A Data Dissemination Strategy for Cooperative Vehicular Systems

Olivia Brickley, Chong Shen, Martin Klepal, Amir Tabatabaei, Dirk Pesch
Centre for Adaptive Wireless Systems
Department of Electronic Engineering
Cork Institute of Technology, Cork, Ireland
E-Mail: {olivia.brickley, chong.shen, martin.klepal, dirk.pesch}@cit.ie, amir@microsist.com

Abstract— **Cooperative systems in transportation can bring new intelligence for vehicles, roadside systems, operators and individuals by creating a communications platform allowing vehicles and infrastructure to share information. The performance of this underlying communication system has a major impact on the effectiveness of the emerging applications for intelligent transportation systems. Similarly, the approach taken to the dissemination of relevant information throughout the vehicular setting is influenced by the network performance characteristics. This paper investigates the concept of data dissemination in a heterogeneous vehicular wireless environment. A communications architecture which consists of infrastructure based transmission for cooperative vehicular systems is described. Following this, a simple, policy-based solution to establish how best to disseminate the data for an envisaged ITS application is presented. This policy considers the application requirements and the quality of the wireless carrier in determining how the information can be propagated to the relevant recipients in the most effective and efficient manner.**

I. Introduction

Over the last decade, the nature of wireless communications has evolved rapidly. The introduction of 3G and WLAN technologies and the recent standardisation of WiMax has helped to realise the vision of ubiquitous connectivity. Currently, much research effort is focusing on exploiting this "always-on" feature for use in vehicular environments [1,2]. Projects such as DRIVE [3], GST [4] and SAFESPOT [5], among others, are advancing the area of Intelligent Transportation Systems (ITS). The primary objective of ITS is the creation of advanced road traffic systems for improved traffic safety, efficiency, and travelling comfort. Applications for collision avoidance, route planning, automatic tolling and traffic control, among others, are considered crucial in achieving this goal and require frequent information exchange between vehicles and infrastructure. The communications technologies used in ITS will play a pivotal role in the efficiency and effectiveness of such applications and is considered a primary concern in all ITS projects. The manner in which pertinent information is disseminated throughout the vehicular environment is also an important aspect of ITS and is critical to the successful operation of cooperative applications. Efficient and timely propagation of information among all affected vehicles is essential and highly dependent on the performance capabilities of the core communications platform.

As part of our work in the EU IST FP6 "Cooperative Vehicle Infrastructure Systems" project (CVIS) [6], this paper proposes a simple data dissemination strategy for a cooperative vehicular environment. A communications framework for cooperative vehicular systems is presented with the aim of providing flexible, "always on" connectivity for vehicles travelling at high speeds. A simple, policy based dissemination management function responsible for the efficient propagation of application information is then proposed. Here, parameters such as the application characteristics and channel quality are used as inputs in determining the most appropriate means of propagating the application data throughout the considered traffic region.

This paper is organised as follows. Related work in the area of data dissemination for intelligent transportation systems is examined in the next section. Section III summarises the motivation and architectural solution to cooperative vehicular systems proposed by the CVIS project. Section IV introduces the concept of policy based systems and details the proposed data dissemination strategy. Section V describes the simulation environment used in evaluation of the proposed scheme and section VI demonstrates and accounts for the results gathered. Finally, the conclusions of this study and planned future work are discussed in section VII.

II. Related Work

The concept of data dissemination in vehicular systems to advance the intelligence of modern transportation systems has received much attention over the last number of years. Many studies investigate information propagation using IEEE 802.11 ad-hoc based inter-vehicle communication (IVC) in isolation [7, 8, 9, 10]. Others propose data dissemination which incorporates existing cellular infrastructure as a gateway technology to provide an internet connection or advertise regional services. The authors in [11], propose a data dissemination technique based on swarming. Here, 802.11 access points act as a gateway to the internet for passing vehicles. In [12], a cluster based communication system is proposed. In this study, the ad-hoc networking paradigm is used to form clusters of communicating vehicles while cellular infrastructure provides reliable inter-cluster communication.

Few papers consider the data dissemination challenge in scenarios where multiple wireless technologies are operating simultaneously, and hence pay little attention to the development of a dissemination strategy with respect to this heterogeneous network environment. This paper proposes a policy based data dissemination strategy in which both lower data rate ubiquitous connectivity and higher data rate connectivity islands are considered for propagating application data throughout a vehicular region.

