Flexible handover solution for vehicular ad-hoc networks based on software defined networking and fog computing

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ABSTRACT

Vehicular ad-hoc networks (VANET) suffer from dynamic network environment and topological instability that caused by high mobility feature and varying vehicles density. Emerging 5G mobile technologies offer new opportunities to design improved VANET architecture for future intelligent transportation system. However, current software defined networking (SDN) based handover schemes face poor handover performance in VANET environment with notable issues in connection establishment and ongoing communication sessions. These poor connectivity and inflexibility challenges appear at high vehicles speed and high data rate services. Therefore, this paper proposes a flexible handover solution for VANET networks by integrating SDN and fog computing (FC) technologies. The SDN provides global knowledge, programmability and intelligence functions for simplified and efficient network operation and management. FC, on the other hand, alleviates the core network pressure by providing real time computation and transmission functionalities at edge network to maintain the demands of delay sensitive applications. The proposed solution overcomes frequent handover challenges and reduces the processing overhead at core network. Moreover, the simulation evaluation shows significant handover performance improvement of the proposed solution compared to current SDN based schemes, especially in terms of handover latency and packet loss ratio under various simulation environments.

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1. INTRODUCTION

The intelligent transportation system (ITS) is developed to improve the customers' daily life since many people spend a considerable amount of their daytime on transportation. The ITS may provide not only the transportation and road safety applications, but also Internet browsing, text chatting, voice communication, video conferencing, and file downloading. Vehicular ad-hoc networks (VANETs) are considered the fundamental technology of ITS that integrates new wireless technology with vehicles [1]–[3]. However, current VANET networks architecture may face several issues caused by rapid growth of the vehicular users and high data rate demands for wide range of applications and services. At high mobility scenario and overcrowded roads, this architecture is unable to satisfy the latency requirements of future ITS [4], [5]. The development of 5G mobile technologies may offer new opportunities to design a flexible VANET architecture with low latency and higher bandwidth demands. The 5G networks support wider spectrum resources; higher data transmission and low latency communication which can be used to improve VANET network performance [6]–[8].

In terms of architecture, the vehicles are considered the main communication nodes in VANET networks. In general, VANET network may include the vehicles, road-side units (RSUs), on-board units (OBUs), and base stations (BSs) that perform the communication protocols through different wireless communication technologies. Particularly, the BS is a transceiver with radio frequency (RF) antennas which provide wireless RF signals to transmit and receive information with other wireless devices. Hence, the wireless client devices such as vehicles can communicate with each other through BSs. In cellular wireless networks, the BS commonly referred to as cell tower that serve the mobile devices in the cell. The cell in the cellular system refers to the geographical area covered by a BS. However, two communication modes can be considered: vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). In V2V communication mode, the vehicles can share information by connecting to each other without need for any external supervision; while in V2I communication mode, the communication may be controlled by the deployed RSUs or BSs [4], [5]. Nevertheless, VANET regularly suffers from dynamic network environment and topology changes caused by high mobility feature of vehicles. Moreover, VANET network gain additional topological instability due to varying vehicles density. This leads to remarkable issues in new connection establishment and ongoing communication sessions activity. In this case, VANET network performance and quality of service (QoS) are affected by handover architecture. Therefore, efficient and seamless handover architecture is needed to maintain future ITS system [4], [7].

Some significant technologies of 5G mobile networks can be used to deal with this issue. The software defined networking (SDN) and edge/fog computing (FC) are considered the most attractive paradigms to maintain network architecture challenges and computing environment for VANET networks. The SDN technology is considered a promising approach for mobile communication due to its flexibility, programmability, and network abstraction. SDN is a revolutionary paradigm that provides flexible network design and management. The SDN paradigm splits the network architecture into two main planes, the control plane, and the data plane. In particular, the SDN concept relies on the decoupling of the control capabilities (control plane) and the forwarding functions (data plane). The control plane includes a centralized controller which is responsible for all decision-making functionalities. The data plane is defined as dumb forwarding elements that managed by the centralized controller. Hence, the SDN controller in the control plane creates and manages the rules which applied to the forwarding equipment or SDN switches in the data plane. The communication between these two planes is performed using OpenFlow protocol. The OpenFlow protocol provides a set of communication messages between SDN controller and SDN switches. These messages include the information for creating and updating the rules in the switches. The rules refer to programmable decisions of the SDN controller that define the actions in the SDN switches, such as forwarding or dropping packets. Also, it includes information about network topology, user criteria, and important metrics. Generally, the programmability and flexibility of SDN architecture supported by centralized intelligence functions provide a global network view with simplified network management [9]. Thus, the SDN controller at the control plane offers up-to-date network information for various applications and services in the data plane. On the other hand, FC is considered an extension of cloud computing which brings the processing of the data at the network edge near the creation of data; compared to centralized processing at cloud server in cloud computing. Hence, FC reduces the pressure at core network and offers an efficient approach to ensure QoS applications that require local information and real time processing, such as location awareness and mobility management [10]. However, VANET network is time sensitive technology which requires less processing time and minimum network latency. The FC is a vital technology that includes the networking and computing services at the edge vehicles. Practically, FC provides decentralized processing and storage and more closeness to the vehicles.

