# Multi-Network Packet Scheduling Based on Vehicular Ad Hoc Network Applications

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***Abstract*—In this paper, we explore a novel online packet scheduling model based on vehicular network applications. The model incorporates multiple networks with non-persistent connectivity where we only know which networks are available at the current time. Our goal is to achieve the minimum requirement of vehicular application classes and also maximize the throughput of these classes. NS3 simulations were performed to analyze the behavior of our scheduling model by comparing it with the standard scheduling using only LTE and WiFi networks, as well as the handover between these two networks. We observed that the proposed scheduling model had a low packet loss and low delay.**

## I. Introduction

Vehicular Ad Hoc Network (VANET) has been of particular interest to the communication research area for several years. Communication and cooperation between vehicles offer great potential in reducing the number and impact of road accidents as well as in improving comfort and efficiency on the roads [1]. The vehicular applications can run simultaneously, since the car could be running a security application as well as entertainment applications. To enable these applications to be used simultaneously, it is necessary to develop mechanisms to store and route messages from these applications without violating the minimum requirements of the application. The way that the applications were developed and how they interact with the layers below can impact their performance [2].

In this paper, we propose and evaluate a multi-network packet scheduling based on vehicular ad hoc network applications. We explored the use of more than one network technology to maximize both sending and receiving of messages to/from applications in vehicular networks. The proposed packet scheduling model deals with different network interfaces at the same time, seeking the maximization of the network throughput and keeping latency and packet loss within the minimum requirements for vehicular network application classes. To achieve this, our scheduling considers that applications are divided into three classes, according to general goals of vehicular network applications: safety, comfort, and user.

This paper is organized as follows. Section 2 discusses some related works. Section 3 presents the proposed multi-network packet scheduling based on vehicular ad hoc network application classes, while in Section 4 we present and analyze simulation results. Section 5 concludes the paper with remarks and future directions.

## II. Related Works

This section presents some proposals related to load balancing and scheduling algorithms.

Al-Zubaidy et. al. [3] implemented balancing packet scheduling policies in a discrete-time multi-server system of parallel queues with independent random queue-server connectivity. These policies are characterized by minimizing the total difference in queue lengths at every time slot. The model uses symmetric queues and multiple servers with random server connectivities.

Martin Karsten [4] implemented the Virtually Isolated FIFO Queueing (VIFQ), which emulates FIFO throughput but also supports differentiated strict delay classes at routers. VIFQ adopts a policy-free point of view where all arriving traffic is treated as equally important and valuable, thus leaving rate allocation decisions to other network components. VIFQ constructs multiple virtual FIFO queues that are configured with a maximum queueing delay.

Zhang et. al. [5] presented a framework for congestion control by classifying different mechanisms. The authors proposed to use channel busy time as metric for network load, and they define three parameters for the network performance of safety messages. The authors also highlight areas of future research, which include the definition of network performance parameters to cope with state-of-the-art technology hardware limit and to choose the most appropriate congestion control mechanisms.

Our Multi-Network Packet Scheduling is based on application classes of vehicular networks, and not at the time that packets must be sent. In other words, instead of classifying the packet by its timestamp to know to which network to send it, we associate each application class with a network technology.

## III. A Multi-Network Packet Scheduling Based on Vehicular Ad Hoc Network Applications

We modeled the multi-network packet scheduling based on three classes of application: *safety*, *comfort*, and *user*. The objectives of the packet scheduling are to maximize network throughput and to keep latency and packet loss within the minimum requirements for each class. To accomplish this, the schedule model associates a priority of access with each different network technology present in the environment according to the needs of each application class. Our scheduling model differs from the others because it does not assign values to

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packets, such as energy spent to send the packet to a particular network or some timestamp. Instead, the packets are associated with the implementing class they belong to.

The multi-network packet scheduling consists of three buffers, one for each type of application class. These three classes will facilitate the change of network technology and avoid crowding any buffer. Each buffer is associated with one or more network technologies. This association is according to the mapping between the classes of application and the priorities each class has on the network interface.

### A. Mapping the Safety Class

Safety applications are geared primarily toward avoiding accidents and loss of life of the vehicles occupants [6].There are a lot of safety applications such as: intersection collision warning; lane change assistance; overtaking vehicle warning; co-operative forward collision warning; pre-crash sensing/warning, and so on. In this paper we focus on safety applications that have connection with road units. This class of application requires [7]: (i) minimum packet transmission frequency of 10Hz; and (ii) maximum latency time of 100ms.

