A concept on signaling spacial network conditions to provide Quality of Service in a VANET

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Abstract— **In this paper we present a signaling mechanism of spacial divided network conditions in order to guarantee Quality of Service (QoS) in a Vehicular Ad Hoc Network (VANET). The target application shares information of sensed objects in the surrounding of the vehicles with its VANET neighbor nodes. Therefore each vehicle broadcasts information of its surrounding periodically which leads to an unscalable bandwidth consumption as the density of communication nodes rises. A higher network load will also lead to a higher latency of the transmitted data as the probability rises that nodes have to wait for a free channel. The latency of data acquired from on-board sensors is critical if it is shared with other nodes as the validity of the data is low.**

We present a signaling method based on a spatial partitioning in order to detect redundant source nodes for the same information. Avoiding redundant broadcasts will limit the application's bandwidth consumption and therefore the latency of the messages can be improved.

I. Introduction

Future vehicles are equipped with RADAR, LIDAR or camera sensors and the acquired data can be provided to driving-assistant-systems. Due to the limited range of the sensors an exchange of the acquired environmental object information through a VANET can be beneficial for the driving assistant systems of other cars. Each vehicle holds a Local Dynamic Map (LDM) containing information from sensor-fusion about its local environment. A LDM is basically a multi-layered database with a static geographical base layer and layers for temporal events or the temporal surrounding of a vehicle. The term LDM was first introduced by the *Car-2-Car Consortium*([1]) in [4]. Nowadays this term is widely used in the context of co-operative systems and current research projects as SAFESPOT [2] and CIVS [3] which are located in this field.

Continuous broadcasts with updates of acquired information to other vehicles improve the global knowledge about the traffic situation and critical situations can be detected earlier. Information stored in the LDM has a certain relevance to the traffic situation. This means there are certain objects or events highly related to other traffic participants and others which have no impact on the road traffic. If all nodes simply broadcast the relevant content of their LDM every node in the VANET can benefit.

As traffic density rises more and more bandwidth has to be allocated on the channel. This leads to an unreliable transmission of data and to a higher latency as the nodes have to wait longer for a free channel. Therefore the broadcast of all relevant information of the LDM by all nodes raises the problem of scaling the bandwidth allocation. If we focus on a single piece of information broadcasted by one or more nodes, this piece of information might be gathered by several sources and stored in their LDM at the same time. This fact leads to redundant broadcast messages. The redundancy could be a benefit for a better tracking of the environment but each rebroadcast consumes a certain amount of bandwidth. Therefore a trade of between bandwidth consumption and reliable information transmission for tracking has to be found.

There was and is currently lots of research on the topic of VANETs. This research mainly focused routing event based message [6], [7], the efficient broadcast of warning messages [5], [10] and also data dissemination [8], [9]. In this paper we focus on frequent 1-hop broadcasts of sensed data in the surrounding of a vehicle. This is contrary to data dissemination where data is aggregated with other sources while it is distributed in the network over several hops.

A 1-hop distribution of LDM-data has strict QoS re-

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quirements as low message latency and a high reliability. This means the update messages have to be distributed and can be received continuously. On the other hand there should be a definable limit of bandwidth usage as in a VANET congestion of the network could affect safety of life applications.

In this paper we describe a spatial network partitioning method respectively signaling method/protocol that helps nodes to detect redundant broadcasts and the coverage area is optimized even for 1-hop broadcasts.

Nodes can adapt on other data sources and therefore they can use their resources to broadcast other information from their LDM.

This paper is organized as follows: The next section (II) describes the concept of spatial partitioning and how to use this to limit bandwidth consumption of the network nodes. Section III describes the impact of the spacial partitioning on a continuous distribution of LDM-data. Simulations are performed to evaluate the proposed method. The simulation environment and the results are described in section IV. The paper concludes with a discussion.

II. CONCEPT

A. Problem description

The main idea of this concept is the introduction of a mechanism for streaming highly dynamic information from multiple and mobile sources to overcome the problem of unscalable bandwidth consumption. We assume that nodes in a VANET collect data of their surrounding with on-board sensors and fuse this information to a LDM. Relevant pieces of information can be extracted and broadcasted to the neighbor vehicles. This means that messages are created holding the description of environmental objects or events. This could be for example the current position, trajectory and classification of an object on or besides the road. A bicycle rider on a highly frequented road cars have to pass is an example. If each vehicle broadcasts a certain amount of data periodically bandwidth consumption rises with a higher density of vehicles on the road. This leads to an unscalable number of messages and if the source vehicles do not reduce their amount of sending data the load on the channel increases.

In a model where a constant portion of LDM-data is broadcasted frequently each node has to transmit the amount of Data D_p in periods of t_p. This leads to a frequent used bandwidth B_p.

$$B_p = \frac{D_p}{t_p} + B_o \tag{1}$$

B_o is the overhead introduced by lower layers like MAC and PHY in order to establish the wireless communication.

