Towards a Dynamic and Adaptative Prioritization of Wireless Broadband Vehicle-to-Ground Communications

Communication Management based on Network Utility Maximization and QoS Requirements

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***Abstract*—The growth of the use of wireless and internet technologies in transport systems, enables the provision of new information services based on vehicle-to-ground communications. There are many broadband management systems, but most of them come from non-mobile environments. This results in a poor performance when deployed to environments where senders and receivers are moving. Such problems appear because transportation systems environments present specific requirements related to coverage, bandwidth and also a mix of communications networks. In order to tackle these challenges, this paper presents the work in progress of a vehicle-to-ground communication middleware that aims to manage communication requests using a dynamic schema. The core of this new communications manager is an adaptive algorithm that selects the most favorable network link taking into account several actual and past aspects of the communications requests.**

Keywords-Communications Management; Limited Bandwidth; Quality of Service; Vehicle-to-Ground Communications.

I. Introduction

Transportation industry is demanding more bandwidth, more immediate response time and more reliability for their communication networks in order to perform intra-vehicle, vehicle-to-ground or trackside communications. In this way, research is being promoted to provide more convenient and efficient vehicular systems by using broadband networks to link onboard systems with ground systems.

Nowadays, the use of wireless and Internet technologies is increasing in the transportation enabling bidirectional vehicle-to-ground communications [1]. However, these kinds of communications applied to this environment have to respond to several challenges related to aspects like coverage, bandwidth, communication disruptions, multiple network interfaces for communications and different priorities in the information transmission, responding at the same time to applications Quality of Service (QoS) [2] requirements.

On the other hand, the existing broadband management systems, which are used in other (non-mobile) environments, do not satisfy the needs of vehicular applications [3] [4]. In addition, there are several applications trying to transmit information to/from the vehicles at the same time. This implies the existence of a bandwidth monopolization problem.

To tackle these challenges, it is necessary a smart intermediate element which manages when the applications (both terrestrial and vehicular-side) can communicate with each other and makes the most favorable available network link selection for communications. This is the aim of the work presented here.

In contrast to existing initiatives, the proposed solution enables a continuous broadband communication channel between applications in vehicles and ground control centers based on an application layer middleware which do not require specific considerations in the rest of the protocol layers. Existing standards for Intelligent Transportation Systems (ITS) communication architectures, such as [5] [6] [7], are principally focused on network level issues in order to fulfill Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication requirements. Unlike the proposed ones, these architectures are usually oriented to traffic security applications that need immediacy and a low volume of data transmission.

This paper is organized into the following sections: the second section includes a brief state of the art. The third section details the proposed communication middleware requirements and architecture. To close, the fourth section of the paper describes the future work indicating the following steps in the work in progress.

II. State of the Art

The presented research work is focused on vehicle-to-ground broadband communications prioritization management focusing on high level protocols. Thus, in the following subsections the state of the art related to the two main issues of the work will be discussed: (1) vehicle-to-ground wireless communications, and (2) broadband communications prioritization and QoS.

A. *Vehicle-to-Ground Wireless Communications*

Wireless communication technologies are growing in vehicular systems due to transportation companies are demanding greater efficiency for their systems while they are also seeking to provide new information services [8]. Consequently, vehicular systems are enabling not only vehicle-to-ground continuous communications, they also tend to install wireless equipment in stations and other wayside locations for broadband communications where large quantities of maintenance [9] [10] and multimedia [11] data can be transmitted between vehicle and ground system while vehicle is in coverage area.

It is important to point out that the emphasis in developing wireless network is on network bandwidth and coverage. Therefore, the applicability of the communication system will largely depends on their ability to provide sufficient data rates (QoS requirements), considering introduced protocol overhead, packet fragmentation and possible retransmissions. A major problem with using unlicensed frequency bands like 802.11x is obviously the interference on and shared access of the wireless medium. These aspects can cause blocking of information services communication. In order to solve this kind of questions, one option is to enable multiple wireless interfaces making possible switching from one interface to other. It is for this reason that the vehicular wireless communication systems tends to be designed using multiple radio and mobile interfaces (GPRS, UMTS, WLAN, etc.) in “always best connected” [12] way to enhance communications availability and obtain the possible major bandwidth capabilities [13], selecting the most favorable link for the communications at every moment. This kind of solutions increases system cost, but can help to improve system availability greatly.

