Evaluation of a low-overhead forwarding algorithm for platooning

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Abstract—In this paper we present a novel message forwarding algorithm, the reachability matrix algorithm, for V2V communication in a platooning scenario. The algorithm uses a communication quality estimate to determine appropriate forwarding candidates. We show that the algorithm achieve a higher reliability in the communication compared to only using broadcast but still keeping the message intensity at a low level. The reachability matrix algorithm can decrease the ratio of missing a data age limit of 0.2 seconds from 18% to 11%, a decrease of 40%, while increasing the message intensity by only 21% compared to only using broadcast. The evaluation has been performed through simulation using input from real-life V2V measurements on heavy duty trucks in a platooning scenario.

Keywords—Forwarding; 802.11p; Platooning; V2V;

I. Introduction

Intelligent transportation systems (ITS) have high potential to change the way transportations will be handled in the future. Several ITS applications have been suggested, ranging from intelligent pedestrian crossing warning systems [1] to highly automated driving in, e.g., vehicle platooning [2]. Vehicle platooning, when vehicles cooperate and automatically follows a leading vehicle, promises several advantages in terms of improved safety and reduced traffic congestion. Also, by making it possible for heavy vehicles to drive with short inter-vehicle distance the air drag will be reduced leading to a decrease in fuel consumption [3].

The ability to maintain string stability in a vehicle platoon depends on each vehicle receiving information from the preceding vehicles within a certain deadline, e.g., position, speed, and acceleration. Communication delays can seriously compromise string stability [4]. In 2010, IEEE 802.11p [5] at 5.9 GHz was proposed as the wireless standard for ITS applications, including data exchange between vehicles travelling on the road and the infrastructure. Since the radio environment is unpredictable, and the distance between vehicles in a platoon consisting of several vehicles is potentially large, fulfilling the reliability requirements can be difficult. This is especially true when considering heavy vehicles (trucks), which are large compared to the wavelength of a signal at a carrier frequency of 5.9 GHz, resulting in shadowed regions. Therefore, issues such as antenna placement and message forwarding algorithms are imperative in order to maintain reliable communication. Forwarding algorithms allow communication nodes to repeat received messages according to a predefined rule, in order to increase the likelihood of messages reaching shadowed regions or vehicles out-of-range from the original sender.

In this paper we present a novel low-overhead message forwarding algorithm for platooning and perform a comparison of this algorithm with two ETSI ITS-G5 standardized forwarding algorithms [6]. The comparison is performed through simulations using real world measurement data as input.

The measurement data used for simulations is from real-life tests using a platoon of four heavy vehicles as test application. The tests were conducted on a public highway using different packet sizes for the information messages sent between vehicles. By extracting the current Packet Error Rate (PER) over time from the experiments, we can then simulate the impact of different forwarding (or multi-hop) algorithms.

The rest of the paper is organized as follows. In section II the field measurement and multi-hop strategy is positioned among related works. Section III presents message forwarding algorithms, both a novel algorithm for improved reliability whilst maintaining low message intensity, and two other message forwarding algorithms for comparison. In Section IV the V2V measurements are described and in Section V simulations are described. Section VI presents results from simulations and finally in Section VII the paper is concluded.

II. Related Work

Measurements reported in [7] show the problem of not having Line-Of-Sight (LOS) conditions when communicating over a carrier frequency of 5.9 GHz. The authors show that when antennas have LOS conditions the PER is in the order of a few percent. However, when a heavy duty vehicle is obstructing the LOS, the PER increases dramatically to values close to 100%. In [8] measurements in street intersections shows that when transmitting and receiving antennas are more than 70 meters from the intersection center and not in LOS due to obstructing buildings, the PER increase above 50%.

In order to mitigate the high PER when communicating in the presence of obstructing vehicles, such as in platooning, several approaches have been presented. In [9] a simulation study of a method using both multi-hop, in order to reach the entire platoon, and a time divided MAC method to get bounded access to the medium, is proposed. In [10] and [11], periodic beacons are utilized to create a map of potential candidates to forward packets from source to destination in general V2V communication. These two methods requires additional beacons to be sent, which increases the message intensity. The authors of [12] suggest a method that selects transmitting antenna based on the road curvature in order to get higher probability of having LOS condition between transmitter and receiver.

