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Autonomous real time route guidance in inter-vehicular communication urban networks

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ABSTRACT

This paper presents an inter-vehicular communication (IVC)-based algorithm for real-time route guidance in urban traffic networks. The algorithm enables communication between *searcher* vehicle and *candidate* vehicles whose origin node matches the destination node of the searcher vehicle, and traveling in the opposite direction. The data entities of knowledge sharing among the vehicles and the algorithmic procedure as well as the conditions for information sharing are presented in detail. The mathematical formulation of the procedure is also presented. A microscopic simulation model is utilized to assess the effectiveness of the algorithm against the benchmark shortest path algorithm. Average travel time, and overall network productivity are presented to measure the effectiveness of the algorithm. Simulation runs are conducted under various network congestion levels, link speeds and link lengths in order to evaluate the network productivity, and the travel time measures of the presented IVC algorithm compared to the benchmark shortest path algorithm, decentralized route guidance systems as well as other IVC-based algorithms.

1. Introduction

The centralized route guidance algorithms [1] have showed many benefits in several traffic management applications, such as congestion evolution, ability to predict path choices, and network-wide signal control, yet some limitations were reported. These algorithms cannot support massive multi-sensor traffic data processing and integration and as such real-time traffic services can hardly be provided [2]. The traffic information is broadcasted to the drivers via traffic management centers (TMC) or transferred on demand through the wireless infrastructure network. These centralized algorithms have disadvantages of great deal of traffic sensor data and requests (demand) need to be processed by TMC, meanwhile massive data need to be communicated between TMC and thousands of vehicles at a time, acquiring huge computing, storage and communication capacities. As a result of the demand exceeding the provided capacity, the TMC is overloaded, yielding to performance deterioration. In addition to the information processing and communication constraints, centralized route guidance is likely to entail high operating cost.

It is critical noting that even though massive work has been done in the R&D of the methodological procedures of the centralized real time route guidance, very little has been actually done in implementing any; not even a fair pilot study. In-vehicle telematics and smart boxes are fairly developed to a level enabling two-way communication (text, visual, and audio) with centralized controllers, GPS positioning, notifications, etc. Furthermore, the application models are fairly developed, tested in simulation environments, and proven to be fairly effective. The main obstacle in implementing such centralized systems is the huge communication bandwidth requirement to enable the deployment even of a portion of the fleet on a small network. One could argue that the limitation of the communication burden could be overridden by using mass media facilities and applications such as variable message signs (VMS) and radio. We argue that the use of (VMS) in urban networks (not freeways) is rarely reported in the literature. VMS is proven to be very effective in communicating short advisory messages for freeways, but very little has been reported on the use of VMS in communicating explicit route directions in general urban signalized networks. For more specific normative exclusive route directions two point communications are needed between the TMC and the very individual vehicle.

Distributed architectures were alternatively developed to operate reactive strategies for vehicle route guidance that may rely on limited available information. In large-scale networks, fast control actions in response to local data inputs and perturbations make such distributed architectures quite promising. Hawas and Mah-

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massani [3] developed a ***non-cooperative pure*** decentralized structure and a family of heuristic-based rules for reactive real-time route guidance. This structure assumes a set of local controllers distributed over the network. Each local controller is responsible for providing reactive route guidance for vehicles in its territory. The local controllers are specific hardware units that may be located at the level of the network intersection; the *decentralization level k* could be coarser or finer depending on the available hardware, the level of investment and the desired accuracy. The local decision rules use available partial information and heuristics to evaluate alternative subpaths emanating from any decision node towards the destination, and assign vehicles at that node to the link(s) immediately downstream. The primary reported drawback is the potential vehicle cycling, which can be prevented somehow by allowing cooperative distributed control.

Bearing in mind the massive data processing and high operational cost associated with the centralized systems, the massive communication requirements for the two-way information sharing with the TMC, Hawas [4] presented improvement to resolve the reported cycling problems commonly encountered in the typical pure distributed systems. The improvement is sought through allowing for information exchange (or cooperation) among the various decentralized controllers. The information exchange would enrich the knowledge base of any individual controller, and potentially improve the quality of routing decisions by providing the opportunity to utilize more intelligence to improve the specification of the heuristic evaluation functions underlying the local decision rules. This new system shall be denoted in this paper by the ***cooperative*** decentralized system. The reader is referred to [3], and [4] for more detailed description of these two systems as well as their respective performance.

