User-centric Mobility Management Architecture for Vehicular Networks

Rodolfo I. Meneguette, Luiz F. Bittencourt, and Edmundo R. M. Madeira

Institute of Computing (IC) - University of Campinas (UNICAMP),
Av. Albert Einstein, 1251 - Campinas - São Paulo - Brazil,
{ripolito,bit,edmundo}@ic.unicamp.br,

Abstract. Vehicular Ad Hoc Network (VANET) is a subclass of Mobile Ad Hoc Networks which provides wireless communication among vehicles as well as between vehicles and roadside devices. Providing safety and user comfort for drivers and passengers is a promising goal of these networks. Some user applications need a connection to internet through gateways which are in the road side. This connection could generate an overhead of control messages and also the handover time among gateways can affect the performance of these applications. This paper proposes an architecture for intra- and inter-system management for virtual environments in vehicular networks, supporting user-driven applications. More specifically, we consider applications that depend on virtual environments which must be constantly updated, such as online gaming. To efficiently support these applications, the proposed architecture includes an extension of the 802.21 protocol to cope with the virtual environment updates. NS3 simulations were performed to evaluate the proposal over the proxy MIPv6 considering VANET and LTE networks as base stations. We observed that the proposed mechanism that extends the 802.21 protocol had a shorter handover time and lower packet loss when acting with the presented architecture.

Key words: mobility comunication, 802.21, vehicular network,

1 Introduction

Vehicular Ad Hoc Network (VANET) is a subclass of Mobile Ad Hoc Networks which provides wireless communication among vehicles as well as between vehicles and roadside devices. These networks have been of particular interest to the communication research area for several years. The benefits from researching in this area are twofold: (i) communication and automatic cooperation between vehicles offer great potential in reducing the number and impact of road accidents; (ii) user-driven applications can improve comfort for car, bus, and train passengers, as well as assist drivers to transit efficiently on the roads. For these reasons, Intelligent Transportation Systems (ITSs) that aim to streamline the operation of vehicles, manage vehicle traffic, assist drivers with safety and other information, along with provisioning of convenience applications for passengers, are no longer confined to laboratories and test facilities of companies [1].

One way to classify vehicular network applications is to split them into two main categories [2] : safety and user (non-safety). Safety applications comprise public safety, traffic management, traffic coordination, and driver assistance. User applications include traveler information support and comfort. Comfort class involves applications that target the entertainment of the passengers, which include games, multimedia information exchange, among others.

In this paper we focus on user-driven applications, more specifically in applications that depend on virtual environments which must be constantly updated, such as online gaming. These applications are characterized by five interrelated requirements: interactivity, consistency, fairness, scalability, and continuity [3]. To achieve these requirements, related applications require a certain level of QoS. In gaming, the most important QoS metrics are end-to-end delay, throughput, and packet loss [4].

The way that virtual environment participants are connected directly affects levels of delay, packet losses, and throughput. For example, participants can be connected through the Internet. In vehicular networks, internet access needs a gateway that could use wireless technologies. This access can be through Dedicated Short-Range Communications (DSRC) or Long Term Evolution (LTE) gateways placed along the road. A vehicle willing to access the Internet first propagates a query looking for gateways. Gateways receiving the query can respond to the requesting vehicle, which chooses one responder based on pre-defined criteria and starts to interact with it. This exchange of messages between the gateway and the vehicle may cause a high overhead that can impact on the virtual environment. Besides the overhead, the time of exchange from an access point to another can also affect the levels of delay, packet losses, and throughput.

This paper presents and evaluates a multi-access wireless network architecture focused on vehicular networks with support for collaborative virtual environments. The proposed architecture provides connection for applications such that the requirements of interactivity, consistency, scalability, and continuity in the virtual environment do not suffer significant impact due to handovers during mobility. The architecture considers the current state of active networks involving the mobile node to perform the selection of the network that best fits the application requirements. Our goal is to decrease the amount of control messages in the network thereby increasing the flow of useful packets and decreasing the amount of lost packets. To achieve this, we extended the 802.21 protocol by adding a new field to it so that each node also knows which applications are running, their users, and who is using the same applications in other nodes.

