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Adapting Contention-Based Forwarding to Urban Vehicular Topologies for Active Safety Applications

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Abstract Contention-based Forwarding (CBF) is a broadcasting technique used to disseminate emergency messages for *traffic safety* applications in Intelligent Transportation Systems (ITS). Its design hypotheses have however been based on three major assumptions: uniform vehicular topology, non-fading channels and homogeneous communication capabilities. Realistic vehicular urban topologies do not comply with any of them, making CBF select relays, which may not exist, may not be reached or may not be optimal due to heterogeneous transmit capabilities. In this paper, we propose to adapt CBF to such challenging environment by first employing two different mechanisms as a function of the topology, and second by considering the dissemination capabilities of the relays, allowing for example road-side units or tall vehicles to preferably act as relays when necessary. Our protocol, called *Bi-Zone Broadcast*, is evaluated in a realistic urban environment and showed to provide around 46% improvement in dissemination delay and 40% reduction in overhead compared to plain CBF or flooding. We finally shed light to other aspects of CBF that remain unsolved and should be addressed in future work to further improve the reliability of dissemination protocols for traffic safety protocols.

Keywords Dissemination protocol · broadcast · contention-based forwarding · vehicular urban topology · performance evaluation · traffic safety applications · intelligent transportation systems

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1 Introduction

In the last few years, Intelligent Transport Systems (ITS) have been considered as one of the most emerging research area due to their promising role in enhancing road safety and promoting traffic efficiency. The identification of future ITS applications and their requirements has been one of the most important issues being investigated. Particularly, traffic safety applications, being the most vital and critical ones, have gained a lot of attention. A particular aspect of such applications is their sensitivity to the delay. Let's consider a scenario where an emergency event occurs in a specific area. In order to convey the emergency information in very brief delay and to all the vehicles located in proximity to the danger, short range multi-hop and periodic broadcasting should be used. Explicit acknowledgements not being available, achieving reliable one-hop and multi-hop broadcast still remains a very challenging topic. It is also a crucial aspect that needs to be solved before any successful deployment of traffic safety applications. As a sender cannot know if its transmission has been successful, it relies on redundant transmissions either directly or via relays. Flooding accordingly appears to be an appropriate method to address such problem. Although efficient in small scale scenarios, flooding does not scale and leads to the well known broadcast storm problem [22], as the number of retransmitters grows exponentially, and eventually saturates the wireless channel with unrequired communication. The challenge is therefore to reach a similar dissemination rate as flooding but with significantly less transmissions and thus, relays.

Many efforts have been conducted to address the reliable multi-hop broadcast problem, such as [12, 9, 27, 20]. One popular solution is to build a priori relaying structure, such as clusters [11, 9] or connected dominating sets (CDS) [24, 25], or explicitly designate relays which would improve the dissemination. This approach is known as *sender-centric* as relays are explicitly selected or known by senders. Yet, this approach remains suboptimal in urban vehicular environments, mostly due to the high mobility and dynamic topology requiring a constant update and maintenance of the structure. Also, conceptually speaking, the vehicular fading environment makes a sender not an appropriate decision-maker for relaying purposes. This led to the development of *receiver-centric* solutions where "broadcast" relays autonomously decide if they should relay a message or not. Each receiver contends to be a potential relay, the node winning the contention relaying and all other nodes overhearing the relay stopping their contention. The efficiency of this approach, also known as *Contention-based Forwarding (CBF)* [16], has been investigated for several contention mechanisms. For instance, *random CBF* makes relays draw a timer based on a random distribution, providing nodes with equal chances to be a relay. *Distance-based CBF*, on the other hand, makes relays draw a timer invertially proportional to their Euclidean progress from the sender, thus implicitly designating nodes with maximum progress in the dissemination area as relays. This approach can be found in most of the safety applications-related schemes [7, 20, 21, 5].

Distance-based CBF yet remains sensitive to the vehicular urban topology and connectivity. If the geographic area providing a maximum progress does not contain any relay or the relay cannot be reached due to intense fading, alternate relays will be penalized and will have to wait longer than required. Moreover, none of these approaches can yet discriminate relays based on their relaying capabilities, which is also a significant particularity of urban vehicular environments. For instance, Road-Side Units (RSUs) have usually a higher transmit power, and with tall vehicles, they also have higher antenna heights, therefore improving their communication range compared to regular vehicles. Accordingly, it becomes clear that the dissemination characteristics of a relay should be considered in the CBF contention timer, as nodes with similar or even smaller progress could make better relays.

In this paper, we address the design of an efficient CBF contention mechanism tailored to the requirements of traffic safety applications and adapted to the specificities of vehicular urban environments. On the one hand, we have a random CBF, which is applied particularly to cope with the problem of high fading (characterizing vehicular environment) to which distant nodes are often more exposed. On the other hand, the distance-based CBF provides relaying mechanisms adapted to traffic safety applications. Also, none of the CBF mechanisms available today differentiates relays based on their dissemination capabilities. We therefore propose an approach, called *Bi-Zone Broadcast (BZB)*, which regroups the asset of both random and distance-based CBF and further adjusts the contention-timer to provide a higher chance for relays with good dissemination properties (RSUs, buses, trams, trucks..) to be a relay. We separate the forwarding area into two zones, one where a random CBF should be applied, and one where a distance-based CBF should be used. The two zones, depending on a distance threshold D_{th}, can be adjusted to the topology and connectivity. The contention-timer is then weighted by the neighbour degree of the relays. Using the iTETRIS [2] platform and a calibrated realistic urban environment of a city of Bologna, we illustrate how this hybrid strategy showed to be significantly more adapted to vehicular urban environment, improving dissemination delay by 46% and reducing the overhead by around 40%. We present then a study on the variation of the parameter D_{th} and its impact on the protocol performance. We finally discuss potential future work and directions in reliable broadcasting for traffic safety applications, by illustrating the cost of redundant transmissions not providing information with added values, which are caused either by uninterrupted contention timers or by multiple sources observing the same event.

This paper is structured as follows. In Section 2, we discuss related works. Section 3 introduces the different challenging trade-offs of existing approaches and the proposed solutions. In Section 4, a simulation study is performed that evaluates the performance of the designed dissemination system. Finally, Section 5 reports the conclusions and provides directions for further research.

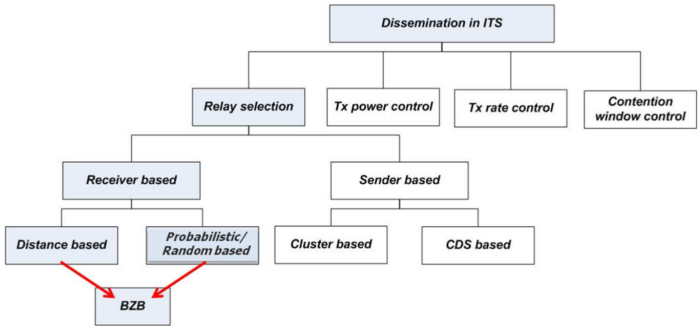


Fig. 1: Classification of dissemination approaches proposed for ITS systems.

2 Related Works

In Fig. 1, a classification of the multi-hop broadcast approaches found in the literature and directed to traffic safety applications is presented. Mostly, they have been focusing on reducing channel congestion by limiting the number of re-broadcasts with the optimal selection of the relays and/or adjusting the nodes transmission parameters according to the network conditions, notably the transmission power, the transmission rate and/or the contention window.

In this work, we investigate the mechanisms that are connected to the concept of relay selection and more precisely receiver-based approach. As mentioned in the introductory part, sender-based mechanisms require an accurate and up-to-date knowledge of the topology to build the system architecture and to maintain it. This aspect turns out to be not compatible with the highly dynamic vehicular environment and can not cope with the requirements of traffic safety applications. For more details on other forwarding approaches, please refer to [17]. As illustrated in Fig. 1, in receiver-based relay selection approach, we distinguish two main categories: random-based (or probabilistic-based) and distance-based.

In probabilistic-based dissemination, the decision of transmission depends on a given distribution that could be built on global and/or local knowledge. In [18], the authors propose REAR, a scheme where each node calculates an estimate reception probability for each of its neighbours based on their position and their environment exchanged via beaconing. The node with the highest estimate is selected as a relay with the mean of a contention procedure. The authors in [6] propose OAPD/DB, an adaptive approach where nodes compute the probability of transmission based on their local network density information within two hops. Nodes with the highest density are given the priority to forward the information. In case of both protocols, the relay selection process relies on a fresh knowledge of surroundings which might be highly variable in dynamic vehicular environment.

