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車両間通信の最新動向と課題

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あらまし　車両間通信は道路の混雑・障害・事故・その他安全に不可欠な情報を適宜かつ短時間に提供するために重要な役割を担うものと期待されているが、高信頼で高効率な車両間通信システム実現のためには様々な課題がある。本論文では、これらのうち、ルーティング層あるいは MAC 層メカニズムに関する最近の取り組みと開発事例について取り上げる。ルーティング層に関しては、一般的な reactive 型や proactive 型、位置情報利用型プロトコルについて触れ、自動車への適用を目指す最近の取り組みについて例を挙げ解説する。MAC 層に関しては、車両間通信において最近提案されているいくつかの方式について解説する。

キーワード：車両間通信、モバイルアドホックネットワーク、ルーティングプロトコル、MAC

Survey of Recent Developments and Trends in Intervehicle Communications

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Abstract Intervehicle communications is expected to play a key role in providing timely information to drivers about road conditions, hazards, collisions and other safety-critical notifications. However, a robust and efficient intervehicle communications system design poses several challenges. This paper addresses these challenges and recent developments with a focus on routing mechanisms and MAC layer mechanisms. In the routing layer, we briefly look at generic reactive, proactive and position-based protocols, and provide examples of recent work targeted for vehicular environments. In the MAC layer, we review a selection of recently proposed methods for intervehicle communciations.

Keywords: Intervehicle communications, mobile ad hoc networks, routing protocol, MAC.

I. INTRODUCTION

Ad hoc networking for vehicles (which we will refer to as intervehicle communications in the rest of the paper), is expected to play a key role in providing timely information to drivers about road hazards, accidents, and many other safety-critical notifications as a means of "active safety" in vehicular environments. Ad hoc networks, by definition, do not rely on fixed infrastructures. Instead, each node performs routing and other network management tasks in a decentralized fashion while also functioning as a host.

Intervehicle communications, in general, can be considered a subset of mobile ad hoc networks (MANETs). However, due to high mobility of vehicles (nodes of network), and the safety requirements associated with their applications, intervehicle communications is different from generic MANETs.

Designing a robust and efficient intervehicle communication system poses challenges in several dimensions. In this paper, we will survey some of these challenges as well as advances available in the current literature. We will focus our attention mainly to the routing and MAC layer mechanisms for vehicular mobile environments and vehicular ad hoc networks.

Physical layer mechanisms together with radio frequency allocations and their implications comprise a whole set of other issues and will not be addressed here. A general overview of these issues is provided in [20]. Another important area we leave out is the security of such systems. For an up to date discussion of security issues in intelligent vehicle environments see [10].

On the other hand, there are multiple government and industry sponsored programs that consider intervehicle communications in Japan, Europe and the USA. Excellent up to date overviews of these programs can be found in [16] and [17].

II. ROUTING LAYER MECHANISMS

In this section, we look at ad hoc routing protocols from the viewpoint of their applicability to vehicular networks. Several routing protocols have been proposed in the context of MANET [11]. These can be broadly classified into three groups as *reactive*, *proactive* and *position-based* routing protocols.

Reactive routing protocols create routes only when a node wants to transmit data to another node. Different route discovery mechanisms of such protocols result in varying performance figures. Generally, an established route is maintained until the destination node is no longer available, or until the route is not needed anymore.

On the other hand, a node employing a proactive routing protocol should maintain information about how data can be transmitted from itself to a destination node, before such a request arrives. In other words, each node maintains a view of the network seen by itself, and exchanges this view regularly with other nodes.

Finally the third group, position-based (or position-assisted) routing protocols eliminate some of the limitations of plain reactive and proactive protocols by using additional information of geographical location for each node. These protocols make their forwarding decisions based on a destination's geographical position. GPS is the common method proposed for obtaining the location information of a node itself, though some other methods exist for location determination.

A generic position-based routing algorithm includes a location service method to determine the location of the destination node and a forwarding strategy to reach the destination node based on its position. Most of these schemes require beacons to advertise the GPS positions of nodes within transmission range. A forwarding decision by a node is primarily based on the position of a packet's destination and the position of the node's immediate one-hop neighbors.

Position-based routing does not require the establishment or maintenance of routes, and the nodes do not store routing tables. However, note that, location services themselves are proactive in the sense that they continuously communicate to maintain the position of all nodes at all times. There are different types of location services and forwarding strategies proposed in the literature and the performance varies among different methods.

Exhaustive overviews of these three classes of routing protocols can be found in [9] and [14].

A legitimate question here is whether reactive, proactive or position-assisted protocols perform better for intervehicle communications. Intuitively, using extra information about the position of a network node should be advantageous compared to not having such information. In the following, we provide examples of such comparative studies available in the literature.

In [7], Fuessler *et al.* start with the assumption that a proactive protocol would perform worse than a reactive one for vehicles. Therefore they pick a reactive routing protocol (DSR, Dynamic Source Routing [11]) and compare it with a generic position-based protocol and show that successful routing of packets is improved by the use of a position-based approach. Furthermore, they show that if the "distance" between the communicating nodes is more than 2-3 hops, position-based approach attains a lower routing overhead.