The authors of [9] use a Nakagami fading channel, which does not take into account the NLOS characteristics for platooning as we do with support of our measurements. Our approach of mitigating the difficulties concerning the communication in a platooning scenario has lower overhead, with respect to message intensity, than both [10] and [11]. In [12] it is only the communication between vehicle one and vehicle three in the platoon that is evaluated, not the entire four vehicle platoon as in this paper.

III. Message Forwarding Algorithms

The aim of message forwarding is to make sure messages reach their intended recipient (or recipients) even if environmental conditions makes it hard for the recipient to successfully receive messages directly from the sender. Given unlimited bandwidth and processing resources, the probability for success could easily be significantly improved by having all nodes repeat every incoming message. However, resource limitations force us to find algorithms that take additional parameters into consideration. In the wireless IEEE 802.11p standard, all nodes within communication range share the available bandwidth. A node is only allowed to send when no-one else within range is currently sending. This means that high message intensity will cause delays and ultimately starvation and failure to maintain reliable communication. The problem is exacerbated in situations where there are additional nodes using the same bandwidth, for instance if two platoons meet or there is roadside ITS infrastructure. Even though multi-channel operation is supported [13], the number of channels is limited and vehicles must still contend for the access to each channel.

The goal of a good message forwarding algorithm for a platooning application with high-intensity broadcast messages (where there is no time or bandwidth available for more complex two-way protocols) should therefore be to reach as many intended receivers as possible with as little messaging overhead as possible. It should be noted that even in good environmental conditions where forwards are less necessary, keeping message intensity low is of importance since messages travel farther in such conditions and forwards are therefore more likely to interfere with other vehicles/nodes.

In the sub-chapters below three message forwarding algorithms and plain broadcasting are presented, including the novel algorithm suggested in this paper.

A. Broadcast

This is the base case of our comparison, where each node sends its packet destined to all other nodes. No repetition or forwarding is performed in this case.

B. ETSI ITS-G5 Simple GeoBroadcast Forwarding Algorithm with Line Forwarding

This algorithm [6] has the objective of reaching all nodes within a specified geographical area. Each node sends its packet according to previous subsection (A), but if a node receiving the packet is within a specified geographical area the incoming packet shall be repeated once, increasing the probability that all vehicles within the area receives the packet. In our implementation of the algorithm we have defined a moving geographical area that comprises the entire platoon at all times.

C. ETSI ITS-G5 Contention based Forwarding Algorithm for GeoBroadcast

This algorithm [6] is based on the idea of letting the node that is most likely to make the best forward progress in distributing a message along the platoon be the node to resend a received message. This is done in the following manner:

- When receiving a message, all receiving nodes calculate a timeout which is inversely proportional to the distance between the receiver and the sender; that is, the node farthest from the sender will have the shortest timeout.
- If the node receives the message again from another node (i.e. a node that has forwarded the message) the timer is stopped and the message is not forwarded.

With these rules, the node farthest away from the sender, and therefore most likely to reach even more nodes with the resend, will be the one to forward the packet. All nodes in between the farthest node and the resending node will cancel their own attempts to resend, provided they can hear the node that performed the forward, thus keeping the total number of sent messages down.

D. Reachability Matrix Algorithm

The rationale behind this algorithm is that a communication node can make a better forwarding decision if it knows between which send/receive pairs in the platoon message transmission is likely to succeed. That is, if node α receives a message from another node β and has knowledge about which of the nodes in the platoon are likely to hear itself and which can hear β, then α can determine if forwarding the message is likely to increase the total number of nodes the message will reach. A requirement for such an algorithm is that each node distributes information about which of the other nodes it can hear; we call this *reachability information*. Since reception of any given message can never be guaranteed, the reachability information will, in some form, represent probability of reception success; and since environment conditions change rapidly, this information should be updated often to ensure it stays reasonably accurate.

One straight-forward way to solve the information distribution, given that the message rates for all nodes are known, is that each node continuously computes packet error rates for messages from all other nodes, and periodically broadcasts these PERs so that the other nodes can update their reachability information. The reachability matrix algorithm is based on this concept, but uses some approximations in order

TABLE I. PARAMETERS FOR THE REACHABILITY MATRIX ALGORITHM.

