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# Efficient Information Dissemination in VANETs

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## 1. Introduction

Vehicular ad-hoc networks (VANETs) enable promising new possibilities to enhance traffic safety and efficiency. The vision of VANETs is that vehicles communicate spontaneously, in an ad-hoc manner over a wireless medium. Based on this inter-vehicle communication (IVC), vehicles exchange important information, e.g., about road conditions and hazardous situations. Moreover, such information can be propagated via multiple hops, thus making the dissemination of important information possible over longer distances.

This is the key advantage of this kind of safety applications compared to conventional safety systems. Whereas conventional safety systems only rely on information sensed in the direct neighborhood by onboard sensors of a vehicle, active safety applications based on IVC can utilize information generated by nodes multiple hops away. Moreover, such information can be enriched on the way with information sensed by relaying cars. This greatly enhances the potential of VANET applications. The advantage is twofold:

- Having information about distant hazardous situations like an accident ahead or icy road, the driver can be warned in-time, thus being able to completely avoid the dangerous situation.
- Aggregating information from multiple cars enables retaining information on a higher semantic level. This way, applications like cooperative traffic jam warning and cooperative parking place detection can be realized.

The enabling technology for such applications is the wireless ad-hoc communication between vehicles. Especially the dissemination of messages in a specific geographic region represents a fundamental service in VANETs to which we refer to as geographic broadcast (GeoCast). This communication paradigm is used by many applications to enhance traffic safety and efficiency but it can also serve as a basic mechanism for other routing protocols. Because of its relevance in the domain of vehicular networks, it is of key importance that the communication protocol enables efficient message dissemination.

The realization of a robust and efficient broadcast mechanism is a challenging task due to the wide range of applications envisioned to build upon this communication technology, the rigorous requirements of safety applications, and the special network characteristics of vehicular networks. Therefore, the main focus of this chapter is the efficient broadcast of information for VANET applications. We want to give a broad and in-depth review of recent research in this topic and present simulation results of efficient dissemination protocols designed for such applications.

This chapter is organized as follows: In Section 2 we discuss briefly different types of VANET applications, followed by an overview of different communication mechanisms

used by these applications. After that, the special network characteristics of VANETs are discussed and the requirements of broadcast protocols are summarized. We conclude that a geographically limited broadcast is one of the most important communication paradigms for VANET applications. Therefore, this communication mechanism is surveyed and classified in Section 3. This is followed by an evaluation of selected protocols by simulations in Section 4. Finally, Section 5 concludes the results and presents possible future works on this topic.

## **2. Inter-vehicle communication**

The main objective of this section is to define the key requirements for IVC (with the focus on broadcast mechanisms) in VANETs. Therefore we first give an overview over different application types with their characteristics, followed by a short description of communication paradigms used to realize such applications. The identified properties of these applications together with the special network characteristics of VANETs allow us to perform a requirements analysis for the dissemination protocols.

### **2.1 VANET applications**

There are many applications envisioned for VANETs, in (Vehicle Safety Communications Project [VSCP], 2005) e.g., more than 75 application scenarios were identified. A successful deployment of such applications would result in a high benefit. According to this benefit the VANET applications can be classified as follows (Bai et al., 2006):

#### **Safety applications**

Active safety applications represent the most important group of VANET applications. The goal of these applications is to reduce the number of injuries and fatalities of road accidents. In the European Union (EU27) e.g., more than 1.2 million traffic accidents involved injury of passengers in 2007 and more than 42,000 accidents ended fatal (EURF, 2009). Hence, there is a high potential benefit in the implementation of such applications (VSCP, 2005). To achieve this goal, safety applications disseminate information about hazardous situations (e.g. about abnormal road conditions or post-crash warning) to vehicles which can benefit from such information to avoid an accident. Thus, this kind of applications rely mostly on the dissemination of information into a specific geographic region, therefore, a geographically limited broadcast – or so called GeoCast – is used (Bai et al., 2006; Bako et al., 2008; Slavik & Mahgoub, 2010). It is also important to note, that safety applications are delay critical, i.e. it is essential that the information is disseminated immediately without any delay. A special case of this broadcast is the one-hop MAC-layer broadcast – also called beaconing – which is periodically sent to neighbors in communication range to exchange information (e.g. position, velocity) sensed by own sensors. This information can be used for safety applications like cooperative collision warning.

#### **Convenience (traffic management) applications**

This kind of applications intends to improve the driving efficiency and comfort on roads by means of communications. Driving efficiency applications intend to optimize the traffic flow on roads, i.e. minimizing the travel time by disseminating information about traffic flow conditions on roads. Therefore, cars periodically exchange information, combine information received from neighboring vehicles with information sensed by own sensors, aggregate them, and disseminate the newly gathered information for other vehicles. This way, applications like a cooperative traffic jam detection or travel time estimation for road segments can be realized.

A driver having e.g. information about a traffic jam in advance, can choose an alternative route (with the assistance of the car navigation system), thus reducing greatly the travel time. Therefore, a successful deployment of such applications could greatly reduce the fuel consumption of vehicles, which would have a great impact on cost reduction as well as on the reduction of CO<sub>2</sub> emission. Comfort applications assist the driver in many situations, e.g. for finding free parking spots or merging into the flow traffic and so on. These applications are delay-tolerant, i.e. they don't impose such tight time constraints as safety applications, but mostly need to exchange information periodically into the direct neighborhood.

### Commercial applications

Commercial applications provide communication services like entertainment, web access and advertisement. Examples are remote vehicle diagnostics, video streaming, and map download for the navigation system. In contrast to the previously discussed types of applications, commercial applications mostly rely on unicast communication and require a much higher bandwidth than the two other application groups.

A more detailed classification with application examples can be found in (Schoch et al., 2008). In the next subsection we briefly overview the different communication mechanisms used to implement the presented application types.

## 2.2 Communication paradigms

Considering the three type of application classes from a network perspective, it can be stated that the broadcast/GeoCast, beaconing and unicast communication paradigms are the building blocks for these applications. According to (Bai et al., 2006), broadcast can be further divided into the event-driven, scheduled, and on-demand sub-classes.

Event-driven broadcast is used by delay-critical applications like road hazard condition warning, and the information is disseminated over multiple hops into a specific geographic region. Scheduled broadcast is used for applications like cooperative collision warning and most of the traffic management applications. Information needed by such applications is exchanged periodically and sent as MAC-layer broadcast only to neighbors in communication range. Applications which require a multi-hop dissemination need to apply some efficient aggregation techniques to overcome the limited bandwidth problem (c.f. (Dietzel et al., 2009a; Dietzel et al., 2009b)). Unicast is important especially for commercial and entertainment applications.

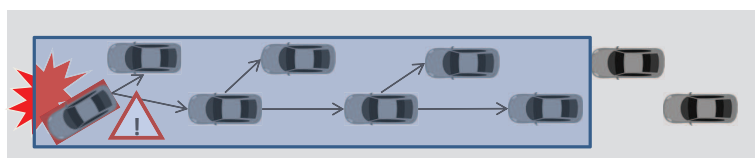


Fig. 1. Example for GeoCast communication.

