Routing approach in CarTALK 2000 project

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ABSTRACT

The CarTALK 2000 project [1] aims at the development of new driver assistance systems that are based upon inter-vehicle communication. To this purpose, a mobile ad hoc network (MANET) consisting of vehicles will be developed as the communication platform to support co-operative driver assistance applications. Routing in such a vehicular MANET faces a number of new challenges, in particular due to the extremely dynamic network topology and a large variable number of mobile nodes. Therefore, an efficient and scalable ad hoc routing mechanism is crucial for the performance of the CarTALK 2000 communication system. After analyzing the system characteristics and requirements, this paper introduces a spatially aware routing protocol and a distributed location service. The key of Spatially Aware Routing is to improve position-based routing performance by integrating spatial environment information into routing, such as the underlying road topology.

I. INTRODUCTION

A mobile ad hoc network (MANET) is an autonomous system of mobile nodes that does not rely on any existing infrastructure. Mobile nodes use wireless transceivers to communicate with each other. Communication between two nodes is only possible when they are within their radio communication range. To overcome this constraint, intermediate nodes are chosen as relay to forward packets from the sender node to the receiver node. Thus, each mobile node in MANET takes an active role in routing for other nodes besides its own communication.

The mobility of nodes can frequently change the network topology and invalidate existing routes, which makes routing in MANET a very challenging issue. A number of routing protocols have been developed for mobile ad hoc networks, see [2,3]. Depending on the type of information used for routing, they can be classified into two categories: *topology-based* routing and *position-based* routing. While topology-based routing uses information about the existing links in the network, position-based routing mainly relies on the nodes' geographic position for routing decisions. Topology-based routing protocols can be further categorized into *proactive, reactive* and *hybrid* approaches, whereas position-based routing protocols can be divided into *geographic forwarding* and *restricted flooding* [4].

To choose an appropriate routing strategy for the CarTALK 2000 system, we have to analyze application scenarios and requirements of the target system. In the following, we introduce some important characteristics of vehicular MANET in the CarTALK 2000 system:

A. Communication locality

Previous work showed that the communication throughput of MANET decreases with an increasing number of intermediate hops [5]. However, cooperative driving normally requires traffic information about its proximity. Thus, the communication is normally limited between vehicles that are geographically close to each other. This communication locality improves the scalability of the whole communication system.

B. High and regular mobility

Vehicles can drive at very high speed (130 km/h or higher on the highway), which makes the topology of vehicular MANET extremely dynamic. Thus, traditional topology-based routing protocols are not suitable due to the high overhead of route maintenance. In contrast to random waypoint mobility model that is so far widely used in MANET routing, vehicles' movement is very regular, restricted by both road topologies and traffic rules. For example, based on the current position and its driving destination, a vehicle's movement is predictable with the help of a digital road map.

C. Road-overlay network topology

As the vehicles' mobility is restricted on the road, the topology of vehicular MANET is strongly correlated to the underlying road topology. For example, the connectivity of the vehicular network in the city or on main roads is normally higher than in rural areas or on minor roads due to the higher vehicle density. In the abstract, we can view vehicular MANET as a highly dynamic overlay network deployed on top of the static road network.

D. Position-based addressing

In contrast to traditional wired networks where nodes' identities are normally known in advance, communication partners of inter-vehicle communication are normally not interested or can not determine the identity of each other. Since traffic information is normally targeted to unknown receivers in certain geographic region, such messages can not be addressed with IP or MAC addresses. A much more natural way is to address the messages with the approximate location of their destination [13]. For example, the sender of a traffic accident message can address the message to its succeeding cars to up to several kilometers.

E. Sufficient capacity and energy supply

In contrast to ad hoc networks consist of battery-powered handheld devices or sensors with very limited storage and computing capacity, vehicles have sufficient capacity and energy supply for communication. Moreover, adaptive radio range may be advantageous. For example, in situations with very high vehicle density like a traffic jam, each vehicle should reduce its radio range to avoid excessive communication collisions with neighboring cars.

F. Available position- and spatial awareness

All vehicles participating in inter-vehicle communication are equipped with GPS devices to detect their current position any time. Thus, they are considered to be position aware. In addition, vehicles are also equipped with digital road maps to get the knowledge of their spatial environment. Digital road maps can provide not only geometric information such as the underlying road topology, but also semantic information like road names or speed limit. Thus, we consider the vehicles to be spatial aware as well.

