Towards SDN-enabled RACH-less Make-before-break Handover in C-V2X Scenarios

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***Abstract*—Future vehicular applications will rely on communication between vehicles and other devices in their vicinity. Technologies, such as LTE-V2X, are awaited to operate under the Cellular Vehicle-to-Everything (C-V2X) standard to make this communication possible. However, current LTE technology has to go through transformations to enhance its performance in vehicular communications. One possible enhancement for LTE is the usage of the latest handover schemes, such as RACH-less and Make-before-break (MBB), to create seamless mobility. In the current study, we propose a RACH-less MBB handover scheme using Software-Defined Networks (SDN). Our main contributions are: (i) unifying lower layer handover operations with controller network updating procedures; and (ii) creating a signaling protocol that allows base stations and controllers to exchange information needed for timing alignment of the UE without executing a RACH procedure. Simulation results show that our proposed handover scheme has a shorter execution time and reasonable signaling overhead when compared to baseline schemes from the literature.**

I. Introduction

Future vehicular applications related to autonomous and remote driving, such as pre-crash sensing and warning, vehicular platooning, and other maneuverings, will rely on communication channels between the vehicle and many different connected devices in its vicinity. C-V2X is an important enabling standard to implement these applications [1]. This standard combines different cellular communication technologies, such as IEEE 802.11p, LTE-V2X (4G), and NR-V2X (5G), to connect vehicles to other devices. Each of these technologies targets different use cases and requirements. Also, these technologies are still in the early stages of adoption or under development. For instance, LTE-V2X is an awaited enhanced LTE technology that will coexist with the NR-V2X under the 5G NR standard. However, to coexist with 5G technologies and serve future applications, a series of enhancements need to be applied to LTE.

Examples of enhancements for LTE are: (i) shorter Time Transmission Intervals (TTI) [2] – i.e., shorter time windows allocated to User Equipment (UE) to transmit and receive messages; (ii) better detection of errors for Hybrid Automatic Repeat Request (HARQ) [3]; and (iii) reduction of Handover Execution Time (HET) [4]. Handover schemes in LTE and 5G NR are almost identical and cannot cope with some requirements of existing and future applications [5]. Therefore, researchers study different ways of shortening the handover communication interruptions and HET. The Third-Generation Partnership Project (3GPP) has proposed strategies to mitigate handover bottlenecks [6], such as Make-Before-Break (MBB), which focus on preparing communication channels before disconnecting from the previous Base Station (BS); and also handover strategies that do not need to execute the Random-Access Channel (RACH) procedure to connect to the target BS, i.e., RACH-less handovers.

MBB and RACH-less handover schemes are options to shorten HET when the UE is in a position where it can communicate to both previous and target BS. MBB schemes allow the UE to maintain connectivity with the previous BS (p-BS) until the moment when all communication setup with target BS (t-BS) is ready for use. Besides the possibility of aborting the handover without disconnecting from p-BS, this scheme also reduces waiting times for configuration updates during the handover. Apart from MBB, RACH-less schemes can also lead to considerable reductions in handover interruption times and HET. The RACH process consists of a four-message handshake between UE and BS to exchange information for timing synchronization and provide an uplink grant to transmit messages for the UE [7]. On average, this process takes around 10-12 ms during the handover procedure, while the entire handover has an average duration of 45 ms [8]. A RACH-less approach consists of acquiring information for time alignment and the uplink grant without using the RACH, thus saving the time spent on the RACH procedure. The traditional RACH procedure would still be used when communicating with both BSs is not possible, yet MBB and RACH-less schemes are important since they can reduce HET for a significant number of handovers.

SDN is another important technology in 5G NR [9]. This technology aims to separate the control and data plane of the network to allow more dynamic control of the communication flows. These communication flows could be designed by intelligent communication manager applications and installed in network switches by SDN controllers. This separation of control and data forwarding is possible by deploying programmable switches capable of receiving commands from

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controllers, e.g., Flow Modification (FM) commands and updating routing tables. Thus, SDN capabilities can simplify the execution of network operations and also enable different implementations of mobility management and handover strategies [10].

In the present study, we propose a handover scheme that uses the recent propositions of MBB and RACH-less handovers together with SDN controller capabilities. We merge the process of BS handover with the update of controller information. In our simulations, we observed that this strategy of merging the procedures and using RACH-less and MBB schemes could lead to shorter HET and relatively low signaling overhead. The remainder of this paper is organized as follows: Table I shows a list of acronyms used throughout the paper. Section II discusses different proposals of RACH-less and SDN-enabled handovers. Section III presents our SDN-enabled RACH-less MBB proposed handover scheme. Section IV presents the performance evaluation of our proposed scheme and also a performance comparison with baseline schemes. Finally, Section V gives final remarks on the study performed.