Another receiver-based dissemination scheme is the distance-based which we can find in [26, 10, 7, 15, 27, 20, 23, 19, 21, 5]. Most of these research works propose a contention time inversely proportional to the distance from the sender. The broadcast procedure is controlled by limiting the number of hops [10] or by setting the geographic destination area and/or the direction of propagation where the safety information must be delivered [7,15,27]. Some optimization techniques are proposed in [20,23,19,21,5]. For instance, authors in [21] introduce the backfire algorithm as a mechanism for suppressing redundant retransmissions. A dynamic scheduling is also proposed to prioritize received packets transmissions. Moreover, a congestion detection algorithm based on neighbourhood density and vehicle velocity has been implemented to alleviate the problem of network congestion. The cut-through concept is used in [5] to allow packets forwarding before being entirely received. To do this, multiple channels are used to reduce interferences.

In [8], Blaszczyszyn et *al.* propose a novel receiver based broadcasting mechanism. Active signalling is used, on one hand, as an acknowledgement technique and on the other hand, to select the best relay offering better progression. Eichler *et al.* in [14,13] introduces the aspect of benefit-based dissemination which is a contention-based scheme that extends the idea of optimising the information progress to the enhancement of the global network benefit. Each node computes the benefit provided by each packet to all the adjacent nodes which depends on various parameters such as the distance to the information source, the information type and quality, vehicle speed and message specific characteristics. The packet providing the highest benefit to all neighbours has the highest priority to be forwarded. Furthermore, a contention scheme is introduced and which depends on the estimated benefit of the message to broadcast.

The common characteristic of the aforementioned receiver-based schemes is that they can be considered as a special case of CBF scheme. The method used in the contention phase differs from one scheme to another but at the end the node wining the contention will be the next to forward the message.

In this paper, we propose a hybrid dissemination protocol BZB that regroups the benefits of both receiver based schemes: distance-based and probabilistic based. On one hand, distance based scheme offers best progression to the safety information dissemination favouring farthest nodes and gives a high timer for close vehicles to sender. On the other hand, probabilistic based approach manages probabilistically and irrespectively from the position the relay selection. We have decided to regroup both features as fading and non-uniform mobility does not guarantee the availability of the relays with best progress.

We have designed two zones, in one zone (the farthest from the dissemination initiator or the forwarder), mainly the distance based scheme is used, and if nodes are present, relays with best progress will have the lowest timer. In the second zone (the closest to the initiator or the forwarder), where distance-based would penalize relays, we use a probabilistic or random timer based on a uniform distribution. We benefit from assets from both schemas random timer for fair relaying at close range, and low timer for nodes with high progress.

3 Information dissemination in ITS environment

In this section, we first study the different limitations that a distance-based CBF presents and then propose a new approach to solve these issues.

3.1 Assumptions

In the scope of this work, we assume that vehicles are equipped with a positioning system e.g. GPS (Global Positioning System) to obtain the accurate positioning information in real time. Moreover, they exchange two types of messages: periodic awareness messages and event-driven messages. Awareness messages are transmitted in single hop mode and include localisation data e.g. geographic position, speed and direction. The second type of messages is triggered when a hazard is detected. It encloses information on the location of the hazard and the dimension of the "destination" or "dissemination area". This destination zone (see Fig. 2) represents the particular area in the network where each vehicle has to receive correctly the safety information.

3.2 Problem statement

Particularly, the main concern of ITS traffic safety applications is to warn drivers about imminent emergency situations so that they can manage to take appropriate actions to prevent any other dangerous event from happening. This information should be conveyed in a particular dissemination zone, as depicted in Fig. 2, with high reliability and with the lowest reachable delay. To fulfil these requirements, flooding could be considered as one of the most effective dissemination scheme since it has shown to have an excellent delivery rate. However, for high density networks, this approach leads to a very serious problem, often well-known as the broadcast storm problem. So, due to the large scale characteristic of vehicular networks, the design of a more sophisticated dissemination procedure is henceforth prominent.

Considering the high dynamism of vehicular environment, building a communication infrastructure, such as a connected dominating set graph (CDS) or a cluster, or explicitly selecting relays requires too much overhead and is in practice hardly feasible. Another approach is to let receiving nodes implicitly and independently participate in the relay selection procedure. Such receiver-based approach is known as contention-based forwarding (CBF). The major concept is that, initially, all receiving nodes are selected as forwarders, but postpone their relaying by a given timer and enter a contention phase. The first receiving node, which timer expires, immediately forwards its packet. Any node overhearing that transmission stops its timer and does not forward. As a consequence, only a specific number of nodes in the network are allowed to forward the message, and the global number of potential transmissions in the network is reduced.

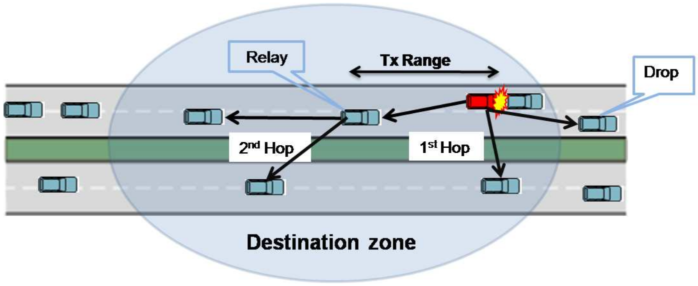


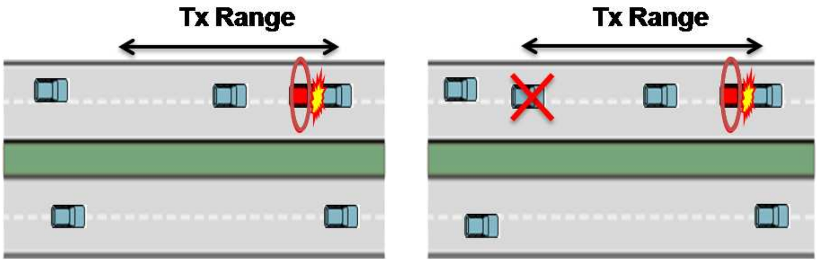
Fig. 2: Illustration of an example of a road situation where a vehicle in a dangerous situation issues emergency messages. The distance-based CBF is used to propagate the information in the destination zone. The farthest node in the communication range is always selected to relay the message. Nodes outside the destination zone are not involved in the dissemination process.

The optimality of such CBF depends partially on the timer selection process. The standard approach of CBF lets receiving nodes randomly select a timer and is called random CBF. All nodes, receiving properly the message, have equal probability of relaying. A popular extension is known as distance-based CBF, where the timer depends on the geographic position of the nodes, farthest ones situated close to the limit of the communication range of the current transmitter are given more opportunity to forward the message. For each node, the length of the contention period is inversely proportional to its progressed distance from the sender. As a result, a significant reduction of the number of transmissions is expected. As shown in the Fig. 2, contrary to the flooding approach where all vehicles receiving the emergency message broadcast, only one (the one with the highest coverage) out of four nodes, is selected to forward.

In spite of their advantages, these approaches are adapted only in some particular situations. Indeed, they have been developed for an environment fulfilling the following three conditions:

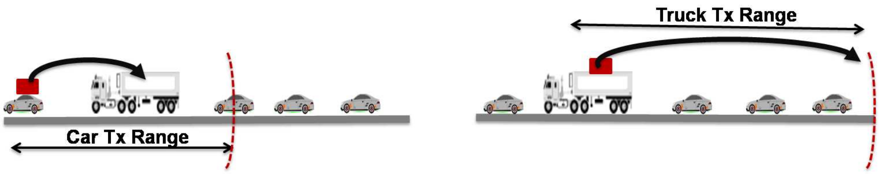
- The homogeneity of topology: all vehicles are uniformly distributed in space.
- The homogeneity of connectivity: the information reception probability is equal in space.
- The homogeneity of communication capabilities: all vehicles have equal transmission capabilities.

Unfortunately, the vehicular environment does not fulfil any of them. In an ideal scenario, as the one depicted in Fig. 2, vehicles are uniformly distributed and the probability that a node is located at the transmission range of another is fairly high. Therefore, farthest nodes are always selected as relays which ensures the effectiveness of the distance-based scheme. However, due to the ITS environment dynamism, network partitions become inevitable and vehicular distribution acquires a non uniform aspect. As illustrated in Fig. 3a, the exis-



(a) (b)

Fig. 3: First limitation of the distance-based dissemination approach. (a) There are no distant nodes at the border of the radio range of the transmitter due to the non uniform distribution of vehicles. (b) Farthest nodes from the transmitter can not receive correctly the message due to fading phenomena.



(a) (b)

Fig. 4: Impact of the participation of the vehicles with important antenna height in the dissemination process. (a) The first case where the farthest car can not act as the next relay because the signal is hidden by the truck. (b) The second case where the truck is selected as the next relay.

tence of distant nodes on the border of the communication range can not be guaranteed in such environment.

Furthermore, the attenuation that is due to buildings and other mobile obstacles as well as multi-path propagation and interferences can lead to severe fading, especially at far distances. As shown in Fig. 3, the node selected by distance-based CBF providing the maximum progress may either not exist (Fig. 3a) or not receive the message (Fig. 3b).