II. CarTALK 2000 APPLICATION REQUIREMENTS

The technological challenge is to design a mobile ad hoc routing strategy to fulfill the demands and requirements of various driver assistance applications. Here we focus on the CarTALK 2000 application's requirements on routing issues in the following three application clusters:

1) Information and Warning Functions (IWF)

IWF messages are urgent information for a large number of receivers whose identities cannot be determined in advance, such as messages about a traffic accident or a traffic jam. IWF has the following two requirements on routing:

Geocast functionality: IWF messages are normally targeted to receivers in a certain geographical area, whose identifiers are unknown to the message sender. For example, the sender of a traffic jam message can define the receivers to be its succeeding vehicles up to the next road intersection. Since the receivers are unknown to the message sender, Unicast is not applicable here. In contrast, *Geocast* (sending information to a certain geographical area) is very suitable. While the existing Geocast approaches are based on hierarchical infrastructures [6], our Geocast does not rely on any infrastructure, but is only based on mobile nodes.

Priority awareness: Comparing to messages in other CarTALK 2000 applications, IWF messages are of greater importance and are more time critical. Thus, routing protocols must assign IWF massages a higher priority to guarantee that IWF messages are first processed and forwarded.

2) Communication-Based Longitudinal Control (CBLC)

CBLC messages including vehicle's driving status information are periodically sent to neighboring cars driving in a line. This enables an adaptive longitudinal control to the traffic in front and leads to a more natural following behavior. Since CBLC messages are also of interest for cars that are located beyond the radio range, multi-hop routing is required. Similar to IWF, the receivers of CBLC messages are also unknown to the sender, thus Unicast is not applicable here. Altogether, a multi-hop multicast routing protocol is required with implicit multicast grouping based on the position and hop count. Additional road information like lane IDs can be used to improve routing performance as well.

3) Co-Operative Driver Assistance (CODA)

CODA application relies on a reliable unicast communication between direct addressable neighboring cars, requiring low latency for connection establishment. CODA messages can be used in situations like negotiation between cars at a road intersection. Another example would be highway entry and merging scenarios. Since the communication participants are direct neighbors, multi-hop routing is not required here. CODA messages have a higher priority than CBLC messages in routing.

III. SPATIALLY AWARE ROUTING (SAR)

Based on the system characteristics and application requirements described above, we introduce Spatially Aware Routing (SAR) that extends traditional position-based routing by making use of the spatial environment model.

A. Spatial awareness

In general, a spatial model describes common high-level abstractions of spatial objects and their relationships. Our spatial model is constructed based on road topology information extracted from digital road maps, which can be internally represented as a *graph G(E,V)* consists of a set *V* of *vertices* referring to road intersections together with a set *E* of *edges* denoting road segments. The *weight* of edges can be used to represent different characteristics, such as the road length, average speed, etc.

In the abstract, vehicles moving from one place to another place can be considered as moving from one vertex to another vertex along edges in the graph, which is called the graph-based mobility model [9]. In contrast to the widely used random-waypoint mobility model in MANET simulations, our graph-based mobility model is much more realistic for the movement of vehicles in the CarTALK 2000 scenario.

Traditional position-based routing approaches like GPSR [8] do routing decisions only based on the nodes' position. A common used approach is *greedy forwarding*, which repeatedly forwards packet to the neighbor whose position is closest to the destination location. While greedy forwarding is simple and scalable, it performs worse with the increasing *holes* in the network topology, where a node cannot find any neighbor closer to the destination than itself. Such *topology holes* can often occur in our scenarios due to the road topology, as shown in Figure 1. In this simple scenario, vehicle *S* has a packet for destination *D*. Based on the greedy approach, *S* should forward the packet to its neighbor *A*, while the underlying road indicates vehicle *B* is a better choice for packet forwarding.

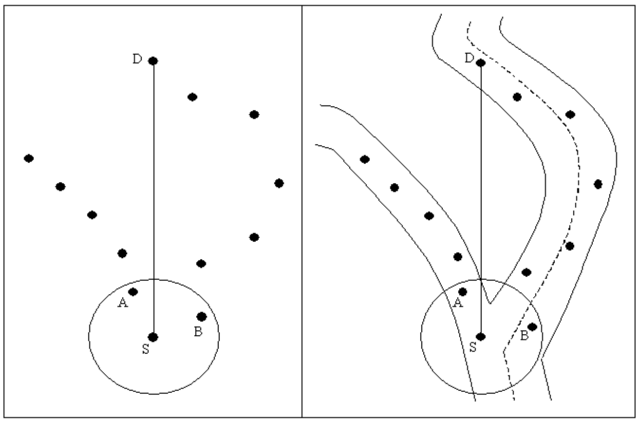

Figure 1: Position awareness vs. Spatial awareness

B. Routing Algorithms

Based on the high availability of spatial awareness, here we introduce a new approach, Spatially Aware Routing (SAR), to improve the performance of position-based routing.

1) Geographic Source Routes (GSR)

We assume a road graph $G(E,V)$ consists of a set V of vertices together with a set E of edges to be available in all vehicles. Each vertex $v \in V$ is defined by its ID and geographical coordinates. Each edge $e \in E$ is defined by the vertices on its two ends with the weight function $w(e)$ set to its geographic length.