III. ARCHITECTURE FOR COOPERATIVE VEHICULAR SYSTEMS

In terms of data dissemination for intelligent transportation, IVC has gained a high level of attention. The authors in [9] state that vehicular ad-hoc networks are the preferred network design for future ITS. They argue that traditional vehicular networks where roadside infrastructure reports to a central controller are expensive and not scalable in design. While IVC has the attraction of being scalable, its sole use does not provide sufficient reliability for safety critical vehicular applications. Due to the highly dynamic environment in which they operate, VANETs are relatively unstable. They are prone to rapid topology changes and link breakages due to the high relative speed of vehicles [13]. This can result in fragmentation of the ad-hoc network where some nodes may experience connectivity isolation; an undesirable quality, particularly for transporting safety applications.

The CVIS project is based on a hybrid architectural approach for ITS. As illustrated in Figure 1, this comprises of a three tier hierarchical structure in which IVC and V2I communication are integrated to create a flexible communication platform. The upper tier is the central management layer, which monitors the vehicular environment on a system-wide level. The middle tier represents the roadside infrastructure and administers the vehicular system at a regional level. The lower tier corresponds to the vehicles themselves which generate and report on information at a local level.

In CVIS, this architecture will be realised using the Continuous Air Interface for Long to Medium range (CALM) communications standard [14] as illustrated in Figure 2. CALM is part of the ISO Standardization Program (ISO CALM TC 204) and aims to provide user transparent, continuous communication in support of emerging ITS applications. It combines complementary media, allowing vehicles to use the best combination in-vehicle and infrastructure communications technology locally available. The communication technologies envisaged to support cooperative vehicular systems include WiFi and Wimax for regional connectivity, cellular systems such as GSM and UMTS for terrestrial coverage, as well as satellite and broadcasting communication technologies. Ad-hoc communication standards such as DSRC, InfraRed and MM-Wave will permit short to medium range communications between vehicles.

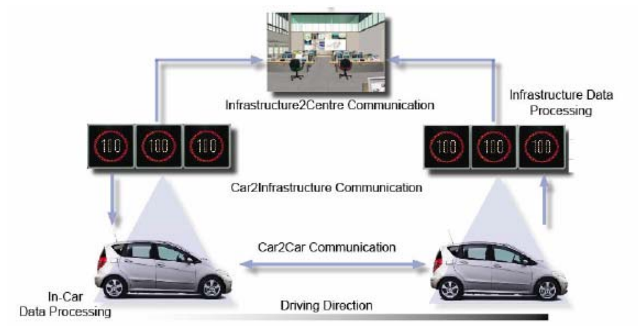

Figure 1: CVIS architecture for cooperative vehicular systems

This study utilises a subset of the complementary radio technologies identified in the CALM specification. The communications framework developed as part of the study presented here includes UMTS and IEEE802.11 wireless protocols. The implementation of these technologies in a vehicular setting offers a comprehensive solution for cooperative application data dissemination and gains from their complementary characteristics; the wide scale availability of UMTS provides an "always on" feature, reinforcing its importance for ITS, while IEEE 802.11 enables vehicle-to-roadside communications providing regional higher speed coverage.

Vehicle-to-vehicle communication based on the ad-hoc mode specified in 802.11 is not examined in our work at this stage, however, we will examine it as a next step in our work. The following section outlines the simple, first approach to the data dissemination decision in a heterogeneous wireless environment for intelligent transportation.

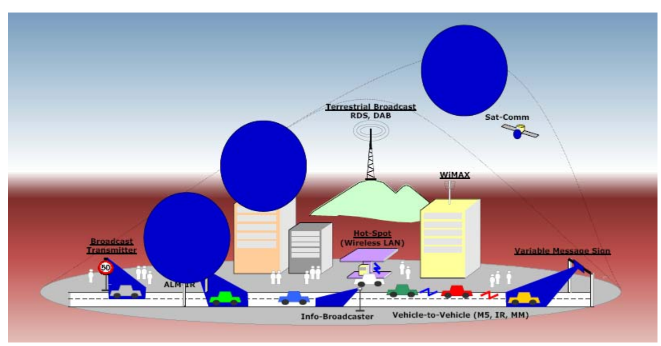

Figure 2: CALM Communications Standard

IV. POLICY BASED DATA DISSEMINATION FOR COOPERATIVE VEHICULAR SYSTEMS

Data dissemination is an especially important feature of cooperative vehicular systems. Vehicles must be able to communicate with each other so as to ensure that safety and traffic management applications can function successfully. In a heterogeneous communications environment where multiple radio access technologies are available, the manner in which information is propagated between the key players is a major issue which ultimately impacts on driver safety.

