Infrastructure Support for Contention-Based Forwarding

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***Abstract*—Geocast is an important forwarding method for vehicular networks. One standard of vehicular communication is ETSI ITS-G5 GeoNetworking. One of the forwarding methods for geocast in this standard is Contention Based Forwarding (CBF). CBF is dependent on a favourable vehicle distribution to forward messages over multiple hops. A method to extend the effective range of vehicles is to use road side infrastructure to help forward messages. We propose a slightly modified CBF algorithm for road side infrastructure to enable infrastructure assisted forwarding for geocast messages, without modifying the CBF algorithm in the vehicles. In this paper we show that such a relatively small modification can significantly increase delivery rates while also reducing wireless load and delivery delays.**

***Index Terms*—geocast, CBF, ITS-G5**

I. Introduction

Connected, and possibly even autonomous, vehicles derive many benefits from communication with each other. Close range communication can include transferring a vehicle's current speed and information regarding acceleration. Such data allows traffic flow to be more efficient. This kind of close ranged data can be transferred through wireless communication to vehicles in range or relayed through a small number of vehicles to others vehicles in the area.

Data from farther away can also be useful to increase traffic efficiency. Consider information on accidents or local weather warnings delivered to vehicles on specific streets. There are many potential reasons such geographically scoped packets (geocast) cannot be delivered to all vehicles in their destination area. Among these reasons are interference, congestion and the distance between vehicles.

Without road-side infrastructure, so called Road Side Units (RSUs), a message sent to an area needs to be forwarded via multiple hops to reach a destination. Depending on the distance and traffic density, there might be gaps between vehicles that are larger than the transmission range of the vehicle. While unlikely to occur in high-density traffic this can regularly occur in medium or low density traffic.

Besides this forwarding problem, the current ad-hoc forwarding mechanisms used in ETSI GeoNetworking [1] can also suffer from high end-to-end delays as shown in [2]. Using RSUs to route messages through a wired network could help reduce this delay by reducing the amount of wireless steps needed. Ideally this reduction in wireless hops can also help reduce the overall load on the wireless medium.

Using infrastructure to help vehicular networks forward geocast messages is not new. However, most past proposals for infrastructure assisted geographic forwarding, such as [3], [4] and [5], make the vehicle an active participant in the routing protocol. We propose to approach the problem from a different angle: We assume an existing Vehicular Ad-hoc Network (VANET) protocol (ETSI GeoNetworking [1]), and propose to add infrastructure assisted forwarding without modifying the forwarding algorithm in the vehicles.

The goal of this paper is to present, analyse and evaluate an algorithm that modifies an existing ETSI GeoNetworking forwarding method to use RSUs in the forwarding process. We have the following goals: 1) minimal modification to the existing forwarding algorithm; 2) lower the number of wireless transmissions needed to deliver a message; 3) decrease message delivery delay compared to the current forwarding algorithm.

ETSI GeoNetworking [1] defines two possible algorithms for forwarding packets towards a geographical area: The Greedy Forwarding (GF) algorithm and the Contention Based Forwarding (CBF) algorithm. The GF algorithm actively selects the neighbour that is closest to the destination as a forwarding next hop. The CBF algorithm works by simply broadcasting the message and hoping a neighbour closer to the destination will forward it [6]. While this might not seem very efficient, there is some redundancy built into the CBF algorithm as we will explain in Section II. As not modifying the algorithm in the vehicle is one of our main requirements, we choose to focus on CBF as it does not actively select a next hop, but rather passively lets the best next hop forward packets.

In this paper we present and evaluate an modified CBF algorithm for RSUs that can prevent further wireless forwarding and instead make use of fixed infrastructure. We assume that all RSUs are connected and their network has geographic routing capabilities. We show that with these minimal modifications we can increase geocast delivery rates and reduce wireless load and delivery delays.

This paper is structured as follows: In Section II we will explain the CBF algorithm used by ETSI GeoNetworking in greater detail. In Section III we present our algorithm, which will allow infrastructure to help with the forwarding of CBF packets towards a destination. We evaluate our algorithm in a simulation in Section IV. Finally we summarise and draw conclusion in Section V.

II. Contention Based Forwarding

CBF is a forwarding technique for ad-hoc networks in which packets are forwarded based on which node transmits first [6].

In the context of ETSI GeoNetworking this is done via a time-out, based on the distance between sender and receiver [1]. From now on, when we refer to CBF we refer to the specific algorithm defined in the ETSI GeoNetworking standard.

