Contention-Based Forwarding for Street Scenarios

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***Abstract*— In this paper, we propose to apply *Contention-Based Forwarding (CBF)* to Vehicular Ad Hoc Networks (VANETs). CBF is a greedy position-based forwarding algorithm that does not require proactive transmission of beacon messages. CBF performance is analyzed using realistic movement patterns of vehicles on a highway. We show by means of simulation that CBF as well as traditional position-based routing (PBR) achieve a delivery rate of almost 100% given that connectivity exists. However, CBF has a much lower forwarding overhead than PBR since PBR can achieve high delivery ratios only by implicitly using a trial-and-error next-hop selection strategy. With CBF, a better total throughput can be achieved. We further discuss several optimizations of CBF for its use in VANETs, in particular a new position-encoding scheme that naturally allows for communication paradigms such as 'street geocast' and 'street flooding'. The discussions show that CBF can be viewed as a concept for convergence of intelligent flooding, geocast, and multi-hop forwarding in the area of inter-vehicle communication.**

I. INTRODUCTION

Mobile ad hoc networks enable the communication between mobile nodes without a pre-established infrastructure. Since the radio range of each node is limited, multi-hop routing protocols are used to allow communication between nodes that cannot reach each other directly [1]. For these protocols all nodes act both as routers and as end systems.

A possible application of MANET principles is vehicle-to-vehicle communication as developed, e.g., in the framework of the FleetNet [2] and CarNet [3] research projects, or as recently considered in the 802.11 WAVE (wireless access in vehicular environments) study group [4]. These Vehicular Ad Hoc Networks (VANETs) will enable new safety and comfort-related applications through enhanced emergency notification services or range extension of access points located along the roadside.

The requirements imposed by vehicle-to-vehicle communication are somewhat different from those of general-purpose ad hoc networks. On one hand, energy consumption and miniaturization do not represent critical factors, and nodes can be equipped with a navigation system so that each car knows about its own geographic position. On the other hand, the network is significantly more dynamic (e.g., high node mobility) compared to other mobile ad-hoc networks. Therefore, packet routing and forwarding in VANETs is a challenging task.

Recent research [5], [6] has shown that Position-Based Routing (PBR) [7] performs well in vehicular movement scenarios, especially for highway environments. PBR uses the geographic position of nodes to decide in which direction a data packet should be forwarded. Traditional PBR protocols such as GPSR [8] or face-2 [9] use beacon messages: each node announces its address and geographic position to all its neighbors via a radio broadcast. Whenever a node receives such a beacon message from a neighbor, it stores the address and position of that node in its neighbor table. When a node has to forward a packet it uses the table to determine the neighbor the packet should be forwarded to in order to make progress towards the final destination. Usually, this decision is based on a geometric heuristic by selecting the neighbor minimizing the remaining distance to the destination (*greedy forwarding*).

Recently, a different algorithm for position-based routing called *Contention-Based Forwarding*

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(CBF) [10] was proposed. CBF does not require the transmission of beacon messages. Instead, data packets are broadcast to all direct neighbors and the neighbors themselves decide if they should forward the packet. The actual forwarder is selected by a distributed timer-based contention process which allows the most-suitable node to forward the packet and to suppress other potential forwarders. It has been shown that CBF outperforms beacon-based greedy forwarding in general two-dimensional scenarios with random way-point mobility. The performance advantage of CBF is most apparent in highly mobile scenarios. Similar approaches were proposed independently in [11], [12].

In this paper we analyze the performance of CBF using realistic movement patterns of vehicles on a highway and show the bandwidth-efficiency of CBF compared to traditional PBR. The "one-dimensionality" of street scenarios facilitates forwarding and allows for several improvements to the CBF algorithm discussed in this paper.

The remainder of this paper is organized as follows: Section (II) outlines the basic concepts of CBF when applied to a highway scenario. A simulation study in Section III compares CBF and traditional PBR and argues why even unmodified CBF is more suitable for these situations. Section IV outlines possible modifications to CBF that facilitate its use in VANETs and enable street-geocasting.