In a VANET all vehicles within a certain range have to share the common wireless medium. If a number of o nodes have to share the available bandwidth B_{avl} it is easy to calculate when the requested bandwidth $B_{requ} = o * B_p$ exceeds the available bandwidth B_{avl}.

As channel usage increases this has also an impact on the average frame or packet delay. We do not want to focus on the analysis of allocating the channel in a VANET as this was done several times for different MAC approaches. But it should be clear that for sharing sensed information a low data latency should be provided, because of the information's low durability. This means there should be a mechanism that adjusts the amount of data that can be send per t_p.

It is further probable that nearby vehicles sense similar information about their common environment. If this data is broadcasted by all vehicles more confidence is introduced but also the network load is increased. There is a trade off between redundant information that increases confidence about the vehicles' environment and the higher bandwidth consumption each duplicate message produces. Therefore it would be not a good solution to decrease the network load simply by determining one car that broadcasts the information of one environmental object or event and all other will not transmit afterwards. Our scheme introduces a mechanism which limits the number of redundant broadcasts and therefore the bandwidth consumption. The main idea is to use a spacial partitioning method to sort the information sources according their location and distribution area. This mechanism optimizes the distribution ranges and still keeps an increase in confidence due to information exchange from several sources.

B. Architecture

This section describes the overview of the system and the communication architecture to have a closer look at the behavior and the requirements of the focused application.

1) System architecture: The system model is shown in figure 1.

Data collected from several on-board sensors are merged within the sensor-fusion module. As a result the objects detected by the sensors can be added to a LDM which is a layered database holding a view of the vehicle's current environment. Environmental data is processed under the term *cooperative object detection*

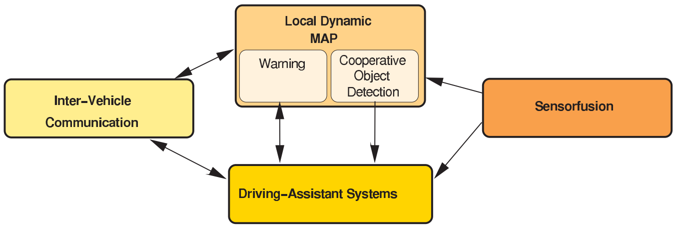

Fig. 1. The LDM-System architecture

whereas traffic warnings can be stored for example in a separate layer of the LDM. The dynamic data stored there can be used by driving-assistant-systems or shared with other vehicles through the VANET. The Driving-Assistant-systems can also use the VANET to inform other cars about the detection of certain events. The LDM's content can be further extended by data received from others via the VANET.

There are three different types of messages that have to be exchanged between co-operative vehicles. First a single event based messages (e.g. an Emergency Break Warning) could be created by an assistant system. Second there are messages which specify events in the surrounding of the vehicle (e.g. detected Obstacle Warning) whose origin is the LDM. The third type of message is environmental object data to establish an cooperative object detection. As objects usually do not vanish immediately, continuous updates can be broadcasted. Durability of this data is low, because environmental data might change quickly. Thus there should be update messages frequently and the messages related to a certain object can be considered as a data stream. The available bandwidth for this application has to be shared for all these message types.

A prerequisite is a proper self-localization of each vehicle. A GPS-system might not have the accuracy that our mechanism will work or that even the exchange of environmental data makes sense. There is a lot of research optimizing the self-localization of vehicles participating in real world traffic. [21] Therefore we can assume that vehicles can determine their position with an accuracy of one meter.

2) Communication architecture: This paper focuses on the VANET communication and therefore this paragraph introduces the functionality of the communication modules and the interface between the VANET message transmission and the LDM / Driving-Assistant-System. Figure 2 shows a layered architecture of the communication modules. Starting from the top, methods for message generation and processing are provided. There is also functionality for indexing certain messages or data streams so that the QoS layer can handle them in a different way. The indexing of messages respectively streams is described in detail in section II-D. A module of the QoS layer is a spatial partitioning mechanism which is described in the next section. The QoS is established with the help of signaling messages (see paragraph II-E) that are created and processed within this layer. The QoS layer is then responsible for pre-scheduling data messages before they are moved to the send buffer within the MAC. The main mechanism within the QoS-module is based on the signaling messages that can detect and prohibit redundant environment data streams to reduce or shape the load on the network.(see paragraph II-E for details)

The base of the communication system are the two layers on the bottom of the architecture which are physical and MAC layer. As physical layer for a PHY802.11.p will suit well. As MAC there could be either a Cluster-based MAC (CBMAC) [12] or 802.11MAC as it is proposed in 802.11p [13].

The introduced stack has a cross-layer scheme. The layers involved can exchange certain data via a cross-layer database (Cross-Layer DB). We assume that the MAC layer has a functionality where each node broadcast its current location to all its neighbors as this is done in CBMAC automatically.