The general concept for CBF is that when a vehicle (or other device) sends a message to a destination area, it simply transmits this message and starts a timer to schedule a retransmission. If the original transmitter later overhears another node transmit the packet, it will know the message was forwarded and cancel the timer so as not to rebroadcast the message. When another node receives a message it starts a timer based on the packet's progress. The progress is defined as the distance the packet got closer to the destination area compared to the previous transmitter. The more progress a packet has made, the lower the timer is. When a timer expires and the node has not received a duplicate of the packet it transmits the packet. This system ensures that the receiving node closest to the destination area retransmits a packet, and other nodes do not. Equation 1 shows the method used by ETSI GeoNetworking to calculate the time-out T.

$$T = \begin{cases} T_{max} + \frac{T_{min} - T_{max}}{D_{max}} \times D & \text{for } D \leq D_{max} \\ T_{max} & \text{for } D > D_{max} \end{cases} \quad (1)$$

In this equation T_{max} is the maximum time-out (100 ms), T_{min} the minimum time-out (1 ms). D is the distance between the transmitter and receiver. The maximum communication distance D_{max} defaults to 1000 meters in the standard [1].

When a node transmits a message it also starts a timer (of T_{max}). When this timer expires and the node has not received the same message from another node, it will rebroadcast the packet. This mechanism prevents single packet losses from leading to an undelivered packet. When all nodes inside a destination area are reached, there are almost certainly nodes left with a broadcast timer running. This will lead to at least one, and depending on the relative position of the nodes possibly multiple, broadcasts of the message that are not strictly needed. This can be considered overhead of the protocol.

There is a small difference between CBF inside and outside the destination area. Outside the destination area the timer is based on the progress towards the destination area, nodes that do not make progress towards the destination area drop the packet. Inside the area the timer is based purely on the distance towards the transmitting node. This ensures a packet is spread throughout the destination area, independent from where it first entered the area.

Like any ad-hoc forwarding mechanism CBF suffers from delivery problems in situation with a low node count, or low traffic density in the vehicular network context.

III. Infrastructure-assisted Geographic Broadcast

Geographic broadcasting that relies purely on ad-hoc forwarding between vehicles has reliability issues in less than very dense traffic. We believe this issue can be solved while improving efficiency and increasing reliability in all traffic densities using available infrastructure (RSUs). RSUs can assist in bridging the 'gaps' between cars on the road described earlier and decrease overall wireless traffic by routing messages between themselves.

One of the challenges for such a system is preventing the vehicles from rebroadcasting messages with minimal, or even zero, modification of the existing protocols. Another is routing the message between the RSUs so that only RSUs that should receive the message do so. We choose to modify CBF as this allows us to prevent vehicle-to-vehicle forwarding without modifying the forwarding algorithm within the vehicle.

This modification is possible with CBF due to its 'cancellation' property. Other available forwarding methods in ITS-G5, such as greedy forwarding, depend on selecting a forwarder by the sending node. These algorithms would require modification in the algorithm for vehicles to enable infrastructure assisted forwarding. With CBF, packets that are received a second time cancel scheduled transmissions of the same packet received earlier. This property allows RSUs to change the forwarding behaviour of vehicles by selectively transmitting packets to cancel these timers.

Our proposal is based on several assumptions: We assume that at least some RSUs are placed along a road. We simplify this road to a one-dimensional line on which vehicles travel. Our RSUs do not participate in the 'normal' CBF procedure followed by the vehicles, but instead use our algorithm. All RSUs are connected through a network that supports geocast to distribute messages between them. RSUs are also aware of the coverage of other RSUs, ideally through the routing protocol on their connecting network.

A. Proposed Algorithm

As our infrastructure assisted CBF proposal makes no modification to the forwarding logic of the vehicles they follow the CBF algorithm as defined in the ETSI Geonetworking standard [1], as we have briefly explained in Section II. For the most part, RSUs act as normal geo-routers, but they make CBF decisions based on their location and proximity to other RSUs and vehicles. As part of their normal operation RSUs also keep track of all vehicles in their range by listening to periodically sent frames containing, among other things, the vehicles position and speed.

When a vehicle transmits a geocast packet it can reach a RSU in two ways, which depends on how many RSUs cover a road: it is directly received by a RSU (single hop) or forwarded by one or more vehicles before reaching the RSU. For our algorithm, and by extension the receiving RSU, both situation are identical. In the text we assume the source of a message is a vehicle, but this could also be any other device with geocast functionality.

The simplest case for our algorithm is that of full RSU coverage. In this situation the RSU that receives the initial geocast packet from a vehicle will forward it to all RSUs that cover (parts of) the destination area. These RSUs can then broadcast the packet. If the initial receiving RSU itself is outside the destination area, it will also send the packet to the next RSU in the direction of the destination area. This RSU can then transmit the packet with a remaining hop limit (rhl) of 0 to cancel vehicular CBF, but it will only do this if a vehicle is present that could have overheard the initial transmission from the source vehicle. This cancelling step prevents the message from still being forwarded through CBF, which would lead to an increase in wireless channel load.