Each sender node *s* maps itself and its destination node *d* into the graph model, and calculates the shortest path $P=\{v_1,v_2,\ldots,v_n\}$ to the destination with a shortest path algorithm, e.g. the Dijkstra algorithm. Each sender *s* then sets a *Geographic Source Route* (GSR) to *P* and embeds it into the header of packets sent to the destination.

The complexity of shortest path computation between any two vertices of the graph is $O(n^2)$, where $n=|V|$ is the total number of vertices in the graph. Some methods like partitioning and multi-level resolutions can be used to reduce *n* in the graph to restrict the computation overhead of GSR.

2) GSR-based Forwarding

All data packets are marked with the location of the sender and the destination node besides the GSR. Instead of simply greedy forwarding, in SAR each intermediate node first maps its neighbors' position into the graph, and then forwards the packet to the neighbor with the shortest path *along the GSR* to the destination. After a vertex in the GSR is reached (i.e. the intermediate node finds the vertex to be within its radio range), this vertex will be removed from the GSR in the packet header and the packet will be forwarded to the next vertex in the GSR. With this approach, a packet will move successively closer to the destination along the optimally selected GSR.

However, there is a drawback of SAR: since the GSR is based on geographic locations instead of existing links, there is no guarantee that a forwarding node can always find a suitable neighbor on the GSR. Some methods have to be used to recover from such a situation, for example:

Suspending the packet: the intermediate node can choose to suspend the packet delivery by putting it into a buffer. Packets in the suspension buffer are periodically checked and forwarded later if possible.

Switching to greedy forwarding: the intermediate node can temporally forward the packet with greedy strategy towards the destination, and switch back to the GSR-based forwarding later if possible.

Re-computing the GSR: the intermediate node can compute an alternative GSR from its current location to the destination to replace the original GSR in the packet header. The packet will then be forwarded along the new GSR.

C. Protocol evaluation

To evaluate the proposed SAR routing approach, we simulated it in the *ns-2* simulator [10] with the CMU wireless extension. Two versions have been implemented: the basic SAR protocol without any recovery method, and the SARB with a suspension buffer, which can store up to 80 packets for a maximum time of 30 seconds. We compare the performance of SAR and SARB with the existing geographic forwarding protocols GPSR.

A section of the city of Stuttgart with an area of about 500 m × 1800 m is modeled in the simulation by a graph consists of 54 vertices and 59 edges (see Figure 2). 100 vehicles are initiated at randomly selected vertices and move along the edges of the graph during the simulation for 900 seconds. Each vehicle chooses another vertex as its destination randomly, and moves along the shortest path along the graph edges to it at a speed randomly chosen in a range from 30 km/h to 60 km/h. After reaching the destination vertex, the node makes a pause of 10 to 30 seconds, and then moves to another randomly selected vertex. We simulate 20 Constant Bit Rate (CBR) traffic flows with senders and receivers chosen randomly. Each

CBR flow sends at 2 kbps, with a packet size of 64 byte. The IEEE 802.11 Medium Access Control (MAC) protocol is used, which implements the Distributed Coordination Function (DCF).

Our simulation results show that basic SAR can effectively improve routing performance in situations with permanent topology holes (nearly 15% relative improvement in packet delivery with a much lower delivery delay than GPSR). SARB shows that a suspension buffer can significantly improve the packet delivery with a compromise on the delivery delay (up to 51% relative improvement in packet delivery than GPSR). Detailed descriptions of the SAR protocol and simulation results see [11].

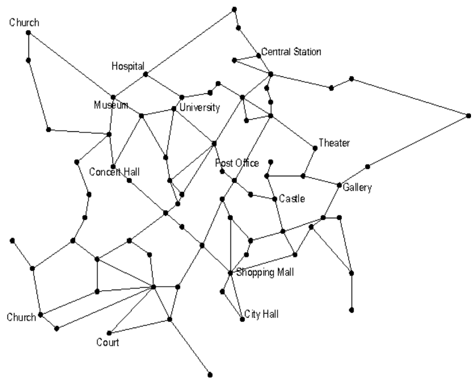

Figure 2: A simple graph spatial model of Stuttgart

IV. MULTI-HOP BROADCAST SERVICE AT MAC LAYER

Multi-hop broadcast service is an important requirement of the CarTALK 2000 system for sending urgent messages, in which some nodes are chosen to relay the broadcast packets to reach all nodes. Plain flooding approach on the network layer has the drawback of generating excessive retransmissions, resulting in collisions and a highly inefficient use of bandwidth. A new Medium Access Control (MAC) protocol, called ADHOC-MAC, is proposed to satisfy this requirement on the MAC layer [12].