C. Spacial partitioning

The base of our mechanism is a spacial partitioning of the network nodes and their environment. As already mentioned an exchange of environmental information makes only sense if the vehicles can localize themselves quite properly. Each location on the surface of the earth can be specified by the Universe Transverse Mercator (UTM) coordinate system. This grid based system projects the populated parts of the earth in a cartesic coordinate system. The surface is divided into 60 longitude zones which have a size of 6° each [18]. The coordinates of a localization are specified by the zone number, an easting and a northing distance. The counting of the first zone is started at the longitude zone between 180° and 174° west of Greenwich.

The Military Grid Reference System (MGRS) is based on UTM and divides the surface into squares of 100km length [19]. A location in MGRS is given by the UTM zone, the MGRS-square, a X- and Y- coordinate as reference to the lower left corner of the square.

These MGRS squares can be used as reference for a spacial division of our network nodes by subdividing

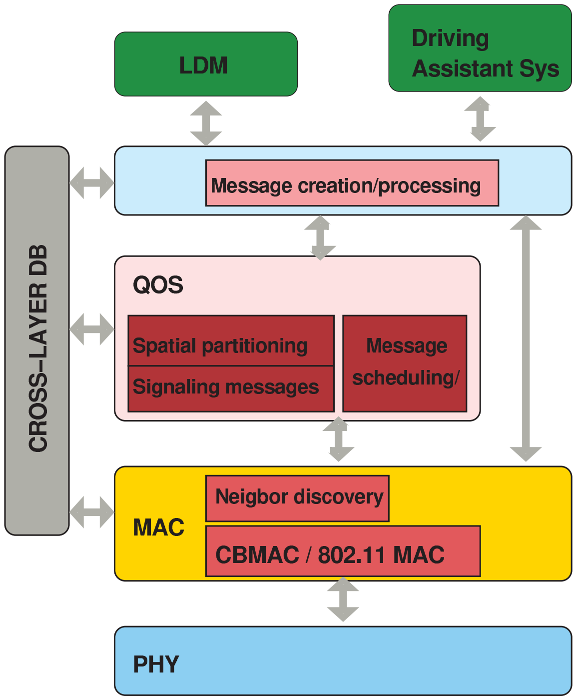

Fig. 2. The communication modules

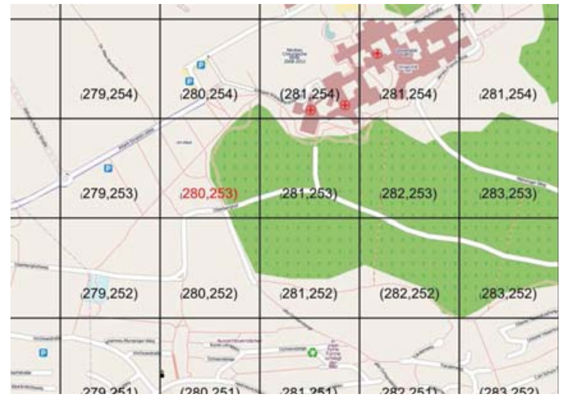

Fig. 3. Campus map of Ulm University divided into LDM-squares corresponding to the MGRS zone 32U NU. Map data is taken from the OpenStreetMap.org project [20]

them in smaller squares with a side length l_{sLDM}. These created squares, which we call from now on LDM-squares, can be counted and labeled by a pair of numbers which are a 2-dimensional reference to the lower left corner of the parent MGRS square. The first pair value counts the squares in X-direction whereas the second one is the counting in Y-direction. That means the square at the lower left corner is labeled (0,0) the right next one (1,0) and so on. This pair can be easily calculated for each location by first converting the position to MGRS from any other coordinate system and second taking the integer result of a division of the X- and the Y-coordinate by the LDM-square-length l_{sLDM} as pair values.

As the communication range of a VANET is in the rage of approximately 500m [14], l_{sLDM} should be chosen smaller than this value, because otherwise spatial partitioning of the network makes no sense.

As an example figure 3 shows the campus of Ulm University in Germany and an overlay grid that was created with the method described above. Ulm University is located at $48°25'12.0''N 9°56'42.26'E$ which can be transformed to UTM respectively to MGRS coordinates. The result for the UTM coordinate system is longitude zone 32U, easting of $570055m$ and northing of $5363473m$. That means the Insitute of Information Resource Management at Ulm University is located in MGRS coordinates at 32U NU 70055 63473. In respect to the MGRS square 32U NU and $l_{sLDM} = 250m$, our institute at Ulm University would be located in MGRS square 280,253.

It is possible to calculate for each location on earth a pair that labels an LDM-square in respect to the current MGRS coordinates. At the boundaries of two MGRS zones for each of the zones a label can be determined. If it should be possible to address LDM-squares for the neighboring MGRS-zone there have to be negative LDM-square-labels. Label pairs are in the range of $-Xk..Xk, -Yk..Yk$ because of this reason.