In the case of incomplete coverage of the destination area the process is more complicated. The RSU that receives the initial broadcast will have to check if the edges of the destination area are covered. If this is the case it will simply transmit the packet to all RSUs that cover the destination area, which in turn will set the correct rhl, with a procedure we will explain later, before broadcasting the packet. In case there are no RSUs covering the edges of the destination area, the RSUs closest to those edges outside of the area will also have to transmit the packet. This method ensures that if there is a forwarding path using CBF to the area it will be used. The downside of this method is that the overall load on the wireless channel will likely be higher compared to a single forwarding path to the destination area. In this case the rhl will also be calculated according to the procedure explained below.

When no RSUs are present there is no difference compared to normal contention based forwarding as defined in the standard, as we make no changes to the CBF procedure in vehicles. Our algorithm works exclusively on RSUs and only interacts with the CBF functionality of vehicles by sending geocast packets.

1) Choosing the remaining hop limit: When there is full coverage by RSUs in the destination geocast area, we can make them broadcast a message with a rhl of 0. Any receiving vehicle that had a timer for that packet will cancel the timer, preventing vehicles from rebroadcasting the message. Vehicles that did not receive the message before will not forward it due to the value of the rhl. However, when there are gaps in the RSU coverage, we need vehicles to forward the message to also reach these areas. We ensure this happens by setting the rhl to a non-zero value that is based on the distance from the transmitting RSU to the next RSU. We calculate the rhl as shown in Equation 2:

$$rhl = \left\lceil 2 \times \frac{d_{rsu} - d_{trans}}{d_{trans}} \right\rceil \tag{2}$$

In this equation d_{rsu} is the distance to the next RSU in the direction of the destination area. If the RSU is inside the destination area this is the distance to the furthest RSU on either side. The variable d_{trans} is the transmission range of a vehicle, which in reality would be highly dependent on external factors, such as interference. Using this rhl the message should always be able to at least reach the edge of the next RSUs coverage area.

This remaining hop limit is based on a worst case scenario in which vehicles are distributed in such a way that two hops are needed to traverse a distance of d_{trans}, as shown in Figure 1. In this situation a vehicle has another vehicle just in front of it and a third vehicle is just out of range of the first, but not the second, and so on. The result of this vehicle distribution is that two transmissions are required to cover a little more than one transmission distance.

2) Initial receiving RSU procedure: We show the algorithm for the initial receiving RSU in Algorithm 1.

The RSU first checks if the received packet has already

Algorithm 1: RSU receiving geocast packet on wireless interface (Vehicle-to-Infrastructure (V2I))

```
Input : Geocast packet gbm
        Source src
        Transmitter src
        Destination area dst
Boolean transmit = false;
if packet ∈ gbm_cache then
    return;            // Duplicate packet, drop
gbm_cache.add(gbm); // Add packet to cache
send_to_RSUs(gbm);   // Send the packet to
    all relevant RSUs
if gbm.rhl ≥ 0 then
    if !covers(dst) & !closest_rsu(dst) then
        transmit = true;  // Not covering area
            and not closest
    else if covers(dst) & calcRHL == 0 then
        // Equation 2
        transmit = true;     // Covers area and
            (local) full coverage
if transmit then
    sleepRandom(0.001, 0.003) ;          // Sleep
    gbm.rhl = 0;                    // Cancel CBF
    Broadcast(gbm);
return;
```

Algorithm 2: RSU receiving packet on fixed interface (RSU to RSU)

```
Input : Geocast packet gbm
        Source src
        Forwarder fwd
        Destination area dst
if packet ∈ gbm_cache then
    return;         // Duplicate packet, drop
gbm_cache.add(gbm); // Add packet to cache
Boolean transmit = false;
if covers(dst) & vehiclesInArea(dst) then
    gbm.rhl = calcRHL();            // Equation 2
    transmit = true;
else if !covers(dst) & !insideArea(src,dst) then
    if isclosestToEdge(dst) then
        gbm.rhl = calcRHL();        // Equation 2
        transmit = true;
    else if containsOverhearers(src) then
        gbm.rhl = 0;
        transmit = true;
    else if isClosestToSrcRSU(fwd) then
        gbm.rhl = 0;
        transmit = true;
if transmit then
    Broadcast(gbm);
return;
```

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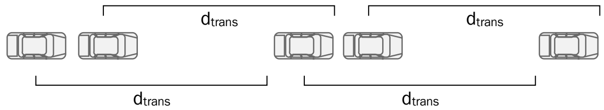


Figure 1: Most un-optimal CBF scenario

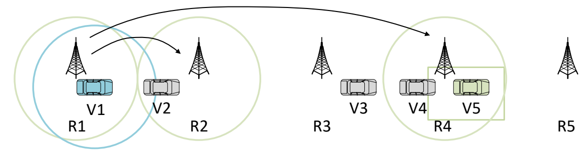


Figure 2: Infrastructure assisted CBF example

been received before. If this is the case the packet is not processed further. If it was not received before we add it the the packet cache and forward the packet to all RSUs that cover the destination area and the first RSU in the direction of the destination area.

