Supporting Handover in an IEEE 802.11p-Based Wireless Access System

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ABSTRACT

The IEEE 802.11p-based wireless access networks are about to be deployed by major highways around the world as one of the main information hauling infrastructure for ITS safety applications. As the most applications of the IEEE 802.11p standard require the delivery of short text-based messages, the standard does not support handover between adjacent Road-side Units (RSUs). However, demand for seamless real-time services such as short video clips of CCTVs on a highway gives rise to support for handover in the IEE 802.11p-based wireless access systems. In this paper, we describe a seamless handover scheme for an IEEE 802.11p-based wireless access system that takes advantage of the fixed-order placement of the RSUs and unidirectional movement of the vehicles along the highways. More specifically, this handover scheme utilizes the IEEE 802.11 disassociation message as to signal the old RSU of an On-broad Unit's (OBU) departure from its coverage area. The subsequent downstream data frames can be proactively forwarded to the new RSU for delivery to the OBU after its link establishment with the new RSU. Simulation results show superior performance of the proposed scheme compared to a poll-based scheme.

Categories and Subject Descriptors

C.2.2 [**Computer-Communications Networks**]: Local and Wide-Area Networks – *Access schemes.*

General Terms

Design, Experimentation, Management, Performance, Standardization

Keywords

IEEE 802.11p, handover, WLAN, MAC, V2I.

1. INTRODUCTION

Traveling in a car is becoming safer than ever with the advent of the new communication technology and services, which create a new driving environment where the drivers are always provided with safety-related information around them. This new communication technology is called the IEEE 802.11p Wireless Access for Vehicular Environment (WAVE) standard, and is going through the final stages of standardization process. Thanks to its technological merits, such as rapid link establishment between an OBU and a Road-side Unit RSU and high-speed transmission, this new standard is expected to be adopted by many advanced transportation infrastructure initiatives as the standard wireless access technology for fast and cost-effective way of delivering important safety-related data on the roads.

Whereas most safety-related data are expected to be small enough to fit in a single WAVE short message (WSM), other types of data, such as those generated from the Internet access, including short video clips of the CCTVs on highways, may require the use of multiple larger-sized MAC protocol data units (MPDUs). Since a fast moving vehicle on a highway can run across the boundaries of radio coverage areas of two adjacent RSUs in the middle of transmitting and/or receiving a group of MPDUs, an unexpected disruption of service can occur unless handover is supported by the network.

One of the basic operations of handover in a cell-based communication system is association or registration of a mobile station (MS) with a new access point (AP) or a base station (BS), i.e., a RSU within the context of IEEE WAVE. This operation also allows the new AP to notify the old AP to release any resources allocated for the MS after the MS's BS switching is completed. The IEEE 802.11 MAC supports a basic handover scheme, i.e., upon determining that it needs to establish a link with a new AP due to low signal strength from the old AP, the MS starts to scan through all channels to select one with the strongest signal, and send a reassociation and reauthentication messages to register its presence under the new AP. The handover delay of this scheme, however, is so large that a seamless handover cannot be achieved.

A number of approaches for enhanced handover schemes for WLANs have been proposed in order to cope with the growing desire for real-time multimedia services such as VoIP on the move. Proactive caching schemes attempt to choose a minimal number of target APs based on neighbor graphs and have the old APs send the MS's context information to the target APs before link to the old AP breaks [1-10]. Standardization groups such as IEEE 802.11 TGf and TGr have been formed to develop specifications to support fast handover in IEEE 802.11-based WLANs [11][12] by reducing the delay in performing QoS

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negotiation as well as reassociation and reauthentication with a new AP during handover. Handover in the IEEE 802.11p is not possible due to the lack of reassociation and reauthentication protocols that were excluded in support of fast establishment of physical links between RSUs and OBUs. Therefore, fast handover schemes mentioned above cannot be directly applied.

