Computer Communications 35 (2012) 2274–2280

Contents lists available at SciVerse ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

Mobility management for efficient data delivery in infrastructure-to-vehicle networks

Boangoat Jarupan *, Eylem Ekici

Department of Electrical and Computer Engineering, The Ohio State University, Columbus, OH 43210, United States

ARTICLE INFO

Article history:
Received 22 December 2010
Received in revised form 17 April 2012
Accepted 30 July 2012
Available online 8 August 2012

Keywords:
Mobility management
I2V communication
Vehicular networks

ABSTRACT

Efficient and reliable communication between base stations and vehicles is becoming increasingly important for meeting the demands of many intelligent transportation applications. The key challenge here is to deal with constant topological changes in the underlying communication network resulting from vehicular mobility. In this paper, we propose a mobility management scheme MMDD that helps base stations track the location of vehicles registered to their services. Registered vehicles send their location updates to corresponding base stations by following either a distance-based or a time-based mechanism. The location information is subsequently leveraged in transmitting data packets in an efficient and reliable manner. We also propose a paging mechanism through which base stations can obtain the latest location information of any registered vehicle. Through a detailed simulation study, we demonstrate that our location management scheme outperforms a state-of-the-art approach RLSMP, both in terms of average packet delay and success percentage. We also show that the impact of control packets from location update and paging mechanisms on the overall performance is minimal.

1. Introduction

Recent research on Intelligent Transportation Systems (ITSs) in Vehicular Networks (VANETs) has focused on providing reliable internet access to vehicles via roadside infrastructure known as base stations. There exist a wide range of applications that require vehicles to access internet services, which include emergency warnings, traffic monitoring, multimedia applications etc. To support ITS applications in VANETs, mobility management techniques that help base stations aware of up-to-date vehicle location information are critical. In this article, we consider the node mobility related issues in Infrastructure-to-Vehicle (I2V) communication where base stations send packets to vehicles. Vehicles make use of control packets to communicate their location information to base stations so that the packets can be sent to vehicles in a reliable and efficient manner. The main challenge is to strike a good balance between vehicle location accuracy and communication overhead due to control packets.

Strategies for mobility management in vehicular networks can be classified into three main categories: *location management*; *handoff management*; and *topology management* [1]. Location management techniques allow base stations to maintain last known vehicle locations in a database. Base stations make use of vehicle information to track the current position of vehicles, and leverage them for effective packet delivery. Handoff management is concerned with issues related to maintenance of active connections with base stations as the vehicles change their location. Finally, techniques related to topology management aim to provide effective routing mechanisms in the presence of constant topological changes in the underlying communication network.

The topology management and data delivery process are useful for designing routing and MAC protocols. There exist several position-based protocols [2–4] that allow vehicles to make adaptive routing decisions as the vehicles move around in the network. These sophisticated methods work well for communication from vehicles to base stations. They, however, are not applicable for communication from base stations to vehicles since the vehicle location information maintained at different base stations is only *approximate*.

In this paper, we propose a Mobility Management scheme for effective Data Delivery (MMDD) in vehicular networks. It is a location management technique that improves the data transmission between base stations and vehicles in I2V systems through multihop communication. While such techniques have been developed in the context of cellular networks [5,6], they are not readily applicable for VANETs because the structure and organization of communication is quite different from that in cellular systems. Communication in cellular networks is strictly between nodes and base stations. Point-to-point communication among vehicles without involving base stations is not feasible. Therefore, the service area in cellular networks is typically divided into regular shaped cells where each cell is served by a different base station.

* Corresponding author. Tel.: +1 614 292 2572; fax: +1 614 292 7596.
E-mail addresses: bea@ece.osu.edu (B. Jarupan), ekici@ece.osu.edu (E. Ekici).

0140-3664/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.comcom.2012.07.020

The communication between vehicles and base stations in MMDD consists of four main processes: *service advertisement*; *registration*; *location update*; and *data delivery*. Service advertisement allows base stations to broadcast their information within their service area. Unlike in cellular networks, a base station can serve vehicles that are located outside its immediate service area by leveraging the multi-hop communication among vehicles. Therefore, vehicles can simultaneously have access to multiple base stations, and they determine the best available station to obtain internet services via registration process. Vehicles update the registered base station with their position information during the process of location update. We study two schemes for vehicle location update – *time-based* and *distance-based*. The location information available at base stations is finally leveraged for effective data packet delivery. Through a detailed simulation analysis, we show that MMDD provides efficiency and reliability in delivering data packets from base stations to vehicles.

Remainder of this article is organized as follows. We first discuss the related works in Section 2. We then present an overview of the proposed system MMDD in Section 3. Section 4 describes the details of different processes in MMDD. We finally present the simulation analysis in Section 5, and conclude in Section 6.