Parameter	Description
N	Number of vehicles in the platoon.
t	Current time.
A	Reachability matrix.
α	Index of local node.
β	Index of source node for incoming message
B	Incoming reachability bit vector.
C	Outgoing reachability bit vector.
limit	Age limit, for which the communication is considered good.
R	Forward Reach number.
d	Wait time.
τ	Adjustable time parameter.

Sub algorithm 1: Update reachability matrix

```
for i = 1 to N
   if Bi == 1 and i ≠ β
      Aβ,i = t;
   end if
end for
Aα,β = t;
```

to keep message overhead and processing requirements low. Instead of computing and distributing a probability, we say that if a node α has successfully received a message from another node β, at least once within a certain time limit, i.e. *limit*, the probability that α can receive additional messages from β is acceptable, i.e., α can hear β. A node can then convey information about which of the other nodes it can hear in the form of a bit vector, the reachability bit vector C, which contains a one for all nodes it can hear, and a zero for nodes it cannot hear. E.g., for a platoon of N vehicles, a bit vector with N bits is needed. Since only a single bit of information is used for each vehicle, the reachability bit vector is small enough to be attached to all regular messages. This means there is no need for extra service messages, and the reachability information is updated as frequently as there are messages sent.

It is assumed that the platooning protocol establishes the order of vehicles in a way such that all vehicles in the platoon have a consistent view of this order. This means that each node can unambiguously map the sender ID of an incoming message to a position in the bit vector and internal matrix representations discussed below. The functionality of organizing the platoon in a feasible order is beyond the scope of this work, as is a discussion of how to reconfigure the order as vehicles join or leave the platoon.

The algorithm is based on a number of actions performed at each message send or receive event. Below, the term local node is used to denote the vehicle performing a certain send or receive action, while a remote node is one of the other vehicles in the platoon. The algorithm can be divided into three separate sub algorithms 1) used when receiving a message, 2) when determining if a message should be forwarded, and 3) when sending a message.

Each node keeps reachability information for all vehicles in the platoon in a local structure called the reachability matrix, which is updated for each incoming message. When receiving a message from node β, the reachability matrix A for node α is updated on row β, with node βs perception of the communication to the other nodes in the platoon. For each

Sub algorithm 2: Forwarding decision

```
R = 0;
Flag = 0;
for i = 1 to N
   if i ≠ α and i ≠ β
         and (t – Ai,α ≤ limit)
         and (t – Ai,β > limit)
      R = R + 1;
   end if
end for
if R > 0
   d = (N – 1 – R) * τ;
   Flag = 1;
end if
timeout = t + d;
while (t < timeout)
   if (Forward Received)
      Flag = 0;
   end if
end while
if Flag
   Transmit Forward;
end if
```

element $A_{\beta,i}$, $1 \leq i \leq N$ and $i \neq \beta$, of row β in the reachability matrix the current time, i.e. t, is inserted if the reachability bit vector, B, from node β indicates good communication, i.e., element B_i equals one. Also the perception of the communication from node α to β is updated at element $A_{\alpha,\beta}$ of the reachability matrix with the current time. For a pseudo code description, see Sub algorithm 1. The parameters are summarized in Table I.

Now the reachability matrix is updated and ready to be used both for taking decisions if the local node shall perform a forward of an incoming message, and to fill the outgoing reachability bit vector C.

After message reception the receiving node shall also determine whether or not the message should be forwarded. This is done by calculating the forward reach number, i.e., R, which indicates how many additional nodes the local node can reach, compared to the original sender, by forwarding the received message. For all nodes except the local (α) or incoming message sender (β), the reach information is compared. If α is expected to reach a remote node that β is not expected to reach, the forward reach number is increased. The time stamps in A are used to determine if the reach information is within the age limit. If the forward reach number is larger than zero a wait time, i.e., d, that is inversely proportional to the forward reach number is calculated. If the local node has not received a forward message from another node during the wait time, the local node will forward the message. If a forwarded message is received the forward reach number is recalculated with the knowledge of the additional sending node, and a new timer is set. That is, the forward reach number is calculated as before but all nodes that are likely to have been reached either by the original sender or the forwarding node are not included in the forward reach number. If the new forward reach number is 0, the forwarding action is regarded as no longer needed and therefore cancelled, see Sub algorithm 2.