Different from previous generations, 5G mobile networks provide several services with improved performance and wider capabilities. Dangi *et al.* [11] explained the emergence of 5G mobile network focusing on key features, applications, research groups and their work. They illustrated a survey on different 5G technologies, such as millimeter wave, massive multiple input multiple output (massive MIMO), mobile edge computing (MEC), beamforming, optimization, and machine learning. They highlighted the most recent improvements and future directions for 5G mobile network. Waheed *et al.* [12] presented a review on all computing paradigms for VANET network, including the features of each paradigm, architectural details, similarities, and differences. They described various computing paradigms such as mobile cloud computing, vehicular cloud computing, mobile edge computing, vehicular fog computing, and so on. A comprehensive survey study on fog computing is performed by Jain *et al.* [13] as a network efficient computing paradigm in 5G-enabled smart city infrastructure. They focused on fog computing as a trustworthy solution for real time and latency specific applications. They presented an algorithmic and architectural evaluation of various fog framework solutions. They also considered many 5G enabled application challenges for sustainable smart city infrastructures. Similarly, da Silva *et al.* [14] demonstrated a systematic mapping study with a deep understanding of the fog computing paradigm applications for smart cities platforms. They presented an overview of the current state of research on this topic and explained the main gaps in the current literature. They also described the promising future directions of FC in smart city applications. Farooqi *et al*. [15] developed a priority-based fog computing to reduce the network delay in smart urban VANET networks. They also benefited from 5G technologies to upgrade the fog architecture by using 5G localized multi-access edge computing (MEC) servers in order to accomplish the QoS and delay requirements.

The idea of using SDN with FC as future candidate technologies for VANET network is discussed first by Truong *et al*. [16] and then by Khan *et al*. [17], who focused one spreading the operation of SDN across centralized controller, cellular base station, RSU, and fog vehicles. Soua and Tohme [18] presented three use cases to show the benefits of SDN and FC for VANET networks. Noorani and Senoonly [19] focused on data forwarding and routing methods using SDN and FC. However, neither handover operation details nor handover performance evaluation was provided in these mentioned works. As the researchers tend to use SDN to overcome poor handover performance, He *et al.* [20] presented handover solution using SDN for vehicular network. They did not explain how SDN control works. Atwal *et al.* [21] suggested a distributed SDN control plane into global controller at cloud working on RSU and local controllers working on vehicles. However, they ignored the location of centralized SDN controller at the core network to maintain overall network operation. A fast handover based on the predicable movement of vehicles using SDN was proposed by Yin and Wang [22]. They did not provide any information about the predication mechanism operation. Following the same idea, Mouawad *et al.* [23] provided a similar study by anticipating the handover by duplicating transmitted packets to improve packet delivery ratio. Nevertheless, duplication process may affect network performance and can cause network congestion. Recently, Duo *et al.* [24] employed SDN and MEC to cache the data before handover happens to restore normal connection faster. Silva *et al.* [25] discovered two architectures based on RSUs are inside or outside of SDN environment. Although they claimed for more proactive detection improvement using SDN at RSU, but the control mechanism of the handover procedure still performed at centralized SDN controller.