Therefore, the use of multiple network interfaces simultaneously allows building a better combined wireless communication channel. The objective is to achieve the highest data rates being able to meet different mobile scenarios as well as mobile applications requirements. To that end, there are solutions that advocate exploiting network diversity from different wireless networks and operators in order to be able to aggregate bandwidths that can then be offered as a single large, more stable pipe to end users [14].

Furthermore, it is important to point out the emergent application of Internet protocols, languages and technologies (TCP/IP, HTTP, XML, etc.) [15].

B. Broadband Communications Prioritization and QoS

Wireless communications applied to mobile environment present several limitations related to coverage and bandwidth that can cause service disruptions. Moreover wireless stations that need to transmit relevant information must deal with wireless stations wishing to transmit less priority traffic.

With the purpose of achieve QoS requirements demanded by services, several communication management and prioritization heuristics [16] [17] and mechanisms exist [18] [19] [20]. Although existing solutions are mainly focused on network aspects and not in final applications and services, other approaches are focused in optimizing the use of the network technologies according to the type of traffic generated by applications (QoS control). Therefore, there is an open research field that can be tackled from two complementary points of view: (1) QoS requirements management which involves technology concepts related to the information to transmit, and (2) aspects about network conditions that make possible the transmission of that information (bandwidth, coverage, latency, etc.).

In addition, many of these solutions are focused on mobile environments and are able to monitor network parameters (like bandwidth). The main idea in these solutions is to prioritize communications services allowing or denying communications, or readjusting its data rates, in accordance with QoS requirements demanded by the communication requests and available networks bandwidth limitations.

These mentioned solutions applied to transportation would allow prioritizing vehicle-to-ground wireless communications taking into account its QoS restrictions. However, they are mostly oriented to regulate wireless stations communications and not final individual applications communication requests. Moreover, they do not monitor previous performance aspects (variable) not allowing to the system to dynamically adjust its performance for more efficiency.

These questions open an interesting line of work to develop adaptive algorithms and interactive control methods that perform this adjustment dynamically. The basic idea is to monitor network conditions in real-time, receive feedback measures of the variables of interest, and based on these measures and QoS requirements, make a wireless communication prioritization assigning them the considered bandwidth data rate.

III. Proposed Communication Middleware

The proposed solution consists on a communication middleware that aims to enable several physical network communication links between vehicle and ground system (3G, WiFi, etc.), choosing the network link considered as the best at every moment according to the bandwidth availability (not having final applications to get involved in the network management).

Focusing on an application layer middleware it is a more flexible approach allowing the introduction of new parameters or factors that can be managed to improve communications performance. So, the objective is to develop a dynamic and adaptive communications requests mechanism based not only on network conditions and applications request priorities. This mechanism will be based also on system historical performance parameters (previous bandwidth values, time in network coverage areas during the transportation routes, previous applications communications performance, etc.).

A. Requirements

The final system should respond to several requirements:

1) Dynamic and efficient communication request management: this system will prioritize vehicle-to-ground communcations requests taking into account communication urgency creteria, as well as previous performance logs.

2) The best bandwidth: the system will always select the physical link considered as the best taking into account the bandwidh in order to respond to final applications communication requirements.

3) *Quality of Service:* it is necessary to know the bandwidth availability offered by the network link which is active at every moment, as well as the bandwidth offered by the rest of communications links (although they are not being used). At this point, it is essential to establish a set of connection procedures which permit to reserve a certain bandwidth for a particular communication.

B. Architecture

The architecture of the presented solution (Figure 1) is composed by two software elements; one in the terrestrial side (Terrestrial Communication Manager, TCM), and the other boarded in vehicles (Vehicular Communication Manager, VCM). The former manages terrestrial aspects of the architecture and the latter vehicular-side issues, and they interact to each other in order to control and manage vehicle-to-ground communications. In addition, this system develops a Bandwidth Measurement Service (BMS) that notifies available links bandwidth values to the VCM at every moment. It is necessary to emphasize that bandwidth measurement would be an independent research field that is not explored in this work.

Therefore, the final objective is to demonstrate that this communication management system improves vehicle-to-ground broadband communications efficiency especially in these situations where applications communications needs are higher than the bandwidth offered by the available network links ensuring at the same time applications QoS requirements.

Thus, the proposed solution is composed by several functional modules:

1) *Active Link Selection:* the communication platform is based on different physical communication link existence so that the combination of these independent links offers a continuous vehicle-to-ground connectivity in order to respond to the final applications communications demand. So, taking into account the availability of enabled different physical links, the system always selects as active link this network interface that offers the best bandwidth (based on the features and coverage of the physical link).

