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A Middleware for Dynamic and Adaptive Vehicle-to-Ground Communications Management

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Abstract— **The widespread use of wireless and Internet technologies in transport systems, enables the provision of new intelligent services based on broadband communications between vehicles and traffic control centres (hereinafter vehicle-to-ground communications). There are many broadband management systems but most of them have been designed for non-mobile environments. This result in a poor performance when are used in scenarios where senders or receivers are moving. Such problems appear because environments where transportation systems are deployed present specific issues related to coverage, bandwidth and also a mix of communications networks. In order to tackle these challenges this paper describes and tests a vehicle-to-ground communication middleware that aims to manage communication requests using a dynamic and adaptive approach.**

I. INTRODUCTION

Transportation industry is demanding more bandwidth, more immediate response time and more reliability for their networks in order to perform intra-vehicle and/or vehicle to traffic control centre communications (hereinafter the previous ones will be referred as vehicle-to-ground communications). In this way, research is being promoted to provide more convenient and efficient vehicular systems by using broadband networks to connect on-board systems with ground systems.

Additionally, 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 data transmission, responding at the same time to Quality of Service (QoS) [2] demanded by applications.

In addition, different kinds of applications with different communications needs are being deployed within the transportation systems [3]. These applications usually share the transmission channel, competing for bandwidth usage [4]. The problem arises when network bandwidth availability is less than the bandwidth requested by applications, causing issues like transmission bottlenecks and bandwidth monopolizations [5]. Furthermore, depending on the functionality or role of these applications, the transmission of information from one of them may be higher priority than others depending on the criticality of the information transmitted [6].

To tackle these challenges, it is necessary a smart intermediate element (middleware) which manages the communication between applications (both in terrestrial and vehicular-side) and makes the most favourable available network link selection for such communication. This paper presents a new approach for vehicular-to-ground communications management that addresses the previously mentioned challenges.

The rest of the paper is organized as follows. First, a brief overview of related work. Second, the proposed solution design. Then, the real scenario in which the system has been tested is described. Finally, the results of the tests are analyzed. It concludes with the conclusions and future work.

II. RELATED WORK

There are numerous papers related to communications optimization, including traffic prioritization and QoS control. However, these works are often focused on network level but no so much in applications or services that use these networks [7].

On the other hand, traffic prioritization and QoS solutions are usually oriented to wired networks, and they do not adjust to changes produced in wireless connectivity environments. Thus, in mobility scenarios like vehicular ones, it is necessary to monitor in real time network conditions, allowing the system to adapt communications schedules dynamically, making an adaptive QoS control possible [8].

At software level, there are solutions generally referenced as middleware that enable distribute services deployments, allowing applications to disengage from communications management issues. However, existing middleware do not offer mechanisms to ensure QoS yet. They are not designed to manage and monitor de status of networks, so that network circumstances influence decisively in applications communications performance [9].

Therefore, in order to address this kind of problems, this paper presents a work that addresses the need to design an intermediate system or middleware [10] that allows you to manage such issues abstracting applications about aspects related to communications mechanisms, as well as

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establishing communications prioritization mechanisms taking into account network conditions [11], responding at the same time to applications QoS requirements [12] (bandwidth, transmitted information criticality, etc.), thereby increasing the overall system performance [13]. So, the presented research work is focused on vehicle-to-ground broadband communications prioritization dealing with application level protocols.

Thus, in the following subsections the state of the art related to the two main issues of the work will be discussed.

A. Bandwidth and Wireless Communications Availability

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" [14] way to enhance communications availability and obtain the possible major bandwidth capabilities [15], selecting the most favourable link for the communications at every moment. This kind of solutions increases system cost, but can help to improve system availability greatly.

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 [16].

B. Broadband Communications Prioritization and QoS

With the purpose of achieving QoS requirements demanded by services, several communication management and prioritization heuristics [17] and mechanism exist [2]. Although existing solutions are mainly focused on network aspects and not in final applications and services, other approaches are focused on 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 management which involves technology concepts related to the type of 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 be able to prioritize vehicle-to-ground wireless communications taking into account 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 the system to dynamically adjust its performance for more efficiency.

III. Middleware for Dynamic and Adaptive Vehicle-To-Ground Communication

The proposed solution consists in a communication middleware that aims to enable several physical network communication links between vehicle and ground system (3G, WiFi, etc.). It chooses 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 being able to introduce new parameters or factors that can be managed to improve communications performance. So, the objective is to develop a dynamic and adaptive communications solution based not only on network conditions or applications request priorities. This system is 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. Addressed Requirements

The proposed communications system includes the following contributions:

- *Dynamic allocation of network bandwidth according to applications QoS requirements*. This middleware is designed to respond to remote communication needs between terrestrial and vehicular applications. Thus, the system indicates to final applications when they can start the communication process, establishing an adequate bandwidth for this communication according to the state of the vehicular network and QoS requirements specified by applications.