TABLE I
LIST OF ACRONYMS USED THROUGH THE PAPER

Acronym	Description
C-V2X	Cellular Vehicle-to-Everything
TTI	Time Transmission Interval
UE	User Equipment
HARQ	Hybrid Automatic Repeat Request
HET	Handover Execution Time
3GPP	Third-Generation Partnership Project
MBB	Make-before-break
BS	Base Station
t-BS	Target Base Station
p-BS	Previous Base Station
RACH	Random-Access Channel
SDN	Software-Defined Networking
FM	Flow Modification command
RTD	Round-Trip Delay
TA	Timing Advance
CTI	Cell Timing Information
C-RNTI	Cell Radio Network Temporary Identification
RS	Router Solicitation
RA	Router Acknowledgment
PBU	Proxy Binding Update
PBA	Proxy Binding Acknowledgment
PBR	Proxy Binding Response
D-PBU	Deregistration Proxy Binding Update
RRC	Radio Resource Control
RRCC	Radio Resource Control connection reconfiguration Complete

II. RELATED WORK

This section contains related studies and existing standards to our proposal. Section II-A briefly surveys different approaches of the literature to reduce communication delay in V2X scenarios. Section II-B discusses strategies to execute RACH-less handovers. Sections II-C and II-D shows in details two handover schemes that are used as baseline for comparison with our proposal in Section IV. Section II-C presents a reactive scheme, whereas Section II-D describes a proactive handover.

A. Reducing Communication Delay for V2X Applications

Future vehicular applications with strict requirements in terms of, for instance, reliability and latency are expected to emerge with the popularization of Connected and Autonomous Vehicles. To meet these requirements, 5G and beyond networks, with modern techniques, algorithms, and protocols, are currently under development by the scientific community. Innovative ideas, such as the usage of meta-surfaces that can be used to redirect wireless signals improving success delivery rate of messages [11] appear for reducing communication delay by avoiding message re-transmission. Also, direct communication between vehicles to vehicles and to roadside units [12] can further reduce communication delays by diminishing traffic sent to the core of the network. Furthermore, SDN [13] and Edge Computing [14] architectures can be used to improve the quality of service provided by LTE infrastructure. SDN can facilitate network management, leading to faster responses to network dynamic changes; and Edge Computing removes the need for tasks to be processed at the Cloud, thus reducing the amount of data transferred through the core of the network.

B. RACH-less Handover

Different RACH-less handover schemes were proposed in the literature. For instance, 3GPP published specifications [8] that consider RACH-less handovers by assuming synchronized networks. RACH-less handovers in synchronized networks were also proposed in the literature [4]. However, network synchronization has a significant impact on signaling operations in the control plane of the network. Therefore, 3GPP also specified schemes to combine MBB and RACH-less handovers [6], but only in simple scenarios, such as intra-frequency and using dual connectivity.

Choi and Shin [5] proposed a RACH-less handover scheme for different BSs that does not rely on dual connectivity and does not require synchronized networks. The authors proposed a model in which it is possible to estimate Timing Advance (TA) values from Cell Timing Information (CTI) collected in both BSs. The authors designed a model in which the UE uses cell timing references together with measurements to evaluate the difference in the air path delay (i.e., transmission and propagation delays) from t-BS to p-BS. To obtain this model, the authors start from the Round-Trip Delay (RTD), which combines path and processing delays for the round trip with different clock offsets to align messages due to these delays.

Figure 1 presents the delays comprised in the RTD. Two timelines are presented, for a BS and a UE clock. The blue and green rectangles represent transmission delays Δ. C_{ul} and C_{dl} are the time references to the start of uplink and downlink subframe transmissions, and δ is the offset used by UE to align messages with the start of the uplink subframe at the BS. Finally, M is the UE information from analyzing downlink messages from both BSs.

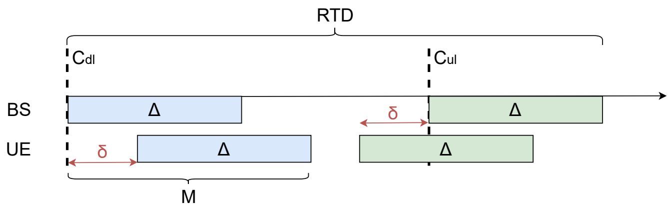

Fig. 1. Timing diagram of RTD in LTE.