The next step is to figure out if we need to cancel packet forwarding by vehicles. The RSU checks if the remaining hop limit is larger than 0. If it is we check if the RSU is not in the destination area or the closest RSU to the edge of the destination area (line 7). If this check passes it means we can cancel further vehicular forwarding of the packet as other RSUs will deliver it. Another reason to cancel CBF is if we are inside the destination area and there is full RSU coverage in our surroundings (lines 9-10).

If one of the previous checks passed the RSU broadcasts the message after a small delay (line 12) with he remaining hop limit set to 0 (line 13) to prevent further vehicular forwarding.

3) Fixed network receiving RSU procedure: The procedure followed by an RSU that receives a geocast message on it's fixed interface from another RSU is shown in Algorithm 2.

As with the previous algorithm the RSU first check if the packet was seen before and if it was, stops further processing (lines 1-2). If the packet is new it is added to the packet cache (line 3). The RSU then performs its transmitting checks. If the RSU covers the destination area and vehicles are inside this area (line 5) the remaining hop limit is calculated according to Equation 2 (line 6). If the previous check failed, the RSU does not cover the destination area and the original source is also outside the destination area (line 8), we perform some extra checks.

There are three conditions under which this RSU will still broadcast the message: i) This RSU is closest to the edge of the destination area (line 9) and will calculate the remaining hop limit if so. ii) This RSU covers vehicles that could have overheard the original source (line 12) and should cancel forwarding with the remaining hop limit set to 0 (line 13). iii) This RSU is the first RSU between the RSU that received the message on its wireless interface and the destination area (line 15). If this is the case the RSU should also set the remaining hop limit to 0 to prevent possible vehicular forwarding (line 16). If any of the checks passed the RSU will transmit the message on its wireless interface (lines 18-19).

4) Routing: Communication between RSUs should be handled by a geographic routing protocol on the fixed network that connects the RSUs. This protocol should ensure that packets arrive at the RSUs that cover the destination area. We have presented such a geocast routing algorithm in [7]. For the rest of this paper we will assume such a routing protocol is running on the network connecting the RSUs. In some cases the RSU that received the packet on its wireless interface should also address other regions. This will ensure CBF is cancelled as soon as possible, and areas not directly covered by a RSU will receive the message through vehicular forwarding.

5) Example: To help illustrate how our algorithm works we will present an example in Figure 2. In this figure we have a full coverage situation with a RSU every 800 meters, assuming a 400 meter transmission range. A car (V1) which is the source of the geocast packet is positioned 100 meters east of one of these RSUs (R1). The destination area is 2km east of the transmitting car (green rectangle). The RSU 100 meters to the west of the car (R1) will receive the geocast message and immediately rebroadcast this message with a rhl of 0. R1 will also transmit the message to all RSUs covering the destination area (R4), and to the RSU directly east of the source car (R2). R2 will broadcast the message with a rhl of 0 to cancel any CBF operations of cars in its reach (V2). The RSUs covering the destination area (R4) will also broadcast the message with rhl of 0 as there is full coverage.

IV. Evaluation

To evaluate our proposal for an RSU assisted geocast system we have evaluated it in a simulation environment. We will first describe the environment used, followed by the different evaluation scenarios used and finally the results.

A. Simulation Tools

Our simulation environment consists of three main tools: OMNeT++, SUMO and Veins. These tools work together to perform the entire simulation. We used OMNeT++ [8] as our network simulator. We use it to simulate the communication between vehicles and between vehicles and RSUs. To get an accurate representation of traffic on a highway we use the SUMO traffic simulator [9].

We build our simulation code on the basis provided by Veins [10]. This framework for OMNeT++ provides us with an implementation of IEEE 802.11p [11] with the Wave protocol stack [12] as described in [13] and [14]. We have extended this system by implementing CBF for the vehicles as specified by the ETSI ITS geonetworking standard [1]. We have added RSUs and given them the ability to communicate with each other over a wired network next to their IEEE 802.11p based wireless capabilities. CBF for these RSUs has been implemented as specified in Section III-A. To connect the Veins framework with SUMO we use TraCI [15]. This protocol and associated set of tools allows us to use SUMO vehicle data in our Veins simulation.