Sub algorithm 3: Outgoing reachability bit vector

```
for i = 1 to N
   if (t − Aα,i ≤ limit) and i ≠ α
      Ci = 1;
   else
      Ci = 0;
   end if
end for
```

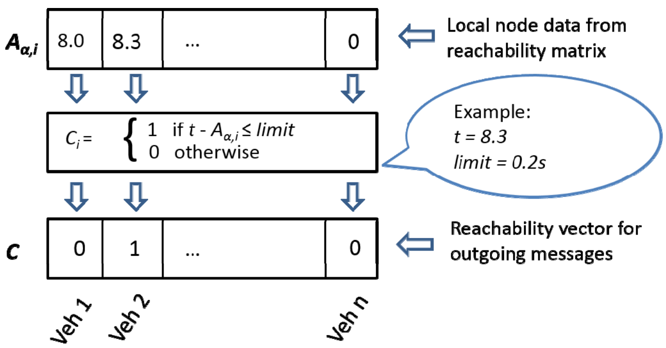

Fig. 1. Description of how the outgoing reachability bit vector is filled with forwarding information.

When a node prepares to send a message of its own (i.e., not forwarding) the outgoing reachability bit vector C needs to be updated with the local node's current understanding of the quality of the communication to the remaining nodes in the platoon. For each time stamp $A_{\alpha,i}$ $1 \leq i \leq N$ *and* $i \neq \alpha$, that is within the *limit*, the outgoing reachability bit vector C is updated with the value one; else it is updated with value zero. The computed vector C is then attached to the outgoing message, see Sub algorithm 3.

The rest of this section illustrates how the sub algorithms are used. Fig. 1 shows how the outgoing reachability bit vector is created according to sub algorithm 3. The top vector is the row corresponding to the local node in the local reachability matrix which contains the time stamps of the last received message from each of the other nodes in the platoon. Each element of the top vector, containing time stamps, is reduced to a single bit using the function shown in the middle box. The result (bottom vector) is the single bit of information for each remote node that is attached to the outgoing message, the outgoing reachability bit vector, where a '1' means that the success probability is acceptable.

Upon receiving a message, the receiving node performs a number of actions according to sub algorithm 1. The following steps are performed in order to update the reachability matrix (in Fig. 2, an example matrix for a receiving node in position 3 of the platoon is shown):

1. Extract the reachability bit vector (shown at the top of the figure) and sender position s (node 1 is sender in the example) from the received message.

2. Update sender information in the reachability matrix. For each receiver position r in the bit vector:

   a) If the bit is 0, do nothing.

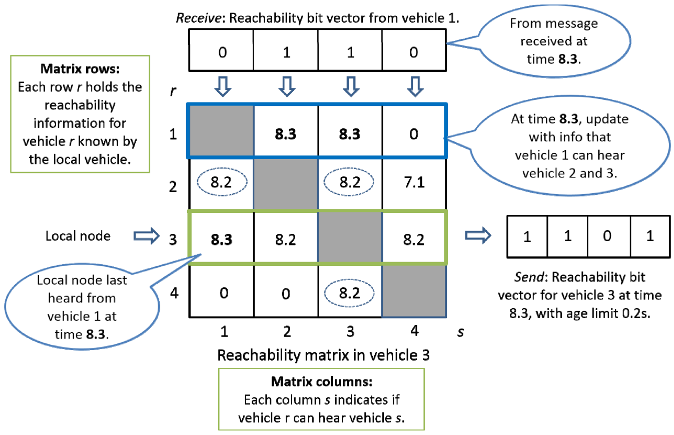

Fig. 2. Illustration of the reachability matrix available in the vehicle at platoon position three.

   b) If the bit is 1, set position (r, s) to current time (node 2 and 3 in the example).

3. Update the receiver information in the reachability matrix. Set the elements of the reachability matrix corresponding to the local node (row 3) and the sending node (column 1), to the current time.

When the matrix has been updated we finally have all the information needed to make the decision whether this message should be forwarded or not. Remember that the goal is to reach as many nodes as possible with as few forward messages as possible. In the example in Fig. 2, the receiving node 3 calculates the forward reach number (see first part of sub algorithm 2) for the incoming message (at time 8.3) from node 1. The remaining nodes in the platoon to receive the message are 2 and 4. The circled time-stamps, all within the age limit, show what is impacting the forward reach number. Node 2 is likely to hear messages from both the local node (3) and the original sender (1). Therefore, it is likely to have heard the original message and no forwarding is necessary. Node 4, however, is likely to have heard the local node but not the original sender. Therefore, it is likely that a forward message from node 3 would result in one additional node receiving the original message; the forward reach number is thus 1.