In both cases, existing nodes close to the previous transmitter and that can be reached will wait wastefully for opportunities to send with a time relatively high (inversely proportional to their distance). This may hinder the reliability of data delivery and introduce extra delay. So, in some circumstances, it is not worth considering the concept of distance-based CBF of giving the highest chance to nodes situated at the border of the communication range to become relay and postponing the transmission of others that would represent the most adequate relays in that situation. Also, the distance-based approach does not distinguish between nodes located at the same distance from the transmitter. They perform similar contention timers which may lead to a severe problem of network collisions especially in case of high density scenarios.

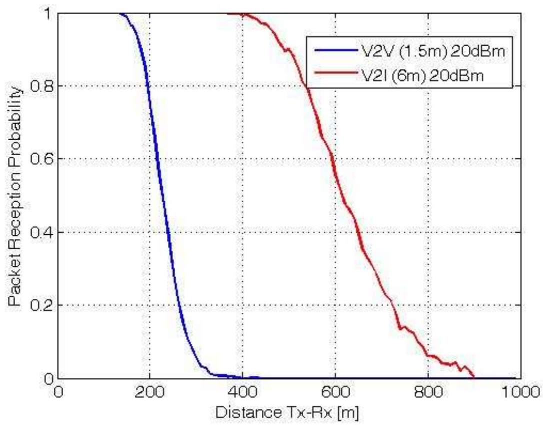


Fig. 5: A representation of the capabilities of V2V communications (with an antenna height of 1.5m) vs. V2I communications (with an antenna height of 6m) [2].

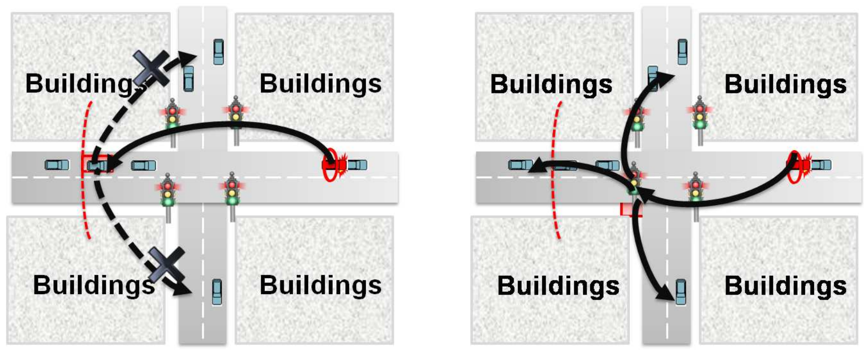


Fig. 6: Road Side Unit role in the dissemination process. (a) The first case where the vehicle is selected as the next relay. (b) The second case where the RSU is selected as the next relay.

Another issue is related to the high diversity of ITS entities that are expected to be deployed in the near future. This would be reflected in a significant non uniformity of their communication capabilities. For instance, compared to standard cars, vehicles with important height e.g. trucks and buses are equipped with high antennas that may ensure more coverage than other network entities. Therefore, they can be considered as appropriate relays. As shown in Fig. 4a and 4b, if the standard car is selected to forward, only the truck could be covered because it will hide the signal to the other car. However, if the truck is selected, all the cars will be able to receive briefly the safety data.

On the other hand, Road Side Units (RSU), if deployed effectively, may contribute to a significant improvement of the efficiency of the safety information dissemination. They can even be connected via wired networks between each other and can communicate directly. A representation of the capabilities of V2I communications with respect to V2V communications is illustrated in Fig. 5. A considerable enhancement of the message reception probability may be perceived. A packet sent by a RSU can reach up to $820m$. However, when it is sent by a regular vehicle less than $400m$ are covered. Fig. 6a depicts a scenario where the information could not be propagated on particular roads in case of an urban environment where various static and dynamic obstacles exist. The forwarder, selected by distance-based CBF, is located far away from the intersection, vehicles situated in the secondary road will not receive the message. Nevertheless, in the second scenario in Fig. 6b, if the RSU, placed in the intersection, participates in the dissemination process, all the vehicles in the other road will be reached.

In the following section, we will give more details on the solutions that we propose to the several limitations of distance-based forwarding presented in this section.

3.3 Proposed Approaches

One of the major goals considered in this paper is to design a new dissemination system that supports and improves traffic safety. It should aim to optimize the network resources usage and fit safety applications requirements in terms of delay and reception reliability. Moreover, the scheme used to select the next forwarder has to face the shortage of the distance-based CBF, mentioned in Section 3.2. We first consider the non-homogeneous topology and connectivity that characterises the vehicular environment then the non-homogeneity in vehicular communication capabilities.

3.3.1 Non-homogeneous topology and connectivity: Bi-Zone Broadcast

We propose a flexible and hybrid CBF that mix together, on one hand the randomness of the standard CBF and on the other hand the main concept of distance-based CBF i.e. taking into account the progressed distance in the contention scheme.

The distance-based CBF showed to be sub-optimal at close range, especially in case where no potential relay at the transmission range exists. We consider to rely on a random timer that can increase the chance of close vehicles to forward faster and avoid to wait wastefully for a non existing farther forwarder. At the same time, the concept of distance-based CBF is preserved after a specific distance threshold. In other words, it is ensured that farthest nodes (after the threshold), if they exist, will wait shorter time before transmitting. Moreover, our approach permits to consider unknown topology and to avoid that nodes in a similar distance get the same timer.

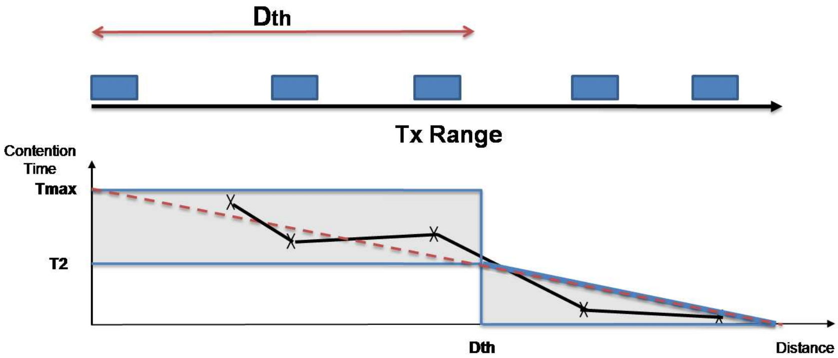


Fig. 7: The BZB contention scheme where the dashed and the plane curves represent respectively the distance-based CBF waiting time and the bounds of BZB.

Our protocol namely, Bi-zone Broadcast (BZB) is based on the idea of dividing the potential receivers into two distinct groups i.e. close and far nodes according to their geographic positions and given a certain distance threshold.

A random CBF approach is applied to the closest vehicles, regardless their relative distances from the sender. It is ensured that they get a waiting time higher than the farthest ones. However, given the random aspect of the applied contention procedure, it can occur that they wait less than they would do in case of standard distance-based CBF. The contention of distant nodes relies on a random distance-based scheme. In worst case, they are supposed to process the standard algorithm of the distance-based CBF. However, they have the possibility to wait less due to the random nature of the contention. Another important benefit of the randomized contention scheme is that it solves the problem of contention between nodes in the same positions. Even if there exist two nodes having identical distance from the last transmitter, they will pick out different waiting times with a high probability.

We assume that the transmission range is partitioned in two adjacent and non-overlapping areas, as depicted in Fig. 7. The former considered as the closest zone to the sender, it is defined by the distance threshold D_{th}. The latter is the remainder of the node's communication range.

As outlined in Fig. 7, where dashed line presents the evolution of the waiting time of a standard distance-based CBF with regards the distance from the sender. Plain lines present the different bounds of BZB contention scheme, the contention each node has to perform, depends mainly on these two zones.

In both areas, the waiting time is selected randomly between two bounds. For closer nodes where the distance is lower than the D_{th}, the interval of contention time selection is fixed to [T2, T_{max}], T2 is given in Eq. 2 and T_{max} is the maximum waiting time. Due to the random fashion of BZB, an improvement of the contention scheme is perceived, as depicted in Fig. 7, closer vehicles i.e. third node after the transmitter acquired a contention time lower than the one obtained by a basic distance-based CBF.

The contention interval of vehicles with distance beyond D_{th} is [0, T1] where T1 is detailed in Eq. 1. Having a lower bound of 0, farthest nodes are granted the possibility to forward immediately the message at reception without waiting a specific time. In worst cases, distance-based forwarding approach is applied.

$$T_1 = T_{max} \times (1 - \frac{d}{r}) \tag{1}$$

$$T_2 = T_{max} \times (1 - \frac{D_{th}}{r}) \tag{2}$$

Where r indicates the transmission range, T_{max} is the maximum waiting time, D_{th} is the distance threshold and d is the distance from the sender.