Safety class can use both WiFi and cellular technologies. We assigned to this class the priority value of 1 (the highest priority) to access any network technology. If some application of safety is sending a message to the network, this message will be sent immediately, because it has priority over all other messages. Moreover, these messages can be sent simultaneously through both WiFi and cellular networks. This integration between WiFi and cellular technology allows a higher bandwidth, thus a higher throughput of your messages [8]

### B. Mapping the Comfort Class

Comfort class applications focus on improving the vehicle traffic flow, traffic coordination, traffic assistance, and also provides updated local information [9]. Its applications include congested road notifications, co-operative vehicle-highway automation systems, electronic toll collector, in-vehicle signage, and so on. In this paper we focus on two basic comfort-related applications. The communication requirements for applications in this class are [7]: (ii) minimum packet transmission frequency between 1Hz and 10 Hz; and (ii) maximum latency time of 100ms.

This class of applications, unlike the safety class, has different priorities of access depending on the network interface: Priority 1 to access the WiFi interfaces (higher priority), and priority 2 for cellular interfaces, thereby not overloading the cellular network.

### C. Mapping the User Class

User class is focused on making travel more pleasant, providing information, advertisements, and entertainment during the journey. This class of application requires [7]: (i) minimum packet transmission frequency of 1Hz; and (ii) maximum latency time of 500ms.

User class is very similar to the comfort class, i. e., both have different priorities of access, where the WiFi technology has higher priority than the cellular technology. To avoid concurrency among packets of these two classes, we consider the size and the waiting time of the packet to make the decision on which packet will be sent first.

### D. Multi-Network packet scheduling operation

Assume the safety application class is mapped to the cellular technology, for instance warning from time to time to a central about a broken car, and that comfort and user class applications are associated with wireless networks and are also sending messages from time to time to a central. The packet scheduling will forward the packets from the safety application class without problems, because besides being only linked to one network interface, this application class has priority over other classes. On the other hand, concurrency exists between comfort and user classes, because both are using the same network interface. To handle this, the scheduler gives higher priority to packets of smaller size and to packets that exceed a threshold of waiting time to be sent.

The algorithm below presents an overview of the prioritization. The function $get\_next\_packet(buffer)$ returns and removes the next packet in the buffer. First, the algorithm checks if there is a packet in the safety class buffer, and sends it (lines 01 to 04). If there is no packet in this class, then the algorithm verifies the user and comfort buffers. If one of them has a packet to send and the other one is empty, the packet from the non-empty buffer is sent (lines 06 to 11). If buffers from applications of both classes have packets to send, the packet with the highest waiting time exceeding the threshold is sent first (line 16). If there is no packet exceeding the waiting time threshold, the smallest packet between the user and comfort buffers is sent (line 18).

```
01. p = get_next_packet(safety_buffer);
02. if (p != NULL){
03.   send(p);
04. }
05. else{
06.  if(!empty(user_buffer)&&empty(comfort_buffer)){
07.     p = get_next_packet(user_buffer); send(p);
08.  }
09.  else if(empty(user_buffer)&&!empty(comfort_buffer)){
10.    p = get_next_packet(comfort_buffer); send(p);
11.  }
12.  else {
13.    p_t = packet with highest waiting time larger than↩
     threshold in buffers
14.    p_s = next packet with smallest size in buffers
15.    if(p_t != NULL)
16.      send(p_t); remove_buffer(p_t);
17.    else
18.      send(p_s); remove_buffer(p_s);
19.  }
20.}
```

Lets now assume that after a given time $t$, the safety application class stops sending packets (i.e., the buffer is empty and the network interface is released), and the other applications are sending packets from time to time. The packet scheduling verifies if the safety buffer is empty and after that it will assign another class of applications for that network interface, for example the comfort class. This association occurs temporarily until some safety application starts to send packets. This approach minimizes the idleness in communication channels, thus increasing the throughput of applications.

## IV. Simulation Environment and Results Analysis

The proposed Multi-Network Packet Scheduling based on vehicular ad hoc network applications has been implemented in the Network Simulator (NS-3.12.1). The purpose of the simulations was to verify the impact that our scheduling model would cause to both network and applications. We used four metrics to evaluate our Multi-Network Packet Scheduling model: throughput, packet loss, delay, and delay per application class.