There may be several receiving nodes with a forward reach number higher than 0. We have no oracle to determine the globally optimal forwarding strategy, i.e. the information in the reachability matrices of all nodes may vary, and each node has no knowledge about which other nodes have successfully received the message. Therefore, as mentioned above, we use a timer-based strategy analogous to the ETSI contention-based algorithm, but based on the forward reach number. That is, we assume it is better that a node with higher forward reach number forwards first, since it is likely to distribute the message to more additional nodes, thereby reducing the need for further forward messages. Note that if two nodes have the same reach and tries to send at the same time, this will be handled by the MAC protocol in 802.11p.

TABLE II. CONFIGURATION OF THE RADIO NODES.

Parameter	Value
Channel	Control Channel (G5CC)
Carrier frequency	5.9 GHz
Tx Power	23 dBm
Data rate	6 Mbs
Update rate	10 Hz
Payload	500 Byte
Cable loss	2.5 dB

IV. V2V MEASUREMENTS

In order to provide the simulator, presented in the next section, with realistic input field measurements were performed. The measurement location was the Swedish highway E4 in the vicinity of Stockholm and test objects were four heavy duty trucks. Types of trucks were: rigid Volvo truck of length 9.5 m at platoon position v1 and v3, Scania tractor with metallic semitrailer at platoon position v2 and Scania tractor with tarpaulin covered semitrailer at platoon position v4, see Fig. 3. Each truck was equipped with two radio nodes from Kapsch (EVK-3300 Evaluation kit) [14] connected to one antenna each. The antennas were placed in the left and right rear view mirrors of the truck, this in order to be able to evaluate communication on both sides of the truck. The radio nodes were configured according to Table II.

Each radio node was equipped with an Aztec antenna designed within the RelCommH project. The antenna has 6 dBi gain in the front and back direction of the truck and -5 dBi gain orthogonal to the body of the truck. All nodes were continuously transmitting, receiving and logging data packets at an update rate of 10 Hz, and the collected data was stored and sorted offline so that communication links between all radio nodes could be analyzed separately.

A. Measurement Scenario

The measurements were performed on a Swedish highway consisting of two lanes in each direction separated by a steel barrier. Tests were performed on an 8 km long section running through the country side; mostly surrounded by fields and forests. Approximately 9 m outside the lanes a wild life fence is located on both sides of the highway. Tests were performed in both south and north direction of the highway section. For comparison, a second test in a highway tunnel with a very rich multipath radio environment was also used. During test the four trucks entered the high way and formed a platoon-like vehicle formation according to Fig. 3. After reaching a stable formation with an inter-vehicle distance of approximately 22 meters (~1 s) and a speed of 80 km/h the measurement was started.

B. Metrics

Metrics to evaluate the algorithms are the Data Age metric, defined in [12], and the message intensity. The Data age is calculated according to:

$$T_{data\_age} = t - t_{tsLRS} \pm t_{clocksync} \quad (1)$$

where t is the current time in the receiving vehicle when the received packet is to be used, t_{tsLRS} is the time stamp from the transmitting node and $t_{clocksync}$ is a time originating from the fact that the clocks in the transmitting and receiving nodes are not perfectly synchronized.

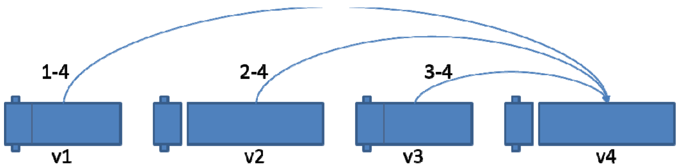

Fig. 3. Order of vehicle in the platoon during measurements. The arrows indicate the communication links 1-4, 2-4 and 3-4, e.g., 1-4 indicating the communication link from vehicle 1 to vehicle 4.

The message intensity is the number of packets sent per second for the entire platoon. The lower the message intensity, the better chance of having successful communication when the number of nodes in the network increases.