This paper is organized as follows. Section 2 describes concepts and technologies involved in vehicular networks (VANETs). Then, mobility management strategies and how to implement them in a heterogeneous environment, as well as the IEEE 802.21 standard, are presented. Section 3 discusses related work. Section 4 presents the proposed architecture for mobility management for vehicular networks, while Section 5 presents an analysis of the results, followed by the conclusion in Section 6.

2 Background

This section presents some basic concepts involved in this paper, introducing VANETs and mobility management.

2.1 VANET

Vehicular Ad Hoc Networks (VANETs) are aimed at communication between vehicles and / or between vehicles and roadside infrastructure [5]. They can use cell phone towers or even an outside access bridge for such communication. In 1999, the Federal ommunications Commission (FCC) allocated a frequency spectrum for inter-vehicle communication and between vehicles and roadside infrastructure, establishing rules and licensing services for the Dedicated Short Range Communications (DSRC) at the 5.9GHz band [6]. This protocol is an extension of IEEE 802.11, the 802.11p, being a technology for the vehicle environment at high speed. The physical layer (PHY) is adapted from the IEEE 802.11a PHY, and the multiple access control (MAC) layer is very similar to the IEEE 802.11 MAC [7].

Applications on the focus of this work, such as games, require quite modest data rates when compared to the DSRC data rate offer (6 Mb/s), with the majority of games generating under 100 Kb/s per player [8]. In [9] the authors set up a worst-case network load scenario based on the formula provided in [10], where the throughput $k(n)$ obtainable by each node n capable of transmitting W bits per second. If a game generates 100 Kb/s per player with 25 players in a game ($n = 25$, $W = 6$ Mb/s), the formula gives the achievable per-node throughput of 1 Mb/s, which is an order of magnitude higher than game requirements.

Devices suffer frequent disconnections and access point changes on their route due to: (i) low network data transmission rate; (ii) high speed vehicles can acheive on a highway; and (iii) decision-making that changes the device's route [11]. Therefore, it is currently a challenge to smoothly change access points in a way that the user does not notice any inconsistency in his/her application [12].

2.2 Mobility Management

Mobility management is the module responsible for maintaining the mobile nodes connection, and it contains two main components [13]: location management and handover management. The location management allows the system to track the location of mobile nodes between two consecutive communications. The handover management allows mobile devices to exchange the network keeping the connection alive.

When a device connected to an access point (AP) moves away from the coverage area, the signal level of the device suffers degradation. When approaching another access point with a stronger signal level, a mechanism is needed to keep the network connection status of the device, transferring the responsibility for communicating to the new access point [14].

There are two types of handovers [15]. Handovers that occur between access points of the same technology are called horizontal handovers. Handovers that occur between access points belonging to different networks (eg Wi-Fi to 3G) are called vertical handovers. Thus a vertical handover occurs between heterogeneous cells of access networks that differ in many aspects such as bandwidth, signal frequency, etc. These particular characteristics of each network make the implementation of vertical handovers more difficult when compared with that of horizontal handovers. In this scenario, it is difficult to integrate various network technologies due to the limitations of each technology to ensure the minimum requirements for the application. Therefore, to jointly run a simulation environment as a collaboration of various network technologies and protocols that change over time turns into a major challenge.

2.3 Vertical Handover

In order to help in vertical handovers, the IEEE 802.21 provides a standard to assist the implementation of vertical handovers. The IEEE 802.21 [16] is a recent effort to allow the transfer and interoperability between heterogeneous network types. The goal of IEEE 802.21 is to improve and facilitate the use of mobile nodes, providing uninterrupted transmission in heterogeneous networks. To achieve this objective, the delivery procedures may use information collected from the mobile terminal and / or network infrastructure. At the same time, several factors may determine the decision of delivery: continuity of service, application class, quality of service, negotiated quality service, security, etc. The most important tasks of the IEEE 802.21 are: the discovery of new networks in the environment and the selection of the most appropriate network for a given need.

The core of the 802.21 is the Media Independent Handover Function (MIHF). The MIHF has to be implemented in all devices compatible with the IEEE 802.21 (in hardware or software). This function is responsible for communicating with different terminals, networks and remote MIHFs, and also for providing information services to higher layers. The MIHF defines three different services: Media Independent Event Service (MIES), Media Independent Command Service (MICS) and Media Independent Information Service (MIIS) [17].

