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5G handover issues and techniques for vehicular communications

Muhamad Ali Zuhdi Rosli, Siti Fatimah Abdul Razak, Sumendra Yogarayan
Faculty of Information Science and Technology (FIST), Multimedia University (MMU), Bukit Beruang, Malaysia

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ABSTRACT

Vehicular communication is gaining popularity, and seamless handover is critical to maintaining a stable and uninterrupted network connection between vehicles and roadside units. This paper investigates the advancements in handover approaches in vehicular networks, with a specific focus on fifth generation (5G) technology. Vehicular Ad-hoc networks (VANETs) face challenges due to high mobility, dynamic network topology, and frequent information exchange. The paper discusses handover issues in 5G-VANET environments, such as too-late and too-early handovers, wrong handover decisions, and unnecessary handovers. It also explores key performance indicators (KPIs) used in handover evaluation. The advancements in handover approaches presented in this paper pave the way for enhanced connectivity and communication management in 5G-VANETs, contributing to the development of safer and more efficient intelligent transportation systems.

Corresponding Author:

Sumendra Yogarayan
Faculty of Information Science and Technology (FIST), Multimedia University (MMU)
Ayer Keroh Lama Street, Melaka, Malaysia
Email: sumendra@mmu.edu.my

1. INTRODUCTION

Vehicular Ad-hoc networks (VANETs) are networks that connect vehicles to each other and to the road infrastructure. The networks are characterized by high mobility, dynamic network topology, unbounded network size, and frequent exchange of information [1]. Currently, the automotive industry is utilising cellular systems to support VANET applications such as vehicle platooning and teleoperated driving. However, the current four generation (4G) technology is not optimal for VANET communication [2]. Given that fift generation (5G) technology has demonstrated its ability to address significant issues in the existing long-term evolution (LTE) network, such as achieving higher data rates, reducing latency, and facilitating high-density device connections [3], incorporating 5G technology into the VANET context is seen as a promising solution due to its extensive connectivity, high throughput, and ultra low-latency characteristics [4]. 5G-VANET network comprises vehicles moving through diverse environments such as highways, rural regions, and urban areas, alongside stationary infrastructure positioned along the roadways, referred to as roadside units (RSUs). These RSUs are connected to the 5G base station and a remote control and management center (RCMC) [4]. Furthermore, it has been observed that 1,000 times more traffic is carried by 5G networks than LTE networks in a heterogeneous environment with macro cells, small cells, and relays [5]. However, a substantial increase in the number of handovers (HO) is caused by the deployment of ultra-dense small cells [6]. Handover is a critical process in 5G-VANET environments with high-speed mobility and high-speed user equipment, as it ensures a smooth and efficient transfer of connectivity to avoid any disruptions to the user experience [4], [6]. It is crucial that seamless transfer of active communication management from one roadside unit (RSU) to another is ensured, so that any change remains unnoticed by the user [7]. Despite this, because of the rapid changes and high mobility within the VANET topology, it is difficult to gauge the period that a vehicle will remain linked to a network before requiring a handover. This paper's goal is to investigate the recent advancements in handover approaches in vehicular networks, specifically with regards to 5G technology. The second and third sections of this paper offer an overview of various handover problems and key performance indicators commonly used in this field. A proposed solution that addresses the handover problems discussed in the previous sections and leverages the identified handover key performance indicators (KPIs) is presented in the subsequent section. Additionally, this paper discusses the potential implementation of the proposed solution in the vehicular network field, which serves as the conclusion of this study.

2. LITERATURE REVIEW

Handover is essential for transferring control of data transmissionfrom one access network to another [4], but it must be performed seamlessly to avoid disrupting the user's experience. The velocity of vehicles during handover impacts the quality-of-service (QoS) experienced by users of ultra-dense 5G networks [8]. This section describes the handover issues, key performance indicators and the handover technique in 5G-VANET environment.

2.1. Handover issues

2.1.1. Delayed handover

In a high mobility environment, where the vehicle is moving at high speeds, the signal quality can deteriorate rapidly due to several factors, such as obstacles, signal interference, and fading. Hence, it can be challenging to initiate handover in time. In the event that the radio link between the vehicle and the serving network collapses before a handover takes place, the on-board unit (OBU) in the vehicle will attempt to reestablish its radio link to another network. Likewise, if a radio link experiences failure in the serving network during the handover procedure, the OBU will make an effort to reestablish its radio link with the target network [9]. However, when the current network fails to initiate the handover process in time before the signal quality deteriorates below a certain threshold, the vehicle may lose connectivity due to the disruption in the communication link as depicted in Figure 1. This can impact the performance of applications such as real-time video streaming, which require a stable and low-latency connection. Though, advanced antenna systems, such as beamforming and multiple-input multiple-output (MIMO), can be used to enhance the signal quality and reduce the likelihood of signal deterioration. In addition, advanced algorithms may be implemented to predict the optimal time to initiate the handover process.