Figure 1 shows the GeoCast communication paradigm. A broken down vehicle (marked red on the left side of the image) initiates a broadcast message about the hazardous situation. This message is disseminated via multiple hops to inform all vehicles in the specified destination region. Beaconing is shown in Figure 2. The vehicle marked red in the figure sends a MAC-layer broadcast message with data about the own vehicle, like position, heading, and

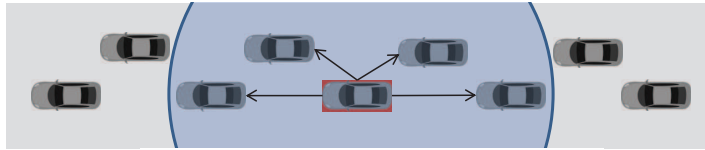


Fig. 2. Example for Beaconing.

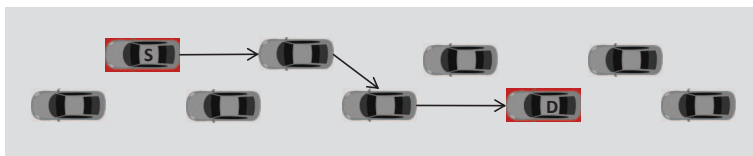


Fig. 3. Example for unicast communication.

velocity. This message is received by all vehicles in communication range and is not further forwarded. The last communication paradigm, unicast communication, is shown in Figure 3. A message is routed hop by hop from a sender (S) to a destination (D).

As already stated, active safety applications are the most important class of envisioned applications and they offer a high potential benefit. Because the majority of these applications rely on broadcast, we can conclude that the broadcast/GeoCast communication paradigm is of eminent importance for a successful application of VANETs. Moreover, broadcast is a basic service used also for route discovery in many reactive unicast protocols like DSR (Johnson & Maltz, 1996), AODV (Perkins & Belding-Royer, 1999), and LAR (Ko & Vaidya, 2000). Therefore, the objective of this chapter is the evaluation of this type of vehicle-to-vehicle communication.

### 2.3 VANET characteristics

Before going into the details of broadcast protocols, we briefly summarize the VANET characteristics. These characteristics, together with the discussed application classes, reveal some important requirements onto the communication protocols.

#### High mobility

Vehicles on highways potentially travel at very high speeds. Thus, the communication period between these vehicles can be very short. Moreover, high node velocities cause more frequent topology changes which result in outdated neighbor tables. Thus, when a protocol relies on such a table, the forwarding decision may be incorrect due to old or nonexistent entries in this table.

#### Dynamic topology

Characteristic for VANETs is a very high dynamic network topology. The reason therefore is twofold: First, the node density ranges from very sparse and partitioned networks e.g. on rural freeways or late night hours to very dense networks at rush hours and traffic jams. Thus, the number of neighbor vehicles in transmission range can vary from zero, up to hundreds of nodes. Second, node mobility can range from static nodes in traffic jams up to very high

velocities on free highways. This implies that a routing protocol has to overcome with sparse and partitioned as well as dense scenarios, which are subject to rapid changes over time due to node mobility.

### **Wireless communication**

The dissemination of information in a VANET is based on a wireless medium which represents an error-prone and scarce resource in the network. Especially in dense scenarios where many cars compete for the wireless medium, the limited bandwidth constitutes a severe problem for the routing protocol. Therefore, an efficient broadcast protocol is of eminent importance for a successful deployment of VANET applications.

### **Delay constraints**

As outlined in the previous subsection, most of the safety applications are delay-critical. This means, they rely on broadcast mechanisms which allow the dissemination of information with minimal delay. Thus, a broadcast mechanism designed for such applications has to forward safety critical information immediately, without introducing any delay e.g. for routing purposes.

### **Geographical addressing**

In VANETs a geographical addressing method is used and it fits for most envisioned applications. This means that a broadcast is not performed network wide (which is simply not possible due to the potential size of several million nodes in the network), but is limited by a geographic region (GeoCast). Similarly, unicast protocols make use of position information available via GPS receiver for route decisions.

### **Mobility patterns**

Another important aspect of VANETs is that vehicle movements are constrained by the road topology. This means, node movements obey mobility patterns imposed by the road network. Thus, node mobility is predictable and can therefore be utilized by routing protocols to enhance the dissemination performance. Roughly three main classes of movement patterns can be distinguished, which directly influence the degree of predictability of node movements: inner city roads, rural roads, and highways.

### **Beaconing**

The presence of up-to-date neighborhood information is a prerequisite for many VANET applications (e.g. for cooperative collision warning). This information is exchanged by periodical one-hop MAC-layer broadcast messages, so called beacons. This information can be used by a broadcast protocol to enhance the rebroadcast decision, without introducing additional communication costs.

### **Pseudonym change**

By communicating information, vehicles reveal personal information which results in a severe privacy problem. To solve this problem, vehicles are supposed to communicate using pseudonyms which they change at a given frequency. By changing its pseudonym, a node may be inserted into the neighbor table multiple times under different pseudonyms. Having such incorrect neighbor entries, routing decision cannot be met correctly anymore. Thus,



pseudonym changes may heavily affect the underlying protocol if it uses neighborhood information.

| Characteristics                | Implications                                                                                                                                                        |
|--------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>High Mobility</i>           | Outdated neighborhood information and short communication periods.                                                                                                  |
| <i>Dynamic Topology</i>        | High variance in network density and node velocity: partitioned networks vs. traffic jams.                                                                          |
| <i>Wireless Communication</i>  | Limited bandwidth and error-prone wireless communication.                                                                                                           |
| <i>Delay Constraints</i>       | Messages need to be broadcast immediately, without introducing any delay.                                                                                           |
| <i>Geographical Addressing</i> | Position information of vehicles are needed and GeoCast is an important communication mechanism for safety applications.                                            |
| <i>Mobility Patterns</i>       | Protocols can benefit from predictable mobility patterns to enhance their routing decisions.                                                                        |
| <i>Beaconing</i>               | More network load, but protocols can benefit from information exchanged by this basic service.                                                                      |
| <i>Pseudonym Change</i>        | Pseudonym changes result in incorrect neighbor tables. Thus, pseudonym changes introduce a new challenge to VANET protocols which rely on neighborhood information. |

Table 1. VANET characteristics and their implications.

Table 1 summarizes the discussed VANET characteristics together with their implications. Based on these implications, a more exhaustive requirements analysis can be done in the next subsection.

2.4 Requirements analysis

The diversity of VANET applications and the special network characteristics impose several requirements to the broadcast protocols. These requirements are deduced from the previous subsections and summarized in the following.

Scalability

The broadcast protocol has to cope with very dense networks like traffic jams in order to enable correct operation of safety applications in such scenarios.

Effectiveness

The broadcast protocol has to assure that all nodes (or a percentage of nodes, defined by the application) in the destination region receive the disseminated information.