The MIES provides sorting, filtering, and event report corresponding to the dynamic changes that occur in the link, such as its features, condition, and quality. The MICS enables MIH users to manage and control relevant features of the link for handover and mobility. The MIIS provides the ability to obtain necessary information for the handover, such as a neighborhood map, information about the link layer, and availability of services through the information elements (IE) to assist in decision making of the handover.

3 Related Works

Horizontal and vertical handover issues have received substantial attention. In particular, many of the recent projects are dealing with handover in heterogeneous wireless networks (vertical handover). This section presents some proposals for mechanisms and architectures that, in some way, perform vertical handover to integrate wireless networks transparently to the mobile user, vehicular or not.

Yang et al. [18] used a cross-layer protocol designed for WiMax mesh networks, called Coordinated External Peer Communication (CEPEC), to provide Internet access services in a motorway environment. To support Internet access, CEPEC separates the road in Multi-segments, and uses the shared channel to retransmit packets. Each segment has a Segment Head (SH) to perform gathering of local packets and retransmission of aggregated packets.

Mussabbir et al. [19] extended the FMIPv6 with the IEEE 802.21 networks on vehicle networks. The authors proposed an improvement in the FMIPv6 mechanism to support Network Mobility (NEMO) in vehicular environments, and used the IEEE 802.21 protocol to achieve better performance in the transmission through the use of a cache to store and maintain the network information.

Chiu et al. [20] presented a cross-layer design to accelerate base station changes, called Vehicular Fast Handover Scheme (VFHS), where the physical layer information is shared with the MAC layer to reduce delay. The VFHS main idea is to use the vehicles approaching from the opposite side to accumulate information from the physical layer and MAC that flows to relay vehicles, which in turn transmit the information to vehicles that are temporarily disconnected. Inactive vehicles can thus perform a fast delivery when they enter the transmission range of an approaching relay vehicle.

Lee et al [21] proposed an improved multicast handover procedure that optimizes multicast group management by utilizing the context of consumer mobile node running multicast applications. They developed analytical models to evaluate the proposed multicast handover procedure compared with the base one. The authors demonstrated that the proposed multicast handover procedure minimizes the service interruption time and prevents the multicast packet loss during handovers.

In the proposed architecture, we use mechanisms to benefit from network monitoring resources from the 802.21 protocol. These mechanisms capture information from the network to make the best decision in performing the handover, always taking into consideration the network requirements as well as vertical handover techniques. This is done by extending the 802.21 protocol, adding more information to its information service in order to know what kind of application users are running.

4 The proposed architecture for mobility management

The proposed architecture considers a common infrastructure for multiple access technologies in a transparent way. We created a multi-access wireless network architecture using the Wi-Fi, Vehicular, WiMax, and LTE technologies, providing a continuous and transparent connection for the user to obtain low inconsistency in the virtual world. The architecture is intended to provide connectivity to the application and ensure that its requirements are guaranteed. To accomplish this, the architecture inputs are the state of the network and application requirements. The requirements are: throughput of the network, packet delay, transmission time and number of lost packets.

4.1 Protocols Used

Information on the state of the network is obtained through the 802.21 protocol, used as a base in the architecture. This information is used to choose the best network for performing the handover. Unlike other protocols, the 802.21 protocol is not tied to any network wireless network technology, it can interact with any network interface to obtain the status of networks, both locally and globally, i.e., the node can know the states of its links as well as the state of other nodes through exchange of messages between nodes. The Proxy Mobile IP version six (PMIPv6) is also part of the proposed architecture, handling with addresses of each node in the completion of the handover, thereby informing the base station the need for a redirection of messages.Differently from Mobile IPv6 and some protocols based on MIPv6, such as the network mobility basic support protocol, the PMIPv6 has a lower overhead on the wireless link than the MIPv6 [22]. Besides this, the PMIPv6 reduces the signaling delay and removes the movement detection team present in NEMO protocol [23].