A handful of research works exist in the literature that propose to add polling operations to the IEEE 802.11p MAC protocol such that an OBU can inform its presence under a new RSU as soon as the OBU is ready to send messages to the new RSU [13][14]. Informing the new RSU about the OBU's presence after the channel switching, however, can't prevent frame loss caused by temporary disconnection between the start of a handover process and the arrival of handover completion notification at the old RSU which can degrade significantly the quality of service at the application level.

In this paper, we describe a novel seamless handover scheme for the IEEE 802.11p-based system. In realistic situations, it can be assumed that the RSUs be deployed in a fixed order along a highway and the movement of all the vehicles be unidirectional. In other words, given the ID of a RSU, that of the next RSU can be predetermined. Our scheme takes advantage of this by making the OBU inform the old RSU before a connection break such that proactive actions can be initiated to prevent frame losses even before its link establishment with the new RSU.

This paper is organized as follows. In section 1, we give a brief overview on the related technologies. Section 2 explains the proposed scheme in detail. Section 3 describes simulation setup along with the simulation results. We finish our discussion with some concluding remarks.

2. BACKGROUNDS

2.1 The IEEE 802.11p MAC

The IEEE 802.11p and the IEEE P1609 standards, which together comprise the IEEE WAVE standards, has been developed as the wireless communication technology for ITS in North America for which the Federal Communication Commission (FCC) of the U.S. approved 75 MHz bandwidth at 5.850-5.925 GHz frequency band. Among the seven channels of 10 MHz band, CH 178 is designated as the control channel (CCH) whose usage is limited to broadcast of safety-related data and transmission of control and management messages. The other six service channels (SCHs) are expected to be used for non-safety-related data including general Internet service.

The default value for the CCH and SCH interval is set to 50 ms in the standard. According to the specification of IEEE P1609.3 standard, data packet transmission is allowed within a WAVE Basic Service Set (WBSS), which is initiated by either an OBU or a RSU who is a service provider. An OBU or a RSU joins a WBSS as a user. The provider broadcast a WSA message periodically on CCH for all persistence services belonging to the WBSS. This message contains all the information identifying WAVE applications as well as link parameters used by a node to join the WBSS (e.g., the ID of the WBSS, the SCH this WBSS will use, timing information for synchronization purposes). When an OBU joins a WBSS via a RSU, it should receive a WSA on CCH to learn about the parameters associated with the WBSS. The OBU may then switch to the WBSS's SCH to join the WBSS and transmit/receive service data frames. Figure 1 illustrate Channel access process of IEEE P1609.4/IEEE 802.11p MAC.

2.2 The IEEE 802.11f Inter Access Point Protocol (IAPP)

The IAPP is designed to facilitate two important operations during a STA's handoff between two APs, i.e., maintaining a STA's association with a single AP and the secure transfer of context information between the two APs involved in the handoff. When a STA changes its association with a new AP, the new AP sends a Move-Notify message to the old AP announcing the STA is now associated with the new AP. This message can also be used by the new AP to request context information such as IP flow-related data, security-related data, QoS parameters and so forth. The old AP can remove the STA's context information from its association table and responds with a Move-Response message. A secure connection between APs can be obtained at the beginning of a reassociation by exchanging a Security Block message with the help of a RADIUS server based on shared keys. When a STA makes the initial connection with an AP, the AP broadcasts an Add-Notify message to all APs within the same ESS informing the STA's association. The APs that receive this message clear the context information from their association tables in order to ensure the single association of the STA with an AP. The IAPP also provides Cache-Notify/Response message for an AP to proactively transfer a STA's context information to the neighboring APs before a handover begins. Figure 2 illustrate the message exchanges during a handover with the IAPP.