Efficiency

Due to the limited available bandwidth, the broadcast protocol needs to eliminate message redundancy. This is achieved by minimizing the forwarding rate, but still achieving a reception of a message by all nodes in a specific geographic region. This helps to avoid the broadcast storm problem (Ni et al., 1999) and enables the coexistence of multiple VANET applications.

**Dissemination delay**

Safety applications require the immediate relaying of information, without the introduction of any delay.

**Delay-tolerant dissemination**

Because vehicular networks are subject to frequent partitioning, it is desirable to cache information in such scenarios and propagate them later when new vehicles are available in the vicinity. Otherwise important information can be lost when the network in the destination region is not fully connected.

**Robustness**

The communication over the wireless medium is error-prone, nevertheless, the broadcast has to cope with packet losses in order to assure the correct function of vital safety applications.

It has to be noted that not all requirements can be met to a full extent because some requirements are contrary. So, for example, when minimizing the forwarding ratio to achieve a high efficiency, the requirement robustness cannot be fulfilled anymore because relaying nodes represent a single point of failure in this case. Thus, when a relaying node fails to forward a message (which is probable due to the wireless nature of the communication channel) the overall reception rate can also drop significantly. Therefore, in most cases an elaborate tradeoff between such requirements is needed.

**3. Review of broadcast protocols for VANETs**

As we have seen, due to the diversity of VANET applications and the special network characteristics, the design of an efficient broadcast protocol is a challenging task. The simplest way to implement a broadcast mechanism is the use of naïve flooding. In flooding every node rebroadcasts a message exactly once (given that it is located inside the destination region), thus the message is flooded into the whole region. The downside of simple flooding is that this mechanism is very inefficient. Given the limited bandwidth of the wireless medium, an inefficient information dissemination scheme like naïve flooding leads to redundancy, contention, and collision, to which is referred to as the broadcast storm problem (Ni et al., 1999). To overcome these problems (and the ones identified in the previous sections), many improved broadcast protocols were proposed by the research community.

In this section we first introduce a classification of different broadcast approaches and discuss them. After that, we review novel broadcast mechanisms which were designed to perform well in highly dynamic environments like VANETs. We not only consider VANET protocols here, but also cover protocols for mobile ad-hoc networks. Thus, we present an up-to-date and broad discussion of broadcast protocols from multiple domains.

**3.1 Classification of broadcast protocols**

One of the first in-depth classification of broadcast approaches was done by Williams and Camp in (Williams & Camp, 2002). They identified four main classes: Simple Flooding, Probability Based Methods, Area Based Methods, and Neighbor Knowledge Methods. More recent works on this topic overtake this thorough analysis and refine it with new properties (cf. e.g. (Heissenbüttel et al., 2006; Khelil, 2007; Yi et al., 2003)). Although such a categorization is useful to evaluate and discuss the properties of broadcast protocols belonging to different classes, it has a significant drawback. Such an exclusive differentiation into rigid classes is not



practicable for many broadcast protocols. We argue that many protocols are not belonging to one fixed class, but combine the properties from different classes. This was also stated by (Slavik & Mahgoub, 2010) and we call them therefore Hybrid Broadcast Protocols.

In the following we give an overview over basic attributes of protocols, which define key characteristics. Knowing such attributes together with their implications, it allows a more thorough analysis of the properties of a protocol. For example, we don't consider area based methods as an attribute class (in contrary to many other classifications in the literature) because it only tells how the rebroadcast decision is calculated (based on the additional coverage), but gives no information about the protocols' properties. To compute the additional coverage, atomic information like position and distance are needed, but it can be also deduced from topology information. If a protocol uses such information, then exact properties can be determined like complexity, weaknesses and strengths. Therefore we consider such information as key attributes which are used in our classification.

### **Probabilistic**

In this scheme, a node rebroadcasts a message with a certain probability. This probability can be fixed a priori (Static Gossip) or adapted dynamically (Adaptive Gossip). In their pure form, probabilistic schemes are very simple and stateless (no need for neighborhood information). They have moderate efficiency but are robust to packet losses due to their probabilistic nature.

### **Topology based**

Topology based protocols use neighborhood information (e.g. 1-hop or 2-hop) to calculate the rebroadcast decision. Such information needs to be exchanged periodically (by so called beacon messages) at a frequency depending on nodes' velocity. This results in higher communication overhead due to the periodical exchange of beacon messages but allows on the other hand very efficient rebroadcast decisions. In dynamic networks this kind of protocols may degrade in performance with increasing node velocity due to outdated neighbor information.

### **Position/distance based**

By using position information, the rebroadcast decision can be calculated more accurately in some cases. E.g. the rebroadcast probability could be adjusted based on the distance to the sender or relays can be selected in a VANET based on their positions.

### **Local decision**

In local decision protocols, a node decides itself on reception to rebroadcast the message or not. This is the contrary of imposed decision and is a desired property of protocols especially in highly dynamic environments like VANETs, because this way rebroadcasts can be decided locally, thus decoupling sender from receiver, which results in a more robust protocol.

### **Delayed rebroadcast based**

This class of protocols introduces a delay before rebroadcasting a message defined by a delay function (randomly or according to some property of the node like distance to the sender). The delayed rebroadcast is useful when nodes overhear the communication channel and gather information about rebroadcasts from other nodes, upon that a more efficient rebroadcast decision can be taken. An example for this type of protocols is the Dynamic Delayed Broadcasting (DDB), introduced by (Heissenbüttel et al., 2006). We consider this

mechanism to improve the broadcast performance as orthogonal to other techniques. Thus, it can be combined with other mechanisms, and therefore, we don't consider them separately in this work.

Clustering, in contrary to other classifications is not considered as a basic attribute of protocols, but is more an aggregation of other properties. A standard clustering scheme utilizes normally topology information to build the clusters and clusterheads utilize the imposed decision scheme to designate the relays. This holds also for more advanced clustering schemes, thus they utilize a combination of the key protocol classes defined above.

### 3.2 Deterministic broadcast approaches

A subclass of topology based broadcast protocols are the imposed decision protocols, where a sender specifies in the broadcast message which neighbors have to perform a rebroadcast. We refer to this type of protocols as deterministic broadcast approaches. Deterministic approaches explicitly select a small subset of neighbors as forwarding nodes which are sufficient to reach the same destinations as all nodes together. Therefore, a relaying node has to know at least its 1-hop neighbors. As finding an optimal subset (i.e. with minimal size) is NP-hard, heuristics are used to find not necessarily optimal but still sufficient relaying nodes.

These type of protocols were one of the first ones suggested by the research community to minimize the broadcast overhead, thus to overcome the broadcast storm problem. Characteristically these protocols achieve a very high efficiency, because based mostly on 2-hop neighborhood information, very accurate rebroadcast decisions can be calculated. Therefore, many variants of deterministic broadcast protocols can be found in the literature. Examples of deterministic approaches are dominant pruning (Lim & Kim, 2000), multipoint relaying (MPR) (Qayyum et al., 2002), total dominant pruning (Lou & Wu, 2002), and many cluster based approaches (see e.g. (Wu & Lou, 2003) and (Mitton & Fleury, 2005)).