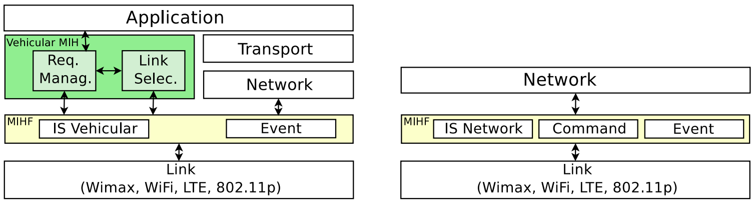
The 802.21 protocol is supported by PMIPv6. While 802.21 captures the network state information and verifies if the base station is available for a new connection, the PMIPv6 performs the exchange of the node address and handles the mechanisms necessary to perform the redirection of these packets to this new address. We used UDP as the transport protocol, which needs no confirmation on receipt of messages, thereby decreasing the amount of traffic on the network.

4.2 Proposed Architecture

The proposed architecture differs from the existing ones by extending the 802.21 protocol. We added another field to the 802.21 protocol that defines what applications the node is using, thus allowing faster searches for nodes that are part of the same application.

The architecture is divided into two modules: a module embedded in the vehicle (Figure 1(a)) and another module that acts in the access points (Figure 1(b)).

The focus of the architecture is on applications that need to show representations of virtual environments to multiple mobile users. Besides gaming, another application of the architecture is on rescue or hostile environments, where teams can be assisted by mobile applications that mimics a disaster map or a hostile territory.



(a) Vehicular architecture (b) Access point architecture

Fig. 1. Components of the proposed architecture.

A mobility management module, called Vehicle MIH, contains a requirement management module, which receives the minimum network requirements that the application needs to run, and also stores information about users who are using the same application. The Vehicle MIH module (Figure 1(a)) has also a module for link selection, which receives the network status information and decides whether it will perform a handover and, if so, to which network it should connect. Both the requirement management module and the link selector module send commands to the MIHF module. An MIHF module is an extension of the functions of the 802.21 protocol. This module has the vehicle network information service (Vehicle IS), which contains information about the vehicle network state as well as the proposed additional field that informs what applications the node is currently using. The MIHF also features the standard Event module of the 802.21 protocol to inform whether the link is active or not. In the link layer, we can use Wi-Fi, WiMax, LTE, or 802.11p (for communication between vehicles).

In the access point architecture (Figure 1(b)), the network layer has the PMIPv6 protocol for handling node addresses and the prefix of the access point required for routing messages. It also has an MIHF module that has the standard functions of the 802.21 protocol, but with the additional field that identifies applications that nodes are using. In the link layer we can also use Wi-Fi, WiMax, LTE, or 802.11p.

4.3 Architecture operation

Figure 2 shows the steps performed when the application is started. First of all, the requirement manager receives the application requirements (step 1), then transmits these requirements to the link selector (step 2), and the link selector sends all the settings to the MIHF (steps 3 to 7). After this first stage, the application will look for other participants by sending a request to the management module which registers it in MHIF and also sends a search request for the application information (steps 8 to 10). The MHIF sends an information search to base stations, which checks if there are any nodes connected to them that are attending the same application. If there exist connected nodes using the same application, the base station sends a request to such nodes in order to verify whether they are still participating (step 11). The nodes receive this information, forward it to the MHIF, which forwards it to the management. Then, the management creates its participant table (steps 11 and 12).

After the completion of the search for participants in a particular application, the verification for participants who are in the same area of interest is started. The application sends a message to all participants to check who is sharing the same area of interest and, after receiving the responses, it sends the request to all participants who have confirmed their request to receive and send the information of the environment update. Figure 2 shows these steps.

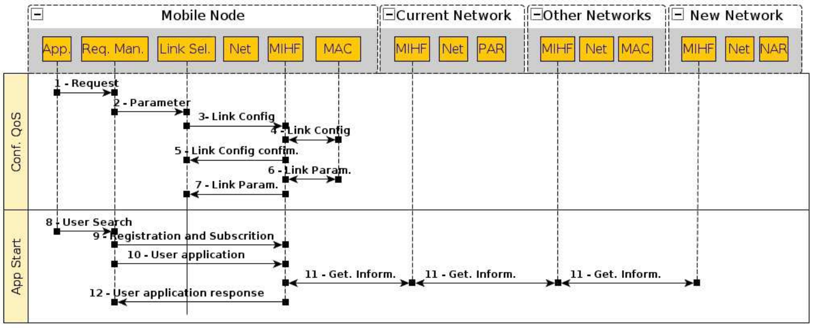


Fig. 2. Steps performed when an application starts.