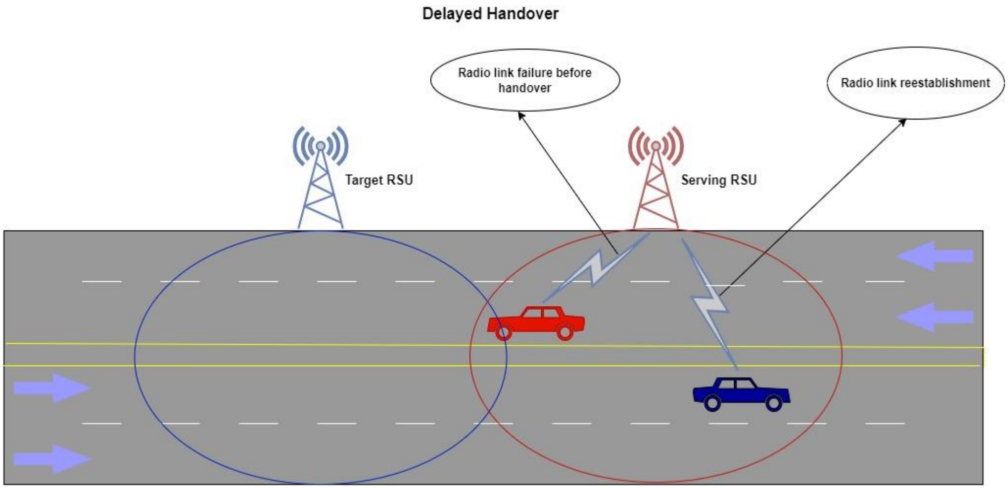

Figure 1. Delayed handover

2.1.2. Prematured handover

If the handover to the target network is successful, there is a possibility that a radio link collapse between the vehicle and the new serving network may occur shortly thereafter, leading to the OBU being reconnected to the original serving network [10]. Even if the signal quality is sufficient to maintain the connection, the current network may initiate the handover process prematurely, as illustrated in Figure 2 [11]. This could happen if the base station relies on an overly strict signal quality threshold value, which may result in unnecessary disruptions to the communication link. These disruptions can cause network latency to increase, network throughput to decrease, and packet loss to rise, making the situation worse. To prevent this issue, the base station can employ advanced handover decision-making algorithms that consider various factors, including network congestion, mobility, and signal strength stability. Essentially, these factors can be categorized into different scenarios to identify the appropriate handover parameter for the base station to make an informed decision. Additionally, the implementation of advanced signal processing techniques like adaptive modulation and coding can enhance signal quality, thereby decreasing the chances of initiating the handover process prematurely.

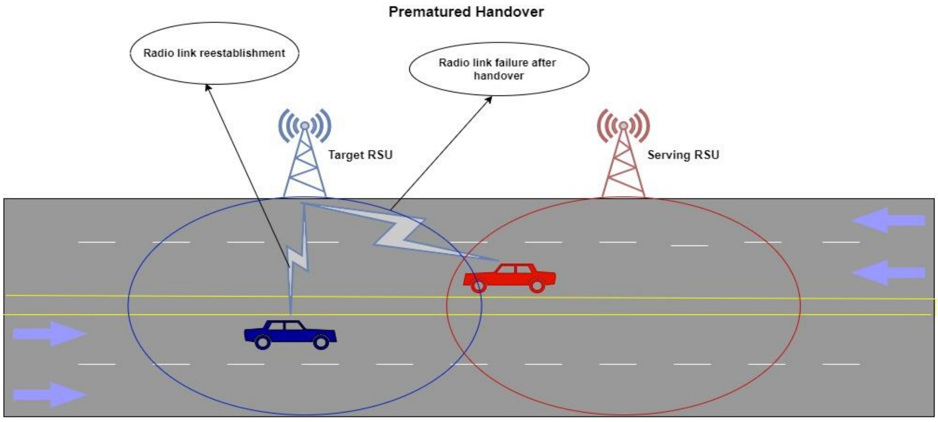

Figure 2. Prematured handover [11]

2.1.3. Wrong cell handover

After a successful handover, the vehicle’s radio link may fail, prompting it to reconnect to a different network than the serving or intended target network [4]. This can happen if the vehicle fails to detect the signal strength and quality of the new cell accurately due to obstacles or interference that obstruct the signal or if the signal from the new cell is too weak [12]. As a result, the vehicle may end up connecting to the wrong cell, leading to communication disruptions as depicted in Figure 3. Moreover, if the RSU or base station initiates the handover process either too early or too late, it could also result in the vehicle connecting to the wrong cell. Additionally, if the network infrastructure is not properly configured or maintained, it could lead to handover failures and incorrect cell connections. Therefore, network operators and designers must implement proper signal strength and quality detection mechanisms, optimized handover algorithms, and effective network management strategies to ensure that vehicles connect to the correct cells or RSUs. By doing so, they can prevent handover to the wrong cell and avoid communication disruptions, latency, decreased throughput, and packet loss, leading to a better overall user experience.

