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Estimating the performance of intelligent transport systems wireless services for multimodal logistics applications

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ABSTRACT

Various wireless technologies including radio frequency identification (RFID), bluetooth, cellular networks and dedicated short range communications (DSRC) might have an impact on logistics and transport operations. Among them, DSRC stands out as a broadband communications technology which has been designed to provide a general purpose Radio-Frequency (RF) link between vehicles and network infrastructure. As such, DSRC is capable of implementing the physical layer of an Internet Protocol (IP) bearer based network designed to facilitate the monitoring and coordination of portside vehicular traffic. This unprecedented application of wireless networking has the potential to greatly enhance the management of the flow of goods and resources, particularly within large, international ports whose activities comprise multimodal operations such as the use of road haulage to move cargo transported by sea. Given the need for reliable services in non-safety business applications, in this work an Intelligent Transport Systems (ITS) approach is used to address two issues. First, in wireless networks reliable data transfer transport layer services are affected where there is an apparent increase in mobility when access point coverage areas are reduced to counter the effects of path loss in the physical layer. Second, a service provisioning protocol intended for vehicle to infrastructure (V2I) data transfer is proposed to illustrate the importance of cumulative costs in wireless networks used for logistics applications. The analysis covers the average response time for requesting on-demand services within the portside network considered. The results of the analysis confirm the suitability of the approach used to provide a logistics network capable of meeting the requirements demanded in multimodal logistics.

1. Introduction

Mobile wireless communications have evolved rapidly over the last 40 years; from low capacity systems based entirely on analogue techniques and delivering voice only services, to high capacity, digitized systems providing a variety of services including voice and data. The popularity and growth of mobile wireless communications has been mainly due to the ability of the technology to provide high data rate communications whilst adhering to stringent Quality of Service (QoS) requirements; in part due to advancements in wireless channel modelling techniques and the subsequent development of sophisticated digital transmission methods (Akaiwa, 1997).

Research on transportation has investigated information propagation in traffic streams using inter-vehicle communications. For example, Jin and Recker (2006) discussed the reliability of inter-vehicle communication in a traffic stream dependent on the distribution of equipped vehicles. By assuming that information propagation is instantaneous compared to vehicle movements, the authors measured reliability as the probability of success for information to travel beyond a location. Wang's (2007) research studied information propagation along a traffic stream where equipped vehicles follow an independent homogeneous Poisson process. The results from that work demonstrated the relationship between propagation distance, equipped vehicle density and transmission range.

The work by Blythe (2005) recognises that Mobile Adhoc Networks or other wireless devices comprise the intelligent infrastructure required to enable vehicles to be constantly in communications with other vehicles near them as well the infrastructure which can then deliver location based services and intelligent control and safety applications. Recent wireless vehicle networks

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developments such as DSRC have improved the reliability of not only V2V but also V2I communications. Moreover, in recent times sophisticated modelling tools have facilitated the design and analysis of complex wireless networks. Nonetheless, new challenges have risen in terms of the need to provide expedient secure services of the highest quality with minimum delays over optimized network designs.

Given the increasing popularity of network-based services and the need for assure of interoperability, roaming, and end-to-end session management, Huang, Chen, Chen, and Wu (2009) proposed a service-oriented information dissemination scheme for vehicle infotainment system to ensure the possibility of heterogeneous vehicular communication and a framework for delivering real-time services over an IP-based network. Fuzzy logic was used to assist in building a reliable and robust communication network environment that showed acceptable levels of performance including average latency and dropping probability.

A recent development in the mobile communications technology market has been a shift to "all IP" networks because equipment and installation costs, as well as operation and maintenance costs are being driven downwards by evolving IP technologies (Janevski, 2003). In the current rate of proliferation of mobile communications and in particular mobile IP networks, it is perhaps inevitable, and indeed expedient, that mobile wireless communications are deployed extensively for logistics (Coronado, Lalwani, Coronado, & Cherkaoui, 2008). It is expected that logistics, like other areas in intelligent transportation, would benefit extensively from adopting current advances in mobile communications.

Mobile wireless communications are a fundamental component of ITS. Indeed, it has been acknowledged that ITS are based in the use of advanced ICT to achieve a reduction of congestion and accidents while making transport networks more secure by reducing their impact on the environment (ERTICO Research Project., 2007). In logistics, ITS play an important role in achieving paperless information flows, efficient traffic management by the use of Automatic Identification and Data Capture (AIDC) and tracking and tracing by using satellite positioning services (Zomer & Anten, 2008).