Figure 3 illustrates the steps when a handover is necessary. In this case, the model of link selection receives an event of going down of the MHIF (step 14), then the node sends a request to its base station, which in turn sends requests to other base stations. After that, the base stations respond with information about their states, and then the current base station forwards it to the node that made the request (steps 15 to 17). The node, through the link selector, verifies which is the best base station that complies with the application requirements. The application is responsible for providing its priorities so the link selector is able to decide to which network to connect. The base station that has the lowest levels and complies with the limitations of delay and throughput of the application is to be chosen. After that the node sends a connection request to its base station that will transfer the request to the selected station (steps 18 and 19). If the selected station responds with a confirmation, the PMIPv6 protocol will terminate the handover process, and the MIHF model will inform that the link is ready for use (steps 20 to 22).

To maintain the active nodes, the requirement manager periodically sends an information request to the MHIF, which forwards it to all access points to find information about the network status. In other words, the requirement manager verifies the type field to check which applications are running, to make sure that the nodes are sharing the same game or simulation. To exit the game or simulation, the requirement manager sends a release message that goes through the whole architecture removing all the information about that application. This

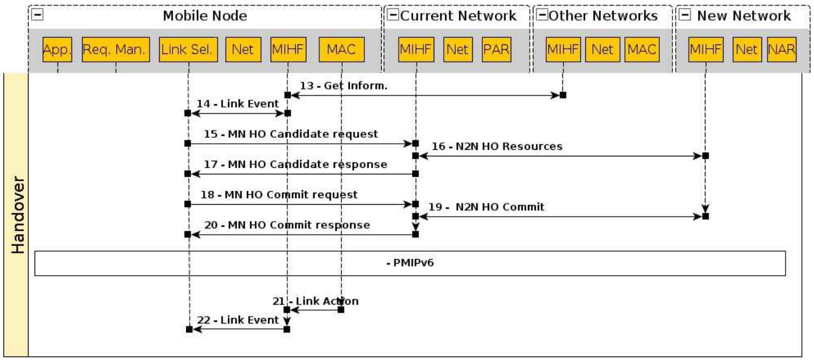


Fig. 3. Steps performed when a handover is necessary.

message is also passed to all access points so they can inform their connected nodes that the participant left the game/simulation.

5 Simulation Environment and Result Analysis

The proposed architecture has been implemented in the Network Simulator (NS-3). We used the PMIPv6 model that was developed by Hyon-Young Choi [24], and the 802.21 model [25].

As application, we modified the overlay support for collaborative virtual environments on vehicular networks [26], which is based on Gnutella [27]. In this scenario, it is assumed that the collaborative virtual environments are divided into hexagons of equal size, generating a set of cells. Users in the same cell form a group of participants with the same interest, being part of what is known as an *area of interest*. This division of the virtual environment aims to reduce the amount of messages that will travel across the network, thereby facilitating the achievement of the networking requirements of a collaborative virtual environment. These network requirements of the application, such as delay, throughput and packet loss, were used in the experiments to make a decision to handover. They were drawn from previous experiments [26] and from the work of Tonguz et al. [28]. In our simulations the link selector will choose the network which provides the following characteristics, in this order: network with lowest message delay; network with highest throughput; network with lowest packet loss in all base stations.

Simulations aimed to evaluate the average handover time and the distribution of connections among network interfaces. Therefore, we chose to not have any node out of reach of any access point. The architecture was evaluated using four metrics: throughput, packet loss, packet delay time, and the handover time.

For the simulation scenario we used: the RandomWaypoint mobility model, 50 vehicles using the overlay support for collaborative virtual environments, as well as a wired node and a router connecting two base stations (one Wi-Fi and one LTE). We used the default parameters of the modules NS3 to configure both the LTE and the WI-FI base stations. These base stations were in the middle of the map, which is 5,000 x 5,000 meters. We conducted several tests with the speed of the vehicles set to 5, 10, 15, 20, and 25 meters per second. At the beginning of each test, all nodes were connected to the LTE access point. We performed 10 simulations for each scenario and we calculated 99% confidence intervals. Some intervals do not appear in the figures because they are too small, though.