The aim of data dissemination is to transport information to the intended recipients while meeting a number of design requirements. The convergence time and lifetime of the data, as well as the reliability of its transportation across the vehicular system are such considerations. Based on the communications architecture described in the previous section, a policy based strategy for the dissemination of application data across a multi-mode wireless environment is proposed.

A policy based system consists of a set of rules and instructions to determine a particular network operation [15]. They are a flexible means of evaluating and controlling system behaviour and can be easily implemented in the proposed ITS environment. Policy based systems consist of a policy repository, policy decision point and policy enforcement point. The policy repository is a database which stores the rules and policies required by the system. The policy decision point (PDP) evaluates the relevant input data using the policy rules and determines the appropriate action for the current circumstances. This decision is then carried out at the policy enforcement point (PEP). Based on the CVIS architecture illustrated in Figure 1, it is apparent that a data dissemination policy is required at three points. On the presence of multiple wireless technologies, the central application system, roadside equipment and participating vehicles will each require a dissemination policy. This policy system design is illustrated in Figure 3.

Determining the most appropriate dissemination strategy is a complicated decision encompassing an array of influential factors. The policy proposed in this work utilises parameters which indicate the achievable throughput and allowable load on the candidate networks.

A. Network Load

It can be assumed that the UMTS network is relatively unaffected by the speed of the mobile users. Therefore, at high user speeds, UMTS can theoretically deliver up to 144Kbps for users in moving vehicles [16]. The major inhibiting factor here is the data traffic load already on the network and the problem of sustaining the quality of service (QoS) for accepted calls. The data dissemination policy must consider the effect of additional data transmitted to/from the vehicular environment. This is carried out using the concept of capacity surfaces [16]. Capacity surfaces are used to characterise the residual capacity in multi-service networks. They define the maximum service mix that is simultaneously allowed access into the network at any one time. Capacity surfaces are used in the proposed policy based dissemination strategy to evaluate the current operating point of the UMTS network and hence, determine the ability of that radio interface to deliver the ITS related data to the relevant recipients. This capacity surface is illustrated in Figure 4.