Despite the high efficiency they offer, deterministic broadcast has a significant disadvantage: relaying nodes represent a single point of failure. If a relay fails to forward a message (e.g. due to wireless losses, node failure, or not being in transmission range due to mobility) then the overall reception rate of the message may drop significantly. Thus, these kind of protocols lack robustness and perform poorly in dynamic environments like VANETs. Therefore, they can't be used for safety critical applications in VANETs and more robust – but at the same time also efficient – broadcast schemes are needed.

### 3.3 Probabilistic broadcast approaches

One of the early probabilistic approaches to improve flooding is static gossiping, which uses a globally defined probability to forward messages (Chandra et al., 2001; Haas et al., 2006; Miller et al., 2005). All these variants work best if the network characteristics are static, homogeneous, and known in advance. Otherwise they result in a low delivery ratio or a high number of redundant messages. To overcome these problems, adaptive gossiping schemes have been developed.

Haas et al. (Haas et al., 2006) introduced the so called two-threshold scheme, an improvement for static gossiping based on neighbor count. A node forwards a message with probability  $p_1$  if it has more than  $n$  neighbors. If the number of neighbors of a node drops below this threshold  $n$  then messages are forwarded with a higher probability  $p_2$ . The obvious advantage of this improvement is that in regions of the network with sparse connectivity messages are prevented to die out because the forwarding probability is higher than in dense regions.

(Haas et al., 2006) also describes a second improvement which tries to determine if a message is “dying out”. Assuming a node has  $n$  neighbors and the gossiping probability is  $p$  then this node should receive every message about  $p \cdot n$  times from its neighbors. If this node receives a message significantly fewer, the node will forward the message unless it has not already done so.

In (Ni et al., 1999), Ni et al. introduced the Counter-Based Scheme. Whenever a node receives a new message, it sets a randomly chosen timeout. During the timeout period a counter is incremented for every duplicate message received. After the timeout has expired, the message is only forwarded if the counter is still below a certain threshold value.

Although all these adaptations improve the broadcast performance, they still face problems in random network topologies. For example, if a node has a very large number of neighbors, this results in a small forwarding probability in all of these schemes. Despite this, there could e.g. still be an isolated neighbor which can only receive the message from this node. An example of such a situation is shown in Figure 4 (example taken from (Kyasanur et al., 2006)).

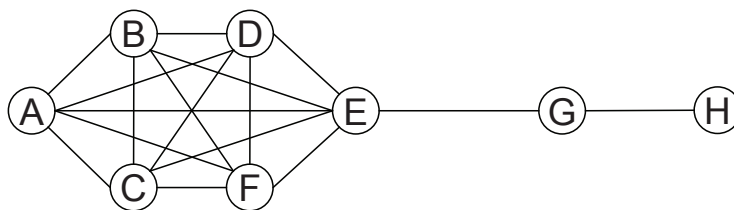


Fig. 4. Sample topology where static gossiping fails

When node  $A$  sends a message, all nodes in its neighborhood receive it. In this example scenario only node  $E$  should forward it with the probability of 1 since  $E$  is the only node that can propagate the message to node  $G$ . If the gossiping probability is only based on the neighbors count, node  $E$  will be assigned a low probability since it has many neighbors. So the broadcast message will “die out” with a high probability and never reach  $G$  and all later nodes. If the part of the network connected only via  $G$  is very large, the overall delivery ratio will drop dramatically. Such situations can occur quite regularly in dynamic networks of a certain density.

### 3.4 Hybrid broadcast approaches

As we have seen, deterministic broadcast approaches achieve a very high efficiency but they lack robustness. On the other hand, probabilistic approaches behave much better in the presence of wireless losses and node failures, but have also other limiting disadvantages. E.g. the adaptation of the forwarding probability to actual network condition is a challenging task and is not solved adequately with simple heuristics. Therefore, recently novel probabilistic broadcast approaches were proposed, which combine the strength of both protocol types, becoming this way highly adaptive to the present network conditions. We call this type of protocols hybrid broadcast approaches.

One of the first hybrid broadcast approaches is the so called Smart Gossip protocol, introduced by (Kyasanur et al., 2006). In smart gossip every node in the network uses neighborhood information from overheard messages to build a dependency graph. Based on this dependency graph, efficient forwarding probabilities are calculated at every node. To ensure building up a stable directed graph, the authors make the assumption that there is only one message originator in the whole network. This assumption may be sufficient in a few scenarios, but especially in the case of VANETs this is not applicable, and therefore, as shown

in (Bako et al., 2008a; Bako et al., 2007) the performance of the protocol degrades massively in such environments.

To overcome these problems, a novel hybrid probabilistic broadcast was introduced by (Bako et al., 2007). In this so called Position based Gossip (PbG) 1-hop neighborhood information are used together with position information of neighboring vehicles to build a local, directed dependency graph. Based on this dependency graph efficient forwarding probabilities can be calculated which adapts to current network conditions. PbG was designed for message dissemination only into one direction, e.g. for a highway traffic jam scenario, where approaching vehicles have to be informed about the traffic jam. Thus, messages are propagated only against the driving direction. This way only one dependency graph has to be built, and therefore this protocol is denoted as the 1-Table version of PbG.

It is obvious that most VANET applications need to disseminate information in both directions of a road and cannot be restricted only to one direction. For example at an intersection, we face four road segments and therefore a message can be distributed in four directions. Therefore, in (Bako et al., 2008b) a 2-Table version of the protocol was introduced, which fits much better for general highway and intersections scenarios.

Furthermore, in (Bako et al., 2008) two more extension of the PbG protocol was introduced: a network density based probability reduction and a fallback mechanism. The first mechanism reduces the forwarding probability in dense networks, thus reducing the broadcast overhead, at the same time achieving similar reception rates as the original protocol. The second extension aims to prevent message losses: A common problem in wireless networks represents the so called hidden station problem. Because MAC layer broadcast frames are used, techniques like RTS/CTS cannot be used to avoid this problem. Especially in very dense networks the hidden station problem has a significant impact on the performance of the protocol. In such cases, the packet loss rate increases and application level requirements for the delivery ratio cannot be fulfilled any more. To overcome this problem, the second enhancement tries to determine if a message is "dying out". The enhancement works as follows. Each node receiving a new message initializes a counter which is incremented every time it overhears the same message being forwarded by some other node. If the counter is below a certain threshold after a fixed period, the message is rebroadcast with the same probability as if it was received for the first time.

A more general gossip protocol similar to PbG was introduced in (Bako et al., 2008a). In this so called Advanced Adaptive Gossip (AAG) protocol two-hop neighborhood information are used to calculate forwarding probabilities similar to PbG. Thus, no position information are needed, which may be imprecise or even not available in some cases. Moreover, this protocol is not limited to any road topology. Furthermore, this protocol was enhanced by a message loss avoidance mechanism in (Schoch et al., 2010), which is similar to the fallback mechanism from (Bako et al., 2008). With this extension the protocol becomes much more robust and is therefore called robust AAG, or short RAAG. In the mentioned work also beneficial properties of RAAG considering security are discussed and evaluated.