Figure 4 shows the average throughput of each interface. We observe that the proposed architecture has a better balance between wireless networks, because the extension of 802.21 protocol provided more relevant information about the state of the network. In other words, the extension of 802.21 provided important data for the best selection of the network, so that the application requirements could be guaranteed. However in the case where we only use the PMIPv6 protocol, most of the connections were managed by the LTE, since the handover mechanism did not have enough information to make the best network choice.

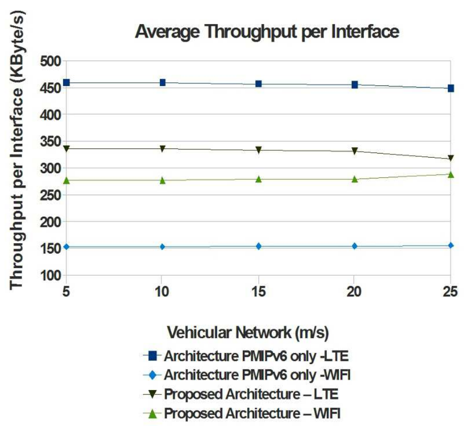


Fig. 4. Throughput per Network Interface

As show in Figure 5, the mechanism that uses the extension of 802.21 protocol provides a little better throughput in the network due to the low packet loss at the time of the handover, and also due to low packet loss during the exchange between areas of interest in the virtual environment. We also observe a drop in network throughput when the speed increases to 25 m/s. This occurs because there is an increase in the number of lost packets, as seen in Figure 6.

The amount of lost packets over the network was higher when using only the PMIPv6. It presented more packet losses during the exchange from an area of interest to another in the virtual environment, and also during handover. This occurs because the architecture with only the PMIPv6 protocol spends more time in searching who is using the same application, besides the higher handover time compared to our architecture, as shown in Figure 7.

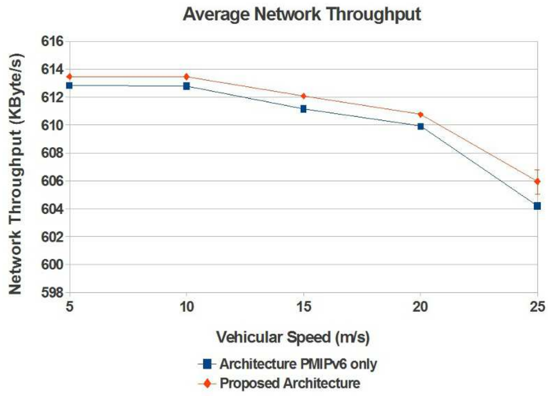


Fig. 5. Throughput

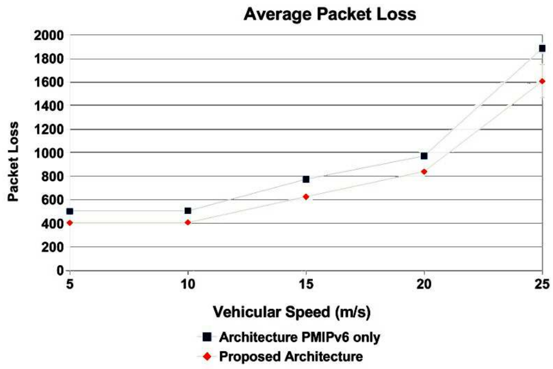


Fig. 6. Packet Loss

Besides the data showed in the figures, we also observed in the simulations that for vehicles with a speed of 20 m/s there was an average of 96 disconnections due to the handover, with an average disconnection time of 0.008s. The mechanism that uses only the PMIPv6 protocol presented 54 percent more packet loss on average than the 802.21 protocol at the time of handover, with an average delay of more than 1.7s.

Figure 7 shows that the handover time of the proposed mechanism, which uses the extension of 802.21 protocol, is smaller than the other mechanism, because the extension of 802.21 protocol eliminates the need for some messages at the time of changing to a new network. The handover time caused a small impact on the packet delay, as shown in Figure 8. We can observe from this figure that the mechanism that used only the PMIPv6 presented greater delay in the delivery of packets than the proposed mechanism. This occurs due to the different handover times and also due to the amount of lost packets, which require some retransmissions.