V. SIMULATOR SETUP

The simulator is implemented in MATLAB and consists of two major parts; in the first part preprocessing of the measured data is performed, and in the second part the communication in the platoon is simulated.

A. Preprocessing of Measured Data

The data collected during measurements according to section IV have been sorted so that communication between all trucks in the platoon can be evaluated, i.e., for transmissions from truck v_i to truck v_j four links are extracted: left-to-left, left-to-right, right-to-left and right-to-right. As the radio channel (the multi-path environment) changes with the physical landscape surrounding the highway, PER is calculated with a sliding window to take these changes into account. The size of the window was selected to be 10 seconds, which is a compromise between number of samples for PER estimate and reaction on changes in the multi-path environment. This gives that the success probability of the next transmission depends on the past 10 seconds of communication.

B. Platooning Communication Simulation

In the second part of the implementation, simulations of the forwarding algorithms are performed based on the data processed in the first part.

Input to the simulator consists of number of vehicles, number of radio nodes per vehicle, message update rate, forwarding algorithm and channel model (sliding PER). Output consists of Data Age as seen from the last truck in the platoon and sent messages per second for the entire platoon (message intensity). The reason that the communication to the last vehicle is chosen for evaluation is mainly that it is the following vehicles that need to react on information from the preceding vehicles, not the other way around.

For the simulations a setup of four vehicles with two radio nodes each, all transmitting with data rate of 10 Hz, was chosen to match the performed measurements. The goal of a forwarding algorithm is to reduce the Data Age and keep it below a certain limit for all vehicles in the platoon. A good

TABLE III. SIMULATION RESULTS - E4 HIGHWAY (AGE LIMIT 0.2S)

Forwarding algorithm. No.	Data age limit miss ratio [-] (Data age limit = 0.2s) Connection:			Message intensity [packet/s]
	1 - 4	2 - 4	3 – 4	
A	0.18	0.03	0.03	40
B	0.05	0.00	0.00	123.5
C	0.04	0.01	0.00	82.3
D	0.11	0.02	0.02	48.5

TABLE IV. SIMULATION RESULTS - E4 HIGHWAY (AGE LIMIT 0.4S)

Forwarding algorithm. No.	Data age limit miss ratio [-] (Data age limit = 0.4s) Connection:			Message intensity [packet/s]
	1 - 4	2 - 4	3 – 4	
A	0.045	0.002	0.001	40
B	0.000	0.000	0.000	123.4
C	0.000	0.000	0.000	82.8
D	0.001	0.000	0.000	48.6

TABLE V. SIMULATION RESULTS - TUNNEL

Forwarding algorithm. No.	Data age limit miss ratio [-] (Data age limit = 0.2s) Connection:			Message intensity [packet/s]
	1 - 4	2 - 4	3 – 4	
A	0.002	0.000	0.000	40
B	0.000	0.000	0.000	157.2
C	0.000	0.000	0.000	80.1
D	0.002	0.000	0.000	40.2

forwarding algorithm does this whilst maintaining low message intensity. Note that quantifying the data age limit needed for collision avoidance and maintaining platoon string stability in different operational situations is beyond the scope of the paper. Therefore, the data age limits used in the simulations should be seen as illustrative examples.

VI. SIMULATION RESULTS

In this section the results from the simulations are presented. The two performance metrics presented in section IV.B are used to show the difference in performance between the four evaluated forwarding algorithms. In Table III a summary of the results for the highway scenario and a data age limit of 0.2 seconds is presented. Each row represents one forwarding algorithm, while the Data Age miss ratio shows the ratio of all sent packets that miss the Data Age limit for packets sent from vehicle 1, 2 and 3 and received by vehicle 4. The last column states the message intensity.

For Table IV the Data Age limit is increased to 0.4 seconds but the environment is still highway.

For reference, the simulation results using the tunnel measurements as input are presented in Table V, where the Data Age limit is set to 0.2 seconds. It can be seen from the table that the Data Age limit miss ratio is only 0.002 in the worst case. However the interesting observation here is that the ETSI proposed forwarding algorithms B and C both have high message intensity while our proposed algorithm, D, is almost as low as the base case, A.