#### 4. Evaluation

In this section we evaluate the performance of selected protocols in different scenarios. Because the simulation of all protocols is very time consuming, we selected one representative protocol for each protocol type discussed in Section 3 and evaluate the impact of mobility, node density, and high broadcast traffic on these schemes. Therefore, we first introduce the simulation parameters and describe the two evaluated scenarios: city and highway. After that,



we show that deterministic broadcast schemes are heavily affected by node mobility, thus they are inapplicable for VANETs. The remaining subsections present the results of the selected hybrid broadcast schemes in a highway and city scenario. For comparison we include also the results of naïve flooding and static gossiping. Results of the following protocols are presented:

- Multipoint Relaying (Qayyum et al., 2002)
- Flooding
- Static Gossiping (Chandra et al., 2001; Haas et al., 2006)
- Advanced Adaptive Gossiping (AAG) (Bako et al., 2008a)
- Robust Advanced Adaptive Gossiping (RAAG) (Schoch et al., 2010)

4.1 Simulation setup

For the evaluation of the broadcast protocols we use the JiST/SWANS (Barr et al., 2005) network simulator, including own extensions. JiST/SWANS provides a radio and MAC-layer according to IEEE 802.11b. This is close to the IEEE 802.11p variant, which is planned for vehicular communication. On the physical layer the two-ray ground model is used together with the additive noise model, thus, the effect of packet collisions can be investigated. The radio transmission power is set to achieve a wireless transmission range of 280 meters. For the city scenario a field size of 1000m x 1000m is used, whereas the simulations for the highway scenario are run on a 25m x 3000m field. Node density is varied from 10 up to 300 nodes, thus comparing sparse as well as dense scenarios.

| Parameter              | Value                                             |
|------------------------|---------------------------------------------------|
| Field                  | City: 1000m x 1000m, Highway: 3000m x 25m         |
| Simulation Duration    | 120s                                              |
| Broadcast Start        | 5s                                                |
| Pathloss               | Tworay                                            |
| Noise Model            | Additive                                          |
| Transmission Range     | 280m                                              |
| Beaconing Interval     | 1s                                                |
| Number Messages        | 3 Messages per node, max 150                      |
| MIA Acknowledges       | 1                                                 |
| MIA Replay Delay       | 2.5s                                              |
| MIA Last Replay Offset | 100s                                              |
| Placement              | Random                                            |
| Static                 | Node Speed: 0                                     |
| Random Waypoint        | Node Speed City: 3 – 20 m/s, Highway: 22 – 41 m/s |
| Highway Mobility       | Node Speed Highway: 0 – 30 m/s                    |

Table 2. Simulation setup parameters.

The number of broadcast messages depends on the node density: Every node generates one broadcast message per second (with a minimal payload), limited by a maximum count of three messages per node. The absolute number of broadcast messages is limited by 150. Thus, in a scenario with 10 nodes 30 messages are initiated, whereas in scenarios with 50 or more nodes 150 messages are created (if not otherwise specified). This way we evaluate the protocols

under low as well as under heavy network load. To hold the neighbor tables up-to-date beacons are used which are exchanged with a rate of 1 beacon per second. The beacon size depends on the information required by the broadcast protocol. Thus with AAG and MPR the entire neighbor list is sent in a beacon, whereas in Flooding only a message with minimal size is sent (we assume this is required by the VANET applications).

A setup is simulated over 120s, where the broadcast of messages starts at 5 seconds. For the RAAG protocol, the message loss avoidance (MLA) mechanism is configured to await at least one acknowledge for a sent message, otherwise the message is rebroadcast again once (if new nodes are present in the neighborhood), with a delay of 2.5 seconds. Messages have a timeout of 100s and if a message was not yet acknowledged at least once, the message is rebroadcast one more time.

To evaluate the impact of node mobility on the performance of the broadcast protocols we use three different mobility models:

- Static
- Random Waypoint (RW)
- Highway Mobility (HM)

The static model is used to measure the protocols' performance in a best-case scenario, i.e., nodes didn't move at all, thus all neighborhood information are up-to-date. With the Random Waypoint mobility model a worst-case scenario is investigated where nodes move in arbitrary directions. A more realistic scenario is provided by the Highway Mobility model, which is an own extension inside the JiST/SWANS framework. With this mobility model cars move in the same direction on a 4-lanes highway with random speeds. They hold a safety distance to other cars, change lanes and pass slower cars if necessary. At the end of the simulated highway the lanes are blocked by 4 cars, thus traffic congestion is simulated here. The exact parameters used for our simulations can be found in Table 2.

According to (Bani Yassein & Papanastasiou, 2005), the optimal fixed probability for static gossip is 0.7. Therefore, we use this value for the static gossip protocol in our evaluations. For each simulation setup 20 simulation runs are done and the results averaged.

#### 4.2 Effect of node mobility on deterministic broadcast

Multipoint Relaying (MPR) was selected as a representative for deterministic protocols to evaluate the impact of node mobility onto this protocol type. Therefore, a highway scenario with three different mobility models is used: static, random waypoint, and highway mobility. Because MPR lacks robustness, and therefore the number of broadcast messages heavily influences the performance of the protocol, we also simulated a scenario where only one broadcast message is initiated (Static 1). The other three simulation configurations (Static 2, RW, and HM) use the normal parameters described in 4.1.

Figure 5 shows the results of this evaluation. As we can see, in sparse networks (10 and 25 nodes) the reception rates in all four simulation setups are very low. These results are as expected, because the network is partitioned and therefore not all nodes can be reached by a broadcast without additional mechanisms. With higher node densities and only one broadcast message per simulation (Static 1), MPR achieves quite good reception rates. With 100 and 150 the reception rate is almost 100% and drops slightly with increasing nodes, but stays over 90% which is an acceptable ratio. This slightly decline is due to the higher overhead introduced by the beacon messages.



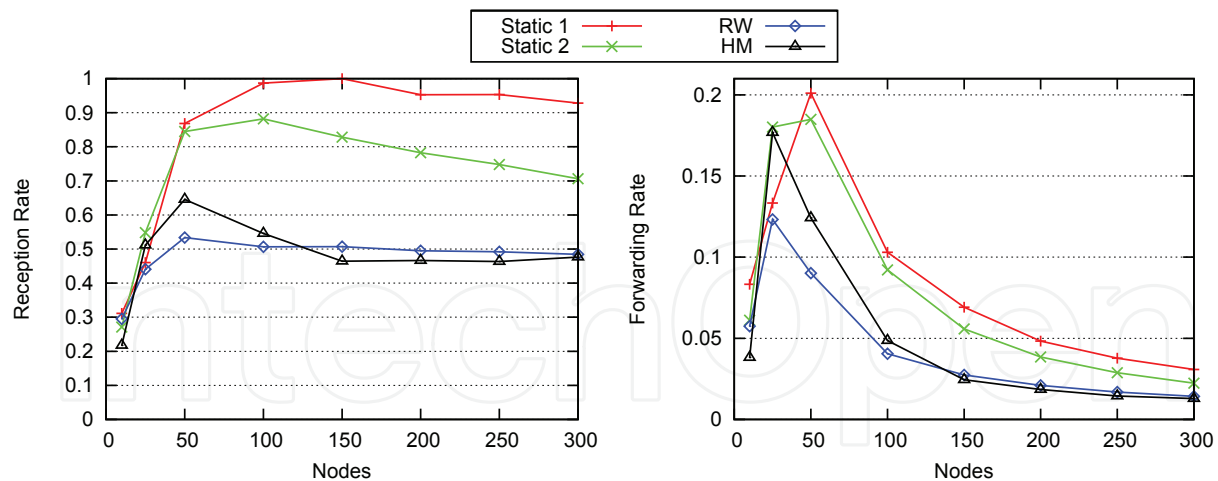


Fig. 5. Performance of MPR in a highway scenario with different mobility models and number of messages.