  Therefore, the variability of the connectivity conditions influences directly in active communications, demanding a dynamic vehicle-to-ground communication management.

  With respect to QoS control, the principal QoS parameter managed by this system is the bandwidth. In this way, the idea is to make bandwidth allocations for different applications communications according to these applications requirements, and allowing them to adjust these allocations depending on the measured available network bandwidth.

- *Dynamic communications prioritization.* This system prioritizes vehicle-to-ground communications requests taking into account communications urgency criteria, as well as previous performance information.

  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.

- *Seamless active network link selection:* The system will always select the physical link considered as the best taking into account the bandwidth in order to respond to final applications communication requirements. Multiple network link availability maximizes continuous communication capacity, being network active link changes not perceived by final applications. So, this middleware is designed to perform active network link changes avoiding final applications communications disruptions.

B. Architecture

The architecture of the presented solution (Figure 1) is composed of 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 includes a Bandwidth Measurement Service (BMS) that notifies available links bandwidth values to the VCM at every moment.

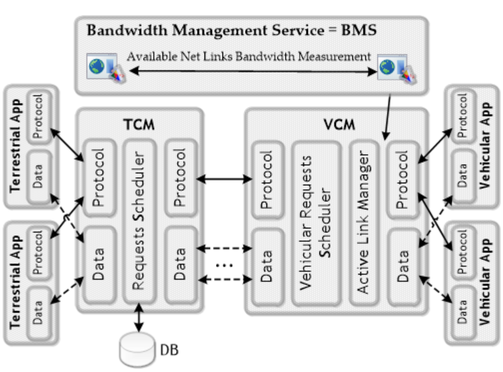

Figure 1. Middleware architecture

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

- *Active Link Selection:* 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 favourable 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 the one established as the active. In these two cases, the active communication link change without affecting the final applications that do not detect connection interruptions if these link changes occur while they are transmitting.

  At this point it should be emphasized that the system always defines a single vehicle-to-ground network link as active for communications (the most favourable). 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.

- *Requests Prioritization:* in order to make communications prioritization, the system defines several parameters (variables and statics) that permit to determine which communications are more critical taking into account connectivity conditions and available bandwidth.

  Static criteria are parameters that not change over time, and are related to QoS needs and other requirements determined by the final applications characteristics.

  On the other hand, the prioritization system uses relevant information stored about previous system behaviours. Thus, the system takes into account several dynamic factors (variable over time), being able to readjust the criteria applied in prioritization mechanism permitting to optimize its performance.

  So, combining these two kinds of criteria, the system calculates a numeric value that represents the fitness of serving a request (priority). 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 priority.

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

- *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 the prioritization of vehicular and terrestrial final applications communications. The control protocol is defined using XML messages where information is exchanged via TCP/IP sockets.

- *Bandwidth Allocation to Final Applications Requests:* when an application attempts to start a new communication makes a request to the platform. Then the system makes a decision about which priority requests can be served concurrently taking into account active link bandwidth limitations, priority parameters and their QoS requirements. Thus, once the system give permission to a communication request, adjust its data transmission rate according to its QoS requirements, the active link bandwidth and the other concurrent active requests. In addition, system could assign more bandwidth than minimally required to a request depending on bandwidth availability and requirements of the rest of active requests.

IV. Tests Set-Up

Once the system is developed, it has been tested configuring several testbeds. The test scenarios include a set of different kinds of final applications that generate different types of data traffic (multimedia, text, files, binary, etc.) which are usual in transportation systems, as well as predefined network conditions (using an external tool that allows you to regulate network interfaces bandwidth values). So, the objective is to evaluate the systems performance, launching several communication requests and causing network active link changes, that enables us to check whether obtained results are as expected.

In a real situation, the vehicle moves from one network coverage area to other, having changes in the conditions of the available access networks and bandwidth values. So, in order to set up a scenario as close as possible to real network conditions and bandwidth values, we measured bandwidth of two 3G links of different mobile phone companies along a route. In the selection of the scenario path it was considered to have a bandwidth fluctuating scenario, so a mixed urban and outskirts path was chosen. The path goes from the University of Deusto (Bilbao, Spain) to the beach of Sopelana (Spain), located to 16km.

Having these values measured, we applied a bandwidth limiter tool (NetLimiter [18]) to simulate these values in our testbed. This external tool enables us to limit the bandwidth of different network links, being able to schedule bandwidth values over time (per minute). So, having measured real values, we estimated bandwidth average (per minute) along the simulated route. Figure 2 shows the bandwidth mean values used in the tests during 9 minutes.