Fig. 4-8 show results from highway measurements and a Data Age limit of 0.2 seconds. For the base case where no forwarding has been applied it can be seen that the message intensity is kept at a low level but that the Data Age limit of 0.2s is missed in 18% of the transmissions, in the communication between v1 and v4 (1-4 link). In Fig. 4 Data Age for algorithm A is plotted as a function of elapsed time. It can be seen that several peaks of 1 second or above are present. The CDF values for algorithm A are presented in Fig. 5.

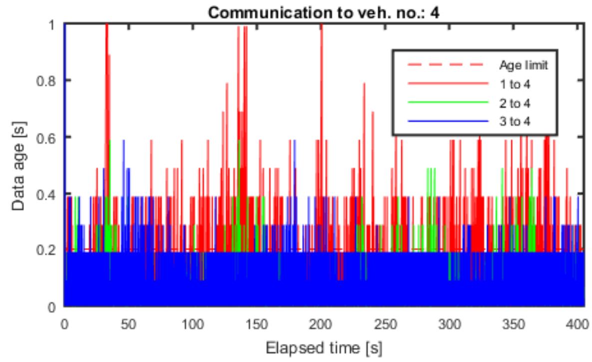

Fig. 4. Data age, no repetition of packets, message intensity 40 packets/s. Input from highway measurement and Data Age limit 0.2 seconds.

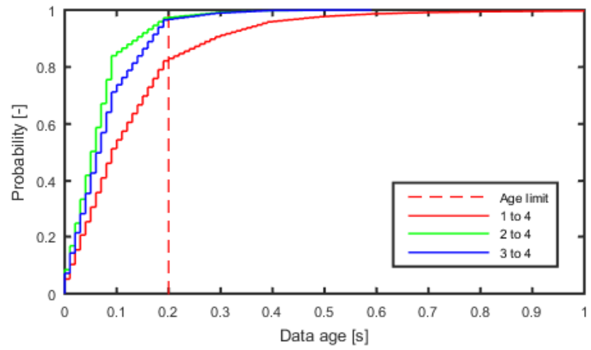

Fig. 5. CDF plot of data age, no repetition of any packets, message intensity 40 packets/s. Input from highway measurement and Data Age limit 0.2 seconds.

For the ETSI simple GeoBroadcast forwarding algorithm (B) it is seen that the limit is only missed in 5% of the 1-4 link communication, but the message intensity is increased by approximately 200%. In Fig. 6 it can be seen that the Data Age is reduced compared to the base case (A). For the ETSI contention based forwarding algorithm (C) the Data Age limit is missed in 4% of the transmissions but there is an increase in message intensity by more than 100% (see Fig. 7). The Reachability Matrix forwarding algorithm (D) misses the Data Age limit in 11% of the transmissions, which is an improvement of almost 40% compared to the base case, while the message intensity is only increased by 21% (see Fig. 8).

VII. CONCLUSION

In this paper we have presented a forwarding algorithm to enhance the performance of the communication in a platooning application for heavy duty vehicles, while still maintaining comparably low message intensity. Simulations show that compared to only broadcasting packets, our reachability matrix

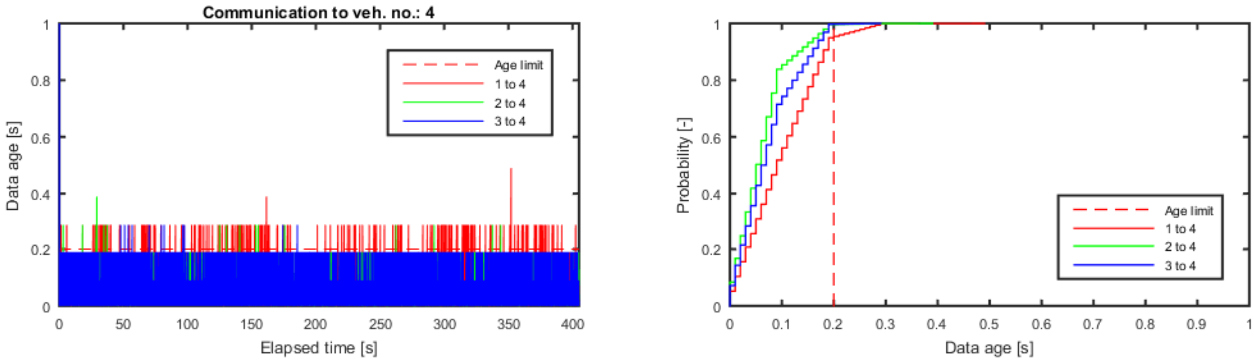

Fig. 6. Data age and CDF plots for ETSI simple GeoBroadcast forwarding, each packet repeated once, message intensity 123.5 packets/s. Input from highway measurement and Data Age limit 0.2 seconds.