Each vehicle can determine its current LDM-square and the network can be partitioned by this method. The spatial relation between the network nodes can be exchanged using the LDM-squares as reference.

The advantage of using such a partitioning method is its general validity. Vehicles just have to be able to self-localize and they know what is their current MGRS-coordinate and thus their LDM-square. Communication partners are always so close that even at MGRS square borders the relation to the reference edge is clear and because of that this spacial partitioning can be used in any situation. The nodes even do not have to exchange the MGRS-square labels, because of the low VANET communication range. It is either not possible to receive a signal from another MGRS square or even at the MGRS-square border there is a unique correspondence. The labeling of the LDM squares is related to the lower left corners and therefore the corresponding MGRS-squares can always be assigned.

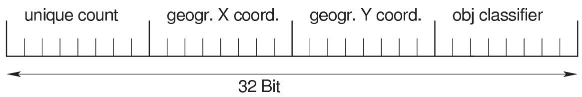

Fig. 4. Geographical object index

D. Geographical indexing of environmental data

In figure 2 in subsection II-B there is an interface between LDM, message creation and QOS layer. To classify a set of messages or generally a certain type of data within the QoS layer some kind of unique identification - an index - is needed. In the case of distributing data from the LDM there is data of different objects in the environment that has to be broadcasted continuously. There is a stream of data for each object that was detected in the environment. Therefore the different data streams need to be indexed by the LDM and the QoS layer can handle them in a different way.

We have chosen the indexing of the LDM-data to have a geographical relation to the projected coordinates of the detected object. In further development of our QoS mechanism the index can be used as geographical relation to the information and handled in a different way.

We have chosen the index to be a combination of a geographical relation to the object location at the time when it was encountered by the vehicles sensors, a object classification and a counter for unification. The geographical representation is chosen to be an X and Y coordinate relative to the lower left corner of the current LDM-square. If $l_{sLDM} < 256m$ and the accuracy is $1m$ the X and Y coordinates can be each represented by an 8 bit value. Because the geographical representation and the object classification are not necessarily unique, there has to be an unifying part as well.

As a result indexes are 32-bit values according to the following scheme and are also shown by figure 4:

Bit 0 .. 7: A classification of the object

Bit 8 ..15: The Y-Coordinate relative to the lower left corner of the current LDM-square

Bit 16..23: The X-Coordinate relative to the lower left corner of the current LDM-square

Bit 24..31: The most significant bits are counting the number of objects with the same geographical representation (the same first 24 bits)

E. Signaling of neighbors - detection of redundant broadcasts

Information on environmental objects and events can be detected by several vehicles. In our case there can be up to k sources for the same information I. Each of these k sources can reach n_i neighbor nodes (where $i = [1..k]$).

$$\begin{aligned} n_i &= |N_i| \\ and\ N_i &= \{nodes\ in\ the\ communication \\ &\quad range\ of\ node\ i\} \\ &\quad with\ i \in [1..k] \end{aligned} \tag{2}$$

If all of the k sources send the information to their neighbors they will reach $|N|$ neighbor nodes.
This means for N:

$$\begin{aligned} N &= \{\ all\ nodes\ in\ the\ communication \\ &\quad range\ of\ the\ k\ sources\} \\ N &= N_1 \cup N_2 \cup N_3 ... \cup ... N_k \end{aligned} \tag{3}$$

It is quite probable that the communication ranges of the k sources overlap so that the sets of neighbor nodes for each source have common subsets to each other. If it is possible to select l of the k sources with $1 < l < k$ where l is the minimum of sources to select that reach all of the nodes that are part of the set N, the distribution range of the information is still the same but the channel usage can be reduced. It is not possible to select the l nodes that can distribute the information I without lot's of overhead and a significant delay before the information can be send. But in the following we introduce an algorithm that prohibits sources to send I if they received a message from a neighbor which coverage range equals or extends the own communication area.

Each vehicle informs its neighbors of the vehicles current coverage area by a special signaling message (SIG-MSG). This SIG-MSG contains the number of neighbor nodes sorted by the LDM-square these nodes are located. The content of a SIG-MSG is generated from a matrix describing the current LDM-squares in the surrounding of a vehicle as it is shown by figure 5. For each LDM-square there is a field in the matrix with the number of neighbors located in this square. This can be extracted from the neighbor table. The content of a SIG-MSG can be created from all matrix elements that are different from zero which are marked yellow in figure 5.