2.3 The IEEE WAVE Four-Address Scheme

The IEEE 802.11 frame format provides four address fields required for a frame to be delivered via possibly multiple APs. The first two addresses (Address 1 and 2) are intended for the address of the receiver (RA) and transmitter (TA) stations of the frame, while the next two addresses (Address 3 and 4) are used to specify the address of final destination station (DA) station and the station that initially generates the frame (SA). Two frame control bits 'To DS' and 'From DS' are used to indicate the direction of frame with respect to the distribution system (DS).

The IEEE P1609.3 specifies three WAVE packet transmission scenarios, i.e., packets passed only on the WAVE link (No DS), packets generated by the OBU and delivered to a host via the DS connected to the RSU, and packets generated by the host behind the RSU and delivered to the OBU. The use of the four addresses in the MAC header is summarized for the WAVE application in Table 1. Note that the transmission of a packet between two RSUs in the DS (ToDS=1, FromDS=1) is not explicitly specified in the standard.

Table 1 summarizes the four-address scheme of IEEE 802.11,

Table 1. IEEE 802.11 Four-Address Scheme

TX scenario	Sender/ Receiver	To DS	From DS	Addr 1	Addr 2	Addr 3	Addr 4
No DS	OBU-OBU RSU-OBU OBU-RSU	0	0	DA	SA	-	-
Receiver on DS	OBU to RSU to Host via DS	0	1	RSU	OBU	SA	-
Sender on DS	Host via DS to RSU to OBU	1	0	OBU	RSU	DA	-

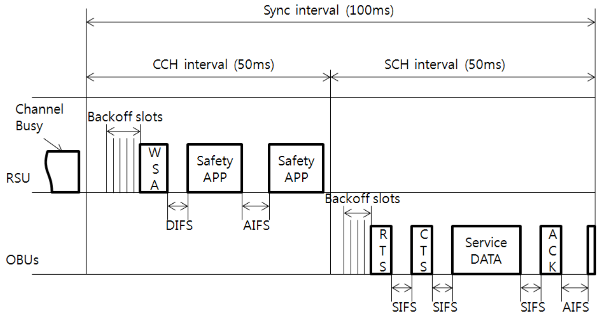


Figure 1. Channel access process of IEEE P1609.4/IEEE 802.11p MAC.

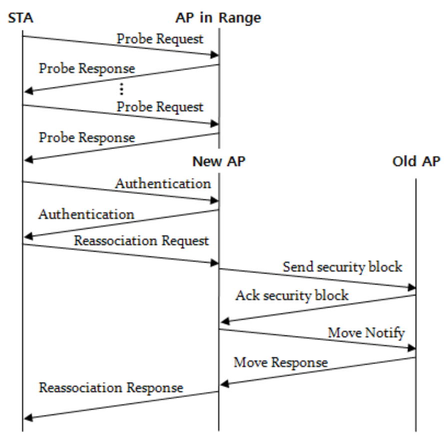


Figure 2. Message exchanges of IAPP.

3. PROPOSED HANDOVER SCHEME

3.1 Network Architecture

We assume that the network is organized in a tree topology with a hierarchy of L2 switches or IEEE 802.1D bridges connected to a gateway router at the root, through which data are delivered from/to the backbone network, and the RSUs at the leaves. Figure 3 gives a conceptual illustration of the network architecture. In this network architecture, built on learning L2 switches, data frames are transported purely based on the MAC addresses. That is, the frames are forwarded by a switch or bridge through one of the output ports according to the filter table entries inserted and updated by reading the source and destination MAC address of all frames that have been received previously. If an entry for the destination MAC address is not found in the filter table, the frame is flooded though all of the ports other than the input port.

In this network, the path from the gateway router to an OBU can be maintained by outbound data frames generated by the OBU or its serving RSU. This means that the mobility management is handled in layer 2 and the entire network appears as a single distribution system with multiple RSUs to the upper layer protocol such as IPv6 which is specified as the L3 protocol for non-safety related applications in IEEE P1609 standard. This also mitigates the use of mobility management protocols for IP such as MIPv6 and PMIPv6 since the entire network can form a single subnetwork.