The transmission delay difference between t-BS and p-BS can be evaluated by subtracting the downlink subframe duration from the RTD for each BS, which results in

$$\mathcal{D} = RTD^t - (C^t_{ul} - C^t_{dl}) - \Big[RTD^p - (C^p_{ul} - C^p_{dl})\Big], \quad (1)$$

where $\mathcal{D}$ is the transmission delay difference and the superscripts t and p stand for t-BS and p-BS. Since UE can measure $M = C_{dl} + \delta + \Delta$ from the downlink of both BSs, we can isolate the difference $M_D = M^t - M^p$ from Equation 1, obtaining

$$\mathcal{D} = 2 \times M_D + C^t_{ul} - C^t_{dl} + C^p_{ul} - C^p_{dl}. \quad (2)$$

With the transmission delay difference $\mathcal{D}$ between the BSs, UE can evaluate TA to align uplink messages. Since M_D can be measured, UE needs for the timing alignment only CTI defined as:

$$CTI = C^t_{ul} - C^t_{dl} + C^p_{ul} - C^p_{dl}. \quad (3)$$

This information is a composition of internal clock references from both BSs and can be sent to UE before disconnecting from p-BS, thus avoiding the RACH procedure. Choi and Shin [5] also consider offsets to compensate for the processing delays in both BSs to compose CTI.

CTI and Cell Radio Network Temporary Identification (C-RNTI) for the UE allow the handover execution without the RACH procedure. While the current study does not focus on the physical layer operations to make a RACH-less handover, the signaling messages of our proposal are designed to ensure that CTI and C-RNTI can be acquired by the UE, enabling RACH-less handovers in non-synchronized networks. We describe the protocol to acquire CTI and C-RNTI in Section III. Our proposal uses RACH-less and MBB handover schemes to allow execution of handover mediated by an SDN controller. Different schemes to execute the handover in SDN are also present in the literature; we selected two of these schemes [15] to compare with our proposal. These schemes are described in Sections II-C and II-D.

C. SDN-enabled Reactive Handover

UE and t-BS execute the reactive handover procedure, p-BS has only a passive role in this procedure when receiving FM commands from the SDN controller. This procedure starts with a successful L2 attachment of the UE to the t-BS. Since there is no communication with the p-BS, there is no way to perform a RACH-less handover. Therefore, a RACH procedure is executed for the attachment. After the successful L2 attachment, as depicted in Figure 2, the following signaling operations are executed:

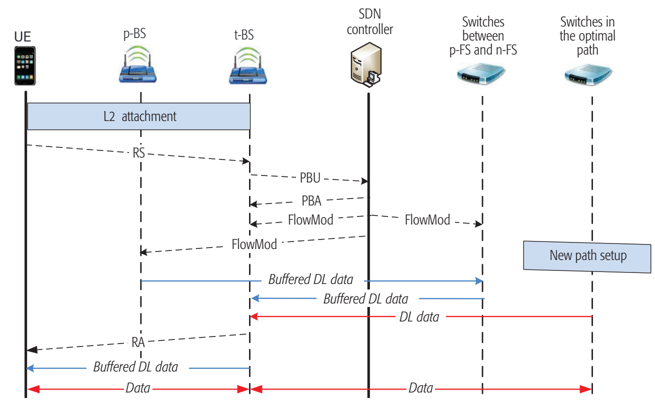

Fig. 2. Reactive Handover in Software-Defined Networks [15].

- the UE sends a Router Solicitation (RS) message to the t-BS to start the procedure;
- upon receiving the RS, the t-BS sends a Proxy Binding Update (PBU) message to the controller to inform that flows have to be updated;
- the controller receives the PBU and starts emitting FM commands to all switches in the paths established from and to the UE, it also sends a Proxy Binding Acknowledgment (PBA) to the t-BS to inform that the flows are being updated;
- after the FM commands update the paths, buffered data in the p-BS can start to be forwarded to the t-BS;
- after receiving the PBA, the t-BS sends a Router Acknowledgement (RA) to the UE to inform that all paths were updated in the network and the communication can be reestablished;
- finally, buffered data received by the t-BS from Down Link and also from the p-BS are forwarded to the UE. Also, normal communication can be sent and received by the UE.

The reactive handover scheme is the one that results in the longest HET since the connection is broken with the p-BS without any preliminary preparation. Yet, reactive approaches are important since both the Proactive Handover described in Section II-D and our proposal depend on the existence of a zone where the coverage of both BSs overlap. Reactive schemes are used as a fallback when this zone does not exist or communication is impossible with the p-BS.