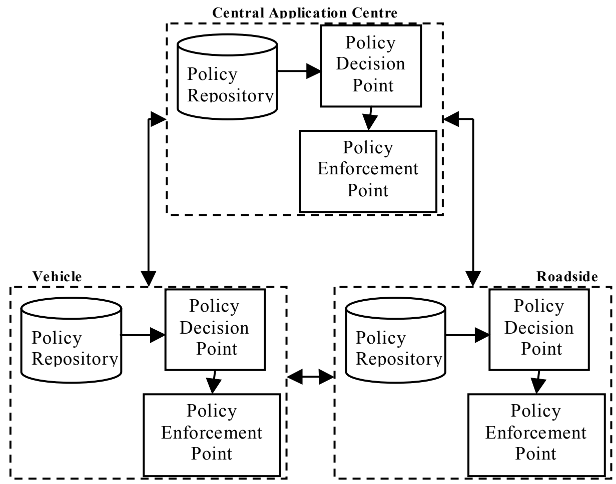

Figure 3: The proposed dissemination policy architecture

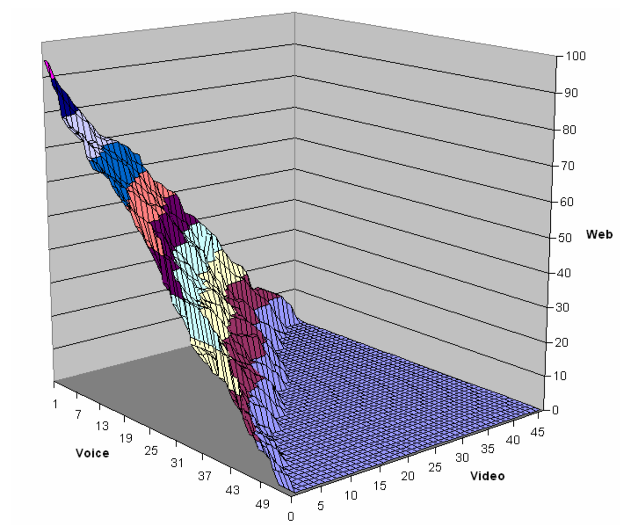

Figure 4: UTRAN Capacity Surface

B. Achievable Throughput

The primary concern in the UMTS network is in satisfying customers with regard to QoS. There is no such requirement for wireless hotspots servicing only the vehicle to roadside communication. The key indicator of the performance offered by the WLAN in the vehicular scenario is the throughput characteristics of the carrier at varying speeds. As WLAN was not designed for high speeds, the Doppler effect has a major impact on the channel quality and achievable throughput for infrastructure based communications. We characterised, based on a series of experiments, the achievable throughput for vehicle to roadside communication using the 802.11 standard as illustrated in Figure 5. An 802.11b access point was placed in a stationery position on a bridge over a major roadway. The vehicle was equipped with an 802.11 enabled laptop and GPS receiver. Data traffic monitoring software was used to gather the speed, link quality and throughput measurements. A number of tests were carried measuring the throughout achieved for fours different vehicle speeds of 50, 65, 80 and 100kmph. As expected, the results demonstrate that as the speed of the vehicle increases, the achievable throughput decreases dramatically from 520kbps at 50kmph to 250kbps at 100kmph.

The proposed dissemination policy considers the achievable throughput a measure of the channel quality when evaluating the suitability of WLAN for the dissemination of ITS application information.

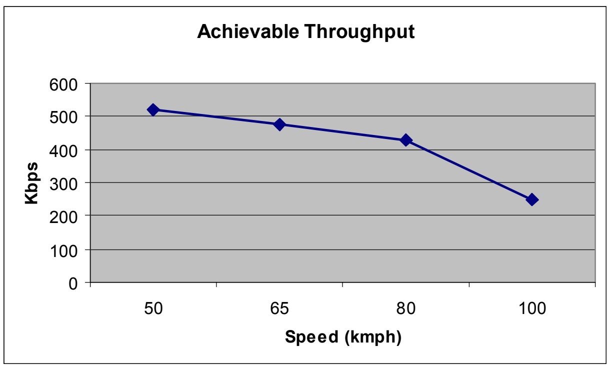

Figure 5: Throughput Characterisation of Infrastructure Communications at high speeds

Based on the candidate network evaluation parameters described above, the policy proposed in this study is shown in Figure 6. WLAN has the larger weighting in this policy; data is disseminated using UMTS only when the vehicle in question is out of WLAN coverage or when UMTS can provide the better throughput. The proposed policy attempts to ensure that the UMTS network operator can maintain a low call blocking probability and high customer satisfaction rating.

V. SIMULATION ENVIRONMENT

We performed computer simulation modelling of a heterogeneous wireless environment. Vehicles travel at random speeds ranging from 50-100kmph throughout the simulated environment. APs are placed at certain locations, e.g. bridges, junctions etc. providing islands of coverage which accommodate vehicle-to-roadside communication. UMTS is configured to provide wide-area coverage of the simulated environment and supports voice, video and web services. It is assumed that the roadside APs and central application centre are connected via a wired backbone infrastructure. Vehicles randomly move in and out of WLAN coverage and are assumed to have UMTS coverage for 100% of the simulation time.