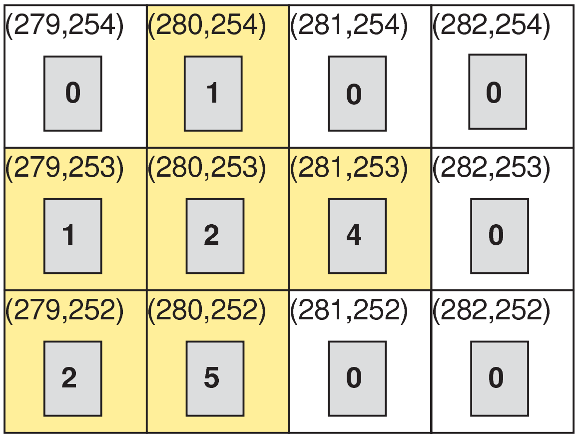

Fig. 5. The number of neighbor nodes and their spacial relation. The yellow marked fields form the content of a SIG-MSG

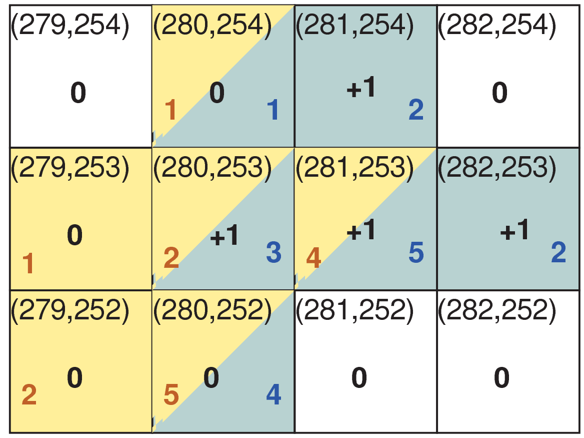

Fig. 6. Aggregation of the content from a SIG-MSG (blue fields) with the current communication status (yellow fields)

Whenever one of these messages is received its content can be stored within the Cross-Layer DB.

Thus each node has an overview what area is covered by their neighbors.

A collection of SIG-MSGs from the neighbor nodes can be used to determine redundant sources for a certain object index. If a node receives data which can be matched to an already known object inside the LDM, it can check which area is covered by this node and decide if sending its packet is still a benefit to others.

A matrix of the communication status can be created for each known object in a database within the QoS layer (QoS-DB). The matrix consists of fields that are corresponding to the surrounding LDM-squares of the current location. An example for the status matrix is shown by figure 6. In this case we can look at the two source nodes A and B that sense information I of a common object. Node A received a SIG-MSG, which content is given by the blue numbers, and the data message from node B. The yellow marked elements are the current transmission area of node A whereas the light-blue elements correspond to the transmission range acquired from the SIG-MSG of node B. The counter is increased if the other source for this object can reach more nodes within the corresponding LDM-square. In the case of the example shown by figure 6 the counter within the blue/yellow marked fields is increased if the blue number is bigger than the yellow one.

According to this scheme SIG-MSGs from all common sources can be aggregated. In case there is a LDM-square with no better suited source the counter stays at zero and there will be periodic broadcasts of the object data. Sources with a smaller coverage area will receive these broadcasts and they will stop their transmission of the data afterwards. This idea is part of the algorithm as it is described in the next section III

III. LDM-STREAM Algorithm Description

In section II there were several mechanisms introduced that merge to LDM-STREAM which we describe in the following. The previous introduced mechanisms and modules interact with each other and these interactions can be described as one algorithm. The modules connected by LDM-STREAM are related to the proposed communication architecture from section II-B.

In order to describe the algorithm properly we will look at one single object that was detected in the environment of a vehicle. The algorithm starts whenever a new object is detected by the vehicle's sensor and its description is added to the LDM. The event of a new object discovery is broadcasted to the neighbors and therefore a message is created by the *Message Creation Module*. As second action a new index will be added to the QoS-database. There will be a new status block created and it is accessible under the object's index.

There will be periodic broadcasts of SIG-MSGs that show the current partition of the nodes neighborhood.

In order to provide frequent updates of the objects to the neighbor vehicles another scheduler starts a check on the index, if the object has to be retransmitted. This will start the LDM-STREAM process which is shown in figure 7 and the entry point is on the lower left of the diagram. The first check will be on the communication status of the index. If a broadcast is no benefit for the neighbors because there are already enough other sources the algorithm stops. If a rebroadcast is a benefit to others this request is given to a module that collects all