D. SDN-enabled Proactive Handover

In the proactive handover, the UE detaches from the p-BS and sends a final L2 report to the p-BS that also starts the process of updating network paths. While this method does rely on an overlap of coverage of both BSs, there are not enough signaling messages to allow the UE to evaluate the

TA required to connect to the t-BS without the RACH process. A RACH-less process could be performed in a synchronized network with the available signaling, yet we assume a non-synchronized scenario. Thus, after the L2 detachment from the p-BS and triggering the final L2 report, the UE starts the RACH procedure, as shown in Figure 3.

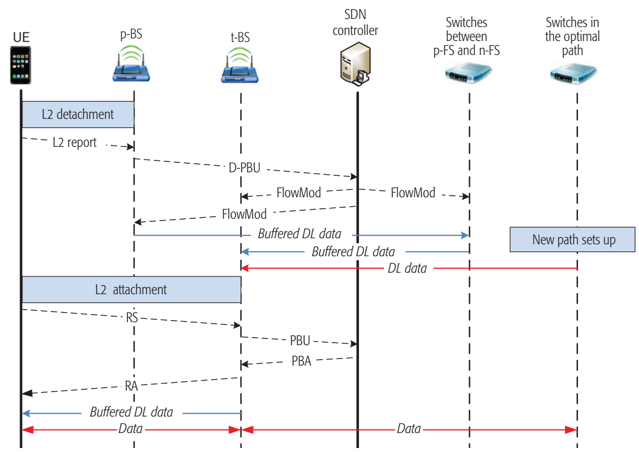

Fig. 3. Proactive Handover in Software-Defined Networks [15].

After this detachment, the steps performed are:

- when p-BS receives the final L2 report, a Deregistration Proxy Binding Update (D-PBU) message is sent to the controller;
- the controller receives the D-PBU and starts emitting FM commands to all switches in the paths established from and to the UE;
- after the FM commands update the paths, buffered data in the p-BS can start to be forwarded to the t-BS;
- after the conclusion of the L2 attachment, UE sends an RS message to t-BS;
- t-BS receives the RS and send a PBU to the controller to inform that the connection has been established with the UE;
- the controller responds the t-BS with a PBA;
- after receiving the PBA, t-BS sends a RA to the UE to inform that all paths were updated in the network and the communication can be re-established;
- finally, buffered data received by t-BS from Down Link and also from p-BS are forwarded to the UE. Also, normal communication can be sent and received by the UE.

This approach uses the time spent with L2 detachment and attachment to prepare the communication paths. This reduces the time required to re-establish communication. However, in edge networks, sending a message through a wireless link has a more significant impact on latency than sending it through a wired link, which results only in a small reduction of HET when comparing proactive and reactive approaches. The authors evaluated the scheme on a scenario where the wired traffic was subject to high link queuing delays (50-100 ms), which causes wired and wireless operations to have similar costs in terms of duration and reduces the differences in gains related to wireless and wired links.

III. SDN-enabled RACH-less Make-before-break Handover

To reduce HET, we merge the lower layers handover operations with the controller updates. This approach also allows a previous preparation of the communication paths in the network similar to the Proactive Handover used as a baseline. Besides this merge, we change some of the signaling messages to enable a RACH-less and MBB handover execution. Instead of breaking the connection after sending the final L2 report containing the information for the BS to decide on the handover, the UE waits until all paths are settled and the Radio Resource Control (RRC) message is received. This custom RRC message also carries CTI and C-RNTI, which is the information needed to perform the RACH-less MBB handover [5]. It is only possible to obtain this information because we create an extra signaling message in the middle of the Proxy Binding Update operation that is sent to the t-BS to collect Timing Information and forward it to the p-BS. Similar to the Proactive Handover, the process is also initialized by an L2 report, which in our case goes together with the RS. The RACH-less MBB procedure depends on the reachability of p-BS and t-BS. If this requirement is not satisfied, our proposal has a fallback that uses the RACH procedure. Both RACH and RACH-less alternatives are shown in Figure 4. The diagram in Figure 4 is executed as it is shown when the RACH-less procedure is possible, while the yellow highlighted steps are moved in case of RACH.