In summary, the traditional SDN based handover in previous mentioned studies [20]–[25] shows notable challenges due to handover operation with the centralized SDN controller. These studies generate higher handover latency and higher packet losses as the handover controller signals take long delay time from vehicle at edge network to the centralized SDN controller at the core network. Moreover, higher numbers of mobile vehicles cause additional processing overhead at centralized SDN controller at the core network. Also, these studies suffer from frequent handover problem which affects VANET performance due to a lot of vehicles connected to the same BS. In addition, these studies may fail to provide QoS demands at high mobility scenario, high data traffic, and delay sensitive applications. Furthermore, they lack detailed simulation evaluation for handover latency (HL) and packet loss (PL) ratio, which is the most important metrics of handover performance [26]. To fill the gap, this paper aims to design a flexible handover solution for VANET networks to overcome previous challenges by integrating the operation of SDN and FC technologies. The paper proposes VANET architecture such that the handover procedure is performed near the network edge without bothering core network. A flexible handover solution is then proposed by incorporating zone SDN controllers near the access network and fog computing vehicles. The proposed solution therefore alleviates the core network pressure by providing the necessary computation requirements to perform handover management near the edge network. Hence, the proposed solution can maintain the demands of high mobility vehicles and high data rate services. This paper also provides simulation implementation and evaluation of handover performance metrics of HL and PL ratio during varying network environment.

The rest of this paper is organized: Section 2 presents a detailed description of the proposed system design and operation. Section 3 describes the simulation evolution and results discussion for the proposed system compared to current traditional system. Section 4 concludes the paper.

2. PROPOSED SYSTEM DESIGN

In general, the handover operation is a vital evaluation function to meet QoS requirements for next generation VANET networks. The latest 5G network paradigms have been used to maintain variety of network mechanisms and also to provide seamless handover solution. Current traditional SDN based handover architecture (clarified in Figure 1 [24], [25]), faces several issues in flexibility and scalability. Therefore, the proposed architecture (SDN-FC) integrates the operation of SDN and FC technologies to satisfy lower handover delay and high reliability solution for future ITS system. The proposed architecture benefits from SDN global view and programmable functionalities to provide flexible controlled network, meanwhile the processing capabilities of FC at network edge offer computational services for ultra-low delay applications.

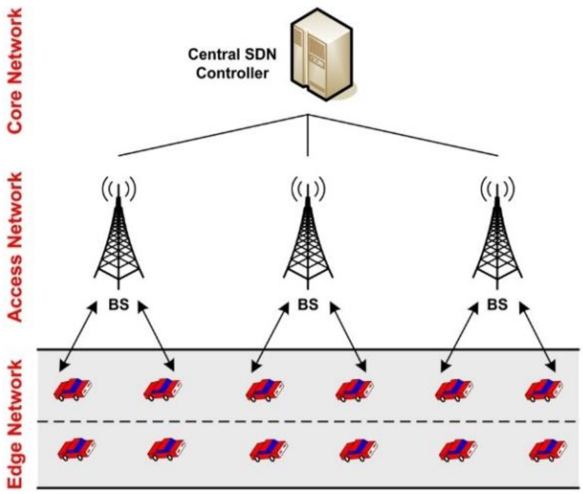

Figure 1. Traditional SDN based handover architecture

In particular, the handover in wireless and mobile communication area refers to process when the active session of a cellular call is transferred from one BS to another one without losing the communication session. Handover scheme (mobility management) defines the detailed handover messages to provide on-the-go communication ability in cellular communication. Handover may occur either by moving from one cell to the new one or when there is signal quality degradation in the serving cell. Handover scheme is considered a critical characteristic in the design of mobile networks to improve the performance in active sessions.

The handover in the proposed solution tends to avoid communicating with core network and supports handover procedure near the access network. To simplify the proposed network design, configuration, and management and also to improve the scalability of the proposed solution, the proposed architecture distributes the integrated (SDN-FC) operation into six levels: central SDN (CSDN) controller, zone SDN (ZSDN) controller, BSs with SDN capabilities, RSUs, FC gateway, and FC vehicles. The central and zone SDN controllers are responsible for SDN operation, BSs provide infrastructure connection, while RSU, FC gateway and FC vehicles represent a FC cell.

The CSDN is the global intelligence device located at the core network. It is responsible for overall network operation, such as resource allocation, traffic management, mobility management, and so on. Also, it controls entire SDN based VANET network behavior. To avoid high delay of control packets from access network to be processed at CSDN controller in the core network, the ZSDN controllers are introduced. The ZSDN controller may reduce the processing at the CSDN controller by maintaining local operations for a dedicated zone near edge network. Hence, the ZSDN controllers play an important role in decreasing the overhead in the control plane. All ZSDN controllers are connected to CSDN controller through backhaul connections. Moreover, ZSDN controller may process the information related to BSs and RSUs, performs emerging services, and orchestrates the computations and communications between FC cells.