In [8], again Fuessler *et al.* propose a position-based approach which they call *Contention-Based Forwarding* (CBF). Their starting point is that a general position-based approach will incur large overhead if nodes are highly mobile. This is due to beacons providing update on location information used to support routing. The beacon information can change widely in a highly mobile environment and thus beacons can cause the largest overhead in vehicular environments (the beacon-based approach can require on average up to three MAC retransmissions).

Their solution, CBF, is a position-based forwarding method that does not use beacons to provide neighboring location information. CBF's forwarding decision is based on the location information that a node has about itself, instead of being based on the view perceived by a forwarding node. In CBF when a node has a packet to forward, it transmits the packet as a single-hop broadcast to all neighbors. This initiates a contention period where neighbors contend to be the next hop for the packet. In this period, all nodes that receive the packet check if they are closer to the destination than the forwarding node. If this is the case, a random timer is set and the node that responds first is selected as the next hop. It suppresses other nodes and forwards the packet (note that there may be duplicate packets toward the destination from the neighboring losing nodes and therefore they should be suppressed).

They show, through simulations, that CBF increases packet delivery ratios compared to beacon-based routing for higher node speeds. Also, CBF is shown to reduce the signaling overhead compared to beacon-based routing.

Another work which shows position-based routing superiority to standard routing protocols is presented in [13] by Lochert *et al*. Their starting point is that general position-based routing does not take into account buildings which changes transmission range, which in turn can cause routing loops and wrong direction routing. They propose a position-based routing mechanism supported by map of the city for more correlated routing to physical topology of city environment (*Geographic Source Routing*). Their performance comparison shows that geographic source routing provides improvement over AODV (Ad Hoc On Demand Distance Vector [11]) in terms of latency for first hop connection, and requires less bandwidth than Dynamic Source Routing to recover when network changes.

Tian *et al.* provide a similar approach in [19]. Their scheme, *Spatially-Aware Routing (SAR)*, is used to predict and avoid forwarding failures that may occur due to permanent topology "holes" especially for vehicular environments where vehicle geographical distribution is restricted by underlying road infrastructure. In comparison with generic position-based approaches, SAR is not based only on the positions of destination and neighboring nodes but it is an "overlay" of a spatial model constructed from digital road maps. It is shown that, SAR deals better with topology holes than generic position-based algorithms especially in case of long radio ranges (e.g. longer than 100m).

In [21], Wang proposes the use of "lifetime" of a path embedded into a decision mechanism in addition to the methods described so far, when selecting a path between a source and a destination. Specifically, he suggests that predicting the lifetime of a route before starting a long-lived transfer session over that route will alleviate the problem of frequently changing transmission paths. The idea is validated thorough simulations for a certain segment of a highway under specific conditions. However, it remains to be seen if it is a cumbersome task to obtain a fairly general analytical expression that can be applied to various road and traffic situations. Once such an analytical generalization is available, then it may be used as a supporting element of the decision making process for routing.

Chisalita *et al.* approach the problem in terms of contextual-awareness [4]. They propose a "reactive" broadcast protocol where the message source does not know who and where the destination is. Each node broadcasts messages that can be received by other nodes in its transmission range. Each node performs an analysis of the received messages to determine whether the message is of importance for itself. If the node decides that an incoming message is important, it accepts the data, otherwise it discards the message or it may decide to forward it. These decisions are based on the momentary traffic situation of the receiving node.

Their evaluations show that this scheme suffers from a huge number of message collisions in the medium access layer, suggesting the use of a more complicated medium access scheme in order to make better utilization of the contextual-awareness.

In a more recent study, Blum *et al.* simulate generic MANET algorithms and conclude that due to rapid topology changes and network fragmentations, neither proactive nor reactive MANET protocols will suffice to handle the intervehicle communications [2]. In particular, they state that proactive protocols suffer from frequent changes and reactive protocols will be slow in responding to route discovery requests. One of the interesting results of their simulations is that even sending small messages over three or four hops is likely to be interrupted by a route error.

Overall, many of the protocols introduced here attempt to improve the basic position-based routing schemes. In general, low density of nodes within the network and high mobility of nodes can adversely affect most of these protocols.

III. MEDIUM ACCESS CONTROL (MAC) MECHANISMS

Medium Access Control (MAC) protocols define general rules for an "orderly" access to the wireless medium which is typically a shared resource. In the ideal case, the medium (i.e. bandwidth or channel) is shared fairly among competing nodes. Through controlling nodes' access to the bandwidth, MAC layer accomplishes several crucial tasks: throughput for each node, congestion control, latency, fairness, and scalability.

MAC layer in the context of MANET and intervehicle communications is a fertile area of new ideas. Two issues that have been extensively studied at this layer are *hidden* and *exposed node* problems. Hidden nodes are two nodes that are both trying to transmit to a same third node, causing a signal collision at that node, unknowingly. Oppositely, exposed nodes are nodes that are within interference range of each other, thus unknowingly prohibiting simultaneous transmissions in opposite directions. Zhu and Roy give an up to date overview of IEEE 802.11-based MAC layer characteristics in the context of DSRC [24].