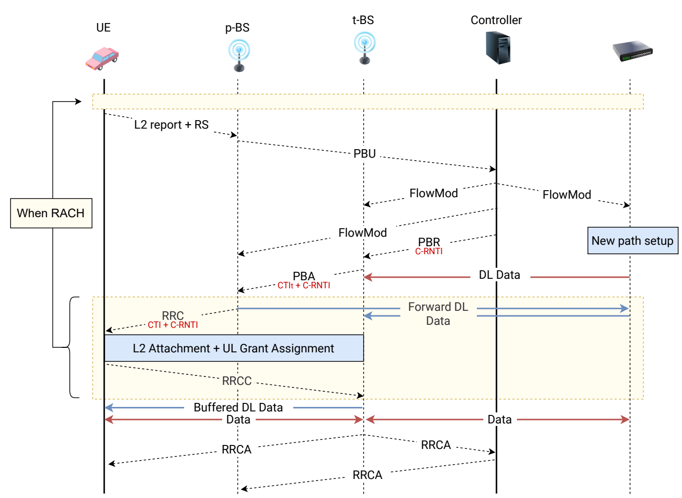

Fig. 4. Flow diagram of signaling operations for the handover procedure.

For the RACH-less procedure, the following steps are executed:

- after receiving the L2 report and RS, the p-BS sends a PBU to the controller;
- when the controller receives the PBU, it sends the FM commands to set the communication paths and also a Proxy Binding Response (PBR) to the t-BS. This message

also contains C-RNTI, which is defined by the controller and needs to be known by both BSs;

- once the PBR arrives in the t-BS, it embeds its timing information CTI_t and forwards it to the p-BS in a PBA;
- after receiving the PBA, p-BS uses the CTI_t received from t-BS and combines it with its own clock references to compute the final CTI, according to Equation 3. This CTI is sent to UE in the RRC message;
- the UE receives the RRC and performs the attachment to the t-BS, it also negotiates the next uplink grant and uses it to transmit the RRC Connection Reconfiguration Complete (RRCC) message indicating that the attachment is complete;
- when the t-BS receives the RRCC, communication can be re-established, and buffered data can be forwarded to the UE. The t-BS now has to emit RRC acknowledgments for the controller, the p-BS, and the UE;
- upon receiving the acknowledgments, the other entities involved in the handover finish the detachment process. This is important since these connections were kept alive to execute the MBB handover, and just now, they can be finished.

When the RACH procedure is used, the detachment and re-attachment, highlighted by the yellow box in Figure 4, occur at the beginning of the handover. Furthermore, the Router Solicitation (RS) is sent to t-BS instead of p-BS. Finally, the PBA message is not needed, as the time synchronization already happened during the re-attachment. Therefore, the following steps are executed when a RACH handover is performed:

- UE uses RACH to connect directly with t-BS;
- after attachment, UE sends RS to t-BS;
- t-BS then issues a PBU to the controller to update information about UE and setup network paths;
- upon receiving the PBU, the controller issues FM commands and sets the new paths to and from UE;
- after issuing the FM, the controller sends the PBA to t-BS;
- when t-BS receives the PBR communication can already be re-established. t-BS still sends an RRCA to UE informing that communication paths were updated.

The two most relevant changes in the handover protocol are the merge of the handover processes and the change in the destinations of the signaling messages. The former enables both processes to run in parallel, leading to a performance similar to the Proactive Handover scheme. The latter allows the execution of an MBB and RACH-less handover.

Compared with the baseline schemes, the different messages of the proposed signaling protocol also affect the overall signaling cost. This impact on signaling cost is caused because these messages are sent to distinct nodes and use alternative paths in the network's topology. For example, in the proactive and reactive schemes, the same BS would send the PBU and receive the PBA. In our proposal, the proxy binding involves both BSs and the controller with the introduction of the PBR. Whether t-BS is on the path from the controller to p-BS or not, signaling costs may increase (also depending on how different these paths are). Yet, we also removed the D-PBU message that is part of the Proactive Handover scheme. Section IV presents evaluations of our proposal and also performance comparisons with the baseline schemes in terms of both HET and signaling cost.

IV. Performance Results

This section presents the performance comparison of our proposal with the baseline schemes [15]. We compare these schemes in terms of HET and control plane signaling cost to emit the messages for the handover execution. We evaluate the mechanisms in a scenario where all components involved (i.e., UEs, BSs, Controller, and Application Server) are at the edge network. Also, in our study, we do not consider the decision process of whether a handover should be performed or not; the handover is triggered whenever a UE detects that there is a better connection available at a different BS. An interesting future work would be to adopt a decision-making heuristic to improve further our results, yet this escapes the scope of the present study. More details about the simulation setup are given in Section IV-A. We compare the HET and the system cost of our proposal with the baseline schemes in Sections IV-B and IV-C. Finally, we vary the BS coverage of the scenario to evaluate the behavior of the different schemes in Section IV-D.