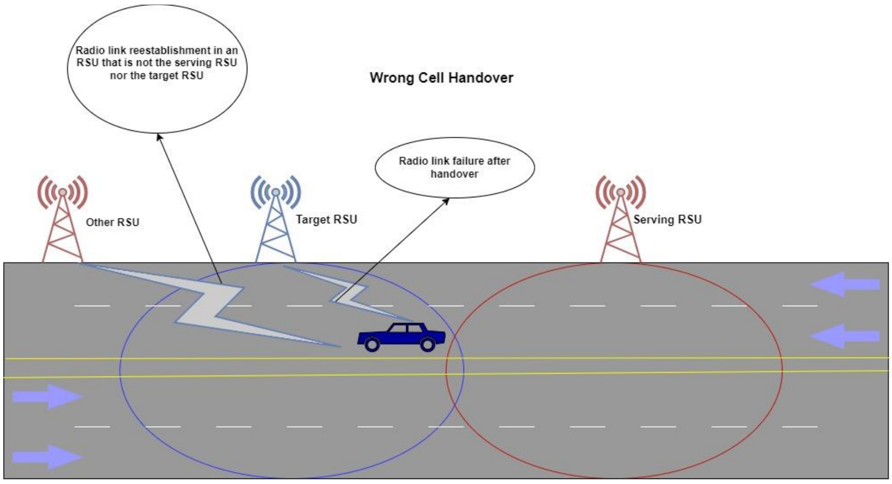

Figure 3. Wrong cell handover

2.1.4. Unnecessary handover

When the serving network handover vehicle to a target network, which in turn hands it over to another target network, the two handovers can be combined into a single handover directly from the serving network to the latter target network. This prevents data transmission from being interrupted during the connection transfer time. Unnecessary handover happens when the vehicle connects to a new cell or RSU, despite the fact that the signal strength from the serving cell is sufficient to maintain a stable connection.. This can occur if the threshold signal quality value that triggers the handover process is set too conservatively. For example, if the base station initiates the handover process prematurely based on a strict signal quality threshold, it may lead to unnecessary handover and connection disruptions as shown in Figure 4. Similarly, if the network infrastructure is not properly configured or maintained, it may cause unnecessary handovers, leading to performance issues. Unnecessary handover can also occur when the vehicle frequently moves between cells or RSUs [13]. This can happen in scenarios where the cells or RSUs are too small or where there are too many cells or RSUs in close proximity to each other. In such cases, the vehicle may need to handover to a new cell or RSU too often, even when the signal quality from the current cell or RSU is still good.

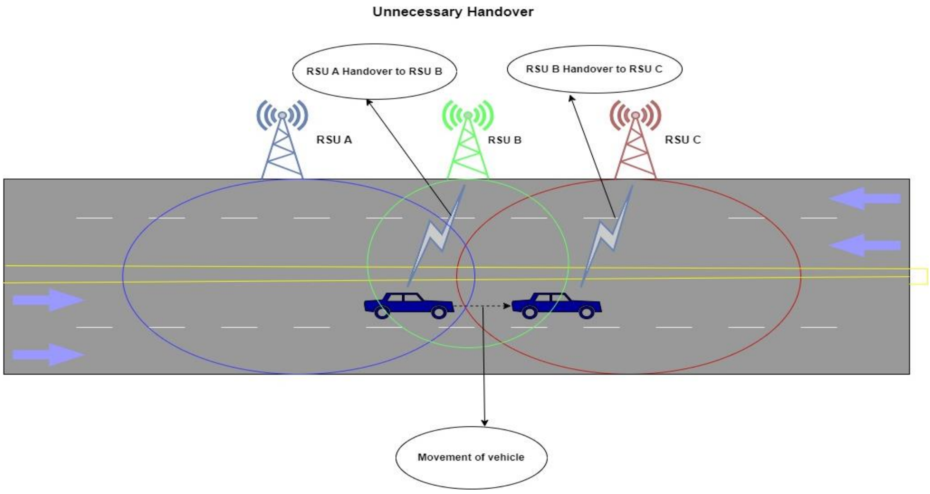

Figure 4. Unnecessary handover

2.1.5. Ping-pong handover

A ping-pong handover takes place when a vehicle in a 5G-VANET environment frequently switches between target and serving network in rapid succession as depicted in Figure 5. The ping-pong handover phenomenon occurs when a vehicle is handed over to the target network but quickly returned to the original serving network [14]. There are several factors that can contribute to this situation. One common cause is incorrect handover (HO) parameter settings, where the network's configuration for determining when a handover should occur is not properly optimized. As a result, the vehicle may be handed over to a new RSU unnecessarily, only to realize that the original RSU still provides a better signal quality or coverage. Another factor that can lead to ping-pong handover is a dominance problem in the terrain area. This refers to a situation where multiple RSUs are within range of the vehicle, and they compete for the connection.