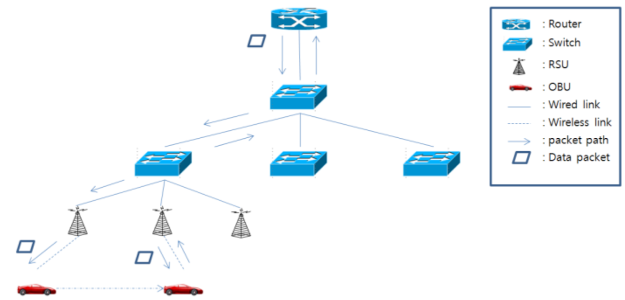


Figure 3. Network Architecture

3.2 Handover Procedure

Handover in the IEEE 802.11 is a process for a STA to change its association with the APs when the received signal strength drops below a certain threshold value. The physical link quality can drop rapidly near the boundary of radio coverage so that the stable reception of data s is not guaranteed. The STA starts a scanning process to find another AP by switching to all available channels to transmit probe messages and/or receive beacons from the APs.

The STA selects an AP with the highest signal strength and initiate a reassociation/reauthentication process in order to make its presence known and identified by the new AP. When the handover process begins, the STA gets disconnected from the old AP which keeps trying to retransmit any s remaining frame in its buffer that are destined to the STA until the STA reassociation response message from the new AP. The new AP can send a Move-Notify message of the IAPP to request the old AP to forward the buffered data frames. Immediately after receiving these frames from the old AP, the new AP transmits them to the STA to achieve a seamless transition of the STA between two APs.

In an IEEE 802.11p-enabled system, on the other hand, there is no need for an OBU to perform the scan operation because the WAVE beacons, i.e., WSA messages are transmitted only in the CCH. Moreover, the reassociation/reauthentication operations have been removed from the current specification of IEEE 802.11p. Thus, it is impossible for an OBU make its presence known to the new AP. A straightforward approach to solve this problem is to introduce a new management message similar to the IEEE 802.11 reassociation message. This approach however has several disadvantages: first, the current protocol specification of IEEE 802.11p should be changed to include the reassociation message, which runs counter to the design philosophy of the IEEE WAVE for instant communication set up; second, a reassociation message may have to be delayed up to 50 ms until the beginning of SCH interval because the unicast of non-safety-related data are not allowed in CCH. Note that this delay period can be lengthened by up to 150 ms if the OBU fails to receive a WSA message in the first attempt due to interference, for instance, in the overlapped transmission ranges of two neighboring RSUs; third, reassociation messages may suffer from high loss probability due to collisions caused by multiple reassociation messages transmitted simultaneously in response to the same WSA message; fourth, radio resource of the old RSU may be wasted by frame retransmissions to the OBU that has already left the old RSU's coverage.

Since a STA can associate with one of the several APs nearby, the STA's presence shall be informed to the AP only after the selection among those APs have been made as specified in handover procedure of the IEEE 802.11. In a highway usage scenario, on the other hand, the identification of the next RSU can be determined, in advance, based on the identification of the current RSU, since it can be assumed that the RSUs are deployed in an ordered fashion along a highway and the movement of vehicles is regular. Taking advantage of this, we can make the OBU inform the old RSU about its intention to handover before breaking its connection with the old RSU, such that the rest of data destined to the OBU can be forwarded by the old RSU and proactively cached by the new RSU even before the OBU receives a WSA message from the new RSU in order to mitigate frame losses. In other words, it is possible to use a proactive scheme in the handover procedure of the IEEE 802.11p-based networks rather than a reactive scheme as in the IEEE 802.11 networks.