On the other hand, with a high number of broadcast messages (Static 2), the reception rate drops significantly in higher node densities. With 300 nodes MPR achieves only around 70% reception rate with is clearly unacceptable for safety critical VANET applications. Thus, these results show that heavy network load has a significant influence onto deterministic protocols. Now considering mobility, we can see that with the random waypoint and highway mobility model the reception rate drops even more drastically. With both mobility models in almost all node densities the reception rates are around 50%. Thus, deterministic approaches are inapplicable for dynamic environments like VANETs.

Regarding the forwarding rates, we can see that MPR is highly efficient, needing only around 3% or less rebroadcasts with 300 nodes. Thus, we can conclude that deterministic broadcast approaches are highly efficient but can't meet VANET requirements in the presence of mobility and high network load.

#### 4.3 Hybrid broadcast approaches in a highway scenario

In this subsection we evaluate two hybrid broadcast protocols (AAG and RAAG) in a highway scenario and compare the results with flooding and static gossip (SG). Figure 6 shows the results for this scenario with static nodes. As we can see, in a partitioned network like with 10 nodes in these results, the reception rates of all four protocols are almost identical. Whereas with 25 nodes (here the network is also not completely connected), static gossip already has a significant lower reception rate of around 10%. This gap is even bigger with 50 nodes, where static gossip has a reception rate of around 57% compared with 83% of RAAG. This is because the static gossip probability of 70%, which is too low for sparse networks.

With higher densities, AAG significantly drops regarding the reception rate, reaching not even 70% of other vehicles for the 300 node setup. Here static gossip and flooding achieve better reception rates, both protocols are slightly under 90%. However, RAAG clearly outperforms the other protocols, reaching almost 100% reception rates.

Regarding the forwarding rates, we can see that flooding has the highest forwarding rates except for the scenario with 10 nodes. Here the message loss avoidance mechanism of RAAG generates more overhead, but has not much impact onto the reception rate because the nodes are static. The rebroadcast rate of flooding is way too high in higher densities, and that is a serious problem causing the so called broadcast storm. We will discuss this effect later in a

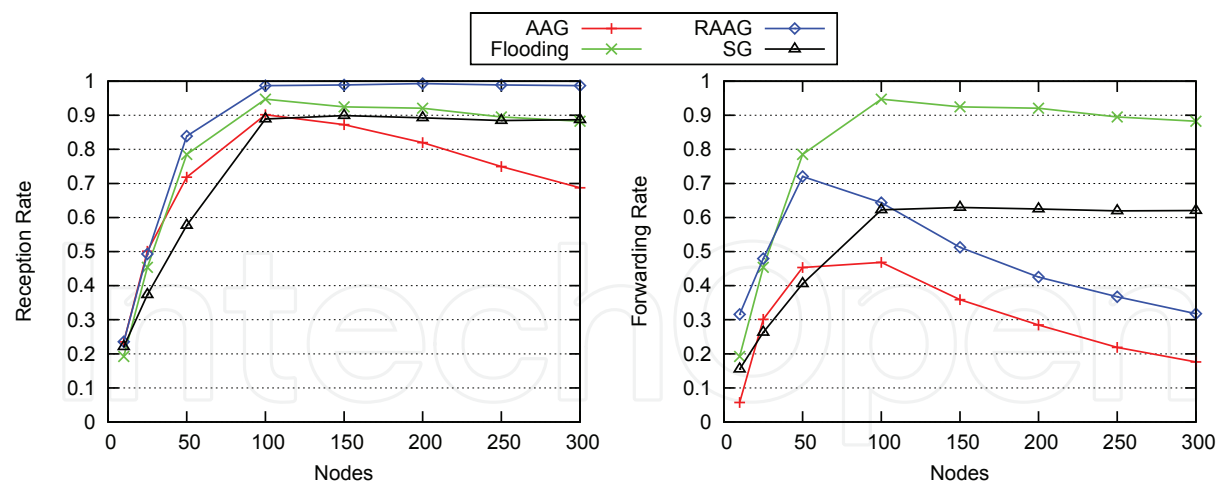


Fig. 6. Performance of hybrid broadcast approaches in a static highway scenario.

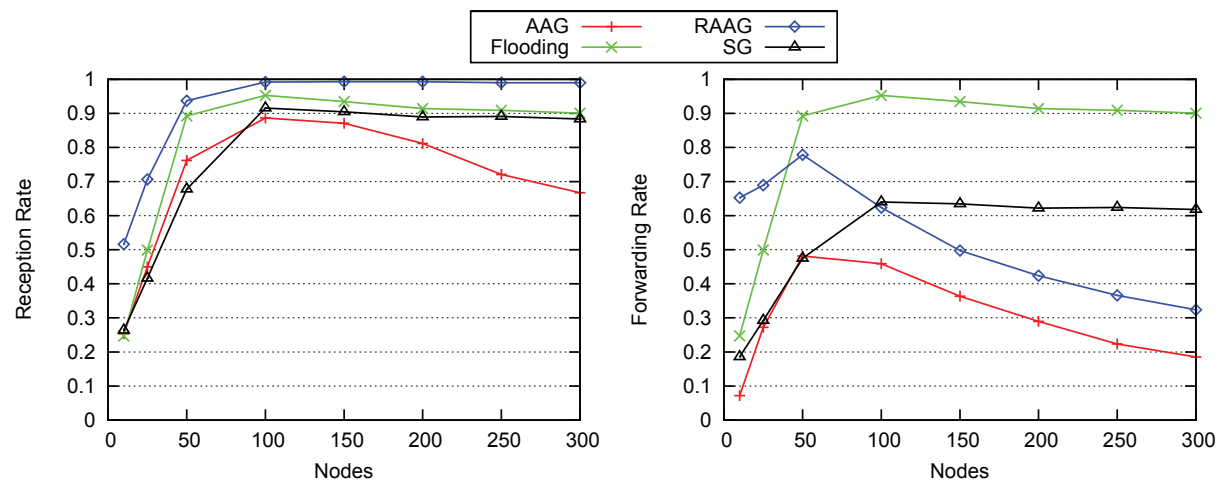


Fig. 7. Performance of hybrid broadcast approaches in a highway scenario using the random waypoint mobility model.