B. Simulation Values

All vehicles in the simulation send a Basic Safety Message (BSM) frame every 0.5 seconds, this is WAVE's equivalent of the ITS G5 Cooperative Awareness Message (CAM). This BSM contains, among other information, the current position and speed of the vehicle. Vehicles and RSUs store (some of) the information in these packets to keep track of surrounding vehicles. The most interesting part of this information for our CBF implementation is the location of vehicles. The RSU algorithm uses this information to decide the remaining hop limits and if it will transmit a packet at all. RSUs are connected to each other on a fixed network with negligible delay.

We use the following settings for Veins: We set the transmission power to 20mW and the bit-rate to 6 Mbps in Veins' IEEE 802.11p mac layer. For the physical layer we set receiver sensitivity to -89 dBm, the thermal noise to -110 dBm. Most of these values influence the effective transmission range in the simulator. Using the values mentioned above the maximum transmission range is effectively 400 meters during all our simulation runs. In the remainder of this chapter d_{trans} can be assumed to be 400 meters when mentioned in relation to the simulation environment. We do not make use of channel hopping in WAVE.

All simulated vehicles have identical properties in the simulation. Vehicles have a maximum acceleration of 2.6 m/s^2 and a maximum deceleration of 4.5 m/s^2. The maximum speed of the vehicles is limited by the maximum speed of the road (120 km/h), but the vehicles speed is multiplied by a random factor that is normally distributed with a mean of 1 and a standard deviation of 0.1. Vehicles start at the maximum allowed speed and only slow down, and speed up again, in response to other traffic. Due to the randomized speed differences, vehicles can and will overtake each other during the simulation just like real road traffic.

C. Evaluation Scenarios

We will evaluate our algorithm in several scenarios with different traffic densities and RSU coverage situations. All our simulations use the same road: An 8 kilometre segment of a two lane highway with a maximum speed of 120 km/h.

We use different traffic densities (given by the inter-arrival rate of vehicles) in different RSU coverage situations. We define our coverage scenarios by the distance between neighbouring RSUs. These distances are based on the transmission distance (d_{trans}), which has a maximum range of 400 meters in our simulations. We evaluate 4 different coverage scenarios: 1) Full RSU coverage (RSUs are spaced $2 \times d_{trans}$ away from each other). 2) Half RSU coverage (RSUs are spaced $4 \times d_{trans}$ away from each other, effectively removing every second RSU). 3) One quarter RSU coverage (RSUs are spaced $8 \times d_{trans}$ away from each other). 4) No RSU coverage (pure CBF).

For the full coverage scenario RSUs are positioned at 1200, 2000, 2800, 3600, 4400, 5200, 6000, 6800 and 7600 meters. For half coverage the RSUs at position 1200, 2800, 4400, 6000 and 7600 meters are used. The one quarter coverage scenarios uses only the RSUs positioned at 1200, 4400 and 7600 meters.

Time of day	Vehicles/h	Inter-arrival rate [λ]
8:00 - 9:00	2679	0.74
9:00 - 10:00	1765	0.49
13:00 - 14:00	2100	0.58
20:00 - 21:00	1177	0.327

Table I: Inter-arrival rates of vehicles used in the simulations, based on traffic on the A1 near Hengelo [16]

In each simulation run, we select a single vehicle that will be the initial source of the geocast packet. This transmission is triggered at 402 seconds into the simulation. The position p of this initial transmitter is selected based on the run id r: $p = 1200 + 32 \cdot r$. The first run ($r = 0$) has the initial source at 1200 meters and the last run ($r = 49$) has it at 2768 meters, for a total of 50 different positions. We start at 1200 meters to give the simulation some time to establish a more realistic traffic pattern. We select the car closest to this location in the simulation after 402 seconds as the initial transmitter.

We use an destination area that is between 200 and 1600 meters long (in steps of 200 meters) and is located 0 to 3200 meters from the initial transmitter (in steps of 200 meters).

We perform these tests under four different traffic conditions by varying the arrival rate of vehicles in our simulation. We use the inter-arrival times in Table I for our simulations. These numbers are based on the INWEVA 2017 working day hourly data [16]. This data represents the average traffic intensity in an hour on a normal working day measured at a road segment of the Dutch A1 highway near the city of Hengelo. We chose a highway with medium traffic specifically as traffic densities close to the road capacity will not have any forwarding gaps.

We run 3600 simulation per inter-arrival time and coverage scenario for a total of 43,200 simulations. Due to space limitations we will only show plots for the 0.74 and 0.237 arrival rates, representing 21,600 simulation runs.

For each simulation run we let SUMO run for 400 seconds before we start the actual simulation. This gives the generated vehicles some time to spread out and fill the simulated road. At 400 seconds we start the network simulator, we broadcast our geocast message at 402 seconds. This two second gap ensures that RSUs have enough time to receive multiple BSMs from all vehicles in their range.