The FC technology can efficiently maintain the data store, computation, and transmission functionalities at the edge network with delay consideration. Thus, FC technology is used to reduce the burden on the transmission backbone and also to prevent frequent handover between BS or RSU and vehicles. The FC cell may compose of RSU and a group of vesicles. The FC cell includes RSU, FC gateway, and vehicles. FC vehicles are considered the end users, which benefits from processing capabilities of the OBU of the vehicle. The OBU provides various types of sensors, GPS localization system, and different telecommunication radio transceivers. Thus, FC vehicles can handle several functionalities, such as packet forwarding, interference selection, channel selection, and transmission type selection (i.e. V2V or V2I). One of FC vehicles is selected to be a FC gateway of the cell. The FC gateway takes care for communication with the BS, while other FC vehicles inside the cell are communicated with FC gateway, as shown in Figure 2.

Typically, the VANET architecture supports a heterogeneous network environment in ITS system. However, the vehicles do not function as sender and receiver only, but also as a router for traffic services to forward information to other vehicles or RSU in VANET network. The OBU of the vehicle uses IEEE 802.11 p wireless access in vehicular environment (WAVE) for short range peer to peer communication between vehicles (V2V) since it provides fast communication with lower latency [27]. Meanwhile, it uses 4G long term evolution (LTE) or 5G for wide range communication between vehicles and BSs (V2I) [28], [29]. Accordingly, the OBU runs WAVE communication between vehicles inside FC cell and runs LTE communication between the FC gateway and BS. All the FC elements are supported with SDN functionalities, which orchestrated by ZSDN controller.

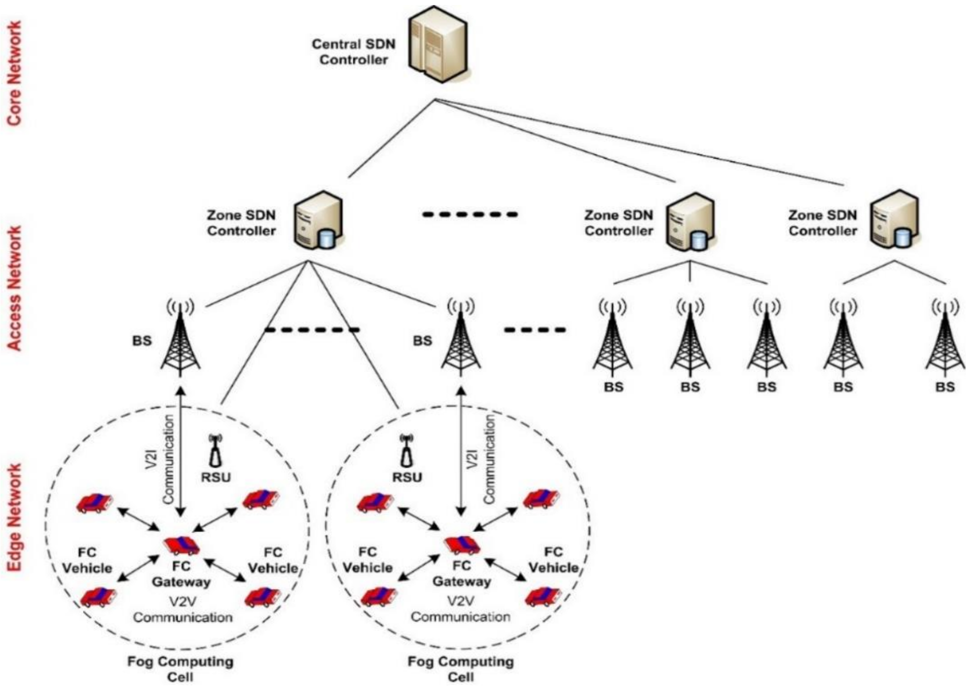

Figure 2. Proposed system architecture of SDN-FC

In general, the BS (which can play as the role of RSU also) may include several FC cells under its coverage area. The FC gateway communicates with BS a long as it is located within the coverage area of this BS, while all other FC vehicles communicate with the network infrastructure through this connection. However, the vehicles that are located out of the coverage area of the BS can use this FC gateway connection to communicate with BS and then with infrastructure whenever there is a direct connection with FC gateway. Notably, the FC gateway transmits period beacons to neighbor vehicles in order to announce their capability of transferring data to VANET infrastructure or Internet through its cellular technology. Thus, the vehicle that wants to benefit from FC cell functions may send a join request to the FC gateway to enter FC cell.