A. Methodology

The simulations were performed using Omnet++ [16] version 5.6 for networking simulation, and SUMO [17] version 0.32.0 to simulate the urban mobility. On top of these simulators, we used three frameworks: Veins [18] version 5.1 to connect Omnet++ with SUMO and allow the simulation of the vehicular use case; INET [19] version 3.6.8 to use different network component models, such as queues, network card interfaces, and protocols; and SimuLTE [20] version 1.1.0 to provide the LTE model.

Figure 5 shows the scenario used for the simulations. The blue node at the center is where the SDN controller is hosted. The red node at the right side is where the application server resides. Black and white nodes are BSs used only for data forwarding and as access points for the vehicles. The black BSs were present in all simulation scenarios, while the white ones were inserted or removed to achieve different coverage scenarios to evaluate the handover schemes. More details about this coverage variation are given in Section IV-D. In the simulations, 100 vehicles were driving along the red line. Each vehicle entered a simulation 10 s after the previous one.

We evaluate two variables, the HET and the system cost with signaling messages. HET is measured as the time from the moment when the last message is sent to p-BS, before disconnection, to the moment that data communication could be re-established with t-BS. To evaluate the system cost of a handover H, we observe the set M_H of signaling messages sent through the topology graph $G = (V, E)$ to allow its

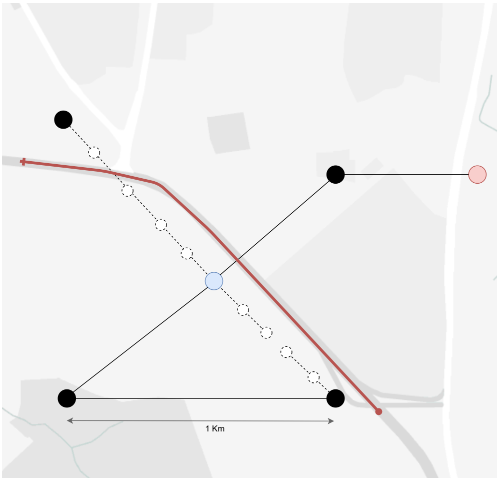

Fig. 5. Network topology used in the experiments.

TABLE II
PARAMETERS USED FOR THE SIMULATIONS

Description	Value
Wired link cost weight	1
Wireless link cost weight	10
Wireless failure probability	LTE model [20]
FlowMod message size	32 Bytes
L2 report size	52 Bytes
RS/RA size	52 Bytes
PBU/PBA/PBR size	72 Bytes
RRC/RRCA size	52 Bytes
Link queueing delay	0.3 ms (±0.18 ms jitter) [21]
Switch processing time	75 ns + n × 5 ns [22]
Controller responses frequency	2000 per millisecond [23]
Transmission Time Interval (TTI)	1ms
Vehicle average speed	20 Km/h

execution. Each message $m \in M_H$ is a tuple of the form $m = \langle P_m, w_m \rangle$, where $P_m \subset E$ is the set of links $e \in E$ used to deliver that message, and w_m is the message size in bytes. The system cost $\mathcal{C}$ is given by:

$$\mathcal{C}[H] = \sum_{m \in M_H} \sum_{e \in P_m} w(e) w_m. \tag{4}$$

where $w(e)$ denotes the weight of a link, which assumes value 1 for wired links and 10 for wireless links. Link weights, message sizes, and other simulation parameters are given in Table II. For the analyses, only successful handovers were considered for all approaches evaluated. Handover failures could happen if messages were lost (generally in the wireless links) or if the handover duration was too long (greater than 100 ms).

B. Handover Execution Time Analysis

The proposed SDN-enabled RACH-less MBB handover scheme consists of a RACH-less proactive handover and a fall back to a RACH procedure. In some situations, due to obstacles, signal quality, and other factors, it is not possible to communicate to both BSs. In this case, the UE will connect to the t-BS using a RACH procedure. The existence of these two strategies leads the distribution of HET to have two modes and a large variation. This variation is shown in Figure 6, where the modes are the thicker areas in the green distribution of the violin plot. The different handover schemes are disposed along the X-axis, while Y-axis displays the HET in milliseconds. The distribution of HET in our proposal shows the expected two distinct modes. The mode at the top of the green distribution is created by the handovers that had to use RACH, while the RACH-less procedures created the mode at the bottom.