1) Packet Loss: There are multiple ways in which packets might not be received by vehicles or RSUs. In general there can be two main causes for undelivered packets in the simulation: 1) The vehicle is out of range or has no RSU coverage. 2) A collision that is not corrected by a retransmission.

The first issue can occur when there is a gap in the forwarding chain that could not be bridged. Another reason can be there is no RSU coverage in the destination area, and no vehicle-to-vehicle path from another RSU to the destination.

The second problem occurs when two packets are transmitted at the same time. In normal CBF a timer will trigger when the sender does not overhear its message being forwarded, transmitting the message again to increase the chance of delivery. Our RSUs do not rebroadcast messages as this introduces complexities in the forwarding cancelling system.

On roads with multiple lanes the situation might occur that there are two cars forwarding a message if they are driving next to each other. This causes the CBF algorithm to roughly have the same time-out on forwarding. If the timing is right this might cause cars further on the road to receive the packet twice, causing them to cancel their timers and stop message forwarding. In the unlikely event they start transmitting at the same time this will cause a collision.

D. Simulation Results

To evaluate the RSU assisted geocast we will focus on delivery ratios, the number of transmissions needed and the delivery delay. These numbers will give us insight into how effective our solution 'intercepts' messages, and the overhead it introduces in terms of wireless transmissions compared to the baseline of normal CBF (no RSUs present). Solutions in which vehicles actively participate in routing packets will always have the benefit of more efficient routing towards an RSU and will also not require transmissions to 'cancel' CBF. As such, we choose not to directly compare against such solutions as our proposal will on average be less optimal.

1) Delivery ratios: For the delivery ratio we look at the fraction of nodes present in the destination area that received the geocast message. We take the number of vehicles that have received the geocast message and divide this by the number of vehicles present in the destination area for a simulation run. We ignore runs with no vehicles present in the destination area.

We show the delivery ratios of our simulation runs in Figure 3 as the fraction of vehicles in the destination area reached. The error-bars represent the 95% confidence interval of this fraction. These two figures each show the results of a different vehicle inter-arrival rate. We show the full coverage situation (blue line), half coverage (orange line), one quarter coverage (green line) and finally no RSU coverage (red line). The no coverage situation is pure vehicle-to-vehicle CBF.

We see that in all cases the full coverage scenario allows the geocast message to reach (almost) all vehicles. The small losses are due to collisions with BSM messages. This highlights the main downside of the RSU based transmission, there is no redundancy. In normal CBF a retransmission will occur.

The half coverage scenario is as reliable as the full coverage in the high traffic density simulation, but less so in the low traffic density simulations. Packets are being routed to the destination area from two sides when the destination area is between two RSUs. We will show the cost of this in number of transmission later. The slightly lower delivery fraction at 0 meters to the destination area is caused by there always being at least two transmissions in the full coverage scenario (vehicle and RSU), the scenarios with less coverage might not have these 'cancel' transmissions.

The delivery ratio for the one quarter scenario is highly dependent on the distance to the destination area. The delivery rate mostly follows that of the no RSUs scenario for the first 1200 meters, this is the (average) distance that has no RSU coverage in this scenario. The further the destination area is from the source the better this coverage situation performs compared to no coverage. One quarter coverage still has a 70% delivery rate at 3200 meters to the destination area in most traffic densities, only dropping to 50% in middle of the night traffic (Figure 3b).

In general we see, as was expected, that we have a very high reliability with 100% RSU coverage. The scenario with 50% RSU coverages also has close to 100% delivery rate, only dropping to just under 90% for the least busy traffic situations. For the coverage situation with one quarter of the RSUs we see that the it becomes less reliable with distance. With no RSU coverage the distance correlation is even higher, resulting in low delivery ratios at larger distances.

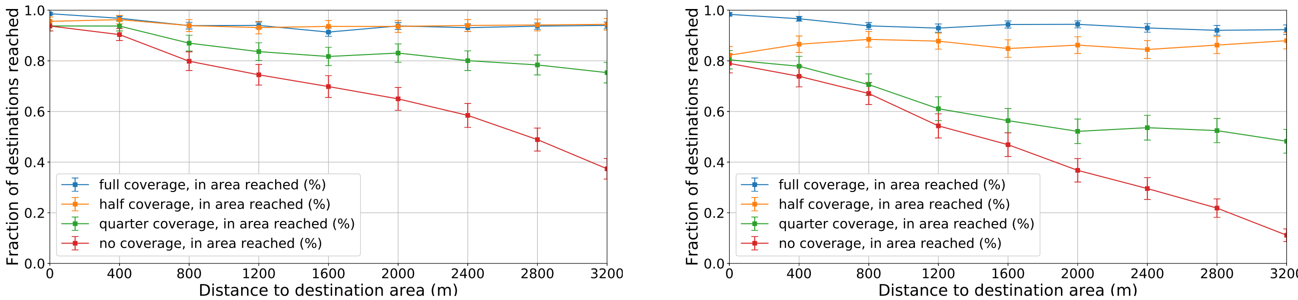
2) Number of Transmissions: We count the number of transmissions per simulation run to compare the efficiency of the different coverage scenarios in this regards. This number is simply the total number of geocast transmissions made by vehicles and RSUs in the simulation.