In our simulation scenario, each vehicle was running one application of each application class, i.e., one application of safety class, one application of comfort class, and one application of user class. The frequency of messages for each application follows the patterns of the European Telecommunication Standardization Institute (ETSI) [7]: the safety application sends a message every 0.1s, the user application sends a message every 1s, and the comfort application sends a message every 0.7s.

We conducted the simulations with 50 simulated cars, which are traveling in the map. For the map, we used an area of 600 square meters which is a central region of Campinas city, in São Paulo State, Brazil. The speed of the nodes varied from 10 to 16 meters per second. We then selected a number of vehicles to send and receive messages from 3 different types of application. We varied among 6, 12, 18, 24, 30, and 36 vehicles running the three classes of application at the same time while the other vehicles only travel on the streets without sending or receiving messages. All vehicles are within the range of both a WiFi access point and a cellular network access point. The network topology consists of a wired node, three backbone nodes, an LTE access point, and an 802.11p access point. We performed 10 simulations for each scenario and we computed 95% confidence intervals.

We defined 5 different scenarios to evaluate our multi-network packet scheduling model:

- LTE: All nodes use only the LTE network to transmit and receive information.
- WiFi: All nodes use only the WiFi network to transmit and receive information.
- LTE + WiFi: Both LTE and WiFi networks are active in the environment, but nodes only send and receive information through a single interface. To switch nodes between networks, we used a previously developed handover mechanism [10]. All nodes are connected to the WiFi access point at time 0.
- Proposal 1: Both LTE and WiFi networks are active in the environment, and nodes can use both networks to send and receive data. In this scenario, the safety application class was directly mapped to the LTE network, and the user and the comfort classes are competing for the 802.11p interface.
- Proposal 2: Both LTE and WiFi networks are active in the environment and the nodes can use both networks to send and receive data. Unlike Proposal 1, in this scenario safety and comfort application classes compete for the LTE network interface, and the 802.11p network interface is directly mapped to the user class.

For all these scenarios, the data stream is from the vehicle to the wired node. All vehicles have two network interfaces, LTE and 802.11p, and both interfaces have pre-assigned addresses. For the configuration of LTE and 802.11p we use the standard configuration of each module of the NS-3, which provides a range of about 5km to the LTE and approximately 1 km to the service channels of the 802.11p protocol.

Figure 1 shows the average packet loss. We observe that both Proposal 1 and Proposal 2 had lower packet losses than the other scenarios, because unlike the other scenarios, the proposals are able to divide the burden of packets which need to be sent to different network interfaces. With 36 participants, Proposal 2 had a reduction in the number of packet loss of 92% when compared to the other three scenarios. Furthermore we observed an increase of packet loss in WiFi and WiFi + LTE scenario, due to interference of the network and also by the overload of WiFi base station. This occurs due to the overload of message retransmissions and the high message sending rate of nodes. These packet losses did not have a relevant impact on the throughput of the network as seen in Figure 2.

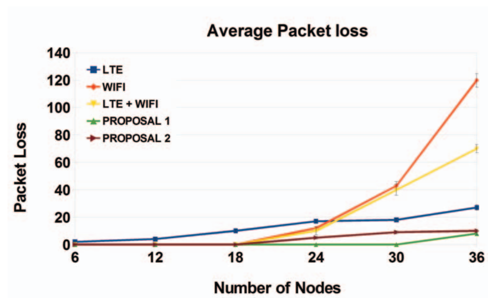


Fig. 1. Average Packet Loss.

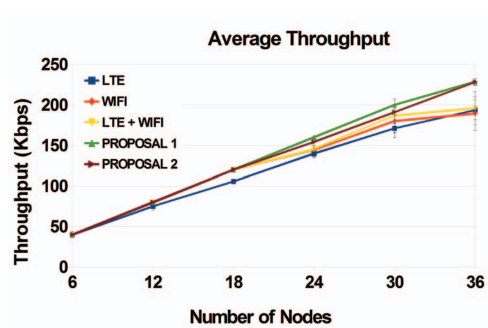


Fig. 2. Average Throughput.

We can see from Figure 2 that when there are 36 nodes, both Proposal 1 and Proposal 2 had the same performance, and they were statistically better than the other scenarios. However, with less participants we find that all scenarios had almost the same performance, considering the overlap of confidence intervals.