A natural extension to such decentralized systems is the use of inter-vehicular communication (IVC) or VANET for real-time route guidance. Researchers in both academia and industry are increasingly interested in vehicle-to-vehicle communication, because they enable numerous safety and end-user application systems. To the author's knowledge, none of the well-developed centralized, decentralized real time route guidance (RG) methodologies has been actually implemented and/or validated in field. The centralized control would mandate a huge communication infrastructure. For a typical city with (say) tens of thousands of vehicles, one would expect huge load on the telecommunication network. The communication network is likely to be overloaded, leading to effectiveness deterioration. On the other hand, VANET technologies can be deployed using various communication media, without any noticeable burden on the telecommunication infrastructure. To conclude, we emphasize that the VANET real time route guidance systems despite that they may not superior to the centralized ones, they have better chances of real life deployment. We argue that if the VANET route guidance performance is relatively close to that of the centralized control, then it is intuitively rewarding to invest in developing such systems.

There is barely any evidence (from the literature) on the effectiveness of the VANET routing protocols or algorithms as compared to benchmark algorithms in general [5]. The effectiveness (from a traffic stand point) of VANET algorithms vary with the geographic network size (represented by number of nodes and spatial extent), the dominant network speed, the congestion level, the number of vehicles, the network control type, the uniformity of the OD pattern distribution among the various OD pairs, etc. With the rapid development of the VANET technology (networking, communication and hardware technology), there is an eminent need to assess the validity and effectiveness of such algorithms under variable network characteristics.

An appealing evaluation approach would be to approve algorithms based on their relative performance as compared to some *benchmark*. Hawas, Napeñas, and Hamdouch [5] suggested the use of a simulation-based framework for comparative assessment of two VANET route guidance algorithms against a *benchmark* of a centralized algorithm. The two VANET algorithms reported reasonable results, yet their performances were somehow significantly deviant from the benchmark centralized algorithm.

The focus of this paper is to demonstrate the details and the mathematical formulation of a newly proposed VANET algorithm. The newly proposed algorithm is supposedly more efficient (as compared to previous VANET algorithms in [5]) in terms of mobility and overall network travel time, data exchange and communication needs. The new algorithm performance will be compared against centralized, decentralized and other previously developed VANET algorithms.

2. Background

VANETs were used in literature to perform traffic network management functions and for various ITS applications (e.g. [6–9]). FleetNet [7,10] was developed to improve the driver and passenger's safety and comfort. VGrid [6] proposed to cooperate and solve vehicular traffic flow control problems autonomously. TrafficView [8] developed a framework to disseminate and gather information about the vehicles on the road using VANET. Yang and Recker [11] investigated the feasibility of a distributed traffic information system based upon vehicle-to-vehicle communication technologies.

There are many articles related to the VANET-based routing protocols and procedures. A good review of the most common routing protocols for VANET applications can be found in [12] and [13]. They indicated that the vehicular nodes in VANETs have very high mobility, and as such many challenges to route the packets to their final destination. Their work provides a detailed description of various existing routing techniques in literature with an aim of selecting a particular strategy depending upon its applicability in a particular application. The applications of routing can be broadly classified into three categories namely safety, transport efficiency and infotainment. Under transport efficiency, major applications are dynamic route scheduling and real time traffic monitoring.

In general routing protocols can be divided into Topology-based, Geographical-based, Hybrid, Clustering-based and Data Fusion routing techniques. Topology-based routing techniques are used to select routes for sending the information from source to destination. These were further classified into proactive and reactive routing categories. Proactive protocols maintain fresh lists of destinations and their routes by periodically distributing routing tables throughout the network [14,15]. That is, it relies on the periodic broadcast of dynamic data network topology. The reactive routing protocols [16] can be viewed as a solution to proactive routing protocols because they only search for a route when one is needed. This type of protocol finds a route on demand by flooding the network with Route Request packets. They overcome the problem of heavy band width consumption but it is slower than proactive routing where the link is available instantaneously. The Geographic routing based protocols rely on the position information of the destination node which is known either through GPS system or through periodic beacon messages. By knowing their own position and destination position, the messages can be routed directly without knowing the topology of network or prior route discovery [17–21].

The Hybrid routing protocols are designed to take the best of both Topology- and Geographic-based routing schemes [22].

In Clustering-based routing schemes, one node (vehicle) in the cluster area manages the rest of nodes called cluster members [23–25]. If one node falls in communication range of two or more clusters, it is called as border node. Different protocols are proposed differing in how the managing node is selected/elected and the way routing is done [26]. In Data Fusion routing protocol, an