In the following, we present detailed equations of our contention scheme. A node receiving the safety message computes its distance from the source. Then, it schedules a broadcast timer. The waiting time, as expressed by Eq. 5, is randomly calculated between two bounds. The upper bound of waiting time T_{upper} and the lower bound of waiting time T_{lower} defined as shown in Eq. 3 and Eq. 4 respectively.

$$T_{\text{upper}} = \begin{cases} T_1 & where\ d > D_{th} \\ T_{max} & where\ d \leq D_{th} \end{cases} \tag{3}$$

$$T_{\text{lower}} = \begin{cases} 0 & where\ d > D_{th} \\ T_2 & where\ d \leq D_{th} \end{cases} \tag{4}$$

$$WaitingTime = random(T_{lower},\ T_{upper}) \tag{5}$$

It is worth to mention that there might be some cases where standard distance-based CBF outperforms our approach. For instance, in Fig. 8, even though distant node at the border of the radio range exists, we observe that BZB selects another node that does not guarantee the maximum progress. This is due to the arbitrary selection of the waiting time within the bounds which may cause in some cases a potential degradation of the performance of the dissemination process. The reduced progress due to our timer however remains minor with respect to the transmission range.

3.3.2 Non-homogeneous communication capabilities

Many approaches, especially for sensor networks, have been focusing on enhancing the contention-based approach when taking into account the capabilities and limitations of communicating entities. For instance, some of them proposed energy-aware or duty cycle-based protocols to limit the power consumption of the dissemination process. For ITS environment, the energy does not represent an issue. However, the dissemination capabilities created by transmit characteristics, i.e. antenna height and transmission power, of different entities building ITS systems could be considered. Vehicles with important

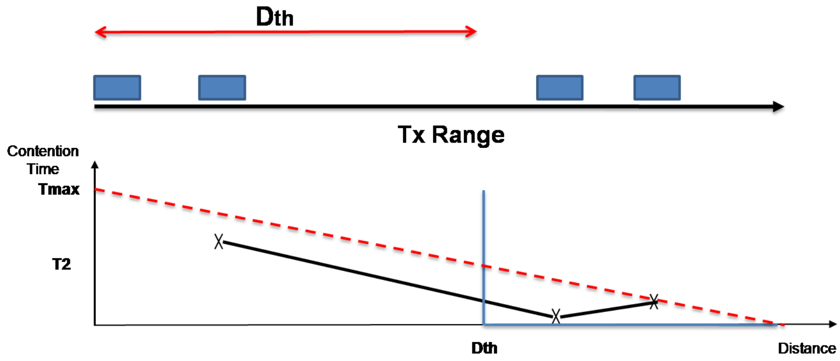


Fig. 8: A scenario illustrating the limitation of BZB.

high antenna may ensure more coverage than other network entities and thus can be considered as the most appropriate relays. We believe that an advantageous usage of these capabilities can significantly improve the dissemination performance. Therefore, we propose an enhanced contention scheme for BZB where we consider the combination of V2I and V2V communications. The dissemination protocol has to benefit from available RSUs to improve data dissemination by weighting the selection process to let RSU or vehicles with high antenna height relay before other vehicles.

Furthermore, we consider that entities having more nodes in the neighbourhood should procure more opportunity to disseminate the emergency information quickly. This may further enhance data reception probability.

As expressed in Eq. 6 and Eq. 7, the contention time depends on the number of neighbours of the vehicle. It guarantees that the timer of vehicles with relevant antenna height will be shorter with high probability than that of ordinary vehicles.

$$WaitingTime = K \times random(T_{lower},\ T_{upper}) \tag{6}$$

$$K = \begin{cases} \frac{1}{N_{neigh}} & Antenna\, height\ > \alpha \\ 1 & Otherwise \end{cases} \tag{7}$$

where T_{lower} and T_{upper} are given by Eq. 3 and Eq. 4, and α is an arbitrary value bigger than the antenna height of regular vehicles. It is worthy to note that the distance threshold D_{th} in T_{lower} and T_{upper} depends on the nature of the vehicle and thus, its radio range.

3.3.3 Main algorithm

The main algorithm of our proposed dissemination approaches is illustrated in Algorithm 1, a Decentralized Environmental Notification Message (DENM) message is generated when the originator detects an emergency event. The original message should contain the required information for other vehicles such as the limits of the dissemination area and the positioning data of the source. After a successful reception of a DENM, the vehicle checks whether the message has been received before and whether the transmitter follows the receiver along the message propagation direction. Then, it should determine the area it belongs to by comparing the geographical coordinates of the transmitter node with its own and then enter the re-broadcast phase. The node executes the contention scheme represented by the procedure $ContentionPhase()$. At this step, either the first contention scheme of BZB (Section 3.3.1) or the second one (Section 3.3.2) is used. At each time step, the waiting time is decremented. Forwarders that countdown until zero, rebroadcast the message by writing their own coordinates in the packet header in addition to the originator's information. Any time a node receives a valid copy of the DENM, it checks whether the message has been received before. In this case, the vehicle aborts the rebroadcast procedure.

It is worthy to mention that our algorithm does not consider the eventual change that can occur on the positioning information during the transmission decision process. We think that the contention time that a vehicle can wait could be considered as negligible. For example, considering a scenario where a car travelling in $120km/h$, the maximum deviation that could occur on the position during a maximum waiting time of $10ms$ goes to $0.5m$. We believe that this deviation is not highly important and that the decision of relay selection could be done considering the outdated position information without any major impact on the relay selection.

4 Performance evaluation

In this section, we evaluate the performance of our proposed dissemination system. As a first step, we assess the impact of the consideration of the non-homogeneity in topology and connectivity in Section 4.2. We perform a comparison of BZB with both the standard distance-based CBF and a basic geo-broadcast protocol that follows the specification of the GeoNet project [1]. Mainly, it is based on a simple flooding approach and does not implement an intelligence in its dissemination process. Then, we evaluate the effect of considering the non-homogeneity of the communication capabilities in Section 4.3, by a comparison with the first scheme BZB. Section 4.4 is devoted to analyse some issues related to the proposed schemes i.e. the impact of the variation of the threshold D_{th} and the effect of increasing the number of sources on the performance of BZB. In the following, we introduce the simulation setup and the configuration of mobility and network scenarios. We present then the set of performance metrics we have measured, and finally the results of our experiments.

Algorithm 1 pseudo-code of the proposed dissemination schemes

```
Procedure: DENMMsgTx ()
if (detectEmergency) then
    TransmitDENMMessage ()
end if
Procedure: DENMMsgRx ()
if (notReceivedBefore) then
    if (inPropagationDirection (myPostion, senderPosition)) then
        if (myPosition in senderForwardArea) then
            ContentionPhase (D_th)
        else
            abort
        end if
    else
        abort
    end if
else
    abort
end if
Procedure: ContentionPhase (D_th)
Time ← Random (T_upper , T_lower)
Contending ← true
Contend (Time)
Procedure: Contend (Time)
while (Time > 0) do
    Time← Time - slotTime
    if (Time = 0 AND notReceivMessage) then
        TransmitMessage()
    end if
end while
```

4.1 Simulation setup

We have conducted a set of experiments to analyse the performance of our proposed contention-based communication protocols under various realistic conditions. We have used the simulation platform iTETRIS, an integrated simulation environment which is designed for large scale ITS evaluation studies. It ensures, on one hand, the simulation of V2X data exchange and wireless communications characteristics and on the other hand the modelling of vehicular mobility and traffic conditions. As illustrated in Fig. 9, a network simulator i.e. ns-3 [3] and a traffic simulator i.e. SUMO [4] are coupled together. An independent application module is designed to implement several traffic efficiency applications. Furthermore, an intermediate entity is designed to manage the interconnection between the different block. In ns-3, the C2C stack architecture with several geo-routing protocols and access technologies have been implemented. Since we are evaluating network protocols, interaction with SUMO and applications entity is not needed. Therefore, we have used the standalone ns-3 part of the iTETRIS platform. SUMO is used only to create mobility scenarios which are fed to ns-3.

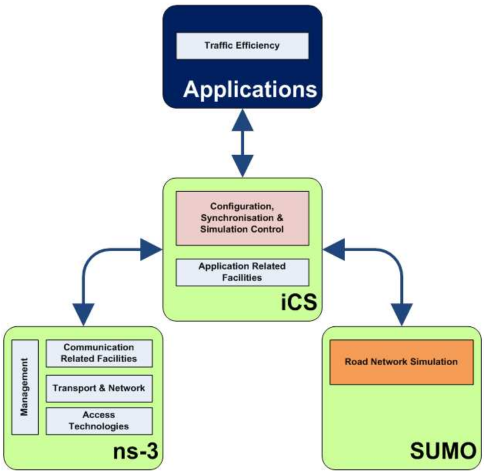


Fig. 9: The iTETRIS platform architecture.