II. CONTENTION-BASED FORWARDING IN STREET SCENARIOS

For the remainder of this paper we assume that each node knows its own geographic position. Either a distributed "location service" is used to determine the position of every other node within (multi-hop) connectivity[1] or the position of the destination area might be determined by the application ("geo-anycast", see [13]). Every CBF data packet contains the position of the node that has just forwarded the packet (called last-hop from the receivers point of view), the ID and position of the final destination, and a packet ID. A node that receives such a packet and is not the final destination sets a timer to determine when to forward the packet. The timeout value is calculated based on the progress the node provides towards the packet's destination.

The packet progress for a given node i is defined as

$$p_i = dist(l,d) - dist(i,d)$$

where *dist* is the euclidean distance, and l and d are the positions of the last hop and the final destination, respectively. The timer value is calculated as follows:

$$t = \begin{cases} \tau\left(1 - \left(\frac{p_i}{p_{\max}}\right)\right) & 0 \leq p_i < p_{\max} \\ \infty & \text{otherwise} \end{cases}$$

where p_{max} is the radio range and τ is the maximum forwarding delay. The value of t determines, how each forwarder participates in the contention process. If infinite, the packet is discarded. Otherwise, the node forwards the packet after t seconds unless it overhears the transmission of a packet with the same ID by some other node. In this case, the timer is canceled. Additionally, each node keeps track of the IDs of forwarded packets to avoid sending duplicates. At the destination, a final acknowledgment is sent to the direct neighbors to inform them of the successful packet reception. For a more detailed description of CBF, please refer to [10].

In general two-dimensional scenarios, it is possible that competing nodes cannot hear the other node forwarding the packet. In order to avoid packet duplication this requires special suppression strategies. In contrast, in street scenarios this is essentially not possible as illustrated in the following simple example.

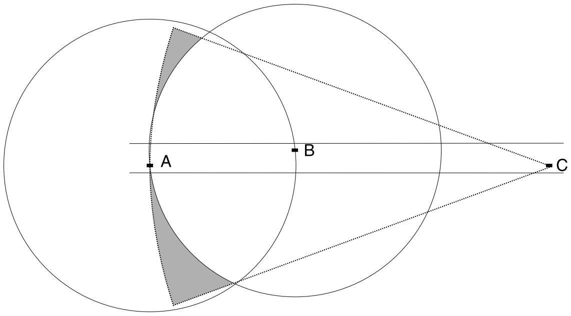

Fig. 1

SUPPRESSION SITUATION ON A HIGHWAY

Fig. 1 depicts a highway and three cars. Node **C** is the destination and the dotted circle segment at **C** indicates the area with greedy progress. We assume that node **A** has just broadcast the packet. Node **B** will be the next to forward the packet. If nodes were located in the shaded area, they would not overhear **B**'s transmission and eventually would forward the packet as well. However, the size of the intersection of this area and the street is negligible and it is very unlikely that forwarders are located in it. Therefore, the use of specific suppression strategies (with additional overhead) as described in [10] is much less important for street

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[1] How these "location services" work is out of the scope of this paper. Some proposals are referenced in [7]

scenarios than in the general two-dimensional case.[2] Packet duplication can still occur when the forwarding of a packet is not overheard due to packet collision or jamming. However, in a street scenario, these duplicates are usually short-lived since the packet soon reaches an area where nodes correctly received a retransmission, stored the packet's ID, and therefore refrain from forwarding the duplicate.

III. SIMULATIVE EVALUATION

Previous work in [5] has shown that position-based routing is superior to topology-based routing for dealing with the dynamics of highway scenarios and that almost perfect packet delivery ratios (PDR) can be achieved with reasonably small beacon intervals. Using a similar set-up, we now demonstrate that CBF achieves a delivery rate as good as PBR but with significantly less load on the wireless medium.

A. *Simulation Setup*

For the simulations we use a modified all-in-one distribution of ns-2 (version 2.1b8a) running under Linux. The beacon-based routing protocol is based on the GPSR code of Brad Karp [8] with non-greedy forwarding (perimeter mode) disabled. In the following, we denote this algorithm as B-PBR (position-based routing with beacons). We investigate B-PBR with beacon intervals of $0.25, 0.5, 1.0$, and 2.0 seconds. In addition, every data packet contains the current position of the sending node. Every node overhearing such a packet updates the corresponding neighbor table entries (piggybacked beacons). CBF is run in base-mode with $\tau_{\max} = 37.5$[msecs], which proved to be a useful setting in [10]. Since both approaches are position-based, no location service was used. The location information of the destination was obtained from the simulators "omniscient" location service.