We propose to use the IEEE 802.11 disassociation message defined in the standard for this purpose. The disassociation message is transmitted in the SCH by an OBU to signal its old RSU of its imminent departure from the coverage to switch to the next RSU. Upon receiving the disassociation message from the OBU, the RSU can stop transmitting data frames destined to the OBU and, instead, forward them to the new RSU for the last-hop transmission to the OBU. This also helps to save a significant amount of radio resource by preventing the RSUs from transmitting frames to non-existing OBUs. The address fields in the MAC header of the forwarded frames are set as follows: both the 'From DS' and 'To DS' flags are set; Address 1 is set to the new RSU's address, Address 2 is set to the address of the old RSU's address, and Address 3 is set to OBU's address (or broadcast address). Since this type of address combination is never used for regular data/control frames within a WAVE-enabled network, as explained in section 2.3, the new RSU can distinguish the forwarded data frames from the other frames. Having received the first forwarded frame from the old RSU, the new RSU recognizes the OBU's entry into its coverage and transmits a null data frame with the OBU's address recorded in Address 3 through the L2 switch-populated backbone network up to the gateway (router) to other networks. This makes all the L2 switches along the path from the gateway router down to the new RSU update their filter table such that the OBU receives all subsequent frames via the new RSU. Since the OBU can receive the forwarded frames only after it receives a WSA message and configures itself according to the information contained in the WSA, the new RSU transmits the forwarded data frames in the beginning of the next SCH.

It should be pointed out that no frames are expected to be lost due to the connection break during a handover, unless the buffer in the new RSU overflows or the new RSU's retransmission count reaches the limit, since the OBU instructs the old RSU to forward the buffered frames to the new RSU. On the other hand, the proactive caching of data frames at the new RSU can cause a head-of-blocking (HOL) problem if the cached frames are not drawn from the buffer and transmitted to the OBU in time, which can increase the average frame delay by a significant amount. Figure 4 shows the disassociation message format and the message sequence diagram.

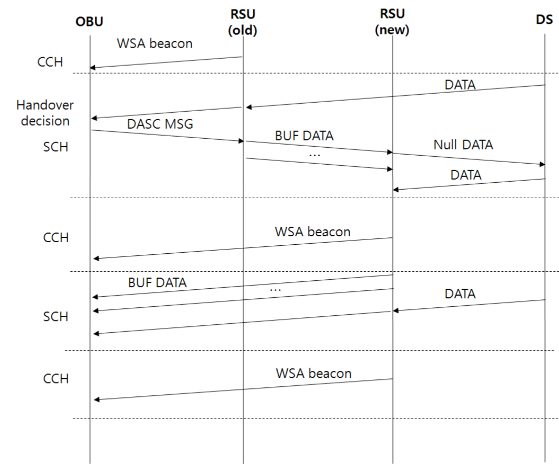


Figure 4. Message exchange sequence of the proposed handover operation

4. SIMULATION RESULT

An ns-2 simulator was used to evaluate the performance of proposed handover procedure. Detailed operations were implemented by modifying an IEEE 802.11e MAC module of the current ns-2 simulator with some changes in the values of parameters listed in Table 2.

Figure 5 gives the conceptual illustration of the simulation scenario. The network consists of 100 OBUs which move along a highway in two lanes, five RSUs which are fixed on a side of the highway at 2,000 m apart, and an L2 switch which connects the RSUs via an Ethernet. The speeds of OBUs are set to be random within 10% range of 160 km/h and the distances between OBUs are set to be random within 10 m range of 160 m which approximately represents the safety distance between cars as calculated by:

$$d_S(v) = d_B(v) + d_R(v) = \frac{v}{3.6} \times t + \frac{v^2}{254\mu} , \qquad (1)$$

where d_S, d_R, and d_B are the safety distance, idle running distance and breaking distance, respectively, t is the idle running time, and μ is the friction coefficient.