4.1.1 Mobility scenario

With the aim to realistically evaluate our proposed approaches, we considered an urban scenario modelling the non-homogeneity of the topology and connectivity of vehicular environment. The traffic scenario that we have used, illustrated in Fig. 10, is a validated calibrated and realistic urban scenario from the iTETRIS project [2] called “Acosta Pasubio joined”. This scenario models an urban environment and is composed of multiple intersections with different lengths of road sections connecting each other. The size of the road network is $2126mx2117m$. Five mobility traces are created by SUMO with each scenario the duration of $200s$ starting from the second $3000s$, respectively $3000s-3200s$, $3200s - 3400s$, $3400s - 3600s$, $3600s - 3800s$, $3800s - 4000s$. The reason to choose this time window is in order to obtain a fully loaded road network i.e. from 1500 to 2200 vehicles.

Regarding the performance evaluation of the integration of V2I communication, RSUs are placed at each intersection and added into the mobility model. Fifty five RSUs are manually positioned at all intersections. The positions of these RSUs are also fed to ns-3. Fig. 10 gives a visual presentation of the “Acosta Pasubio joined” scenario taken from SUMO GUI.

A summary of the configuration parameters of our mobility scenario can be found in Table 1.

4.1.2 Network scenario

In our communication scenario, we consider that vehicles communicate through periodic awareness and event driven messages (DENM). The awareness is conveyed by beacons at network layer, which are sent with the frequency of $1Hz$ by all the nodes existing in the network. For the event driven data, an ITS

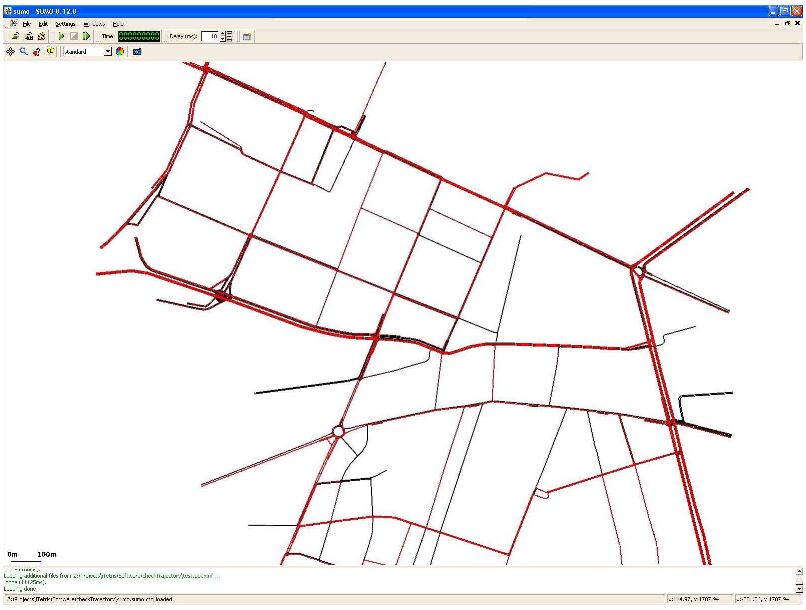


Fig. 10: Acosta mobility scenario.

Parameter	Value
SUMO scenario	Urban-acosta pasubio joined
Scenario size	$2126mx2117m$
Average number of vehicles generated	1500 to 2000
Equipped vehicles rate	100%
Number of RSUs	55
Mobility traces	$3000s - 3200s$, $3200s - 3400s$, $3400s - 3600s$ $3600s - 3800s$, $3800s - 4000s$

Table 1: Configuration parameters of the mobility scenario.

application implemented in iTETRIS namely DENM, has been used for the testing. It consists in the transmission of DENM messages at the detection of an emergency event. They are sent at the maximum allowed transmission power.

Each simulation is executed for $200s$. In order to obtain reliable results, simulations have been carried out several times with five different values of the random number seed to vary the network topology and configuration. At the beginning of each simulation, the dissemination area, where the emergency information should be propagated (as mentioned in Section 3.2), is selected randomly. The closest node to this area initiates the DENM transmission process. Only nodes located at this specific area will participate at the dissemination procedure. DENM are required to be transmitted to $1000m$ from the originating node. The geographic coordinates of the center of the dissemination area are picked out from the map.

The variation of the network topology as well as the connectivity is ensured, on one hand, by the various mobility scenarios that we have used and, on the other hand, by the random selection of the source for each run. At this level, we vary the packet size to evaluate the impact of the overhead on the performance of the different schemes. Four packets size have been selected: 500 Bytes, 1500 Bytes, 2000 Bytes and 2200 Bytes. The propagation model that has been used is the WINNER B1 model for urban environment, which takes into account correlated log normal shadowing and LOS/NLOS visibility between vehicles. Since we are targeting ITS traffic safety applications requiring brief dissemination delays, we have set the maximum waiting time (T_{max}) to $10ms$. Table 2 gives an overview of the configuration parameters for the communication scenario.

Parameter	**Value**
Awareness messages	Network beacon
Event-driven messages	DENM
Destination area size	$1000m$
Network beacon rate	$1Hz$
Packet sizes	500 Bytes, 1500 Bytes, 2000 Bytes, 2200 Bytes
Simulation Time	$200s$ for each run
Maximum waiting time (T_{max})	$10ms$
Number of simulation runs	100
Propagation model	WINNER II LOS/NLOS
Shadowing	Correlated log-normal
Fast Fading	Rician (LOS) / Rayleigh (NLOS)
Transmission power	$20dBm$
V2V maximum transmission range	$400m$
V2I maximum transmission range	$900m$

Table 2: Configuration parameters of the network scenario.

4.1.3 Performance metrics

To evaluate the issues associated with dissemination protocols in ITS environment, we have defined a set of performance metrics.

1. Average information reception delay:
   This metric is the most relevant metric to analyse the performance of safety related communication protocols. When an accident occurs the faster that other drivers receive the safety message, the greater the chance they will be able to avoid an accident. The Information reception delay is defined as the interval from the time an application generates a DENM message and handed over to the network layer to the time this message is firstly received by the corresponding network layer at another vehicle located at a specific distance from the originator:

$$\delta_r(DENM) = t_r(DENM) - t_s(DENM) \tag{8}$$

$\delta_r(denm)$ the information reception delay is the time that the DENM, generated by s, takes to reach the node r.
$t_s(denm)$ is the time at which the DENM has been generated by the node s.
$t_r(denm)$ is the time of the first reception of the DENM at the network layer by the node r.

To show the distribution of the information reception delay over all the nodes in the simulation, we have measured the probability delay function (PDF).
The Cumulative Distribution Function (CDF) of the delay has been used also to validate our data dissemination algorithms.

2. Transmission redundancy factor:
This performance metric is the second relevant metric that we have measured. It evaluates the degree of efficiency of the networking protocol in terms of network overhead. In case of flooding-based approaches e.g. basic geo-broadcast protocol, every vehicle that receives the DENM will rebroadcast it creating a high redundancy in packet transmissions and, thus, severe network overhead. Enhanced dissemination protocols are expected to alleviate this problem and ensure lower redundancy.
The overall network traffic being created and received by all the nodes in the network are measured using the equations below:

$$TxOverhead = i * PS \tag{9}$$

$$RxOverhead = j * PS \tag{10}$$

Where PS is the packet size, i is the number of transmission and retransmission of the packet during the simulation, j is the number of packets received.
The transmission redundancy factor is expressed by:

$$RedundancyFactor = \frac{RxOverhead}{TxOverhead} \tag{11}$$

4.2 Impact of the non-homogeneity in topology and connectivity

In this section, we evaluate the performance of our proposed concept BZB. A comparison between BZB and both distance-based and the basic geo-broadcast protocols is performed. In the following, we analyse the results of the conducted simulations. As mentioned above, transmission redundancy and information reception delay are considered as evaluation metrics. The distance threshold D_{th} is fixed to the half of the transmission range 200m.

Fig. 11 plots the global redundancy factor or the overhead with respect to the packet size. Various payload sizes of 500, 1500, 2000 and 2200 bytes have been used. We can deduce, first, that by the increase of the packet size,

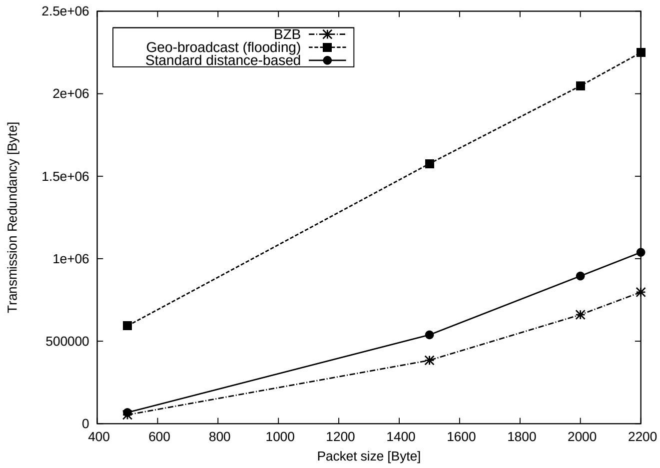


Fig. 11: The variation of the transmission redundancy factor in case of BZB, flooding and standard distance-based approaches with regards to the payload.