In case of possible disconnection or loss of signal when the FC gateway departs the FC cell, another backup FC vehicle may be elected to works as FC gateway. This is required to ensure seamless vehicular communication with the BSs. The candidate backup FC gateway selection process may depend on fog computation capabilities, SDN functions, and the position of the vehicle. Moreover, the original FC gateway informs the ZSDN controller about the address of the backup FC gateway. Hence, all vehicles in the FC cell can maintain continuous wireless communication while they are moving along the road. Even though some RSUs may be available in the roads, it is impractical for implementation along all the roads. Therefore, vehicles may benefit from communication with available BSs, especially at highway roads. Important to realize that the adjacent ZSDN controllers can share the information of neighboring FC cells at the edge of the coverage area of different ZSDN controllers through CSDN controller. This is to avoid requesting CSDN controller for information update during handover procedure, which generates a high delay. Therefore, seamless connectivity is provided between adjacent ZSDN controllers.

Figure 3 illustrates the handover procedures for both the current SDN handover [24], [25] and the proposed (SDN-FC) one. Figure 3(a) shows the handover procedure for traditional SDN handover. The handover process starts when the received signal strength indicator (RSSI) of the vehicle decreases, then the vehicle sends a handover request to the current BS. The current BS forwards this request to CSDN controller, which selects the target BS based on the available information. The CSDN controller informs the target BS and then replies to the current BS. The current BS notifies the requested vehicle in turn. After that, the vehicle executes handover to new BS. On the other hand, Figure 3(b) presents the proposed SDN-FC handover solution. The proposed solution works as follows. As RSSI degrades during vehicle movement; the vehicle in the fog cell sends a request to the FC gateway with measurement parameters including location, speed, direct, available BSs and so on. The FC gateway forwards the request to the current BS with measurement parameters. The current BS informs the ZSDN controller, which takes the action to select the target BS and replies to current BS. The current BS then informs the FC gateway vehicle to notify the requested vehicle. The vehicle then performs handover from the old BS to the new BS. Note that the vehicle can request BS directly for handover but requesting FC gateway may provide more control functions and better management for FC vehicles in the cell. Also, this may reduce the number of requested handovers on BS and reduce the pressure on it. However, requesting FC may add a very short delay using WAVE communication compared to LTE communication delay with BS. Remarkably, the handover management operations in the proposed approach are controlled by the ZSDN controller, where there is no need to communicate with CSDN controller. Moreover, the FC gateway can make the handover process for group vehicles in some circumstances, like when they are in same the direction and speed. In addition, the FC gateway can extend the coverage area of BS for vehicle that makes direct connection with it.