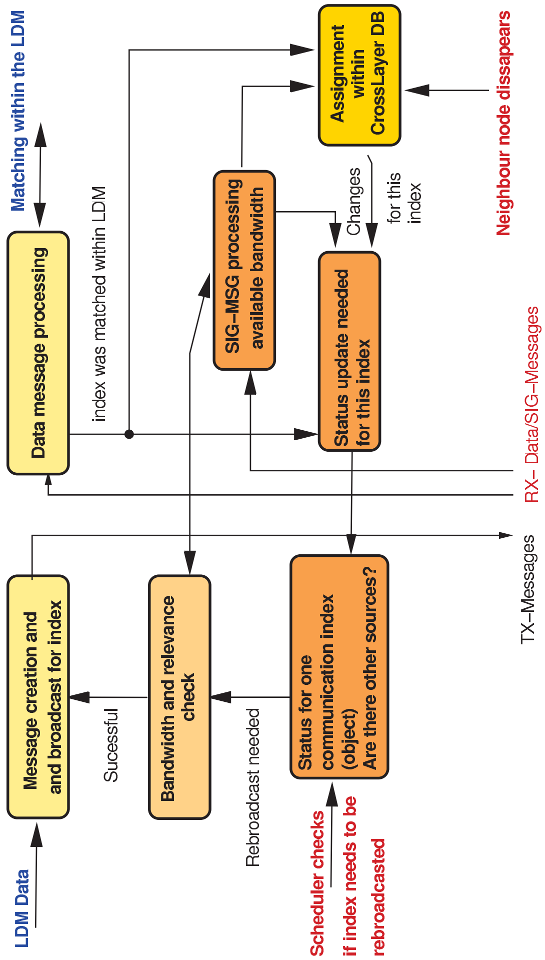

Fig. 7. LDM-STREAM process chart

requests of this type. This module can pick, under the condition of how much bandwidth is available for the current time period the most relevant object indexes and forward them to the message generation module. There is an assignment for the maximum number of messages a node can transmit per time period. This means there can be a defined bandwidth limit for the LDM-STREAM application. In order to generate the message the object index is used to extract the data from the LDM. As a result the message can be send.

The next entry point to the process is the reception of a data message that was broadcasted by another node. This data is processed and it is matched within the LDM. If the LDM detects that it already knows the object it can inform the process that the last message is connected to the specific object index in return. Therefore the communication status of the index can be updated. The coverage area, known due to SIG-MSGs, of the last message's source will be aggregated to this index status block within the QoS-DB. There is also an assignment of the object index to the ID of the source node within the Cross-Layer-DB in order to change the communication status block if one of the following conditions occur: If a SIG-MSG is received from a neighbor node then the status block can be updated by this assignment within the Cross-Layer-DB. An update is needed as well if the source node disappears from the neighbor table.

IV. Simulations

A. Environment

The LDM-signaling process and the performance of LDM-STREAM is evaluated by running several simulations. Our simulation platform is based on the microscopic traffic model of Nagel and Schreckenberg [16], which is a time-discrete model. Vehicles are created on a street map and they move to random destinations while the simulation is running. These vehicles can drive in both directions of a road and they will overtake each other if for example a faster car drives behind a slower one. They adjust their current speed according to the traffic situation around them. A car and the following ones will for example stop because of a red light at an intersection area. The updating process for the position and velocity of the vehicles is done in time steps, which are in our case adapted to be 100 ms. This simulation environment also provides environmental data in the surrounding of the vehicles. These are for example bicycles also taking part in the traffic or simply vehicles that are not equipped with a communication unit. There can be also static objects besides the road like trees. Each car can sense objects which are close and in line-of-sight to them (100m in front and up to 50m to the back) and thus a LDM layer with dynamic objects can be created for each vehicle.

On top of this traffic model an extension for radio-wave and packet propagation is added to the simulation environment [17]. For the following simulations we use CBMAC [12] as MAC protocol. The communication systems data rate is set to $32\frac{MBit}{s}$ which is comparable to the current technology. The maximum packet length, which corresponds for CBMAC to the amount of data that can be sent in a time slot, is set to 225 bytes, including a header of 25 bytes.

The introduced algorithm in section III was implemented as module to the communication system. It will get data from the sensor modelling within the traffic simulation part. The length of the LDM-squares are set to: $l_{sLDM} = 255m$ and signaling time period is set to

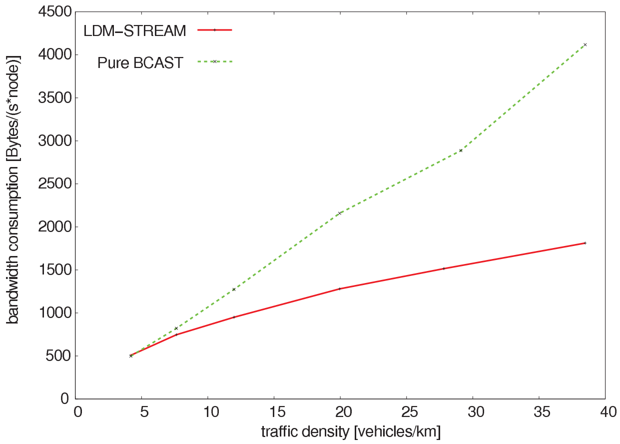

Fig. 8. Comparison of bandwidth consumtion per node in relation to traffic density for inner-city-szenario

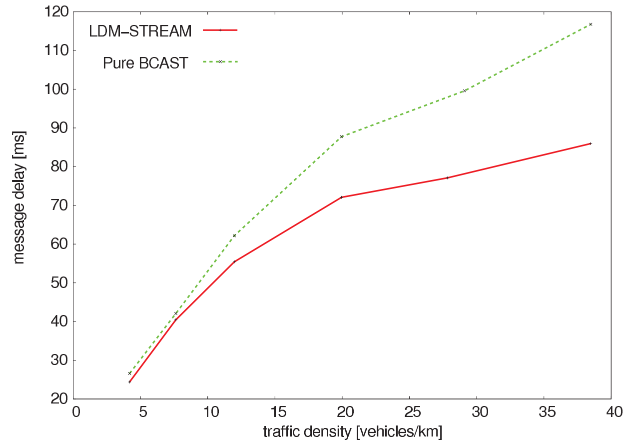

Fig. 9. Comparison of data message delay in relation to traffic density for inner-city-szenario

$t_p = 0.5s$ which is also the broadcast period of object data.