Table 2. Handover protocol parameters

parameter	value
CWMin(slots)	31
SlotTime(microseconds)	16
SIFSTime(microseconds)	32
DIFSTime(microseconds)	64
Preamble length(bits)	120
PLCPHeaderLength(bits)	24
PLCPDataRate(Mbps)	6
data rate(Mbps)	27
bandwidth(MHz)	10
operational frequency(GHz)	5.9
transmission range(m)	1,000

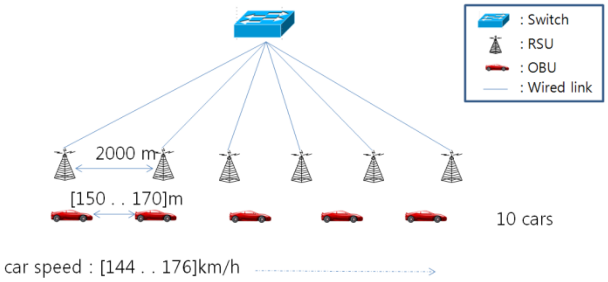


Figure 5. Simulation scenario

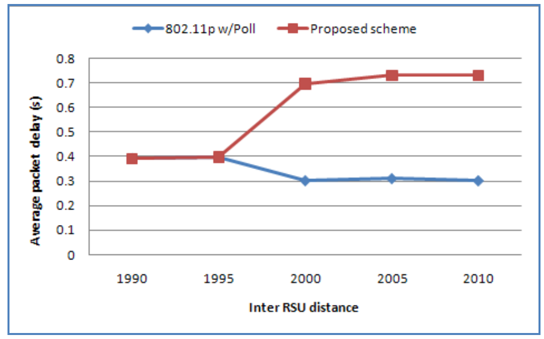
Both the OBUs and RSUs have 1,000 m transmission range. Each simulation run lasts for 60 seconds with all OBUs moving in the same direction. Two types of data traffic flows, one for video stream and the other for CBR data are used to model downlink traffic from the RSUs to the OBUs.

We compare the performance of the proposed handover procedure to that of the IEEE 802.11p with a subsequent poll message transmission. In this protocol, the OBU transmits a poll message destined to the gateway router, upon reception of a WSA message, in order to inform the new RSU of its presence and have all the L2 switches update their filter tables for the potential change of a downstream path from the gateway router the new RSU. Upon receiving this poll message the new RSU sends a Move-notify message to request the old RSU to send the buffered data frames. This handover scheme is conceptually similar to the poll-based schemes proposed in other works mentioned earlier. Simulations are repeated with different values of the distance between RSUs in order to study the effect of handover delay on the performance of application in terms of average packet delay, throughput, and handover delay.

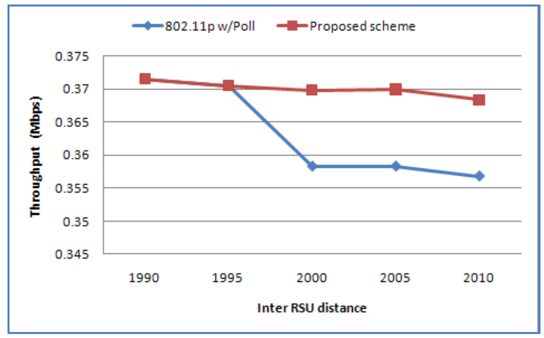
It should be noted that the inter-RSU distance of less than 2,000 m results in a partly overlapped RSU radio coverage. There are two kinds of traffic flows and each OBU receives a single traffic flow during an entire simulation period. One of the traffic flows is a CBR traffic of the priority 2 (AC_BE) with transmitted at the rate of 8 Kbps, with the packet size of 100 bytes, and the packet interval of 100 ms. The other flow is a video stream of priority 1 (AC_VI) transmitted at the rate of approx. 823 Kbps with the packet size of 1,144 bytes and the variable packet intervals. The number OBUs receiving CBR traffic flows and video streams are made the same.

The average packet delay is calculated by dividing the total transmission delay by the total number of packet transmission and the throughput is calculated by dividing the total amount of transmitted data by the total transmission time. The handover delay is calculated by measuring the interval between the moment that an OBU receives the last data frame from the old RSU and the moment that the OBU receives the first data frame from the new RSU.