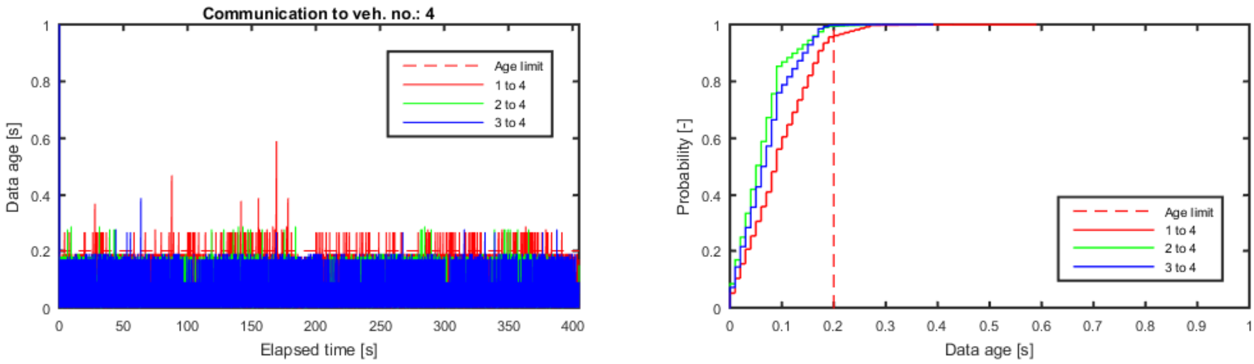

Fig. 7. Data age and CDF plots for ETSI contention based forwarding, message intensity 82.3 packets/s. Input from highway measurement and Data Age limit 0.2 seconds.

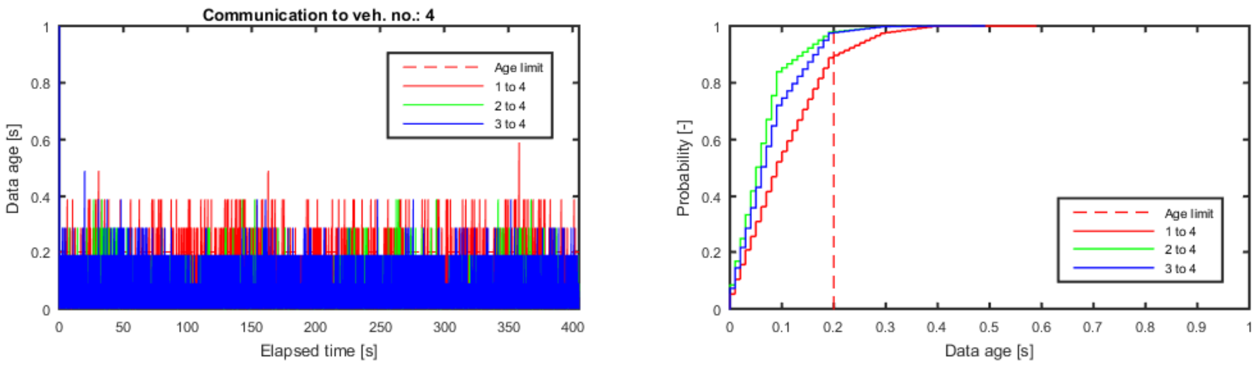

Fig. 8. Data age and CDF plots for the reachability matrix algorithm, message intensity 48.5 packets/s. Input from highway measurement and Data Age limit 0.2 seconds.

algorithm can decrease the ratio of missing a Data Age limit of 0.2 seconds from 18% to 11% while increasing the message intensity by only 21%.

Our simulations also show that the ETSI simple GeoBroadcast often perform reasonably well when it comes to keeping the Data Age within the chosen limit. However, the message intensity is high. The ETSI contention-based algorithm also perform well in most situations but does produce unnecessary messages, which is especially noticeable when reception conditions are very good.

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