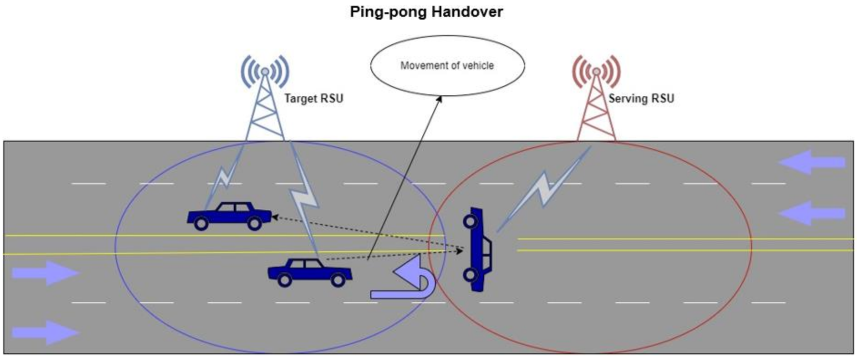

Figure 5. Ping-pong handover

Due to varying signal strengths, interference, or other factors, the vehicle may repeatedly switch between RSUs without stabilizing the connection with any one of them. This constant switching disrupts the network performance, increases latency, and hampers the vehicle's ability to maintain a stable and reliable communication link. Table 1 summarizes the handover issues related to 5G VANET environment.

Table 1. The handover issues related to 5G VANET environment

Handover issues	Description
Delayed handover	The vehicle may lose connectivity when the current base station fails to initiate the handover process in time before the signal quality deteriorates below a certain threshold.
Prematured handover	The current base station may initiate the handover process prematurely based on signal quality threshold value.
Unnecessary handover	Vehicle connects to a new cell or RSU based on conservative threshold signal quality value even though the signal quality from the current serving cell is still sufficient to maintain a stable connection.
Ping-pong handover	A stable connection is difficult to maintain when vehicle travels at high speed. Frequent stitching between two base stations may cause disruption in the communication link.
Wrong cell handover	Radio link failure during handover to the target RSU cause OBU seeks to reestablish its radio link in a non-serving RSU that is not the intended target.

2.2. Key performance indicator

Network operators consider various KPIs to gauge and supervise handover performance across the network, with handover success rate serving as a critical measure of user satisfaction. This ensures that users can freely traverse the network while remaining connected and receiving quality services. These KPIs are essential for identifying any performance issues within the cellular network and ensuring that the handover process occurs swiftly and seamlessly, without compromising network performance. Reference signal received power (RSRP) [15], HOP [16], radio link failure (RLF) [17], handover interruption time (HIT) [18], and HOF [19] are among the diverse KPIs employed to assess handover performance.

2.2.1. Reference signal received power

An important measure of signal strength in telecommunications normally expressed in dBm. This metric is used to evaluate the quality of signals that are directed towards a user equipment (UE) on the downlink channel. It is a significant KPI that is commonly used to assess wireless network performance during handover process. RSRP involves measuring the mean power of the resource element that carries cell-specific reference signals across a wide spectrum [15]. Accurate measurement of RSRP is crucial in ensuring reliable and high-performance communication between network operators and end-users [16].

2.2.2. Handover probability

Handover probability is a crucial metric in telecommunications that measures the probability of a UE undergoing handover when it moves from one cell to another [16]. HOP is usually expressed as a percentage and represents the likelihood of handover occurring. One of the key factors that can increase the HOP is the handover ping-pong (HOPP). When the HOP increases, it can lead to an increase in system complexity and negatively affect the overall performance. Therefore, accurately measuring and managing the HOP is essential for maintaining efficient and reliable communication between network operators and end-users.

2.2.3. Radio link failure

In the event of a malfunction in the backward HO signaling between the source cell and the UE, a critical communication issue called radio link failure (RLF) occurs. Despite satisfactory radio reception, the UE is incapable of deciphering the HO command transmitted by the source radio base station (RSU). In such cases, the UE initiates a recovery procedure and triggers an RLF timer, typically set at 500 or 1,000 ms, upon detecting an RLF during the handover process [17]. The service provider has the flexibility to adjust this timer based on network drive tests. Subsequently, the UE, still connected to the original cell, dispatches a connection request to an alternate target cell after the expiration of the RLF timer. If the source RSU has already established the target cell in response to the UE's measurement report, successful connection to the target cell can be achieved.

2.2.4. Handover interruption time

Handover interruption time (HIT) is the time during a HO where data exchange between source and target cell is interrupted by the mobile terminal. HIT is a crucial metric in cellular networks, as it represents the minimum time required for a successful HO. In 4G LTE deployments, HIT usually ranges from 30 to 60 ms, influenced by handovers and radio conditions [18]. The 3GPP community is actively reducing HIT for future B5G applications, aiming for near-zero HIT in B5G networks [19].

2.2.5. Handover failure

Handover failure is a critical metric that measures a system’s performance. HOF can occur at any stage, but poor radio conditions and patchy coverage due to fading and path loss are the primary causes [14]. The decision to perform a handover may be prematured, delayed, or even wrong decision, resulting in failures before the HO command is delivered. Without successful handover, users cannot experience mobility, and their connection is disrupted when moving from one cell to another [20]. Table 2 summarizes the key performance indicator to 5G VANET environment.