2. Related work

Mobility management systems have been studied extensively in the context of cellular networks [5,6]. The service area of a cellular network is divided into so-called location areas where a mobile terminal can be located. Within the location area, mobile terminals do not need to update their location information to the base station. Since the location area may consist of several cells, a data delivery process is preceded by a paging process to find the location of the mobile terminal and determine the base station to serve it. Location areas can either be predefined or they can be changed dynamically based on several factors including time, movement of the mobile terminal, geographic locations, or a combination thereof.

Several applications that rely on I2V communication make use of roadside base stations as "gateways" for accessing the internet. Traditional cellular and mobile ad hoc networks provide internet access to its agents via an Internet Engineering Task Force (IETF) standard called *Mobile IP*. Several research efforts have focused on the use of this protocol for mobility and handoff management in MANETs [7] i.e., allowing mobile device users to move from one network to another while maintaining a permanent IP address. Such techniques however are not directly applicable to VANETs as vehicles often rely on multi-hop communication to interact with base stations. For example, solutions based on Mobile IPv6 standard require a direct connection between a mobile node and the roadside infrastructure [7]. Similarly, IETF NEMO standard is aimed at managing the mobility of an entire network, which changes, as a unit, its point of attachment to the Internet are not directly applicable to VANETs. For example, a mobile network in NEMO is assumed to be a leaf network, i.e., it will not carry transit traffic [8]. Furthermore, as Baldessari et al. [9] pointed out, NEMO basic support protocol alone can not provide connectivity over multi-hop, intermittent access to the infrastructure.

Woo and Singh [10] proposed a method known as SLURP. It divides the entire network into rectangular regions and each vehicle is assigned to one of the regions (called as home region) through a hash function. Subsequently, each vehicle constantly updates its location by sending information to its home region. A vehicle *S* that wants to transmit data to a destination *D* sends a location-request to the home region of *D* to obtain *D*'s information. If the home region is far away then this method is likely to incur high overhead both in updating and in querying the location information. Similar space partitioning strategy called XYLS has been proposed by Stojmenovic et al. [11] in which network is divided into vertical and horizontal strips. Kieß et al. [12] proposed HLS method that partitions the network into a hierarchy of regions. HLS, in a similar spirit to SLURP, uses hash functions to assign vehicles to regions in each level in the hierarchy. Whenever a vehicle crosses the boundary of one level, it sends its position information to a hierarchy of responsible regions. This method however is not efficient as a node may oscillate between regions in two different levels. While all these methods incorporate some mechanisms to reduce the signaling overhead, they are not scalable to large networks [13].

Recently, Saleet et al. [13] presented another region-based location service management method known as RLSMP, in which the road network is divided into *fixed* geographical clusters or segments, which are in turn divided into multiple cells. Since this partitioning is fixed, each vehicle can easily determine its geographic cell and cluster (similar to a hash function). Each cell has a cell leader (CL), and for each cluster a cell located in the center acts as the home region or the location service cell (LSC). Vehicles in a cluster send their location information to their CL, which aggregates this information and forwards the same to its LSC. Nodes that are physically located in LSC are responsible for maintaining the current location information about all vehicles in that cluster. A vehicle *S* that wants to transmit a data packet to a destination *D* sends a location-request to its CL, which then forwards the request to its LSC. If *S* and *D* belong to the same cluster, then *S*'s request can be answered *locally* by nodes in their LSC. If *D* is not present in the same cluster then *S*'s request is forwarded to all other clusters in the road network in a special spiral form [13]. As we show later in this article, this method incurs higher overhead and it delivers poor performance in terms of packet delay and success percentage.

In this work, we propose an I2V mobility management scheme that is based on multi-hop communication. Unlike in RLSMP, base stations search for destination vehicles in a geographic area that is constrained by their last known location information. This information is kept up-to-date via an efficient location update process that either follows a time-based or a distance-based mechanism. Furthermore, base stations use a special process known as paging to locate the vehicles with high accuracy prior to sending data packets.

3. System overview

We consider an urban environment where roads are laced with intersections, and the communication among and with vehicles is facilitated through special roadside infrastructure known as base stations (BSs) – see Fig. 1(a). BSs are internet gateways installed at fixed locations along the road, and they can communicate with each other through wired connections. Vehicles moving in the network are equipped with wireless devices to communicate with each other and also with BSs. Vehicles are also equipped with Global Positioning Systems (GPS) that help them determine their location information. For the sake of simplicity, we represent vehicle positions using Cartesian coordinates. In a more general scenario, they can, for example, be denoted using longitude and latitude information. In our setup, BSs can extend their service area to vehicles that are not present in their immediate service area through multi-hop packet transmission. This is a key difference when compared to cellular networks, in which a BS can serve only those nodes that are reachable in a single hop.

Since the vehicles constantly change their location, the communication network in VANETs is highly dynamic and incurs problems like frequent route disconnections. We propose a location