The simulation results compare the distribution of acquired object data through the introduced algorithm (LDM-STREAM) with simply broadcasting the whole content of the LDM periodically (Pure BCAST).

As simulation scenarios we have chosen two different street maps. The first one is an inner city map of Ulm to analyze the general behavior of LDM-STREAM in the bigger context of a city map. As a second scenario we have chosen a smaller section representing one block in an inner city area.

This scenario consists of four streets with two lanes in each direction. Two of them are oriented from east to west and the two other are oriented from north to south. Thus they build four intersections as it can be found in many inner city areas. This scenario can be used to analyze the behavior of LDM-STREAM in case of a high object density in the surrounding of the vehicles.

B. Results

In the beginning of the result section we will show the behavior of LDM-STREAM compared to Pure BCAST under a general view.

1) Inner-city scenario: The chosen scenario is a inner-city map of Ulm, Germany. The simulation runs differ by the following parameters: the overall traffic density, the density of nodes equipped with a communication unit and the object density the distributed data is acquired from. These parameters are related to each other, as for example the traffic density has an impact on the communication unit density, which means they affect the behavior of LDM-STREAM.

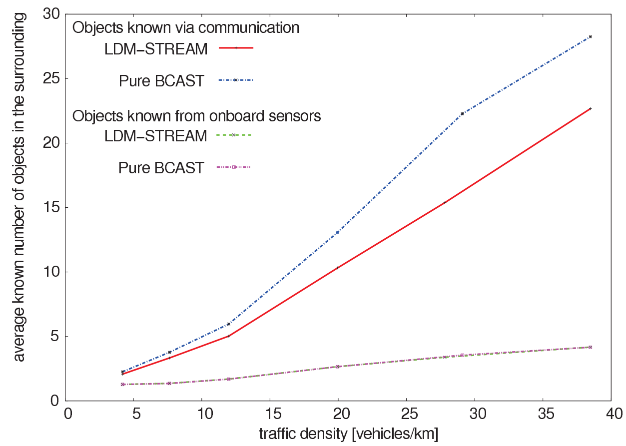

Fig. 10. Comparison of distribution area for inner-city-szenario

In our first analysis the traffic density is chosen as variable and several simulations were performed for different traffic densities. As penetration rate of vehicles equipped with communication units a value of 40% was chosen. Because object density depends on the traffic density (all vehicles are recognized as objects) the number of recognizable objects will change in relation to the traffic density.

With a constant penetration rate and rising traffic density the number of vehicles equipped with a communication unit increases. The figures 8 and 9 show the bandwidth consumption per node and the message delay related to the traffic density for LDM-STREAM and Pure BCAST. There is an increase in bandwidth consumption per node with higher traffic density for both LDM-STREAM and Pure BCAST. As the object density is related to the traffic density there is more bandwidth needed to distribute the LDM content. But the increase is much smaller for LDM-STREAM than for Pure BCAST as the number of transmitted messages is reduced and limited at each node. For the same reasons the message delay increases in respect to the traffic density but LDM-STREAM also performs better than Pure BCAST. These two figures show an improved performance using LDM-STREAM compared to Pure BCAST as the bandwidth consumtion and the delay of the data messages is much smaller. For the exchange of environmental object data the latency is a critical factor, because severe situations should be detected as soon as possible.

The performance of LDM-STREAM can not be determind by just analyzing bandwidth consumption and message latency as the algorithm is only efficient if the distribution of information is comparable. Figure 10 shows the comarrison between average number of vehicles that are able to sense an object and the number of vehicles that received information about this object via the VANET link. With an increase of traffic density the information distribution is better with Pure BCAST. At some nodes packets will not be transmitted becasue the bandwidth limit was already reached. Therefore the information is not distributed which results in less distribution range. But if you compare bandwidth consumption per node with the information gain it should be clear that LDM-STREAM is more efficient. The goals for the design of LDM-STREAM are the scalability of bandwidth consumption as the network node density rises. Therefore these results show that with LDM-STREAM the bandwidth consumtion can be limited and therefore this goal can be satisfied.