Table 2. The key performance indicator to 5G VANET environment

Key performance indicator	Description
Reference signal received power (RSRP)	Assesses downlink signal quality for the UE and is essential for evaluating wireless network performance during handover, expressed in dBm.
Handover probability (HOP)	Indicates the probability of a UE experiencing handover while transitioning between cells. Accurate measurement and management of HOP are crucial for ensuring efficient and reliable communication between network operators and end-users.
Radio link failure (RLF)	Critical communication issue that occurs when there is a malfunction in the backward HO signaling between the source cell and the UE. Despite having good radio reception, the UE cannot interpret the HO command from the source RSU.
Handover interruption time (HIT)	Duration during a HO when the mobile terminal experiences a pause in data exchange between the source and target cell. It is a critical metric in cellular networks, representing the minimum time required for a successful handover.
Handover failure (HOF)	Crucial performance metric that evaluates system effectiveness. HOF can happen at any stage, primarily caused by unfavorable radio conditions and incomplete coverage due to fading and path loss. Poor timing or incorrect cell selection can lead to failures in delivering the handover command. When handover fails, users experience disrupted connections and lack mobility as they move between cells.

Handover problem is a significant challenge in VANET environments due to the high mobility and dynamic changes in the network topology [21]. Handover is essential for transferring the management of active communication from one RSU to another [4], but it must be performed seamlessly to avoid disrupting the user's experience. As 5G-VANET technology continues to evolve, it is crucial to develop efficient handover algorithms to ensure that vehicles stay connected to the network without interruption, thus enabling a seamless and uninterrupted VANET experience for users. A vehicle trajectory prediction scheme, combined with a Markov chain predictor, is proposed in [22] to efficiently manage handovers in the 5G cellular network. In the proposed scheme, a synthetic dataset of vehicles’ mobility trace and handover history is generated, guided by the concept that vehicle movement adheres to the same pattern along specific roads. When a handover event takes place, the time, vehicle coordinates, source gNB, and target gNB are recorded to predict the vehicle’s destination and the timing of the handover. An improvement in handover reduction by over 60% is achieved by the proposed technique compared to the 3GPP A3 and A2A4 algorithms.

Skip-HoVe [23] is another handover algorithm proposed for video distribution in ultra-dense VANET scenarios. In Skip-HoVe, autoregressive integrated moving average (ARIMA) is used to predict vehicle mobility, packet data rate is used as a quality-of-service requirement, hybrid QoE estimation is used as a Quality of Experience parameter, and reference signal received quality is used to make handover decisions.

Skip-HoVe employs the analytic hierarchy process (AHP) to assign varying degrees of importance to each criterion, allowing it to calculate the quality level for each cell and select the appropriate cell for vehicle connection. The simulation results show that Skip-HoVe outperforms NC-skipping [24], signal-to-interference-plus-noise ratio based [25], and power budget handover techniques, achieving improvements of up to 14% in structural similarity (SSIM) for video delivery and up to 30% in subjective evaluations based on the mean opinion score (MOS), all while keeping the ping-q\pong rate below 2%. Additionally, an improved handover scheme that minimizes handover latency and the ratio of packet loss is proposed in [26], which does not require authentication again if UE moves within the same PMIPv6. The performance of the proposed scheme is evaluated in NS-2 and a real test-bed, demonstrating effective reduction of handover latency and packet loss. However, it should be noted that the proposed scheme only works for intra domain handover.

Furthermore, the handover algorithm for vehicular networks (HoVe) [27] is introduced as a predictive QoE and mobility-adaptive vehicular network handover algorithm. HoVe provides a robust handover decision and a high quality-of-experience for video-based applications in 5G-VANETs by taking user location, quality-of-experience, and radio resources into account. Based on vehicle and network conditions, analytic hierarchy process provides varying degrees of importance to each criterion and assigns a score to each network attribute. In vehicular scenarios, simulation results show that HoVe achieves an 18% improvement in quality-of-experience over state-of-the-art algorithms.

Finally, the D-HCP algorithm is proposed to optimize handover parameters based on handover types for heterogeneous networks [28]. The objective of D-HCP is to decrease radio link failure and handover ping-pong probability by optimizing TTT and HOM values in accordance with mobility scenarios to enhance mobility robustness. The performance of the D-HCP algorithm is assessed through a two-tier model simulation and is compared with three scenarios involving static HCP values. The results indicate that the system performance is enhanced by D-HCP when compared to the static values across a range of mobile speeds. Table 3 summarizes the handover techniques used in existing works.