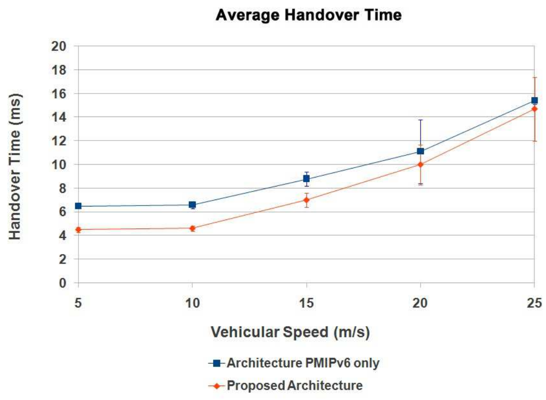


Fig. 7. Handover Time

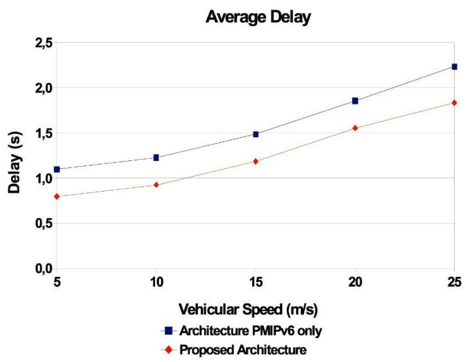


Fig. 8. Packet Delay

In summary, the graphs shown that the proposed architecture achieved a better balance between connections, a shorter handover time, and also smaller packet delay compared to the architecture that only has the PMIPv6 protocol. This improvement is fundamental for the interactivity, which refers to the delay between the generation of an event in a node and the time at which other nodes become aware of that event. Also, it influences consistency, which regards to uniformity of the current virtual world state viewed by all participants.

6 Conclusion

We present and evaluate a wireless multi-access network architecture for vehicular networks to support collaborative virtual environments. The architecture considers people on the move using applications of virtual world representation without losing the connection, switching between different access networks.

The architecture and the proposed extension of the 802.21 protocol presented a better performance than using only the PMIPv6 protocol, showing shorter handover times and lower packet loss due to elimination of some messages when performing the search for new networks. An increase of packet losses in the PMIPv6 occurs during the periods of disconnection, as well as during handover. With the management and use of the extension of the 802.21 protocol and its additional information, a better balance between networks was obtained. Thus, the link selection mechanism can make better decisions when performing handover.

As future work we intend to perform new simulations to verify the impact in the time inconsistency of the virtual environment. The next handover mechanism will be the diagonal, which allows to use more than one network interface simultaneously, thereby increasing the rate of packet delivery.

Acknowledgment

The authors would like to thank CNPq, CAPES, and FAPESP (2009/15008-1) for the financial support.

References

1. Karagiannis, G., Altintas, O., Ekici, E., Heijenk, G., Jarupan, B., Lin, K., Weil, T.: Vehicular networking: A survey and tutorial on requirements, architectures, challenges, standards and solutions. Communications Surveys Tutorials, IEEE **13**(4) (quarter 2011) 584 –616
2. Asgari, M., Jumari, K., Ismail, M.: Analysis of routing protocols in vehicular ad hoc network applications. In: Software Engineering and Computer Systems. Volume 181. Springer Berlin Heidelberg (2011) 384–397
3. Gerla, M., Maggiorini, D., Palazzi, C., Bujari, A.: A survey on interactive games over mobile networks. Wireless Communications and Mobile Computing (2012)
4. Zhou, S., Cai, W., Lee, B.S., Turner, S.J.: Time-space consistency in large-scale distributed virtual environments. ACM Trans. Model. Comput. Simul. **14** (January 2004) 31–47
5. Faezipour, M., Nourani, M., Saeed, A., Addepalli, S.: Progress and challenges in intelligent vehicle area networks. Communications of the ACM **55**(2) (February 2012) 90–100
6. Lee, U., Gerla, M.: A survey of urban vehicular sensing platforms. Computer Networks **54**(4) (2010) 527 – 544
7. Kakarla, J., Sathya, S.S.: Article: A survey and qualitative analysis of multichannel mac protocols for vanet. International Journal of Computer Applications **38**(6) (January 2012) 38–42
8. Feng, W.c., Chang, F., Feng, W.c., Walpole, J.: A traffic characterization of popular on-line games. IEEE/ACM Trans. Netw. **13**(3) (June 2005) 488–500
9. Tonguz, O.K., Boban, M.: Multiplayer games over vehicular ad hoc networks: A new application. Ad Hoc Netw. **8**(5) (July 2010) 531–543
10. Gupta, P., Kumar, P.: The capacity of wireless networks. Information Theory, IEEE Transactions on **46**(2) (mar 2000) 388 –404