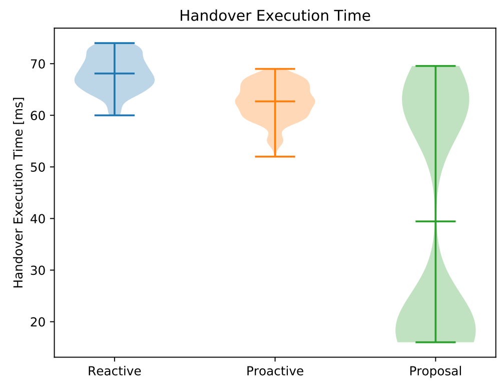

Fig. 6. Handover Execution Time distribution.

The reactive and proactive handovers display a smaller variation with less distinguished modes because both always use RACH. The average HET, displayed as the horizontal line in the middle of the distributions, shows that our proposal performs better than the baseline schemes. The general position of this average in our proposal is driven by the number of times RACH or RACH-less procedures were used, which is a consequence of BS coverage in the scenario. We further study this coverage in Section IV-D.

C. System Cost Analysis

Similar to the HET, the system cost distribution also presents multiple modes. However, these different modes are caused by how the signaling messages are exchanged during the handover. These messages are exchanged between each BS and the controller. This exchange is different in each handover scheme because of the different BSs sending and receiving the signaling messages. Besides that, different network topologies could also affect the signaling costs, yet the experiments in this section were performed using the same topology. Figure 7 shows the cost distribution of handovers. Each evaluated scheme is disposed along the X-axis, and the system cost is displayed in the Y-axis. All schemes have multiple modes, indicated by the wider zones in the violin plot. These modes occur due to the different paths connecting the two BSs and the controller. All vehicles were subject to the same BS transitions for each one of the three schemes. For every transition, the same messages had to be sent in each scheme. We observe that our proposal obtained the highest cost values, but on average, it performs better than the proactive scheme and worse than the reactive scheme.

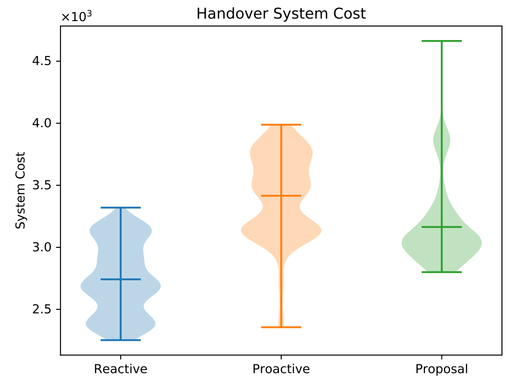

Fig. 7. Handover system cost distribution.

D. Coverage Analysis

The handover scheme proposed in this study depends on the reachability of p-BS and t-BS to obtain better performance. Thus, we evaluate how this performance behavior in different coverage scenarios. Multiple BSs were added and removed from the scenario presented in Figure 5 in order to achieve the desired coverage. We changed the average distance from one BS to the next for each coverage scenario, increasing from 100 m to 600 m with a 100 m step. This also caused the topology to vary, leading the scenario to have 13, 8, 5, 4, 3, and 3 BSs in the vicinity of the main road, for the average distances from 100 m to 600 m. We also present in this section system cost analyses for these different scenarios.

Figure 8 shows the raise in HET when the BS coverage varies. The Y-axis presents the latency in milliseconds, while in the X-axis, the average distance between two consecutive BSs is shown. It is possible to observe that the proactive and reactive handovers have similar performance for all coverage scenarios; this happens because the most time-consuming operation, the RACH, is not affected by the proximity of the BSs since it only needs to reach one BS to be performed. Our proposal, on the other hand, suffers in more sparse scenarios. This happens because the number of times both BSs were reachable for the handover decreases with reduced coverage, causing the handover to be performed also using the RACH approach. It is also possible to observe a small HET reduction when the average distance between BSs varies from 100 m to 400 m. This is caused by the change in the number of BSs positioned close to the road where the cars are driving. More nodes lead to longer paths in the network. These links are subject to queuing delays as described in Table II, which results in a few milliseconds difference in round-trip times for signaling messages.