We show these numbers in Figure 4, where we plot the number of transmissions against the distance to the destination area. As with the delivery ratios, we show the full coverage situations as a blue line, the half coverage situation as a orange line, the one quarters coverage situation as a green line, and the no coverage situation as a red line. The error bars represent the 95% confidence interval of the results.

We can see that the full coverage scenario (blue line) has a consistent number of transmissions in both traffic densities. The number of transmissions is always three at 0 meters to the destination area: The initial transmission of the source vehicle, the cancelling transmission of the RSU, and finally another cancelling transmission of the next RSU. The total number of transmissions increases with distance until it stabilizes at an average of 5 transmissions. Two of these are caused by the initial transmission and the cancelling transmission of the receiving RSU. The other three are a combination of the one to three RSUs needed to cover the destination area and a possible 'cancel' transmission from the next RSU as seen from the initial receiving RSU towards the destination area. This behaviour is consistent over all inter-arrival rates as the presence of vehicles is irrelevant in the full coverage scenario.

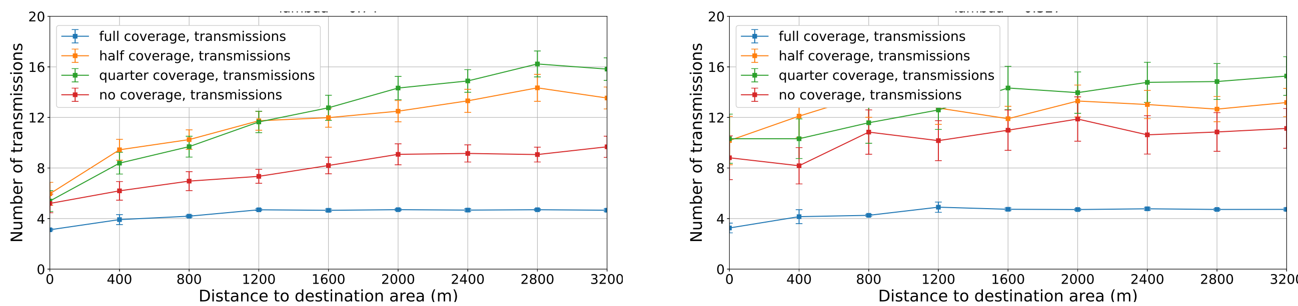
With the half and one-quarter coverage scenarios we see an increase of the number of transmissions with distance. This is caused by three things: 1) The message taking multiple hops to reach the initial receiving RSU, as coverage of the initial source is not guaranteed in these scenarios. 2) A later 'cancel' message from the next RSU as seen from the initial RSU. 3) Messages being transmitted by RSUs at both sides of the destination area. Note that the delivery rate of the quarter coverage scenario is lower than the half coverage scenario as we have shown in Figure 3. We can not conclude that quarter coverage is better than half coverage based on the roughly similar number of transmissions as the delivery rate is lower.

Note that the no coverage scenario (red line) has a lower number of transmission as the half or quarter coverage scenarios. This is a result of the lower delivery ratios of pure CBF, as



(a) $\lambda = 0.74$ (b) $\lambda = 0.327$

Figure 3: Geocast delivery rates for different distances to destination area



(a) $\lambda = 0.74$ (b) $\lambda = 0.327$

Figure 4: Number of transmissions needed to reach destination area

have been shown in Figure 3. If a message did not reach the destination area there are also no corresponding transmissions.

Overall full RSU coverage gives the lowest number of transmissions. It is important to note that this number is consistent with the size of the destination area. Had we chosen even larger destination areas, or smaller RSU coverage areas due to a lower transmission range and more RSUs, the number of transmissions would have scaled accordingly.

3) Delivery Time: An important aspect of packet forwarding is the time it takes to deliver a message inside the destination area. Specifically, we measure the time (in seconds) that is needed to reach vehicles inside the area. We ignore runs in which no vehicle inside the area were reached.

The average delivery times of our simulation runs can be seen in Figure 5, where the blue line represents the full RSU coverage scenario, the orange line represents the half coverage scenario, the green line the one quarter coverage scenario and the red line represents no RSUs. The error bars represent the 95% confidence interval of the results.