11. Tayal, S., Tripathy, M.: Vanet-challenges in selection of vehicular mobility model. In: Advanced Computing Communication Technologies (ACCT), 2012 Second International Conference on. (jan. 2012) 231 –235
12. Prakash, A., Tripathi, S., Verma, R., Tyagi, N., Tripathi, R., Naik, K.: A cross layer seamless handover scheme in ieee 802.11p based vehicular networks. In: Contemporary Computing. Volume 95. Springer Berlin Heidelberg (2010) 84–95
13. Akyildiz, L., McNair, J., Ho, J., Uzunalioglu, H., Wang, W.: Mobility management in current and future communications networks. Network, IEEE **12**(4) (jul/aug 1998) 39–49
14. Chen, Y.C., Hsia, J.H., Liao, Y.J.: Advanced seamless vertical handoff architecture for wimax and wifi heterogeneous networks with qos guarantees. Computer Communications **32**(2) (2009) 281–293
15. Yusof, A., Ismail, M., Misran, N.: Handoff architecture in next-generation wireless systems. In: 2007. APACE 2007. Asia-Pacific Conference on Applied Electromagnetics. (dec 2007) 1–5
16. Dutta, A., Das, S., Famolari, D., Ohba, Y., Taniuchi, K., Fajardo, V., Lopez, R.M., Kodama, T., Schulzrinne, H.: Seamless proactive handover across heterogeneous access networks. Wirel. Pers. Commun. **43** (November 2007) 837–855
17. Taniuchi, K., Ohba, Y., Fajardo, V., Das, S., Tauil, M., Cheng, Y.H., Dutta, A., Baker, D., Yajnik, M., Famolari, D.: Ieee 802.21: Media independent handover: Features, applicability, and realization. Communications Magazine, IEEE **47**(1) (january 2009) 112–120
18. Yang, K., Ou, S., Chen, H.H., He, J.: A multihop peer-communication protocol with fairness guarantee for ieee 802.16-based vehicular networks. IEEE Transactions on Vehicular Technology **56**(6) (nov 2007) 3358–3370
19. Mussabbir, Q., Yao, W., Niu, Z., Fu, X.: Optimized fmipv6 using ieee 802.21 mih services in vehicular networks. IEEE Transactions on Vehicular Technology **56**(6) (nov 2007) 3397–3407
20. Chiu, K.L., Hwang, R.H., Chen, Y.S.: Cross-layer design vehicle-aided handover scheme in VANETs. Wireless Communications and Mobile Computing (2009)
21. Lee, J.H., Ernst, T., Deng, D.J., Chao, H.C.: Improved pmipv6 handover procedure for consumer multicast traffic. Communications, IET **5**(15) (14 2011) 2149 –2156
22. Kim, J., Morioka, Y., Hagiwara, J.: An optimized seamless ip flow mobility management architecture for traffic offloading. In: Network Operations and Management Symposium (NOMS), 2012 IEEE. (april 2012) 229 –236
23. Lee, H.B., Han, Y.H., Min, S.G.: Network mobility support scheme on pmipv6 networks. International Journal of Computer Networks and Communications **2**(5) (2010) 206–213
24. Choi, H.Y., Min, S.G., Han, Y.H., Park, J., Kim, H.: Implementation and evaluation of proxy mobile ipv6 in ns-3 network simulator. In: 5th Intl. Conference on Ubiquitous Information Technologies and Applications. (dec. 2010) 1 –6
25. Salumu, M.: ns3 - 802.21. Available at: http://code.nsnam.org/salumu/ns-3-mih/ Accessed in 2012.
26. Meneguette, R.I.: Overlay network to support collaborative virtual environments in vehicular networks. Master's thesis, Universidade Federal de São Carlos (2009 (in portuguese))
27. Kirk, P.: Gnutella protocol development. Available at: http://rfc-gnutella.sourceforge.net (Accessed in 2012)
28. Tonguz, O.K., Boban, M.: Multiplayer games over vehicular ad hoc networks: A new application. Ad Hoc Networks **8**(5) (2010) 531–543