2) 4-intersections scenario: The second simulation scenario just is one block as it can be found in many inner-city areas. This scenario is chosen to analyze LDM-STREAM at a high object density. The traffic density is kept constant for the simulations of this set. This means there should be approximately the same object density. As a parameter the penetration rate of communication units is variable. With a higher number of communication units objects can be sensed by more vehicles. The results of the average bandwidth consumption per node related to the penetration rate is shown in figure 11. There is less bandwidth consumption per node using LDM-STREAM than Pure BCAST for the simulated penetration rates. As penetration rate of the communication units rises the bandwidth consumption per node drops for both LDM-STREAM and Pure BCAST. The fact that the measured bandwidth consumption also decreases for the Pure BCAST case seems strange. But in this case the number of packets each node is trying

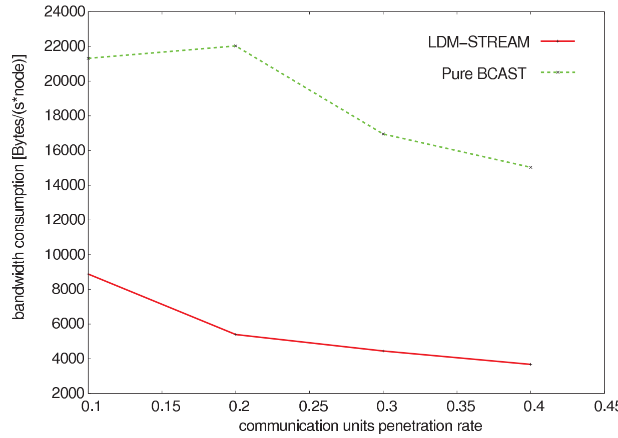

Fig. 11. Comparison of bandwidth consumption in relation to communication node penetration (4-intersection scenario)

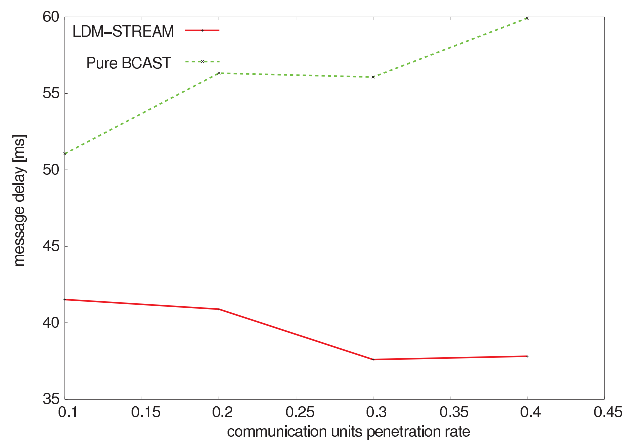

Fig. 12. Comparison of data message delay in relation to communication node penetration (4-intersection scenario)

to send reaches the maximum capacity of the simulated channel. Therefore with more nodes each node has to wait longer for a free channel. This fact is underlined by figure 12 which shows the relation between packet delay and the penetration rate of communication nodes. For the case of Pure BCAST packet delay increases at higher node density (penetration rate) and thus follows a higher load of the communication channel.

The discovered results match the results from the Ulm inner-city scenario. Due to LDM-STREAM the delay of packets is lower than transmitting the data as Pure BCAST and the bandwidth consumption is limited and therefore scalable. The delay of data packets transmitted via LDM-STREAM does not increase for higher penetration rates. Thus the load of the network does not increase as nodes in average do not have to wait longer for a free channel.

V. Conclusion

In this paper we presented LDM-STREAM, a QoS mechanism that avoids redundant broadcasts of object data from the surrounding of vehicles. LDM-STREAM is based on a signaling mechanism that uses spatial partitioning in order to detect the redundant transmission areas. Bandwidth consumption can be limited and the delay of packets can be improved as the presented simulation results show. Under terms of distribution range there is a difference between LDM-STREAM and Pure BCAST as the information reaches less vehicles with increasing traffic density. Due to the fixed limitation of bandwidth each node transmits only a limited number of packets when using LDM-STREAM. Therefore some information is not transmitted and as result the distributed information seems better using Pure BCAST. But under terms of efficiency, taking into account the distributed information in relation to the bandwidth consumtion and message delay LDM stream is a benefit for distributing LDM data. As object and node density increases the bandwidth consumption can be limited by LDM-STREAM. If there is more information that has to be transmitted LDM-STREAM can pick the most relevant data and the available bandwidth can be used in an optimal way. Whereas using Pure BCAST the relevance of broadcasted data can not be controlled.

Future improvements of the proposed algorithm could be an adaptable packet generation rate on the number of nodes that share the channel. This means each node needs an estimation of the current number of nodes it has to share the channel. In future work there could be an investigation on how this estimation can be determind easily. This estimation can improve the distribution range of the object data as nodes can adapt their bandwidth limitation on the current channel usage. Therefore there should be room to improve the efficiency of LDM-STREAM.

There could be a further analysis of how to determine the optimum or an adaptable size of the squares the network is divided.

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