Table 3. The handover technique used in existing works

Author	Descriptions	Results
Costa *et al.* [22]	An efficient VANET handover management scheme in the 5G cellular network is enabled using a vehicle trajectory prediction scheme employing a Markov chain predictor. This scheme involves the generation of a synthetic dataset for the mobility traces of vehicles and their handover history, guided by the concept that vehicle movement patterns are road dependent.	Analysis and simulation results shows its superior performance to the 3GPP A3 and A2A4 algorithms, reducing the number of handovers by over 60%.
Demarchou *et al.* [23]	A multi-criteria handover algorithm is used in ultra-dense VANET scenarios to improve QoE and reduce ping-pong rates. This is accomplished using a handover skipping technique and the consideration of a combination of mobility prediction, QoS, QoE, and radio parameters. AHP is used to weight the criteria and select the best cell for connection.	Simulation results show that Skip-HoVe outperforms other handover algorithms in terms of video delivery quality, with up to 14% improvement in SSIM and up to 30% in MOS, while maintaining a low ping-pong rate below 2%.
Pacheco *et al.* [26]	An improved handover scheme that reduces handover latency and packet loss without requiring authentication if UE moves within the same PMIPv6. However, the scheme is only suitable for intra domain handover.	The performance was evaluated in NS-2 and a real test-bed, showing that the proposed scheme effectively reduces handover latency and packet loss.
Alhammadi *et al.* [27]	A predictive handover algorithm that is aware of QoE and mobility for vehicular networks is known as HoVe. It delivers a robust handover decision and ensures high QoE for video-based applications in 5G-VANETs by considering user location, QoE, and radio resources. HoVe utilizes AHP to allocate varying degrees of importance to each criterion based on vehicle and network conditions, thus assigning a score to each network attribute.	Analysis and simulation results shows its superior performance to the 3GPP A3 and A2A4 algorithms, reducing the number of handovers by over 60%.
Saad *et al.* [28]	Handover parameter optimization (HPO), which is based on handover types, is used in HetNets to reduce radio link failure (RLF) and handover ping-pong probability (HPPP). The algorithm optimises Time to Trigger (TTT) and HandOver Margin (HOM) values for improved mobility robustness across various mobility scenarios.	Simulation results show that Skip-HoVe outperforms other handover algorithms in terms of video delivery quality, with up to 14% improvement in SSIM and up to 30% in MOS, while maintaining a low ping-pong rate below 2%.

3. DISCUSSION

In order to enhance connectivity and performance in high-speed mobility scenarios, it is crucial to develop advanced algorithms that accurately predict the optimal time for initiating handovers. These algorithms take into consideration various factors such as signal quality, network congestion, mobility patterns, and signal strength stability. Besides, exploring techniques to enhance the accuracy of signal strength and quality detection in VANET is an important area of research. By leveraging advanced antenna systems like beamforming and MIMO, along with signal processing techniques such as adaptive modulation and coding, we can significantly improve the reliability of these detection mechanisms. This, in turn, helps in minimizing wrong handover decisions and unnecessary handovers, leading to a more efficient and reliable VANET environment.

In areas where multiple base stations provide overlapping coverage, it becomes essential to develop solutions for coordinated handover decisions. By designing algorithms or protocols that enable seamless coordination between base stations, we can avoid conflicts and ensure uninterrupted connectivity for vehicles. This research area directly tackles the issue of uncoordinated handovers and holds great potential for enhancing overall network performance and user experience. Additionaly, to gain a comprehensive understanding of handover performance in VANETs, it is important to delve into KPI such as RSRP, HOP, RLF, HIT, and HOF. By accurately measuring and managing these KPIs, while considering the unique characteristics of vehicular mobility and communication, we can optimize handover operations and ensure a more reliable and efficient VANET environment.

One of the major challenges during handover transitions is minimizing disruptions and maintaining continuous connectivity. To address this, we need to explore seamless handover techniques that optimize HIT and enable smooth transitions for vehicles. Thus, by implementing mechanisms and strategies would enable users in high-speed vehicular environments experience minimal disruptions and enjoy uninterrupted connectivity, thereby enhancing their overall satisfaction. Apart from that, efficient network management plays a crucial role in preventing unnecessary handovers and optimizing handover decision-making. By focusing on designing efficient configurations and maintenance procedures for base stations and RSUs, we can ensure that these network elements are well-prepared to handle handovers without delays or disruptions.

4. CONCLUSION

In conclusion, efficient handover algorithms are crucial for seamless vehicular communication in 5G-VANETs. The advancements in 5G technology, with its ultra-dense small cells and increased traffic handling capacity, offer great potential for improving handover performance in VANETs. However, there is still room for improvement in advancing 5G deployment for vehicular communication. The number of connected vehicles are increasing, the network becomes more complex, and the handover process becomes more challenging. Handover algorithms must be able to handle a large number of simultaneous handovers and maintain a high level of network performance without introducing delays or other issues. Thus, the scalability of these algorithms in large-scale VANET scenarios needs to be investigated. Future research should focus on the practical implementation of the proposed solution and its evaluation through simulations and field tests.