Node movement follows the 10km highway behavior with 2 lanes per direction described in [5]. This paper also contains a deeper analysis of the movement pattern itself. All experiments were conducted with two different MACs. One was IEEE 802.11 using the TwoRayGround propagation model with 2MBit/s as provided by ns-2. The other one was an idealized MAC implemented to abstract from MAC-specific effects. This *0-MAC* allows communication between two nodes if they are 250 meters or less apart and does not impose any upper limit on the amount of transmitted data. Collisions or interference between concurrent transmissions does not occur with the 0-MAC.

The communication pattern is chosen as follows: At all times, there are 10 sender/receiver pairs sending 4 ping packets with 64 bytes payload per second. Whenever a receiver obtains a packet, it is acknowledged by a 64 byte echo packet. Every sender/receiver pair communicates for 5 seconds (i.e. 20 packets). After that, a new pair is chosen. All communication pairs obey the constraint to be at least $(\delta - 500)$ and at most δ meters apart during the whole communication process (with $\delta = 500 \cdot n | n = 1, 2, \ldots 9$) *and* to be in the same network partition, i.e. at all times there is a (multi-)hop connection between the communicating nodes.[3].

Communication starts $t = 10$ seconds after the start of the simulation (to allow neighbor tables to stabilize for B-PBR) and lasts until $t = 25$ seconds, resulting in 600 ping packets in total.

The metrics used for evaluation are the packet delivery ratio (PDR) of the packets from sender to destination and the total amount of data transmitted on the link-layer.

B. *Simulation Results*

Figure 2(a) shows the PDR for simulations using the 0-MAC. Both routing approaches, PBR and CBF, achieve a very high PDR of 96%-100%. Similar but slightly lower PDRs are achieved with the 802.11 scenario, omitted due to space restrictions. The beacon-based approach needs a certain beacon rate to cope with high mobility. At a beacon interval of 2 seconds and in the $\delta = 4500m$ communication pattern, the number of lost-link callbacks, i.e. callbacks from MAC to the routing layer indicating that the intended next hop could not be reached, was on average over 3000 as opposed to 1600 for the 0.25s beacon interval. The latter number shows that even for a high rate of 4 beacons per second, the intended next hop cannot be reached frequently due to the network's mobility. Thus, PBR has to follow a trial-and-error strategy of selecting a new neighbor at the expense of additional load on the wireless medium. In contrast, CBF only requires a retransmission to resolve collisions, i.e., when two nodes select the same MAC slot. Accordingly, Figure 2(b) shows that increasing the communication distance and thus the number of hops a

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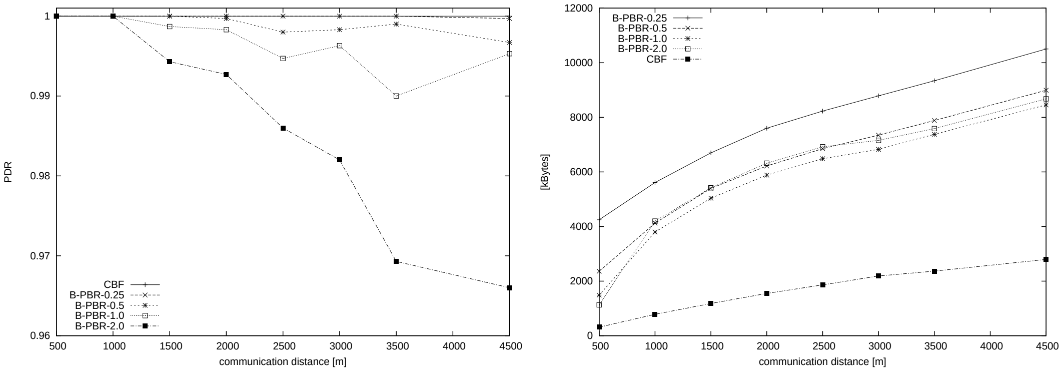
[2] For the sketch we assume the radio range to be five times the street width whereas this value will probably be much higher for actual VANETs.

[3] We acknowledge that this selection process seriously narrows statistical significance. To provide a wider statistical base is subject to current work.