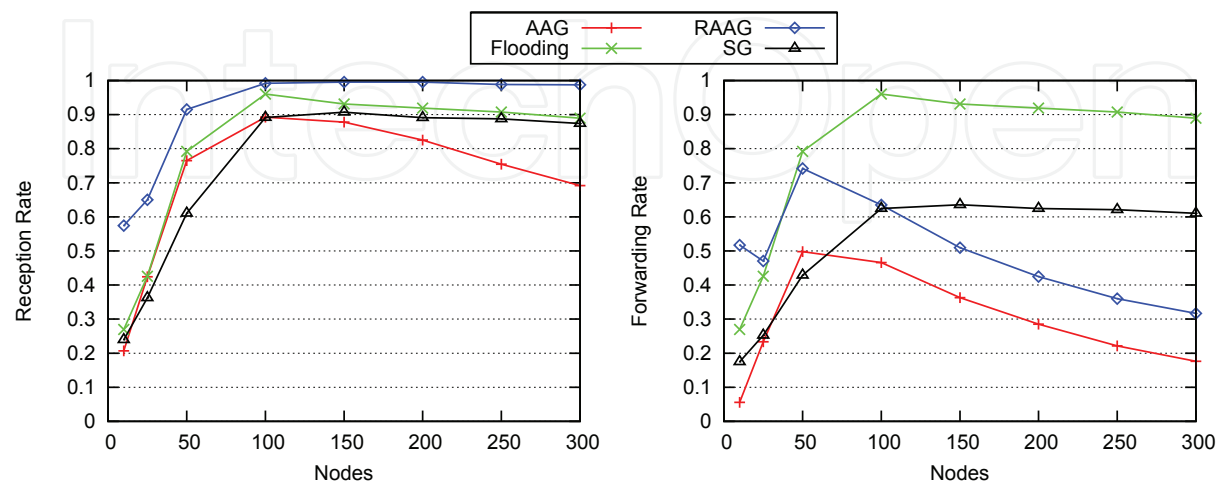


Fig. 8. Performance of hybrid broadcast approaches in a highway scenario using the highway mobility model.

scenario with higher network load. AAG achieves the best forwarding rate, but as we saw, the performance is insufficient for this scenario. Static gossip has a lower forwarding rate as RAAG with few nodes, but remains constant slightly about 60% with higher node densities. Thus, static gossip doesn't scale well with increasing node density. On the other hand, the forwarding rate of RAAG decreases constantly with increasing density and is constantly around 10% higher as AAG due to the message loss avoidance mechanism.

Figure 7 and 8 show the same scenario with random waypoint and highway mobility models. As we can see, there is almost no difference in the reception and forwarding rates compared with the static scenario. This means, that all these protocols are not affected at all by node mobility. This is a very important property which makes these protocols well suited for VANETs. The only difference compared with the static scenario is the reception and forwarding rates of the RAAG protocol in low densities. Due to node mobility, the cached messages are here physically transported and rebroadcast later. Thus, RAAG manages to overcome network partitions and achieves a much higher (at a cost of more rebroadcasts) reception rate.

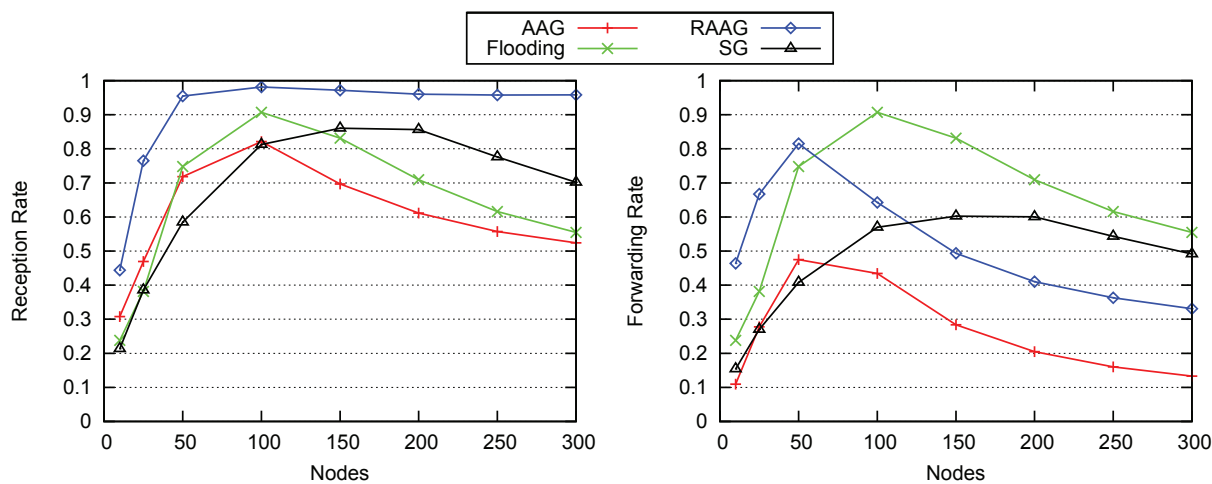


Fig. 9. Performance of hybrid broadcast approaches in a highway scenario under high message load using the highway mobility model.

In the next simulation setup we evaluate the performance of these protocols under high network load. Therefore, we increased the payload of broadcast messages to 512 bytes and raised the limit of the absolute number of messages to 300. This means, every node creates exactly 3 messages, with a rate of one message per second. The results for this simulation setup are shown in Figure 9. As we can see, AAG and flooding can't cope with increasing network load, thus the reception rate is dropping significantly, reaching almost only 50% of the nodes in the 300 node setup. The reception ratio of static gossip also declines constantly with increasing node densities. Thus, these protocols are not scalable and can't be used for VANET applications in such scenarios. Only RAAG manages to reach good reception ratios in the tested setup, and as can be seen, it clearly outperforms the other protocols. Thus we can conclude, that RAAG allows an efficient and effective dissemination also in scenarios with extreme high network load. The forwarding rates can be compared with the other results. AAG, flooding, and static gossip have lower forwarding ratios due to the packet losses.

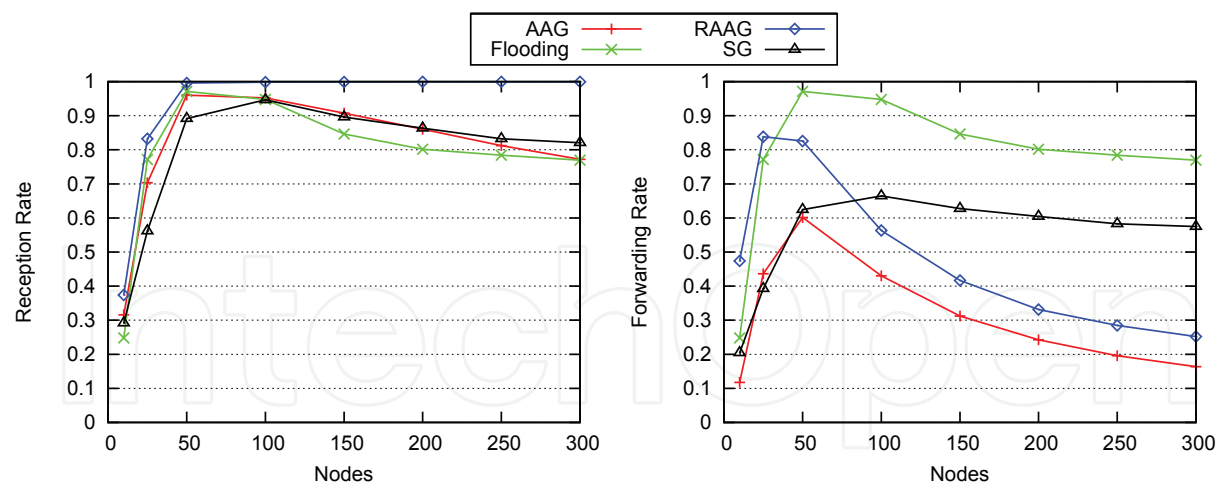


Fig. 10. Performance of hybrid broadcast approaches in a static city scenario.