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REFERENCES

[1] S. Alam, S. Sulistyo, I. W. Mustika, and R. Adrian, “Utility-based horizontal handover decision method for vehicle-to-vehicle communication in VANET,” *International Journal of Intelligent Engineering and Systems*, vol. 13, no. 2, pp. 1–10, Apr. 2020, doi: 10.22266/ijies2020.0430.01.

[2] F. Cunha *et al.*, “Data communication in VANETs: Protocols, applications and challenges,” *Ad Hoc Networks*, vol. 44, pp. 90–103, Jul. 2016, doi: 10.1016/j.adhoc.2016.02.017.

[3] A. A. Ahmed and A. A. Alzahrani, “A comprehensive survey on handover management for vehicular ad hoc network based on 5G mobile networks technology,” *Transactions on Emerging Telecommunications Technologies*, vol. 30, no. 3, Mar. 2019, doi: 10.1002/ett.3546.

[4] B. Canada, C. MobileDan Wang, T. Sun, B. Yang, and W. Chen, “Service-based architecture in 5G by NGMN Alliance,” *Cellular (Sebastian Thalanany)*, 2018.

[5] M. M. Elsayed, K. M. Hosny, M. M. Fouda, and M. M. Khashaba, “Vehicles communications handover in 5G: A survey,” *ICT Express*, vol. 9, no. 3, pp. 366–378, Jun. 2023, doi: 10.1016/j.icte.2022.01.005.

[6] A. U. Rehman, M. Bin Roslee, and T. Jun Jiat, “A survey of handover management in mobile HetNets: current challenges and future dpirections,” *Applied Sciences (Switzerland)*, vol. 13, no. 5, p. 3367, Mar. 2023, doi: 10.3390/app13053367.

[7] M. S. Sheikh and J. Liang, “A comprehensive survey on VANET security services in traffic management system,” *Wireless Communications and Mobile Computing*, vol. 2019, pp. 1–23, Sep. 2019, doi: 10.1155/2019/2423915.

[8] J. Cao *et al.*, “A survey on security aspects for 3GPP 5G networks,” *IEEE Communications Surveys and Tutorials*, vol. 22, no. 1, pp. 170–195, 2020, doi: 10.1109/COMST.2019.2951818.

[9] A. Abdulraqeb, R. Mardeni, A. M. Yusoff, S. Ibraheem, and A. Saddam, “Self-optimization of handover control parameters for mobility Management in 4G/5G Heterogeneous Networks,” *Automatic Control and Computer Sciences*, vol. 53, no. 5, pp. 441–451, Sep. 2019, doi: 10.3103/S014641161905002X.

[10] H. Martikainen, I. Viering, A. Lobinger, and T. Jokela, “On the basics of conditional handover for 5G mobility,” in *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC*, Sep. 2018, vol. 2018-Septe, pp. 1–7, doi: 10.1109/PIMRC.2018.8580946.

[11] S. Patil, M. Bakhar, and P. Biradar, “Estimation and influence of decision time intervals on wrong decision probabilities of multi handover criteria,” in *2021 2nd International Conference for Emerging Technology, INCET 2021*, May 2021, pp. 1–6, doi: 10.1109/INCET51464.2021.9456203.

[12] M. R. Palas *et al.*, “Multi-criteria handover mobility management in 5G cellular network,” *Computer Communications*, vol. 174, pp. 81–91, Jun. 2021, doi: 10.1016/j.comcom.2021.04.020.

[13] D. Zidic, T. Mastelic, I. Nizetic Kosovic, M. Cagalj, and J. Lorincz, “Analyses of ping-pong handovers in real 4G telecommunication networks,” *Computer Networks*, vol. 227, p. 109699, May 2023, doi: 10.1016/j.comnet.2023.109699.

[14] J. Kurjenniemi and T. Henttonen, “Effect of measurement bandwidth to the accuracy of inter-frequency RSRP measurements in LTE,” in *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC*, Sep. 2008, pp. 1–5, doi: 10.1109/PIMRC.2008.4699694.

[15] I. Shayea, M. Ergen, A. Azizan, M. Ismail, and Y. I. Daradkeh, “Individualistic Dynamic Handover Parameter Self-Optimization Algorithm for 5G Networks Based on Automatic Weight Function,” *IEEE Access*, vol. 8, pp. 214392–214412, 2020, doi: 10.1109/ACCESS.2020.3037048.

[16] S. Alraih, R. Nordin, I. Shayea, N. F. Abdullah, A. Abu-Samah, and A. Alhammadi, “Effectiveness of handover control parameters on handover performance in 5G and beyond mobile networks,” *Wireless Communications and Mobile Computing*, vol. 2022, pp. 1–18, Mar. 2022, doi: 10.1155/2022/2266282.

[17] A. B. Abdulkarem, L. Audah, A. B. Abdulkareem, and M. B. Abdulkareem, “A comprehensive study of handover mechanism with minimal resources in 5G cellular networks: architecture and challenges,” *Journal of Ambient Intelligence and Humanized Computing*, Apr. 2022, doi: 10.1007/s12652-022-03839-4.