On the other hand, based on our previous experience working with transportation systems [5] [19] [20], our communications middleware have been tested by simulating the traffic which is usually generated by applications and services deployed in transportation systems that require vehicle-to-ground communications. Thus, the TABLE I show the selected applications types to perform the tests. This table indicates four kinds of services, their bandwidth requirements (QoS parameters) and the priority levels of transmitted information. Therefore, in order to perform the tests, we have developed a final applications simulator that simulates the network traffic which is usually generated by transportation applications.

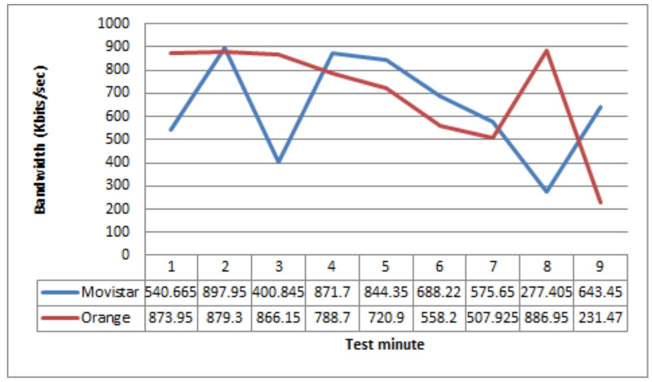

Figure 2. Estimated bandwidth mean values

TABLE I. TABLE I. Set of Test Applications

Service	Required Bandwidth	Priority
Positioning	1 KB/s	CRITICAL
CCTV (Real Time)	250 Kbits/s	HIGH
CCTV (Deferred)	340 Kbits/s	NORMAL
Vehicular Applicatioón Log Download	50 Kbits/s	LOW

Based on these bandwidth values and the set of example applications, we deployed the test scenario. It was composed of a laptop for the vehicular system, a PC for the terrestrial system, and a wireless router and two WiFi network links connected to the laptop (Figure 3). Thus, the VCM and a final applications simulator were setup on the laptop, whereas we installed the TCM and also the final applications simulator on the PC. So, the idea is that the vehicle has two different network links to perform communications with terrestrial side. The bandwidths of these two network links are established by NetLimiter tool based on bandwidth measurements mentioned before (Figure 1).

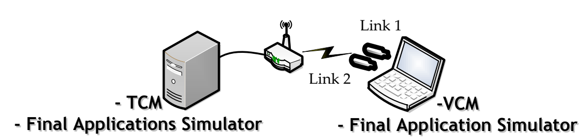

Figure 3. Test set-up

Once deployed the scenario, we schedule bandwidth limitations on NetLimiter, and applications communications requests on vehicular side using final applications simulator.

V. Tests Results

Once the network bandwidth limitations and communication requests of the scheduled applications have been configured, we run the tests in order to evaluate system performance.

Tests started launching first the high priority (CCTV in real time) and normal priority (deferred CCTV) requests. Critical requests are related to positioning service. So, this kind of request was created every 10 seconds, similarly to a real situation. In addition, during the tests, in the second minute was scheduled the launch of the low priority request (vehicular applications log downloads).

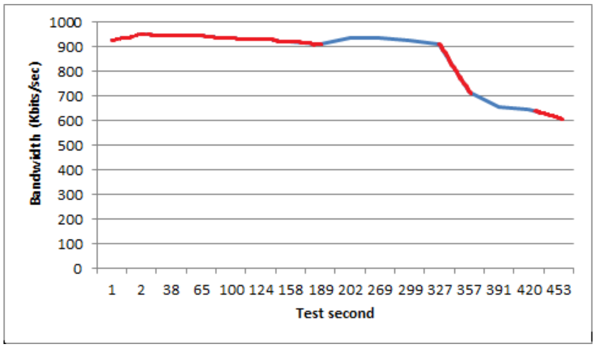

Figure 4. Bandwidth of the active link

Figure 4 represents the bandwidth values of the available active link for communications notified by VCM to TCM during the tests. Based on this bandwidth values, the middleware manages scheduled communication requests, adjusting the assigned bandwidth to each one taking into account their QoS requirements. In addition, system prioritizes active requests. Thus, if requested bandwidth for communications is higher than available bandwidth in the access network selected by the system as active, the middleware selects which requests are more critical, and pauses those that assumes less critical until conditions changes and they can be attended.

On the other hand, this test has been done through two network interfaces. So, Figure 4 not only represents the active link bandwidth values, it also distinguishes the active link changes produced during the tests. So, bandwidth values related to link 1 (Orange) are represented with red color, while those related with link 2 (Movistar) are represented using blue color. At this point, it is important to say that these network link changes do not affect to final applications communications. Therefore, when middleware changes the active link, the applications that are transmitting data at this moment do not perceive communication disruptions. So, it can be said that these active link changes are not perceived by final applications.