(a) Packet delivery ratio using 0-MAC

(b) Data volume transmitted on link-layer using IEEE 802.11b

Fig. 2

MAC TRANSMISSION COST OF CBF AND B-PBR

packet has to travel, the load on the wireless medium is moderately increasing in the case of CBF while for B-PBR the load is significantly increasing due to the trial-and-error next-hop search on top of the rather constant beaconing overhead.

IV. MODIFICATIONS TO CBF

A. Position Encoding on a Street

In general purpose position-based routing, the position of nodes is encoded as absolute values, e.g., as a latitude/longitude pair. This information may occupy a significant portion of a data packet, in particular if multiple positions must be included (original sender, destination, last hop). Since cars usually move only on streets, an encoding with a lesser degree of freedom may be possible and can reduce the number of bits for encoding position information.

One way of providing a more efficient encoding would be to make use a map as it is provided by current car navigation systems. From this map a Graph $G(V,E)$ can be generated as follows:

Each street is approximated by linear segments. Each point where these linear segments connect is added to the set of vertexes and each linear segment is added to the set of links. Each vertex and each link is associated with a unique ID. A vertex with more than two connected links is called “junction”. Any subgraph of G connecting exactly two neighbouring junctions is called a street. Any link is called a street segment. A street can be seen as a path in the graph with a junction at each end and zero or more non-junction points in-between. To achieve ordering, we define the beginning of a segment as the vertex with the lower ID.

The position of a car in the graph can then simply be encoded as the edge-ID and the distance to the vertex with the lower ID. A distance between two nodes on the same link is then merely given as the absolute value of the difference of both relative positions.

B. Application to CBF

In the following we assume that position information is encoded as defined above, i.e., as edge-ID and distance rather than geometric position. CBF uses a timer-based contention scheme to let the best next hop “select” itself and suppress less suitable nodes. To use CBF together with a street-based position encoding scheme, a new distance function has to be found to calculate each potential forwarder’s suitability. A simple geometric operation is no longer sufficient, since the position information does include topological information rather than absolute values.

A solution to this problem is fairly straight forward. Either the final destination is on the same street segment as the potential forwarder in which case the distance can be calculated as the difference between the distances of both nodes towards the end of the segment. Otherwhise, all segments on the shortest path between the two nodes as well as the distance of both nodes to the end of the segment they are located on have to be summed up.

As shown in [6] the use of geometric positions may lead to the frequent use of recovery strategies to escape local optima. This is caused by the fact that two points may be geographically very close but topologically far apart, e.g., when they are separated by an obstacle such as a house. Using information about the topology (e.g., the shortest path) of the network of streets can reduce this problem: since a valid street is the basis of the calculation, obstacles are implicitly taken into account.

C. Geocast and Flooding

An interesting observation is the convergence of unicast, geocast and flooding in highway scenarios.[4]

Assuming all nodes are able to listen to communication not originally destined for themselves (promisicious mode), unicast between two nodes is similar to flooding or geocasting to the highway segment between them. This allows for very efficient flooding algorithms.

Geocast is usually defined as addressing all nodes in a geographic region defined by a geometric shape. For street-bound car traffic, this region is the intersection of the geometric shape and the streets themselves. Street-based position encoding allows applications to address these streets directly. This can be highly desirable, for example when a safety application wants to let all cars traveling behind know that something dangerous happened. With street-based position encoding, limiting the area of information forwarding to a street comes natural whereas standard geocast requires that the street geometry itself is transformed into a geometric shape.

V. CONCLUSIONS AND FUTURE WORK

In this paper we compared plain CBF with plain beacon-based greedy forwarding for a highway scenario by means of simulation. As an extension of [5] and [10], we showed that CBF achieves similar delivery ratios as "beacon-based greedy" routing (B-PBR) while using less reactive and no proactive overhead. Moreover, we showed that B-PBR suffers from inaccurate neighbor information leading to a trial-and-error forwarding strategy.

We further described a position-encoding scheme suitable for VANETs and its applicability to CBF. Finally, CBF can help to bring together forwarding, "intelligent" flooding, and geo-cast in a conceptual way.

Subject to future work is the complete integration of the new components in the simulation and – combined with a wider range of movement patterns – a deeper evaluation of its performance. Also the application of the new CBF-street scheme as a building-block for two-dimensional scenarios will be investigated.

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[4] Geocast ist the addressing of a geographic region and fboding is the addressing of all nodes, often within a certain hop-range.

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