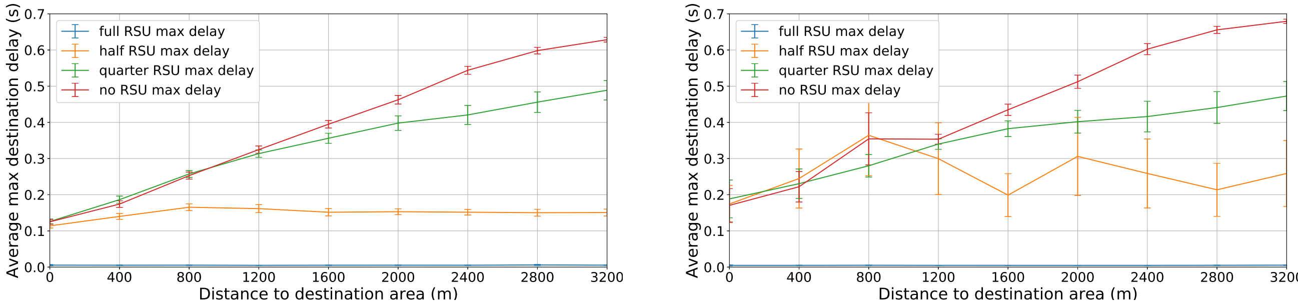
We observe that the delivery time using infrastructure assisted geocast with full coverage is almost instantaneous. This makes sense as there is only a very low delay following the initial RSU receiving the message. The main factor of the delay is the forwarding distance based timer of CBF, which does not come into play in our full coverage scenario.

The half coverage scenario is more interesting, the delay is relatively consistent. This effect is due to the situations where the destination area is (partially) between two RSUs. The message is forwarded by vehicles on the path to the last nodes. This vehicle-to-vehicle forwarding path has a worst-case distance of 800 meters, where the only forwarding path is from one RSU up to the edge of the other RSU's coverage area. The confidence interval in the low traffic density simulation (Figure 5b) is relatively wide due to placement of the vehicles.

In the one quarter coverage scenario we see an increase in delivery time with the distance to the destination area. There does not appear to be a maximum value as with the half coverage scenario, although there is noticeable less increase per distance after 1600 meters. This is caused by the relative positions of RSUs and initial transmitter in these simulations. The first RSU is relatively near the initial transmitter, the next RSU is 3200 meters further down the road. As the initial transmitter's position moves in the different simulations between the first and second RSU, a distance of 1600 meters is on average just before the second RSU.

The no coverage scenario has a delivery delay that, as could be expected, scales with the distance. The increase in delay looks linear, except near the end of our distance scale. This is caused by packets never reaching the destination area, as we only measure delivery time inside the destination area. Packets that do reach the destination area likely have a faster path due to a more ideal traffic distribution.

Overall we can conclude that the traffic density has almost no impact on the delivery delay in any of our simulation scenarios. All delivery delays are close to identical with the exception of the lowest traffic density. The size of the confidence interval shows that there is a wider range in delays due to the positions of the relatively small number of vehicles on the road.



(a) $\lambda = 0.74$

(b) $\lambda = 0.327$

Figure 5: Geocast delivery delay over distance

V. Conclusions

In this paper we have presented a modified CBF algorithm for infrastructure-assisted geocast in which RSUs help forward geocast messages from vehicles towards a destination area. Our algorithm does not require changes in the vehicle for ETSI ITS Geo-Networking, it only requires additions to RSUs.

We have shown that this relatively simple algorithm can help increase the probability that messages are delivered. Even when the RSU coverage of a road is only 50%, delivery ratios are only slightly below 90% for a low traffic scenario, and above 90% for denser traffic. The size of a destination area seems to have little influence on the delivery ratio.

We have also shown that the overhead of infrastructure assisted geocast in terms of the number of wireless transmissions is very low. Full RSU coverage has around half of the transmissions needed by normal CBF. Half RSU coverage has about 50% more transmissions compared to pure CBF but has a much higher delivery ratio.

Infrastructure assisted geocast also reduces the delivery delay of geocast packets. The delay with full RSU coverage is almost fully dependant on the transmission delay between RSUs, and as such is close to 0 seconds. The half coverage delay is mainly determined by the CBF timer delay and is around 0.16 seconds given our simulation values.

We can conclude that infrastructure assisted geocast can greatly increase the delivery ratio and reduce delivery delay of geocast packets. The downside is that RSUs and the infrastructure between them are required for this system to function, where CBF requires no fixed infrastructure. Due to this trade-off RSUs might only be feasible in places where high reliability is required. In these places infrastructure assisted geocast can help reduce wireless traffic and increase reliability.

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