This test lasts 9 minutes. If we look at the Figure 4, Figure 5 and Figure 6, the horizontal axis indicates the second of the test. Figure 4 shows the bandwidth values of all active links notified to TCM during the tests. However, Figure 5 and Figure 6 represent two different and descriptive situations managed by the middleware. As can be seen, these graphics do not illustrate critical requests data transmission (positioning service). The reason is that the bandwidth requirement of these requests is very low compared with the other types of services. Thus, the critical requests are not representative and attending to an easier to understand graphic, have not been shown in the results presented here.

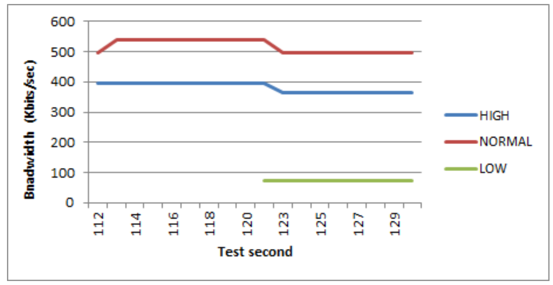

Figure 5. Low priority request launch and bandwidth reassigment

Figure 5 shows the moment when the low priority request is launched and admitted to be served by the middleware, starting its data transmission. This kind of request require 50 KB/s of minimum bandwidth to respond to its QoS requirements, so the middleware adjust all active requests bandwidth based on their bandwidth requirements and the active link bandwidth availability. In this case, the global requested bandwidth is lower than the available for communications, so the middleware assigns more bandwidth than the minimum demanded by each request. In addition, in the previous situation, when the low priority request is launched, there were two active transmissions related to high and normal requests. The entry of this new request makes the system readjust the bandwidth assigned to these two requests.

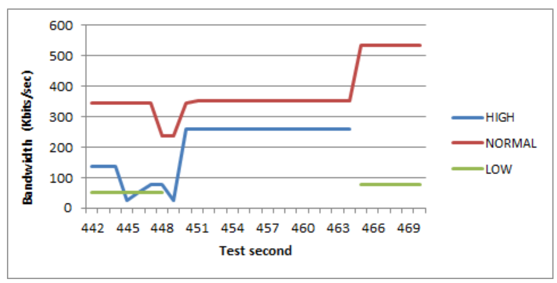

Figure 6. Requests prioritization caused by bandwidth changes

The situation presented in Figure 6 is caused when the available bandwidth of the active link changes and the bandwidth requested by applications is higher than the available bandwidth for communications. Then, the middleware prioritizes the requests and pauses the least priority ones, which cannot be served according to their QoS requirements (minimum bandwidth values, in this case). Therefore, we can observe that in the second 448 of the test the available bandwidth is reduced, so the system stops the low priority request (related to log download service) and readjusts the bandwidth assignation to the other active requests that can continue being served. Then, after the 463 second, the communication corresponding to the high priority request finishes releasing the bandwidth allocated to it, which can be assigned to other pending and active requests. Thus, in this case, the system resumes the communication related to the low priority request and regulates the bandwidth allocation to each of them according to their requirements.

Previous functional tests demonstrate that the system performance is successful taking into account its design objectives. The results determine that the middleware improves the performance of the most priority communications, and ensures that all data transmission will perform in order to final applications QoS requirements.

VI. Conclusion and Future Work

In this paper we have presented a research work focused on vehicle-to-ground communications management. The result is a communication middleware designed to respond to communication requirements demanded by transportation applications, managing aspects related to QoS and using multiple radio and mobile interfaces (GPRS, UMTS, WLAN, etc.). It is done adopting an "always best connected" approach to enhance communications availability and obtain the best bandwidth capabilities, selecting the most favorable network link for the communications all the time.

In addition, we have presented the results of functional tests performed in order to demonstrate system performance. We defined a test scenario which includes different kinds of final applications that generate different types of data traffic, which are usual in transportation systems. Moreover we reproduced some specific network conditions according to those measured in a real transportation route. The test results demonstrate that this middleware is able to dynamically monitor the bandwidth of the network links, always adapting active communications to the bandwidth available. Furthermore, system is able to maintain continuous communication, using multiple networks links and selecting always the one that offers the best bandwidth capabilities. All the previous without being affected the continuity of the transmission of the final applications which do not perceive the active link changes.

Finally, there is also pending work relative to system testing. So the future work includes the definition of additional performance tests, to compare this system with other similar communication systems with the aim of demonstrating the advantages and contributions of this research work. In addition, future work also includes new tests that enable system validation in real environments with multiple vehicles and applying different kind of network links.

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