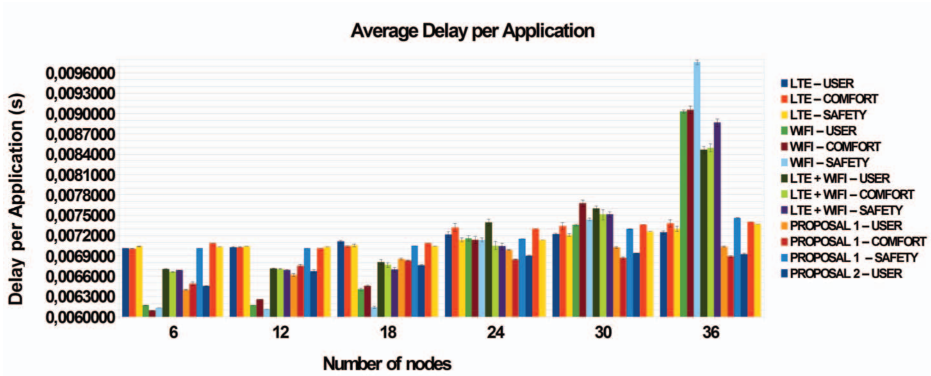


Fig. 4. Average delay per application.

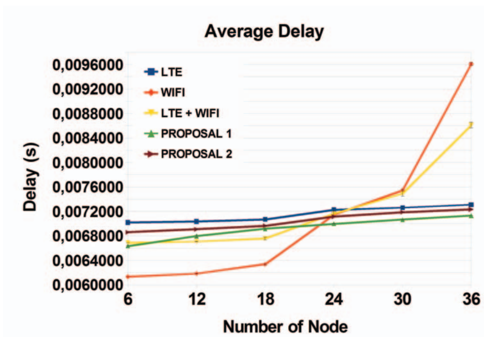


Fig. 3. Average Delay.

Proposal 1 and Proposal 2 had an average of 8% higher throughput than the other three scenarios. This similarity is related to the type of lost messages. If we compare a scenario which is losing too many packets but these packets are small, such as safety class packets (20 bytes), with a scenario which loses less but larger packets, such as packets of user class (512 bytes), we observe a similar network throughput.

Figure 3 shows the average delay of all application classes. We can see that with up to 24 participants, the scenario using only WiFi presented better performance than the other scenarios, because the 802.11p protocol uses four service channels to send messages. Although Proposal 1, Proposal 2, and LTE + WiFi used WiFi technology, these scenarios had their delays affected due to the delivery time of messages in the LTE network. The Proposal 1 and Proposal 2 had an average reduction of 4% in the delay when compared to the average time delay of the handover. With 36 participants, Proposal 1 and Proposal 2 had an average reduction of 26% when compared to WiFi and an average reduction of 2% when compared with the LTE. Proposal 1 and Proposal 2 performed a better balance for the burden of packets to be sent, as seen in Figure 4.

The delay of all applications are granted below the standard values of ETSI [7]. We observed that beyond 24 participating vehicles, smaller application delays are found in Proposal 1 and Proposal 2. However, depending on the application class, these delays are equivalent. With 36 nodes the delay time of the safety application classes for LTE, Proposal 1 and Proposal 2 are nearly the same. For the same number of vehicles we can observe an increase of delay in the scenario WiFi due to the number of retransmissions occurred by interference from the network and also by the overload packets in the base station.

Proposals 1 and 2 used all features of the proposed multi-network packet scheduling model and they achieved low packet loss, maintaining a good network throughput and also a low delay that did not exceed the standards established by ETSI [7]. These results were possible because the proposed scenarios divided the burden of packet transmissions between different network interfaces.

## V. Conclusion

In this work, we explored the use of more than one network technology to maximize both the sending and receiving of messages for applications in vehicular networks. The proposed packet scheduling model deals with different network interfaces at the same time, seeking to maximize network throughput and satisfying minimum requirements of latency and packet loss for each class of vehicular network application.

Scenarios which took advantage of the use of the proposed multi-network packet scheduling model presented better performance than the others. The use of more than one network technology at the same time provided a better load balancing in messages to be sent, thereby achieving lower packet losses and short delays when there is a large number of participants. Furthermore, no delay in applications exceeded the standard time established by ETSI.

As future work we intend to perform new simulations to verify the efficiency of this scheduling when using the control channels of 802.11p protocol, adding communications among vehicles in the roads. We intend to use the 802.21 protocol to make application mapping more dynamic.

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