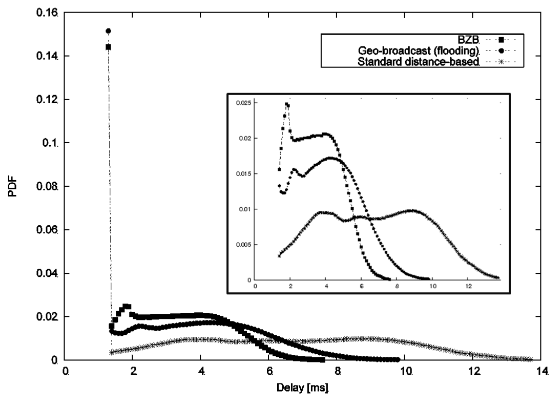


Fig. 12: The PDF of the average information reception delay in case of BZB, flooding and standard distance-based approaches for packet size 500 bytes.

overheads increase linearly for all protocols. Obviously, distance-based protocol performs better than flooding-based geo-broadcast approach in terms of transmission redundancy since it ensures a selective retransmission of the safety information. BZB, in his turn, outperforms both distance-based and geo-broadcast. In case of the first curve related to the basic geo-broadcast protocol, the redundancy factor increases from 500M till reaching up to 2G. However, for BZB it goes to only less than 800M for 2200 bytes of packet size. This could be explained by the fact that BZB is designed to reduce the number of forwarders and, accordingly, network congestion. BZB provides a

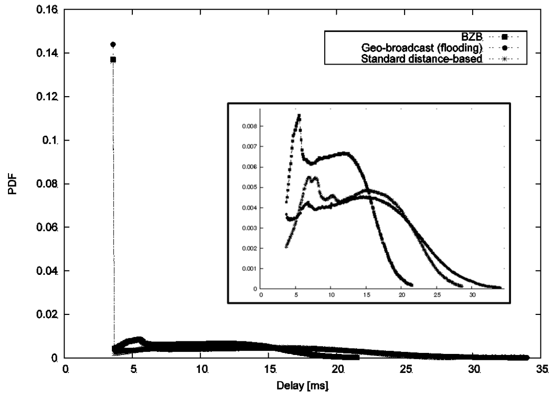
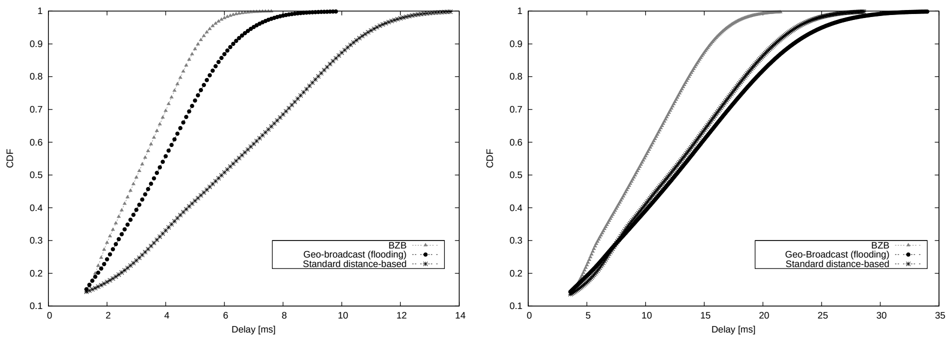


Fig. 13: The PDF of the average information reception delay in case of BZB, flooding and standard distance-based approaches for packet size 2200 bytes.



(a) (b)

Fig. 14: The CDF of the average information reception delay in case of BZB, flooding and standard distance-based approaches. (a) Packet size 500 bytes. (b) Packet size 2200 bytes.

forwarding scheme that ensures an accurate relay selection in order to increase information dissemination reliability and reduce network overhead.

An aspect that is worth investigating is the behaviour of the information reception delay of BZB when varying the packet size. Fig. 12 and Fig. 13 illustrate the PDF regarding the average information reception delay for packet sizes 500 bytes and 2200 bytes respectively. We can observe that, for all of the protocols, around 15% of nodes can receive the message in less than 1.8s in case of the first scenario (500 bytes) and around 14% are able to receive it in 4s for the second one (2200 bytes). This is explained by the fact that, all the nodes that are covered by one-hop communication can receive the information quickly. However, the performance of our proposal is more perceived for multi-hop communication where BZB achieves the lowest delays.

Fig. 14 shows the obtained simulation results in terms of CDF with respect to the average information reception delay. We plot the most relevant results that better illustrate the performance of the different protocols. Only results for packet sizes 500 bytes and 2200 bytes are shown. From the first sight, we can deduce that for all the protocols when increasing the packet size, the average delay to reach the corresponding geographic destination area increases. For instance, in case of geo-broadcast, 90% of receivers receive the corresponding packet within less than 10 ms for a payload of 500 bytes. However, only 50% of transmissions reach within 10 ms time frame for payload 2200 bytes. We can observe that geo-broadcast outperforms the standard distance-based scheme in the first scenario i.e. 500 bytes. They perform approximately the same way for the other scenario. This is because of the trade-off that a distance-based approach presents: reducing redundancy by performing contention and at the same time introducing extra delay due to that contention. Indeed, flooding-based geo-broadcast may succeed to propagate the information with admissible delays especially in the case where the network load is not very important (500 bytes).

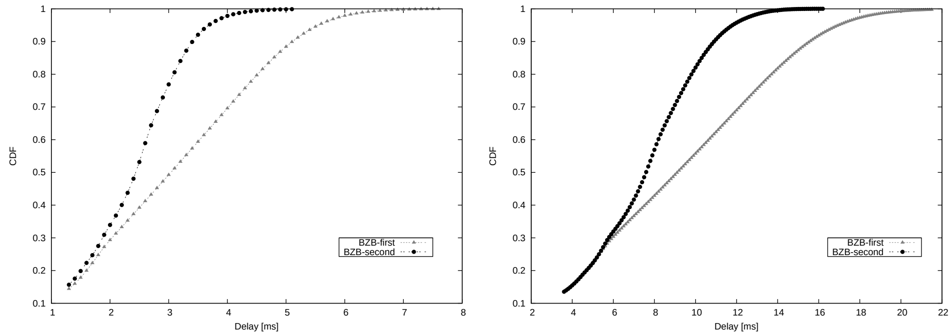
Regarding BZB, up to 90% of intended receivers get the packet for each payload within less than 22 ms. However, the average delay is about 35 ms in case of distance-based CBF and geo-broadcast protocols. So, we conclude that BZB outperforms both protocols in terms of average delay. Furthermore, we can deduce that, in contrast to distance-based dissemination scheme, the performance of BZB remains almost stable when varying the packet size. This is due to the intelligence in our dissemination strategy and its reliability to provide the lowest delay to reach all neighbours.

The obtained simulation results reveal that BZB achieves its design goal of delivering information within a geographical area in a rapid and efficient manner as compared to the flooding-based geo-broadcast and the standard distance-based schemes. BZB performs better in terms of information reception delay and overhead factor.

4.3 Considering the heterogeneity in communication capabilities

In this section, we analyse the results obtained in the simulation of the impact of the non-homogeneity in communication capabilities. A comparison with the first contention scheme of BZB is performed. Without loss of generality, we have considered only RSUs in the dissemination phase to represent the vehicles with high antennas height. We fixed α to $6m$. The distance threshold D_{th} used here is fixed to 200m for vehicles and 450m for RSUs.

Fig. 15 illustrates the CDF with regards to the data reception delay. All the scenarios with the several packet sizes are presented in the figure. We deduce that, when considering the non-homogeneity in communication capabilities, the second contention scheme proposed for BZB shows better results. In all the cases, as expected, from payload 500 bytes to payload 2200 bytes, the reception delay does not exceed around 16 ms however it goes to 22 ms in case



(a) (b)

Fig. 15: The CDF of the average information reception delay. (a) Packet size 500 bytes. (b) Packet size 2200 bytes.