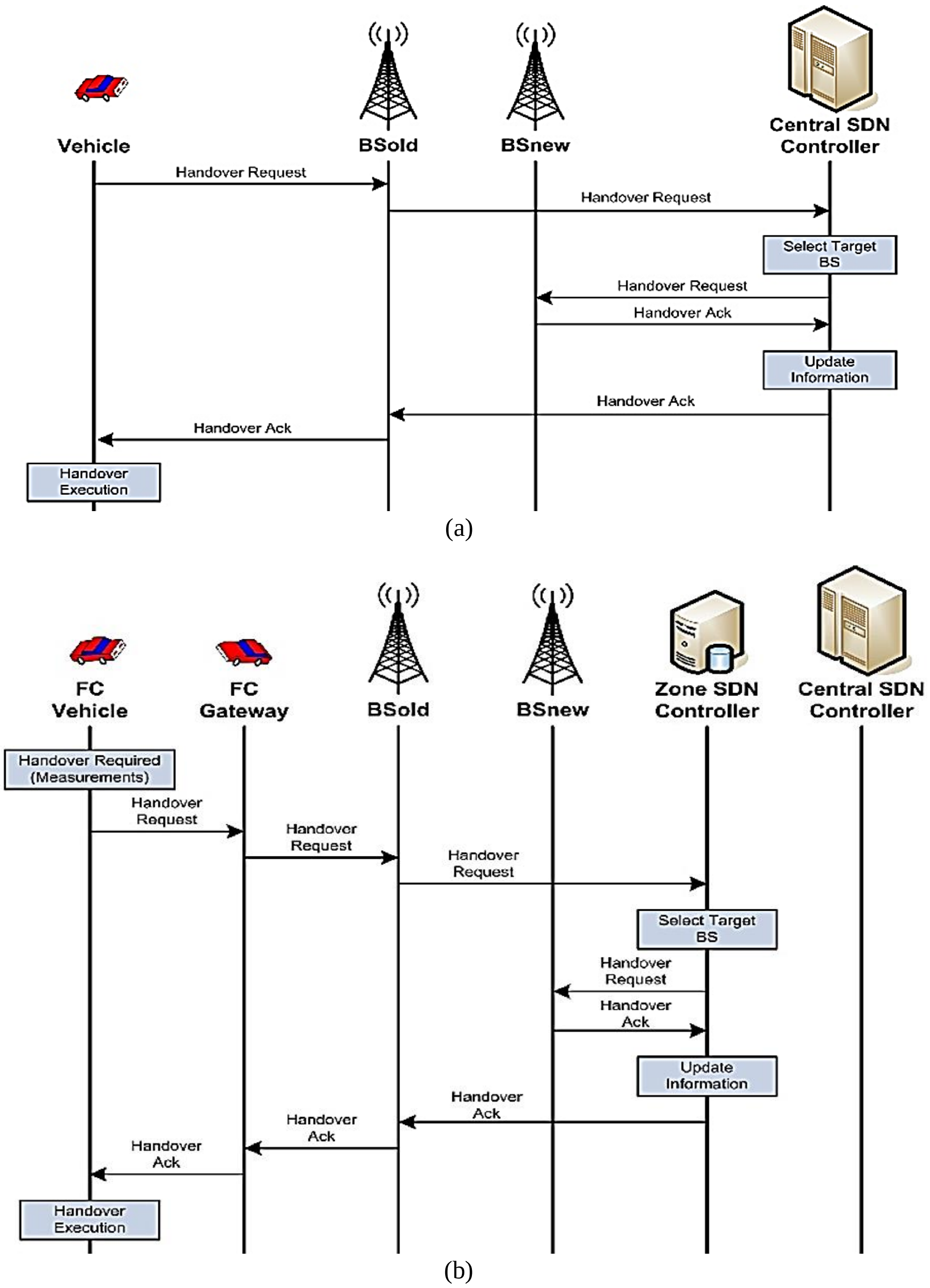

Figure 3. Handover procedure for (a) current SDN solution and (b) proposed SDN-FC system solution

As an illustration, the handover may occur when there is a signal degradation during vehicle movement in the serving BS. In traditional SDN based architecture, the handover procedure from the old BS to the new BS requires a communication with the centralized SDN controller at the core network, as explained in Figure 3(a). This communication is necessary to determine and prepare the target BS. However, the communication with the centralized SDN controller produces several issues since the handover controller signals may take long time delay from vehicle at edge network to centralized SDN controller at the core network. These issues come into view with higher handover latency and higher packet losses, which affects VANET handover performance. Moreover, higher number of mobile vehicles cause additional processing overhead at the centralized SDN controller at the core network. In addition, this current SDN architecture cannot cope with the high mobility scenario, high data traffic requirement, and delay sensitive applications.

On the other hand, the proposed SDN-FC handover procedure is performed by incorporating zone SDN controllers near the access network and fog computing vehicles. The zone SDN controller is responsible for selecting the target BS when the signal quality degrades during vehicle movement from the old BS to the new BS, as shown in Figure 3(b). Therefore, the SDN-FC solution alleviates the core network pressure by providing the necessary computation requirements to perform handover management near the edge network, without any communication need with the centralized SDN controller at the core network. The short delay of handover control messages to zone SDN controller can maintain the demands of high mobility vehicles and high data rate services for VANET network. Moreover, the decentralized processing and storage capabilities of FC technology provide the necessary networking and computing services for handover operation at edge network. Hence, the FC gateway in FC cell relives frequent handover problem caused by the high number of vehicles connected to same BS. This is done by reducing the number of requests handover on the serving BS. Furthermore, the FC gateway not only can extend the coverage area of serving BS, but also it can provide a handover process for a group of vehicles simultaneously. This may happen in some cases, such as when they are in the same the direction and speed. In the next section, we will investigate the performance of the proposed SDN-FC architecture compared to the traditional SDN architecture.