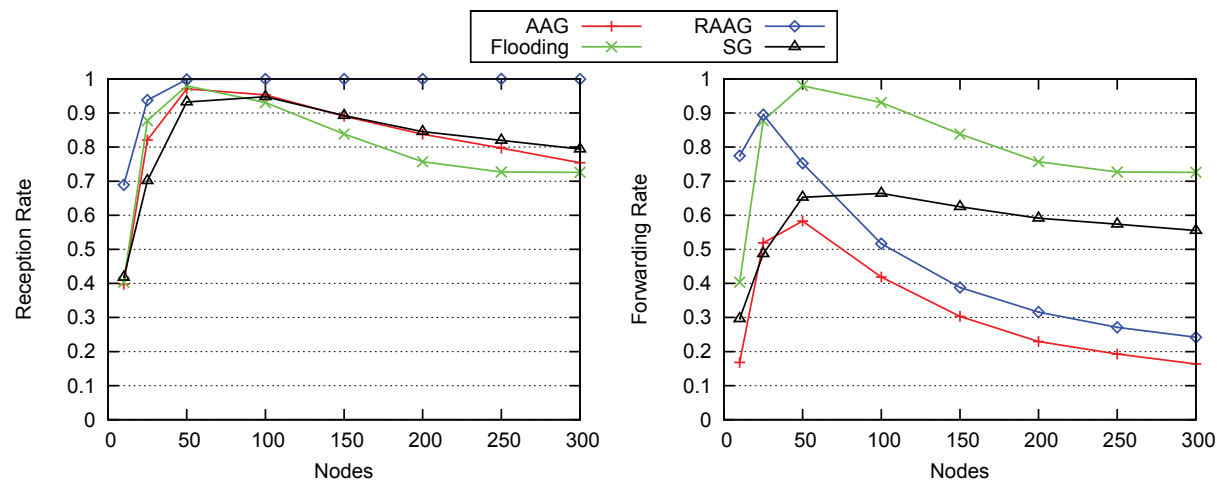


Fig. 11. Performance of hybrid broadcast approaches in a city scenario using the random waypoint mobility model.

4.4 Hybrid broadcast approaches in a city scenario

For the city scenario we simulate a field of 1000m x 1000m with static and random waypoint mobility. Figure 10 shows the results for the static scenario. As we can see, the results are similar to the static highway scenario. RAAG achieves the best reception rates for all node densities, reaching almost 100% with 50 and more nodes. The reception rates of the other protocols drop constantly with increasing nodes, and reach only around 80% with 300 nodes. This is clearly not sufficient for critical safety applications in VANETs. The forwarding rates are also similar to the previous scenario: flooding and static gossip have very high forwarding rates and these rates don't scale well in contrary to RAAG and AAG. Considering the mobile city scenario shown in Figure 11, we can here also conclude that mobility has almost no effect on these protocols. Except for the RAAG protocol, where the message loss avoidance mechanism positively benefits from nodes' movements. In highly partitioned networks, like with 10 nodes in this figure, RAAG manages to achieve a reception rate of around 30% higher than the other protocols, or RAAG itself in a static scenario. This is a significant gain and these results underline the need of a message loss avoidance mechanism for partitioned networks.

## 5. Summary and outlook

In this chapter we gave an overview over possible VANET applications and showed different communication paradigms used for such applications. We also pointed out the importance of broadcast mechanisms for active safety applications. This was followed by an overview of the special network characteristics of VANETs. From that, we deduced a set of requirements for broadcast protocols which have to be fulfilled for a successful deployment of VANET applications.

Also a classification of broadcast protocols was introduced which enables a more systematic analysis of broadcast mechanisms. Based on this, we have reviewed state-of-the-art broadcast protocols designed for inter vehicle communication. The main focus here was on hybrid protocols, which combine positive properties of more protocol classes and offer thereby promising characteristics for broadcast applications in vehicular networks.

The theoretical evaluations were confirmed by extensive simulations. We have shown that deterministic protocols are heavily affected by node mobility and network load, and they are therefore not suitable for VANET applications. Furthermore, we have shown that pure flooding, as well as static gossip, is not scalable, i.e. they cause the so called broadcast storm problem. Thus, with increasing node density and network load their performance drop significantly and they are therefore unfeasible for VANETs.

On the other hand, the RAAG achieves very promising results in sparse as well as in dense networks. We have shown that the message loss avoidance mechanism yields a significant performance gain in sparse scenarios and increases the robustness of the protocol also in dense networks. Moreover, RAAG is not affected by node mobility which is a very desirable property of VANET protocols. Thus we can conclude that RAAG is predestinated for dynamic networks like VANETs and satisfies the requirements in such networks also in the presence of critical safety applications.

Although the presented results are very promising, there are some issues we want to address in future work. First of all, RAAG requires 2-hop neighborhood information which generates more overhead. We aim to reduce this required knowledge to 1-hop neighbors, similar to the PbG protocol but in a more general way. Moreover, we have to evaluate the performance of RAAG in the presence of pseudonym changes, which may have a significant effect on broadcast protocols. Also a detailed evaluation of the message loss avoidance mechanism in partitioned networks and its optimization could result in a significant gain in delay-tolerant networking.

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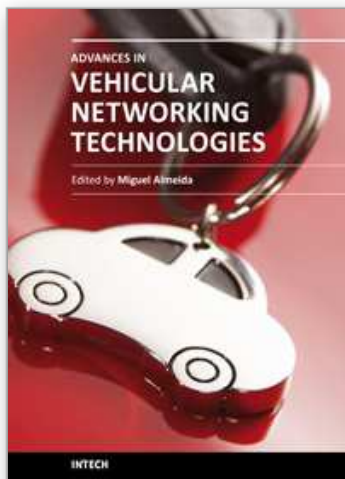
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This book provides an insight on both the challenges and the technological solutions of several approaches, which allow connecting vehicles between each other and with the network. It underlines the trends on networking capabilities and their issues, further focusing on the MAC and Physical layer challenges. Ranging from the advances on radio access technologies to intelligent mechanisms deployed to enhance cooperative communications, cognitive radio and multiple antenna systems have been given particular highlight.

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