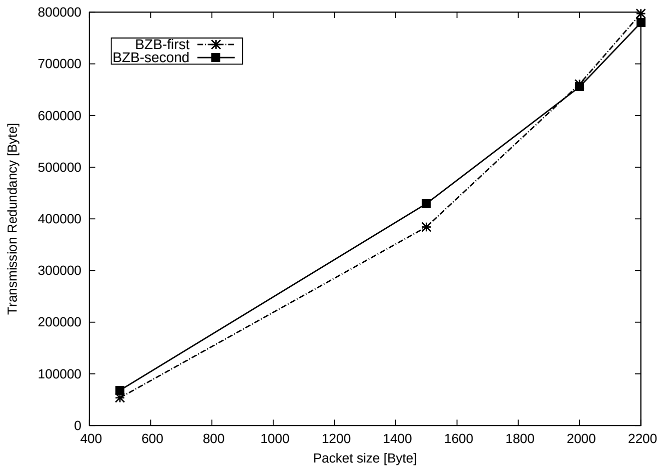


Fig. 16: The variation of the redundancy factor with regards to the payload.

of the first approach of BZB. This is due to the beneficial impact of the use of RSUs in the dissemination procedure.

Fig. 16 plots the global redundancy factor with respect to the packet size. Various payload sizes of 500, 1500, 2000 and 2200 bytes have been drawn. We can notice, that both approaches perform slightly in a similar way. Indeed, our main concern is to further improve the propagation delay of the safety data. The transmission redundancy is already enhanced by the BZB concept.

So, by considering infrastructure nodes as potential relays, dissemination delay can be reduced noticeably. This aspect can be explained first by a better communication range due to higher antenna and increased transmit power, but also due to optimized distributions of the infrastructure nodes.

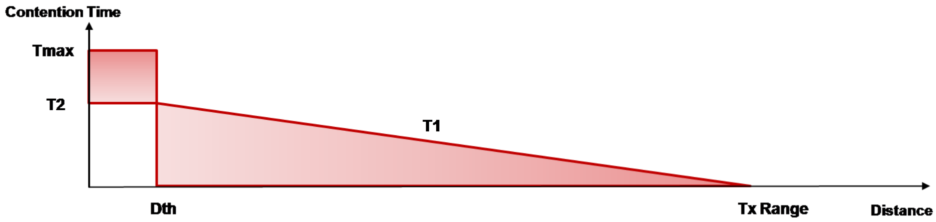


Fig. 17: The variation of the contention timer for low values of the D_{th}.

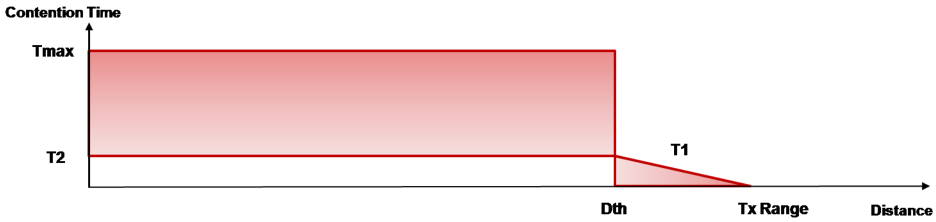


Fig. 18: The variation of the contention timer for high values of the D_{th}.

4.4 Discussion

We discuss in this section the behaviour of BZB when varying the distance threshold parameter D_{th}. Moreover, we evaluate the effect of the increase of the number of sources on the performance of the protocol and its repercussion on the transmission redundancy and the delivery delay.

4.4.1 Impact of the variation of the threshold D_{th} on the performance of BZB

For the effectiveness of BZB, the parameter D_{th} is of key importance. Particularly, adapting its value according to a set of environmental constraints influences strongly the performance of our approach. Fig. 17 and 18 show the variation of the contention timer in both zones when varying D_{th} value.

We can see that for very low values of D_{th} (Fig. 17), nodes that are in the second zone (after the distance D_{th}) and are relatively close to the sender are given the opportunity to forward before potential distant nodes. In the other case (Fig. 18), for very high D_{th}, only distant nodes (located after D_{th}) have the highest probability to be selected as relays.

In the simulation analysis that we have conducted, we have considered four different values of the threshold D_{th}: 200m (half of the communication range), and three other close and far distances 50m, 100m and 300m. Fig. 19 shows the obtained simulation results in terms of transmission redundancy in various packet size scenarios. We can deduce that D_{th} 200m corresponding to about half of the maximum communication range performs the best comparing to other D_{th} values: 50m, 100m and 300m. However, when setting the distance threshold too close to the transmitter (50m and 100m), the probability that

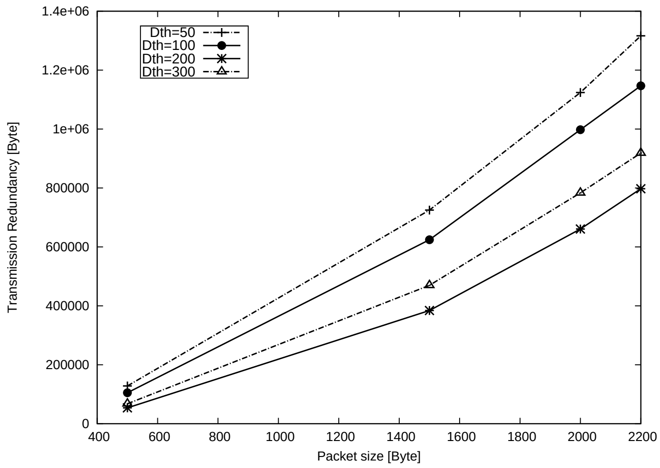


Fig. 19: The BZB transmission redundancy factor when varying the D_{th} value with regards the payload

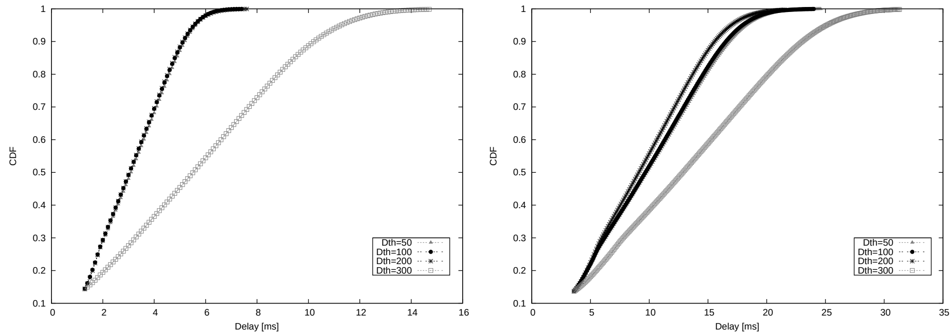
close nodes (located just after the D_{th}) transmit become important, as demonstrated in Fig. 17. Therefore, the network overhead becomes important due to the increase in the number of hops.

For high values of D_{th} i.e. 300m, the network overhead is not that important as compared to D_{th} 50m and 100m, since it ensures the maximum progress. But, it is still higher than D_{th} 200m. This can be explained by the fact that when we maximise the chances of the selection of distant nodes as relays, and due to the fading effect, the probability that close nodes to the transmitter (with distance lower than D_{th}) receive correctly that transmission (of the selected relays) and cancel accordingly their transmissions is reduced. Therefore, the transmission redundancy is increased. Another case that can occur is when potential nodes situated after D_{th} i.e. 300m are not present, close nodes will be selected and again the number of hops is increased.

Fig. 20 plots the CDF of the information reception delay for the different values of D_{th}. We can observe that for the different network loads, D_{th} 300m performs poorly with regards to the data reception delay. Again, D_{th} 200m outperforms all the other values, particularly, for high network load. This is due to the fact that when there is not any node situated after 300m, an extra delay is introduced because close nodes with higher waiting time will be selected as relays.

So, the system performance is optimised in case of D_{th} 200m i.e. the average of the transmission range. This could be explained by the fact of running many scenarios that have different vehicle distribution and 200m have ensured a fair relay selection procedure between these different scenarios.

Therefore, the optimal value of D_{th} could not be deduced because it depends on multiple criteria i.e. the traffic density, the vehicular inter-space



(a) (b)

Fig. 20: The CDF of BZB delay when varying the D_{th} value. (a) Packet size 500 bytes. (b) Packet size 2200 bytes.

and/or the vehicle coverage range, but could be adapted as a function of the topology.

For instance, it can be tuned according to the network density state: sparse or dense. In case of very dense network, where the probability of the existence of nodes with the maximum progress is high enough, the threshold D_{th} must be set as close as possible to the transmission range so that existing vehicles that are far away from the source obtain the highest priority. However, in case of sparse network, it is not guaranteed that nodes do exist at the border of the transmission range, D_{th} should be lower than the transmission coverage, in order to give other close distances the opportunity to relay. As a result, BZB acquires a contextual adaptive aspect taking into account the environment characteristics and dynamics.