3. SIMULATION RESULTS AND DISCUSSION

The development and implementation of the proposed system model has been achieved using network simulator 2 (NS2) simulator [30]. The VANET simulation area was designed using simulation of urban mobility (SUMO). The SUMO was integrated with NS2 simulator considering heterogeneous wireless networks through high way environment [31]. The default parameters of the simulation scenario are presented in Table 1.

Table 1. Default simulation parameters

Parameter	Default Value
Simulation area	3000*3000 meters
Wireless network environment	Heterogeneous (Cellular+WAVE)
Long range communication	LTE
Short range communication	802.11p WAVE
Radius of LTE cellular coverage area	500 m
Radius of WAVE coverage area	200 m
Propagation model	Two ray model
Routing protocol	DSDV
Vehicle speed	10 m/s
Number of vehicles	30
CBR packet size	1000 Bytes
CBR packet interval	0.01 second
RSU to central SDN controller delay	10 ms
RSU to zone SDN controller delay	2 ms
Transmission link bandwidth	100 Mbps

The study focuses on the HL and PL since they represent the most important metrics for handover system evaluation. The HL represents the amount of time from when the vehicle disconnects from the old BS to when the vehicle receives first packet correctly from the new BS. The PL measures the average number of packets dropped during handover from the old BS to the new BS.

The effect of vehicle speed on HL is shown in Figure 4. It can be seen that low vehicle speed demonstrates lower HL compared to high vehicle speed. This is related to the fact that the handover control signals have sufficient time to reach to the SDN controller to take action for handover management at low vehicle speed. Particularly, the proposed system of SDN-FC produces lower HL compared to the traditional

SDN based system [19], [20]. The reason is twofold: first, the processing capabilities of FC at the edge network, which provides the best measurement parameters to select the new BS. Second, the short period of time delay in which to perform all mobility messages with ZSDN controller near the edge network, compared to performing them with CSDN controller at the core network in the traditional SDN based system. However, the proposed system shows 11% HL reduction at low vehicle speed and about 30% HL reduction at higher vehicle mobility speed compared to the traditional SDN based system.

Figure 5 illustrates the effect of vehicle speed on PL ratio. Clearly shown that the generated PL ratio is similar to the obtain HL since the PL is directly affected by the time period of HL. Consequently, the proposed SDN-FC based VANET system demonstrates notable PL ratio reduction compared to the traditional SDN based system. Thus, the proposed system improves the network performance and QoS requirements.

The influence of the delay between the BS and the SDN controller on HL is presented in Figure 6. It is obvious that the HL escalates with BS to SDN controller delay increases for both proposed and traditional systems. However, the HL of the traditional SDN based system increases more rapidly compared to the proposed SDN-FC system. Specifically, the proposed system shows 11% lower HL at low vehicle speed and 53% lower HL at higher vehicle speed compared to the traditional system. This is because the proposed SDN-FC system manages handover operations at ZSDN controllers which is working near the edge of the network, while the traditional system manages handover operations at the CSDN controller at the core network. Thus, the proposed system needs lower time to reach the controller to perform handover process compared to high time delay to reach the core network for the traditional system. Moreover, the distribution processing of the ZSDN controllers gives another advantage for the proposed system compared to the heavy processing at the CSDN controller for the traditional system. Particularly, the processing overhead presents another delay challenges for the traditional SDN based system.

Figure 7 displays the effect of the different data rate services presented by constant bit rate (CBR) packet interval on PL ratio. Various data types can be generated by changing the time of the packet interval between successive packets. Lower data rate applications such as voice can be presented by large CBR packet interval, while higher data rate applications such as video can be presented by small CBR packet interval. It can be noted that proposed SDN-FC system outperforms the traditional SDN one, especially at high data rate applications with a small packet interval. More specifically, the proposed system demonstrates 8% reduction in the PL ratio at low data rate services and 16% lower PL ratio at higher data rate services. This outcome is attributed to the fact that the proposed system produces lower HL compared to the traditional system. Subsequently, the proposed SDN-FC system reduces the communication disruption during handover operation; and then reduces PL ratio.