Logistics is an important knowledge-based economic activity that plays a major role worldwide. Logistics deals with everything involving planning, organising and managing activities that provides goods or services (Anonymous, 1997). In Europe, logistics expenditure is in the order of €800 billion whilst representing 7% of GDP and with transportation costs representing 43% of the total logistics expenditure (Zomer & Anten, 2008). According to the European Commission the trend in market share of freight transport modes comprises 45% road haulage and 41% sea transportation (Browne, Allen, & Woodburn, 2006).

Advances in mobile communications are suitable for complex logistics arrangements that result from the combination of different sorts of transportation like road, sea and air. For example, port operations are a complex arrangement in which road transportation can be seen as a feeder to sea transport. In Europe, sea routes (short sea) between neighbouring countries today offer high quality regular services that can be combined with other transport modes to provide efficient alternatives (Anonymous, 2007).

The amendment to the IEEE 802.11 set of standards for wireless local area networks (WLAN IEEE 802.11p) which adds wireless access in a vehicular environment (WAVE) gives the opportunity to develop innovative applications and services that can be used in logistics and transportation. The 802.11p standard is set to pave the way to enhancing existing dedicated short range communications (DSRC) standards (Anonymous, 2008), which provide wireless channel specifications for roadside to vehicle (vehicle to infrastructure, V2I) and vehicle to vehicle (V2V) communications environments. DSRC technology operates in the Super High Frequency (SHF) Band at 5.9 GHz, where radio waves propagate mainly in the Line-of-Sight as well as due to multipath propagation (Zhao, Kivinen, Vainikainen, & Skog, 2002). By operating at 33 dBm (2W), DSRC is expected to provide coverage over a range of up to 1000 m with a data rate up to 27 Mbps (NHTSA, 2005) per channel (including two control channels and seven service channels). However, this maximum specified communications range may not be realised in all cases of DSRC technology deployment as, for example, the portside environment presents a significant challenge due to obstructions such as warehousing and stacks of shipping containers which can adversely affect radio reception. Indeed, the received signal power can fall of with distance raised to the fifth power (50 dB per decade) due to the resulting multipath propagation and path loss phenomenon with significant repercussions on the network application. DSRC is designed to handle the transmission of both safety and non-safety messages into two modalities: vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). Within this technology two types of messages are transmitted: Wireless Access for Vehicular Environment (WAVE) Short Messages (WSM) and IPv6 traffic (WAVE, 2005). WSM messages involves low latency and critical safety-related messages assuming a real-time propagation while IPv6 traffic is generally related to commercial services such as download or streaming of data.

In the particular context of logistics applications, which are motivated by the need for efficiency in logistics and visibility and transparency in the supply chain, we propose the adoption of a ubiquitous wireless networks in which vehicles transmit periodic information updates that can be interpreted by higher level applications. Data transfers that meet the needs of logistics are at the watershed between real-time and elastic network applications, where both reliable data transfer and application response times are required for the efficacy of the application. To counter the effects of multipath propagation and path loss, coverage areas can be reduced with the disadvantage being an increased number of handoffs and increased application latency (Dellapos, De Marco, & Trecordi, 1998) due to Mobile IP (MIP) control message overheads and handoff latency due to the cell switching algorithm (Campbell et al., 2000).

The IEEE 1609 (.3) standard describes the transport and network layer services including addressing and routing in support of reliable WAVE data transfer. The IEEE 1609.3 standard specifies the Transmission Control Protocol (TCP) in the transport layer which relies on sequence numbers and acknowledgement to provide a best effort service for end system data transfer. MIP is an internet architecture and protocol for supporting mobility by allowing the mobile user to maintain a single address when moving from one network access point coverage area to another. In so doing, Mobile IP makes the user mobility transparent to the network application, and the user appears stationary for the purposes of data transfer. The current standard specifies the use of indirect routing to the mobile node, which is facilitated by agent discovery and handoff. However, this scheme is characterized by inefficient triangular routing and home agent overloading and route optimization in mobile IP has been proposed as an alternative. The performance evaluation in terms of end-to-end delay for both schemes is provided in the literature (Dellapos et al., 1998), but these results are yet to be extended to the analysis of a ubiquitous, mobile IP network where the offered data traffic pattern is determined by a logistics application.

In the particular case of logistics applications, the success in the deployment of service provisioning models for highly mobile environments depends on the implementation of robust architectures capable of maintaining their overall performance when facing hostile environments (Coronado & Cherkaoui, 2007). Perhaps the greatest challenge for this type of service deployment (services offered on the roadside infrastructure likely to be