Therefore, to establish vehicle-to-ground communications, VCM and TCM can communicate through different communications network physical links. The VCM is who selects the active link considered most favorable for communications based on available links bandwidth measurements notified by BMS, and then establish active link connection with TCM. So, BMS is continuously monitoring all enabled network links status, and VCM switch from one to other in two cases: (1) when active link connectivity is lost and (2) when BMS measurements indicate that another link is better than this established as the active. In these two cases, the active communication link change is transparent for final applications that do not detect connection interruptions if these link changes occur while they are transmitting.

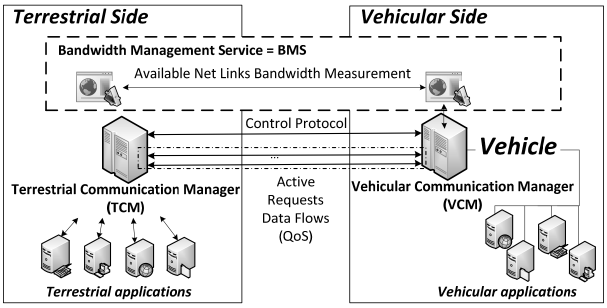

Figure 1. Dynamic Communication Prioritization Architecture for Vehicle-to-Ground Communications based on QoS Requirements and Network Conditions

At this point it should be emphasized that the basis is that the system always defines a single vehicle-to-earth network link as active for communications (the most favorable). So, all communications will always be generated by the channel set as active (WiFi, GSM/GPRS, Tetra, etc.) regardless of the availability of other physical channels simultaneously.

2) *Requests Prioritization Management:* the objective is to prioritize vehicle-to-ground communications based on several criteria so that the transmission of critical information has more priority over other information that need less "immediacy" when being transmitted. Therefore, this platform proposes a set of communication requests prioritization criteria divided into two categories: (1) static criteria and (2) dynamic criteria. Static criteria are related to applications QoS requirements like information priority level, required minimun data rates, or requests cronological order. Dynamic criteria are variable factors that are related directly with the communications that have been carried out previously (the average duration of vehicles stopping in a known wireless network coverage area, the average duration that takes the communications of a particular application at certain data rates, bandwidth values obtained previously, wireless networks coverage values, etc.). Thus, combining these two kinds of criterias, the system calculates a numeric value that represents the fitness of serving a request. Once calculated this value, it is used to discern which communication request is served. Hence, in order to perform requests prioritization, this system develops several queues where requests are sorted by vehicle and this calculated value (priority).

Therefore, the idea is that the system reconfigures how it prioritizes the communication requests depending of its behavior over time, always seeking the most optimal configuration based on system feedback.

3) Vehicle-to-Ground Control Protocol: TCM and VCM on each vehicle communicate each other and exchange commands in order to establish active links and manage vehicular and terrestrial final applications communications requests prioritization. The control protocol is defined using XML messages where information is exchanged via TCP/IP sockets.

4) Final Application Communication Control and Management: the described platform aims to enable vehicle and terrestrial vehicular applications to communicate each other in a more efficient way. So when an application attempts to start a new communication makes a request to the platform. Then the system makes a decision about what priority requests can be served concurrently taking into account active link bandwidth limitations, priority parameters and requests QoS requirements. Thus, once the system give way to a communication request, adjust this communications data rate taking into account its QoS requirements, active link bandwidth availability and active priority requests communicating concurrently. In addition, system should assign more bandwidth than minimaly required to a request depending on bandwidth availability and priority active requests requirements.

C. Developing State

The proposed middleware is already developed and is being debugged in order to improve its performance and fix detected errors. Besides, with the purpose of test the platform there have been developed applications simulators that permit making communication requests to the system under different QoS requirements.

IV. FUTURE WORK

Once the system is developed, it will be tested configuring several testbed scenarios. The idea is to have a preconfigured scenarios including a set of known communication requests (generated both on terrestrial side and on vehicles) and network conditions.

Therefore, the testing scenarios will include different kind of final applications that generate different kind of data traffic (multimedia, text, files, binary, etc.) that are usual in transportation systems, as well as predefined network conditions (using an external tool that allows to regulate network interfaces bandwidth values). The objective is to evaluate the systems performance, launching several communication requests and causing network active link changes (because of more favorable link or link lost detections), that allows checking whether obtained results are as expected.

On the other hand, these tests will be useful to evaluate communications prioritization algorithm in order to improve its efficiency.

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