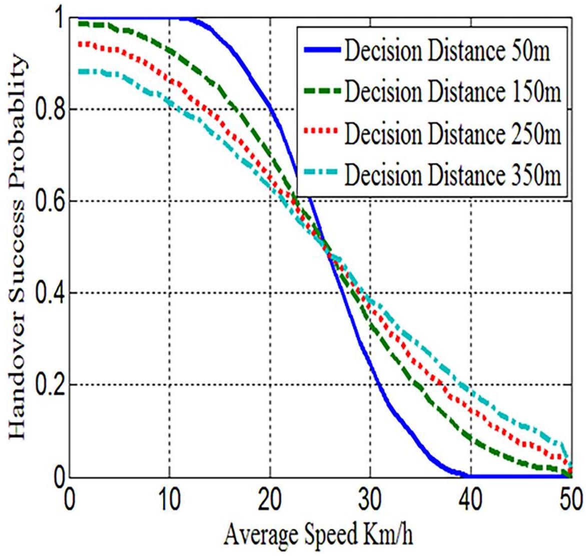

FIGURE 9 Handover probability for different values of decision distance.

before the turn (d_d), Wi-Fi data rate (D_{WiFi}), and cellular data rate ($D_{cellular}$). The distance of observation represents the range within which the system can detect and hand over the mobile node from Wi-Fi to cellular networks. The decision distance before the turn indicates the point at which the handover decision is made. The Wi-Fi and cellular data rates represent the amount of data that can be transferred per unit of time over each network. These parameters play an important role in determining the system's performance, and they were carefully chosen to reflect realistic values that are commonly used in practice. Specifically, in the simulations, the distance of observation was set to 2000 m, the decision distance before the turn was varied, the Wi-Fi data rate was set to 11 Mbps, and the cellular data rate was set to 0.2 Mbps.

Figure 10 illustrates that when the average speed of the mobile node is lower, there is a higher data transfer. This is because the slower speed allows the mobile node to spend more time in both the observation distance and the Wi-Fi region. On the other hand, when the speed is increased, the mobile node spends less time in these regions, resulting in a decrease in data transferred. This observation is quite evident in the graph 10 where the slower node spends more time in the Wi-Fi region, and thus, more data is transferred compared to the faster node.

6 | CONCLUSION

This research paper presented a detailed mathematical and performance analysis for the VHO triggering estimation in heterogeneous mobile networks. The study demonstrates that handover latency and block distance have a significant impact on system performance efficiency. By selecting appropriate values for these parameters, handovers can be successfully performed for fast-moving mobile nodes. Increasing the number of averaging points enhances the handover success rate, but only if the average speed is calculated as close to the turning junction as

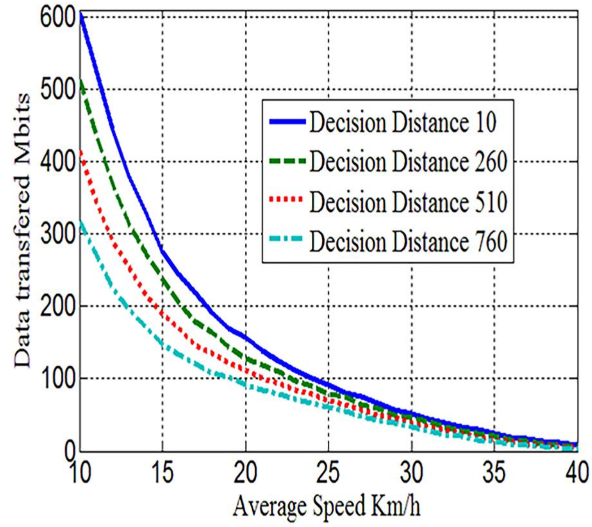

FIGURE 10 Effects of early handover upon the data transfer.

possible. In conclusion, the proposed handover scheme provides an effective solution for maintaining a seamless network connection for vehicular nodes, leading to a better user experience and improved network performance.

Applying this model by considering various handover techniques used in heterogeneous mobile network environments and its evaluation is one of the main future research directions.

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AUTHOR CONTRIBUTIONS

Asad Ali Malik, Adeel Iqbal, Atif Shakeel, Riaz Hussain: Conception and design of study, Simulation, Acquisition of data, Writing - original draft. Asad Ali Malik, Adeel Iqbal, Ali Nauman, Muhammad Ali Jamshed, Riaz Hussain: Analysis and/or interpretation of data, Writing - original draft. Asad Ali Malik, Adeel Iqbal, Ali Nauman, Riaz Hussain: Writing - review and editing.

CONFLICT OF INTEREST STATEMENT

There is no conflict of interest.

DATA AVAILABILITY STATEMENT

All data generated or analysed during this study are available and included in this published article.

ORCID

Muhammad Ali Jamshed https://orcid.org/0000-0002-2141-9025
Adeel Iqbal https://orcid.org/0000-0001-8692-173X

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