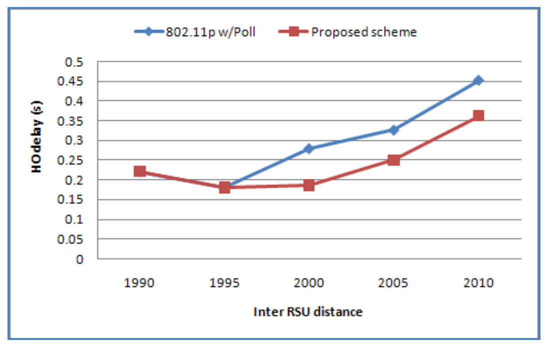
In the simulations, we varied the inter-RSU distance by 5 m from 1,990 m to 2,010 m in order to study the performance of proactive caching used in the proposed handover protocol. Since the distance that a vehicle can move in 100 ms is approximately 4.4 m, the OBU should wait for another SCH to receive a frame from the new RSU.



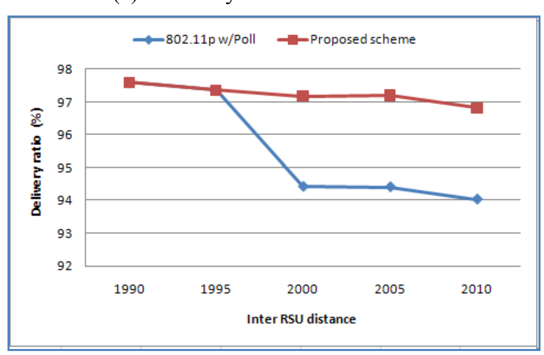
(a) Average packet delay vs. inter-RSU distance



(b) Throughput vs. inter-RSU distance



(c) HO delay vs. inter-RSU distance



(d) Delivery ratio vs. inter-RSU distance

Figure 6. Performance comparison between the proposed scheme and the IEEE 802.11p with Poll messages

All four graphs show that the performances of the two handover protocols remain approximately the same when the inter-RSU distance is less than 2,000 m. This is because the OBU receives data frames in the immediate next SCH of the new RSU after it fails to receive a frame from the old RSU and the length of handover delay is too short to benefit from the proactive caching. As the inter-RSU distance increases to 2,000 m and higher, the proposed scheme starts to outperform thanks to the proactive caching. Figure 6(a) shows the average packet delay increases by a significant amount in the case of proposed scheme indicating that more packets are delivered to the OBU by the new RSU delayed by a certain amount of time. It should be noted that the dropped packets are excluded in calculating delay. As shown in figure 6(b), the throughput of the proposed scheme is higher for the proposed scheme. Figure 6(c) shows shorter handover delay achieved by the proposed scheme. Namely, the OBU begins to receive the buffered frames from the new RSU immediately after receiving a WSA message according to the proposed scheme, whereas the IEEE 802.11p with poll scheme should first send a poll message to bring the buffered frames in the old RSU. A significant number of these packets are removed due to the retransmission limit. This is reflected in Figure 6(d) as the lower delivery ratio for the IEEE 802.11p with poll messages.

5. CONCLUSION

In this paper, we proposed a novel seamless handover scheme for the IEEE 802.11p-based system. Our scheme takes advantage of this by making the OBU inform the old RSU before a connection break such that proactive actions can be initiated to prevent frame losses even before its link establishment with the new RSU. This paper gave a brief overview on the related technologies and explained the proposed scheme in detail. We described simulation setup along with the simulation results. The simulation result showed that proposed scheme have less handover delay, higher throughput and delivery ratio than IEEE 802.11p with poll messages.

As the inter-RSU distance increases to non overlap each RSUs transmission range, the proposed scheme starts to outperform thanks to the proactive caching.

6. ACKNOWLEDGMENTS

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