During the experiments, HET was observed close to the 40-50 ms mark, which might be critical for future applications that require very low latency levels to be executed. However, different factors may be considered when analyzing this latency. First, sending messages over wireless links leads to delays proportional to TTI, yet the literature on LTE-V2X advocates for the reduction of TTI duration [2], which consequently would reduce HET. Second, service requirements are specified based on averages calculated over time windows; thus not all requests need to be under the latency threshold as long as later requests can recover the time lost. As the number of handover operations is small compared to the number of messages sent by applications, regular messages sent while the vehicle is not performing handover should be sufficient to lower the averages and make it feasible to meet the latency requirements of applications. Finally, other LTE enhancements are awaited to further shorten the communication delay, for instance, reducing time used for HARQ [3].

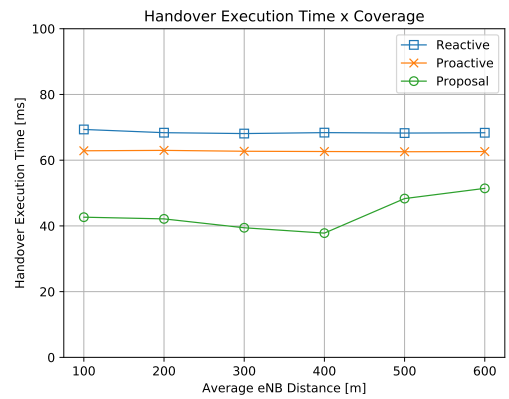

Fig. 8. Comparison of average HET for different coverage scenarios.

Figure 9 shows the behavior of the system cost for different BS coverage. The Y-axis presents the weighted cost, and the X-axis shows the average distance between BSs. Since the topology was changing to vary the coverage, we observe a significant variation for all schemes in the system cost. This variation is mainly because of the number of links existing in the scenario being changed. In general, sparse scenarios have fewer links, which drive the average cost per handover down. The proactive and reactive handovers have very similar behavior. This happens because the messages sent in these approaches interact with the topology in a similar way. However, for our proposal, the way messages are sent to BSs is different, also resulting in a different interaction with the topology and different behavior in the cost curve. Our proposal tends to be in between the proactive and reactive schemes, which changes only for scenarios with very high coverage when our proposal has the highest cost. In our experiments, the topology was varied in a controlled manner. Different ways of changing the topology could lead to a better understanding of the impact on the cost.

V. Final Remarks

This study proposes an SDN-enabled handover procedure that allows the application of modern handover schemes, i.e., RACH-less and MBB schemes. Our proposal further

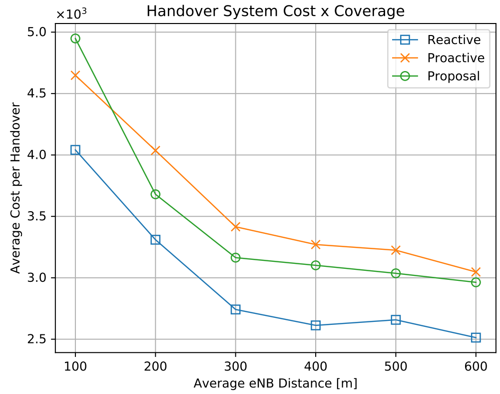

Fig. 9. Comparison of average system cost for different coverage scenarios.

advances handover procedures from the literature by re-designing the signaling protocols to perform the handover. This handover signaling protocol has two main contributions: unifying the lower layers signaling messages for handover with the signaling for SDN network path updates; it also allows the exchange of CTI and C-RNTI between BS and controller necessary to perform the RACH-less handover in non-synchronized networks. Evaluation via simulation shows that our proposal reduces HET while keeping a reasonable signaling overhead compared to baseline handover schemes from the literature. The results in the study also provide an insight into how BS coverage impacts the usage of RACH-less MBB handover schemes. Such an insight is important because these are important handover schemes awaited by 3GPP to enhance the performance of legacy RACH handovers despite SDN usage. Finally, in the present study, we focus on designing a signaling protocol for handover, omitting the decision process of whether the handover should be performed and how to choose the best available BS. Studying this decision process would be an interesting future work to continue the present study. Another possible future work would be to perform a more exploratory analysis of different scenario configurations, e.g., random mobility, changing vehicle speed, or topology variation. Specifically for high-speed mobility, handover success rates tend to decrease, thus increasing HET, which might require the usage of other handover mechanisms to achieve expected HET.

Acknowledgment

The authors would like to thank the São Paulo Research Foundation (FAPESP), grants #2020/11259-9, #2018/12447-3, #2018/19639-5, #2015/24494-8, #2018/23064-8, #2020/05121-4, FAPEMIG, Grant #APQ-02510-18, CNPq, Grant #427672/2018-0.

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