[18] C. Lee, J. Jung, and J. M. Chung, “Intelligent dual active protocol stack handover Based on Double DQN Deep Reinforcement Learning for 5G mmWave Networks,” *IEEE Transactions on Vehicular Technology*, vol. 71, no. 7, pp. 7572–7584, Jul. 2022, doi: 10.1109/TVT.2022.3170420.

[19] Z. Alireza and H. Sara, “Study, analysis and improving of handover process in LTE system,” *Indian Journal of Science and Technology*, vol. 11, no. 35, pp. 1–10, Sep. 2018, doi: 10.17485/ijst/2018/v11i35/98797.

[20] J. Balen, B. Tomasic, K. Semialjac, and H. Varga, “Survey on using 5G technology in VANETs,” in *2022 45th Jubilee International Convention on Information, Communication and Electronic Technology, MIPRO 2022 - Proceedings*, May 2022, pp. 442–448, doi: 10.23919/MIPRO55190.2022.9803468.

[21] A. Aboud, H. Touati, and B. Hnich, “Handover optimization for VANET in 5G networks,” in *2021 IEEE 18th Annual Consumer Communications and Networking Conference, CCNC 2021*, Jan. 2021, pp. 1–2, doi: 10.1109/CCNC49032.2021.9369552.

[22] A. Costa *et al.*, “Skipping-based handover algorithm for video distribution over ultra-dense VANET,” *Computer Networks*, vol. 176, p. 107252, Jul. 2020, doi: 10.1016/j.comnet.2020.107252.

[23] E. Demarchou, C. Psomas, and I. Krikidis, “Mobility management in ultra-dense networks: Handover skipping techniques,” *IEEE Access*, vol. 6, pp. 11921–11930, 2018, doi: 10.1109/ACCESS.2018.2810318.

[24] V. Raida, M. Lerch, P. Svoboda, and M. Rupp, “Deriving cell load from RSRQ Measurements,” in *TMA 2018 - Proceedings of the 2nd Network Traffic Measurement and Analysis Conference*, Jun. 2018, pp. 1–6, doi: 10.23919/TMA.2018.8506494.

[25] H. Yu and M. Zhou, “Improved handover algorithm to avoid duplication aaa authentication in proxy MIPV6,” *International Journal of Computer Networks and Communications*, vol. 10, no. 3, pp. 75–85, May 2018, doi: 10.5121/IJCNC.2018.10306.

[26] L. Pacheco *et al.*, “A handover algorithm for video sharing over vehicular networks,” in *2019 9th Latin-American Symposium on Dependable Computing, LADC 2019 - Proceedings*, Nov. 2019, pp. 1–9, doi: 10.1109/LADC48089.2019.8995680.

[27] A. Alhammadi, M. Roslee, M. Y. Alias, I. Shayea, and S. Alraih, “Dynamic handover control parameters for LTE-A/5G mobile communications,” in *Proceedings - 2018 Advances in Wireless and Optical Communications, RTUWO 2018*, Nov. 2018, pp. 39–44, doi: 10.1109/RTUWO.2018.8587895.

[28] W. K. Saad, I. Shayea, B. J. Hamza, H. Mohamad, Y. I. Daradkeh, and W. A. Jabbar, “Handover parameters optimisation techniques in 5g networks,” *Sensors*, vol. 21, no. 15, p. 5202, Jul. 2021, doi: 10.3390/s21155202.

BIOGRAPHIES OF AUTHORS

Muhamad Ali Zuhdi Rosli is a Bachelor of Information Technology (Hons) student in Faculty of Information Science and Technology, Multimedia University (MMU), Melaka, Malaysia, majoring in data communication and networking. His research interests include internet of things, mobile and wireless network, sensor technology, and embedded device. He can be contacted at email: 1181302884@student.mmu.edu.my.

Siti Fatimah Abdul Razak is a Senior Lecturer at the Faculty of Information Science and Technology, Multimedia University, since 2005. She graduated from Multimedia University (MMU) with a Doctor of Philosophy (Ph.D.) in Information Technology in 2018 and a Master of Information Technology (Science and System Management) in 2004. She is also an active member of the Centre for Intelligent Cloud Computing. Her research interest includes vehicle safety applications, the internet of things, rule mining, information systems development, and educational technology. She can be contacted at email: fatimah.razak@mmu.edu.my.

Sumendra Yogarayan is a Lecturer at the Faculty of Information Science and Technology, Multimedia University (MMU), Melaka, Malaysia. He is an active member of the Centre for Intelligent Cloud Computing (CICC), Multimedia University (MMU). He graduated from Multimedia University (MMU) with a Master of Science (Information Technology) in 2019 and a Bachelor of Information Technology (Security Technology) in 2015. He completed his Doctor of Philosophy (Ph.D.) in Information Technology at Multimedia University (MMU) in 2022. His research interests include intelligent transportation systems, vehicular Ad-hoc networks, wireless communication, and mesh networks. He can be contacted at email: sumendra@mmu.edu.my.