Suitability of IEEE 802.11b for using in intervehicle communications is investigated in an experimental study by Singh *et al.* [18]. They experiment with 802.11b between two vehicles in suburban, urban, and freeway environments. They show that throughput decreases with increasing vehicle speed and distance. They suggest to optimize the throughput by changing packet size based on intervehicle distance (e.g. larger packets at shorter distances and smaller packets at larger distances).

In a more recent experimental and simulation study, Yin *et al.* conduct a feasibility study of delay-critical applications over DSRC [23]. They first quantify the physical layer performance of the current DSRC standard in terms of bit error rates in an outdoor high-speed vehicle environment. Then, they plug these values into a vehicular ad hoc network simulation where the main application is collision avoidance. Their simulation consists of 100 vehicles moving on a city road map. Their application is modeled as a single-hop broadcast and it does not address multi-hop relaying of messages. They find that current DSRC has promising latency support under the conditions described, however it should be doing a better job in the throughput arena. Specifically, they transmit 100 and 200 byte packets with a latency of within 100 msec for varying packet generation rates. However, throughput, defined as the percentage of neighbors successfully receiving a packet is less than 60%, suggesting a need for a QoS mechanism.

Bana and Varaiya [1] propose the *Space Division Multiple Access (SDMA)* scheme which relies on location information of the nodes. SDMA provides access to the medium based on a node's physical location. It divides a geographical space (e.g. a road) into smaller pieces and consequently performs a one-to-one mapping of space division and bandwidth (channel) division which could be TDMA, FDMA or CDMA.

A similar method is proposed by Katragadda *et al.* in [12] is *Location-based Channel Access (LCA)*. It allocates channels to the nodes based on their instantaneous geographical positions. Like SDMA, LCA divides a geographic area (e.g. a road) into smaller cells. Whenever a vehicle wants to transmit information, it first determines its position and finds the exact cell into which its coordinates fall. Using this cell identity, consequently, it obtains the corresponding channel by performing a cell-to-channel look-up.

In a more recent study, Nagaosa et al. apply the concept of position-based transmission to CSMA [15]. Unlike SDMA and LCA, they do not divide the road into identical cells but allow vehicles to transmit pulses proportional to their lengths. Their scheme is shown to perform well in environments with bit rates under than 5Mb/s.

All three of SDMA and LCA and position-based CSMA are collision-free schemes, however a fairly high accuracy positioning system is a must for the success of these schemes.

In [3], an improvement over Reservation ALOHA (R-ALOHA) using a slotted channel is proposed. In R-ALOHA, a centralized repeater is necessary for correct operation. Since such a centralized repeater is not feasible in a vehicular environment, they extend R-ALOHA by having neighbors of a node to determine if a node's request for a slot has succeeded. This extended method is called Reliable R-ALOHA (RR-ALOHA). It operates by transmitting additional information about a frame thus by letting a node about the status of each slot (i.e. whether a slot is available or reserved).

A different approach defines a MAC extension layer working as an overlay on CSMA to transmit multiple repetitions of very short messages [22]. In this overlay, there is no acknowledgement requirement from the receiver, however the probability that a safety-critical message is received correctly is maximized via repetitions.

Finally, an inspiration from the wireline world, *Wireless Token Ring Protocol (WTRP),* attempts to bound latency in ad hoc networks by giving each node a right (token) to transmit in turn [6]. When a node joins a ring, it "connects" to its predecessor and successor by looking up a connectivity table. Similarly, when a node leaves the ring, its predecessor finds the next available node to close the ring by looking up its connectivity table.

WTRP was deployed in an actual automated highway project involving a platoon of up to 20 vehicles with 100 bytes of data per vehicle to transmit periodically. Moreover, the authors present a comparison of WTRP with 802.11 showing that WTRP recovers quickly from failures and has higher throughput.

IV. SUMMARY AND CONCLUSIONS

Intervehicular networks comprise a subclass of the mobile ad hoc networks with more stringent requirements. In the previous sections, we attempted to give a brief snapshot of the state-of-the-art mainly in two active research areas: routing layer and medium access control layer. While doing so, we deliberately excluded security issues, physical layer issues, information dissemination methods in higher layers, multicasting among vehicles and clustering (grouping) of vehicles. These emerging areas are equally important in deploying real intervehicle ad hoc networks and deserve further attention.

In the routing layer area, we divided the existing literature into three broad classes as reactive, proactive and position-based approaches and put special emphasis on position-based algorithms and their variations as these are more promising to be applied in vehicular environments.

MAC layer in the vehicular communications is also a very active research area. We overviewed two experimental and simulation work addressing the suitability of IEEE 802.11b and current ASTM-DSRC standard in single-hop vehicular communications.

We also overviewed three position-assisted MAC layer protocols all of which used exact position of vehicles to determine transmitting opportunity. These are theoretically collision-free schemes however they have strong dependability on accurate location (position) determination.

Other approaches reviewed are extensions of CSMA, token ring and R-ALOHA, all applied to the dynamic vehicular environment.

Overall, intervehicle communications remains to be a challenging subject of research, possibly requiring novel approaches for many of its problems to be solved.

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