VI. RESULTS AND ANALYSIS

The data dissemination policy is implemented for an Enhanced Driver Awareness application (EDA). This is designed to inform subscribed drivers about emergency situations and traffic conditions in their immediate vicinity. This is a data push application where data is generated and transmitted by the application control centre at aperiodic intervals. The size of the information to be disseminated is uniformly chosen and within a range of 200 and 1024 bytes and the dissemination "session" is treated as a web session when evaluating the UMTS capacity surface. It is assumed that the central management centre where the EDA is located has information on the speed and location of each subscribed vehicle when executing the proposed dissemination policy.

```
If: no WLAN coverage
        Choose UMTS
If: WLAN coverage
        Check load on UMTS network
        Calculate WLAN achievable throughput
        If: WLAN throughput > UMTS
        throughput
                Choose WLAN
        If: UMTS cannot accept traffic
                Choose WLAN
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Figure 6: Proposed Data Dissemination Policy

Figure 7 illustrates the average network coverage ratio for vehicles travelling throughout the simulated environment. Cars are within coverage of the UMTS network 100% of the time while WLAN connectivity is present for approximately 48% of the simulated time.

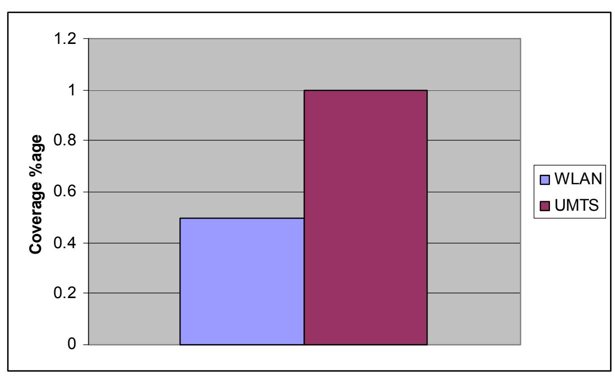

Figure 7: Average network coverage ratio

The speed profile of two cars is demonstrated in Figure 8. Vehicles move at fluctuating speeds in the range of 50-100kmph. The travel speed of vehicles has an effect on the throughput that can be obtained from WLAN connectivity and hence influences the policy decision. The second parameter which affects the dissemination decision is the current load on the UMTS network.

This is illustrated in Figure 9. When the UMTS load is high, the policy is biased towards WLAN selection. Since vehicles have no WLAN connectivity over 50% of the time as shown in Figure 7, UMTS, if capable, will be used to disseminate the application data. This accounts for the high number of web sessions at some points during the simulation since dissemination of ITS application data is recorded as a web session. Figure 10 depicts the policy decision statistics. As expected, WLAN is chosen on over 50% of occasions with UMTS disseminating the data in approximately 47% of decision scenarios.

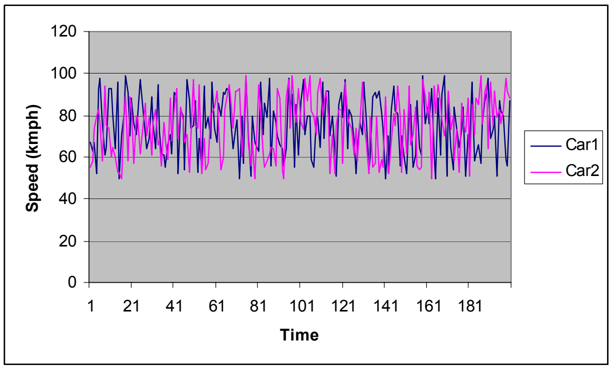

Figure 8: Sample Vehicle Speed Profiles

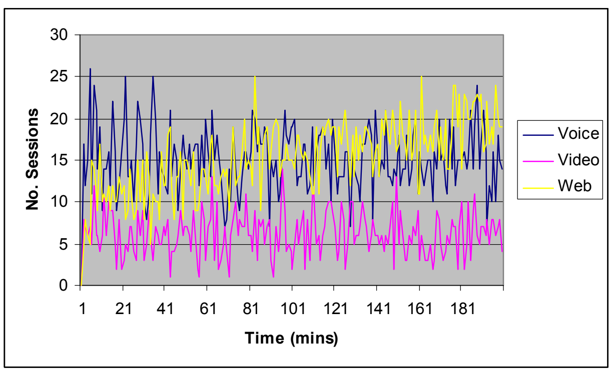

Figure 9: UMTS loading

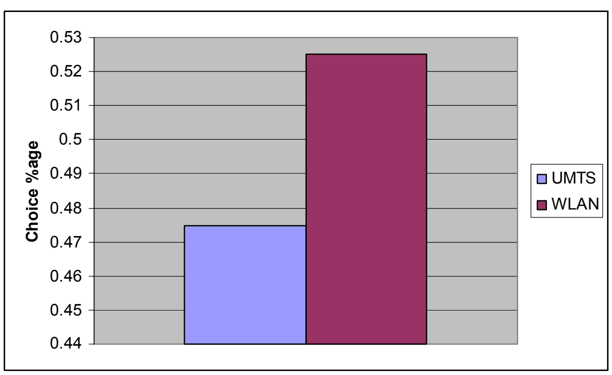

Figure 10: Network Choice Ratio

VII. Conclusions and Future Work

This paper presents a strategy for data dissemination in cooperative vehicular systems. A simple policy based dissemination management function responsible for the efficient propagation of application information is proposed. The UMTS network load and estimated quality of the wireless channel are used as inputs to the policy decision point and based on their values, an appropriate means of propagating the information is determined. A push-based ITS application is considered in the analysis of the dissemination policy. Results show that WLAN is the network of choice in over 50% of the cases.

Future work plans to include more applications that require higher levels of cooperation among key players in the vehicular system. This will require the inclusion of the vehicle-to-vehicle communication scenario to provide a more flexible communication platform which can support a more diverse set of cooperative applications.

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