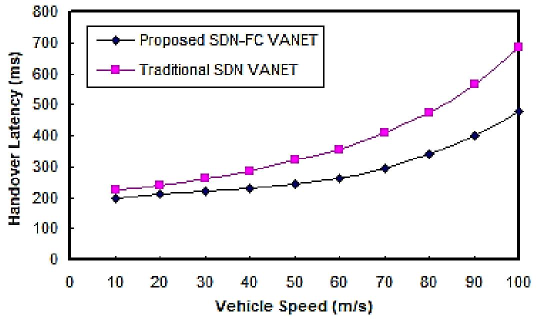

Figure 4. Impact of vehicular speed on HL

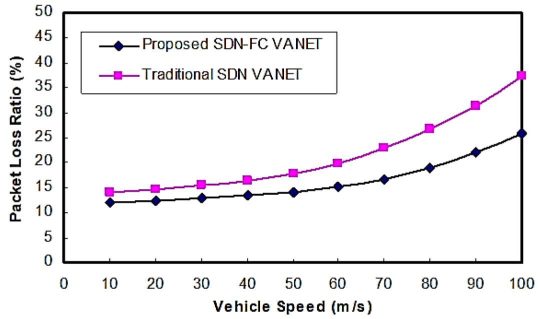

Figure 5. Impact of vehicular speed on PL ratio

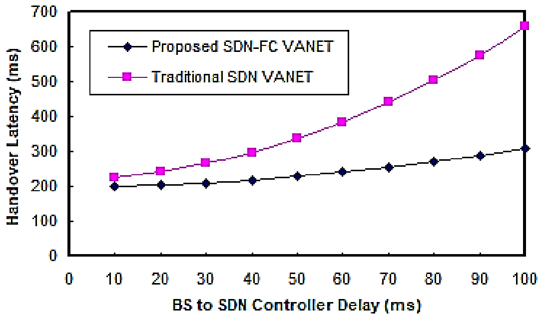

Figure 6. Impact of BS to SDN controller delay on HL

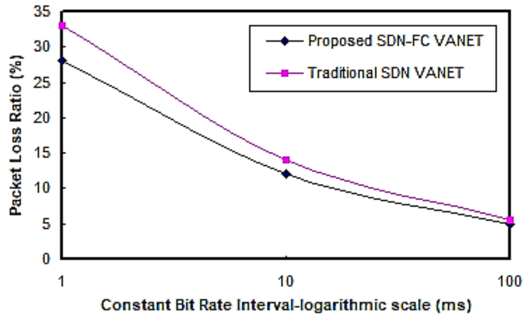

Figure 7. Impact of data rate (constant bit rate interval) on PL

4. CONCLUSION

This paper proposes a handover solution to address the challenges of next generation VANET networks using recent technologies of 5G mobile networks. The proposed SDN-FC architecture integrates the operation of the SDN and FC technologies to solve the issues of the current traditional SDN based architecture. The SDN offers programmability and network flexibility requirements, while FC provides computation and transmission functionalities to maintain the demands of delay sensitive applications.

Practically, a flexible SDN-FC handover solution is proposed by incorporating zone SDN controllers near the access network and fog computing vehicles. The flexible solution is twofold architecture improvements: First, it employs a distributed SDN management through several zone SDN controllers spreading across the network. This may reduce the processing overhead on the centralized SDN controller and minimize the handover delay by avoiding any communication with the core network. Second, the SDN-FC solution benefits from decentralized processing and storage capabilities of FC technology to provide the necessary networking and computing services for handover operation at edge network. The proposed solution therefore alleviates the core network pressure by providing the necessary computation requirements to perform handover management near the edge network. Hence, the proposed solution can maintain the demands of high mobility vehicles and high data rate services.

The operation of the FC gateway in FC cell provides another key point for the proposed SDN-FC solution. The FC gateway offers several benefits: first, it relieves frequent handover problem caused by the high number of vehicles connected to the same BS. This is done by reducing the number of requests handovers on the serving BS. Second, the FC gateway can extend the coverage area of the serving BS by letting other vehicles use its connection. Third, it can provide a simultaneous handover process for a group of vehicles in some cases such as when they are in the same direction and speed.

The simulation implementation and evaluation reveal the notable outcomes of the proposed SDN-FC solution compared to the traditional SDN architecture. The proposed solution gives a remarkable reduction in HL and PL ratio under various simulation environments. Thus, the proposed system provides high reliability and flexibility architecture to overcome current VANET networks challenges and can meet the QoS satisfaction for future ITS system.

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