ADHOC-MAC is based on a completely distributed access technique, the Reliable R-ALOHA (RR-ALOHA), and it can be adapted to operate on the physical layer of different standards, including the UMTS Terrestrial Radio Access TDD (UTRA-TDD) and the IEEE 802.11. It is based on a frame structure, in which a broadcast signaling channel is set up in a completely distributed way. Based on the information of this channel, each nodes knows the activity of its two hop neighbors in order to implement an optimal multi-hop broadcast service. Moreover, this MAC allows a simple method to attain a low number of relaying nodes to cover all the network, thus solves the network broadcast problem in an efficient way. In fact, for any packet that has to be broadcasted to the entire network, a limited set of nodes are chosen to relay the packet, with no additional information except the one intrinsic in RR-ALOHA. According to the defined rules, these nodes are chosen in an optimal way, which makes the broadcast very efficient. Furthermore, the choice is dynamically made on a frame by frame basis, so that optimal choices can be made even in presence of great mobility of nodes. Some work is in progress to define the implementation details and to obtain more accurate performance evaluations considering all the parameters of real networks scenarios.

The multi-hop broadcast service at MAC layer, as proposed in the ADHOC-MAC, will allow to simplify the routing protocol while guaranteeing a lower delay of urgent messages.

V. CarTALK 2000 LOCATION SERVICE

Since the information of nodes' geographic position is crucial for Spatially Aware Routing, the performance of SAR strongly depends on the location service used. In the following we propose the location service for the CarTALK 2000 system.

A. Neighbor Discovery

Since there is no infrastructure available, a distributed location service must be deployed in the vehicular MANET. An efficient neighbor discovery mechanism provides the basis for distributing location information among a large number of nodes.

To provide neighbor discovery at the network layer, each vehicle periodically sends *beacons* (or HELLO messages) to its direct neighboring cars, reporting its existence. CarTALK 2000 beaconing messages include the vehicle-ID, MAC and an optional IP address, its current location and driving speed and direction. Each vehicle selects its beaconing interval depending on the mobility and the local node density. The interval should be chosen proportional to the local node density to avoid excessive beacon collisions. A vehicle should reduce its beaconing interval with the increasing mobility to keep its status information up-to-date on its neighboring cars.

B. Location Service

Based on the communication locality and high mobility of the CarTALK 2000 system, we propose a local location service for Spatially Aware Routing with the following design issues:

1) Local proactive, global reactive location service

We choose to deploy a proactive local location service based on the application requirements: IWF and CBLC rely on Geocast for message delivery, where destination geographic areas are determined by the message content. Since receivers of such messages are unknown, the sender does not need to query location of the receivers. CODA requires reliable unicast between negotiating nodes, thus the position discovery of destination nodes is needed. However, since communication only occurs between vehicles in close vicinity, a local location service is sufficient. Each vehicle continuously provides its location information to its direct neighboring cars through beacon messages. This proactive approach avoids frequent location discovery and leads to a low message delivery delay.

To query the location of a remote destination node, an expanded-ring approach is used: a vehicle first launches a local broadcast querying its direct neighboring cars, which will send a location reply if the location for the destination is found in the local cache. If no location reply message is received, the sender vehicle increases the query range by doubling the hop count limit in its location query messages. The reactive location discovery approach leads to a longer delay before sending the message to a remote node, but avoids excessive location update messages between remote vehicles.

2) Adapting location update to distance and mobility

Besides geographically limiting location updates in a certain geographic area, we can further improve the scalability of global location service by adapting the location update rate to the distance and mobility. Based on the *distance effect* used in DREAM [7], the greater the distance separating two nodes, the slower they appear to be moving with respect to each other. Thus, nodes that are far apart need to update each others locations less frequently than nodes closer together. In case that a global location update is needed due to an active multi-hop communication, each vehicle should update its location less frequently with the increasing distance to the destination. Similarly, each vehicle should increase its update frequency proportional to its mobility.

3) Location caching and piggybacking

To increase the location availability, each vehicle can keep the location information of other cars that it has received or forwarded in its local cache. On receiving a location query, each vehicle first checks its local cache for the queried location to reduce the delay of location discovery. To keep the cache coherency, cached location information should be invalidated after a certain period of time. Furthermore, piggybacking location information into data packets can improve the efficiency of global location update.

VI. CONCLUSIONS

After analyzing CarTALK 2000 system characteristics and requirements, this paper introduces a spatially aware routing protocol, the multi-hop broadcast service at MAC layer and a simple distributed location service. A spatially aware routing approach is based on the high availability of GPS and digital road map information in CarTALK 2000 systems. The spatially awareness can be used in both unicast and Geocast protocols, to fulfill the requirements of different application scenarios. More in depth investigations are still needed in order to proceed with specific technical choices and to reach the final routing design. These detailed analyzes together with supporting simulation results are in progress.

VII. ACKNOWLEDGEMENTS

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