4.4.2 Impact of multiple sources on the performance of BZB

In the following, we intend to study the behaviour of BZB when multiple sources detect the same emergency event and trigger several alerts, or in the case we have retransmitted message from uninterrupted timers. Without loss of generalities, we only assume in this work multiple sources. As illustrated in Fig. 21, node (A) and (B) trigger two different messages that contains information about the same event. Node (C), upon receiving the two messages, will send two distinct messages. Moreover, due to the significant diversity of ITS applications, the same event can be triggered using different applications. Thus, the information redundancy coming from multiple sources and/or applications should be addressed.

To evaluate the performance of BZB under these circumstances, two scenarios have been considered, mono source and multiple sources. In the second scenario, four different sources have been used to trigger the safety information transmission.

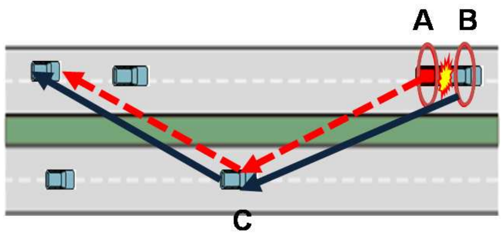


Fig. 21: An illustration of a scenario where two nodes detect the same emergency event and send different packets to the network.

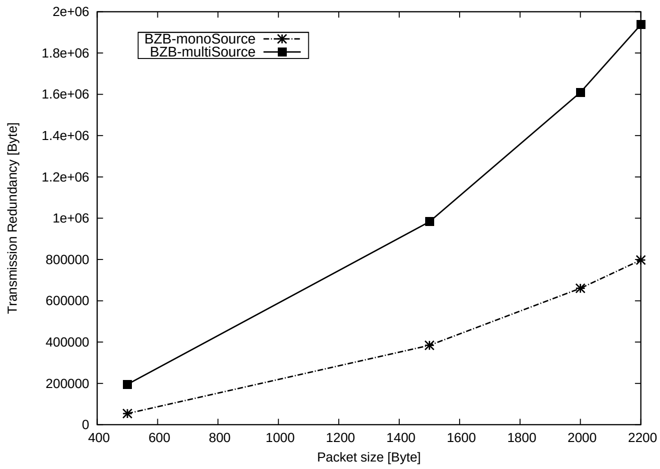
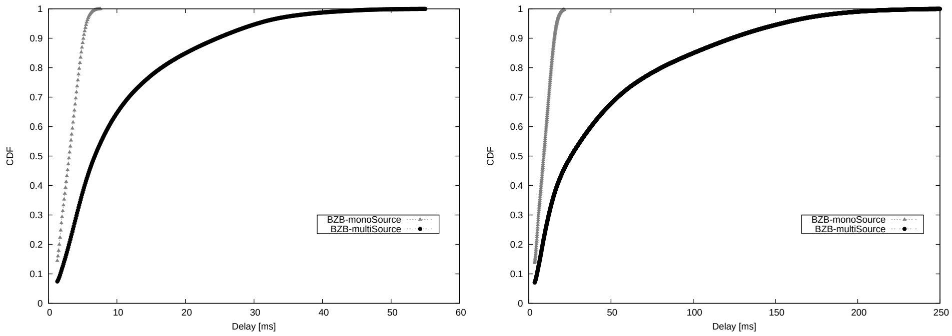


Fig. 22: The variation of BZB transmission redundancy factor with regards the payload in case of multiple sources scenario.

Fig. 22 depicts the measured transmission redundancy. The network overhead of multiple sources scenario is highly important as compared to mono source. It corresponds almost to more than the double in case of the packet size 2200 bytes which is nothing but an extra and useless overhead. Analogously, in Fig. 23, it is clear to observe that when increasing the number of sources, BZB fails to respect ITS safety applications requirements in terms of delay. At best case, up to 90% of the receivers get the packet within more than 50 ms.

There are still many other issues that need to be addressed in data dissemination. The fundamental limitation of BZB is that it cannot detect redundant information from different sources. Nevertheless, optimizing the number of duplicated messages remains a critical aspect of a scale potentially significantly larger than the performance variation between BZB and flooding or CBF and is part of our future work. However, this action cannot be solely addressed at



(a) (b)

Fig. 23: The CDF of BZB delay in multiple sources scenario. (a) Packet size 500 bytes. (b) Packet size 2200 bytes.

the network layer, but rather at higher layers where information is processed, extending our approach from *receiver-centric* to *information-centric.*

5 Conclusion

In this paper, we have proposed *Bi-Zone Broadcast (BZB)*, a new hybrid Contention-Based Forwarding (CBF) approach dedicated for ITS safety applications. We have identified limitations of the benchmark distance-based CBF considering the challenging vehicular urban topology. We then described BZB, a randomised distance-based scheme first considering the non homogeneous topology and connectivity characterising urban vehicular environment, and second the non-homogeneity in communication capabilities of the various ITS actors such as road-side units, buses, trams, or vehicles.

The obtained simulation results showed that BZB achieves its design goal by delivering traffic safety information in a geographic area in a fast and efficient way compared to the benchmark distance-based CBF or flooding schemes. Also, involving vehicles with considerable communication capabilities in the dissemination process further improves the performance of the system, in particular in terms of reception delay. Finally, using the bi-zone distance threshold of BZB, we can adapt its characteristics to the environment constraints e.g. the traffic density and the vehicular inter-space, in order to cope with the non-homogeneity of urban vehicular systems.

An aspect that we further investigate is the behaviour of BZB in case of important information redundancy. In particular, we consider the case of multiple sources transmitting the same information. BZB remains sub-optimal as it is unable to detect redundant information. Aggregating information redundancy requires information-centric dissemination strategies developed at higher layers in the protocol stack, as it also depends on the global context perceived by vehicles. In future works, we therefore plan to define a global and generic *information centric* framework for information dissemination.

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References

1. GeoNet project. `http://www.geonet-project.eu/`.
2. iTETRIS project.
3. ns-3 simulator. `http://www.nsnam.org/`.
4. SUMO simulator. `http://sumo.sourceforge.net/`.
5. P. Akkhara, Y. Sekiya, and Y. Wakahara. Efficient Alarm Messaging by Multi-Channel Cut-Through Rebroadcasting based on Inter-Vehicle Communication. *in Proc. of the IAENG Journal of Computer Science (IJCS)*, 2009.
6. H. ALshaer and E. Horlai. An optimized adaptive broadcast scheme for inter-vehicle communication. *in Proc. of the 61st Vehicular Technology Conference (VTC'05)*, 2005.
7. A. Benslimane. Optimized Dissemination of alarm messages in Vehicular Ad-hoc Networks (VANET). *in Proc. of the 7th IEEE International Conference on High Speed Networks and Multimedia Communications (HSNMC'04)*, 2004.
8. B. Blaszczyszyn, A. Laouiti, P. Muhlethaler, and Y. Toor. Opportunistic broadcast in vanets (ob-van) using active signaling for relays selection. *in Proc. of the 8th Intelligent Transport Systems Telecommunications(ITST'08)*, October 2008.
9. L. Bononi and M. D. Felice. A Cross Layered Mac and Clustering Scheme for Efficient Broadcast in Vanets. *in Proc. of the IEEE International Conference on Mobile Ad hoc and Sensor Systems (MASS'07)*, October.
10. L. Briesemeister, L. Schafers, and G. Hommel. Disseminating Messages among highly mobile hosts based on Intervehicle Communication. *in Proc. of the IEEE Intelligent Vehicles Symposium*, October 2000.
11. W. Chen, J. Chennikara-Varghese, J. Lee, S. Cai, and T. Hikita. Dynamic Local Peer Group Organizations for Vehicle Communications. *in Proc. of the Second International Workshop on Vehicle-to-Vehicle Communications (V2VCOM'06)*, July 2006.
12. M. Durresi, A. Durresi, and L. Barolli. Emergency Broadcast Protocol for Inter-Vehicle Communications. *in Proc. of the 11th International Conference on Parallel and Distributed Systems (ICPADS'05)*, 2005.
13. S. Eichler and C. Schroth. A Multi-Layer Approach for Improving the Scalability of Vehicular Ad-Hoc Networks. *in Proc. of the Conference on Communication in Distributed Systems (KiVS'07), Workshop: 4th Workshop on Mobile Ad Hoc Networks (WMAN'07)*, March 2007.
14. S. Eichler, C. Schroth, T. Koscht, and M. Strassbergert. Strategies for Context-Adaptive Message Dissemination in Vehicular Ad Hoc Networks. *in Proc. of the Second International Workshop on Vehicle-to-Vehicle Communications (V2VCOM'06)*, July 2006.
15. E. Fasolo, R. Furiato, and A. Zanella. Smart Broadcast algorithm for inter-vehicular communications. *in Proc. of the Wireless Personal Multimedia Communication (WPMC'05)*, September 2005.
16. H. Füßler, H. Hartenstein, J. Widmer, M. Mauve, and W. Effelsberg. Contention-Based forwarding for street scenarios. *in Proc. of the 1st International Workshop on Intelligent Transportation (WIT'04)*, March 2004.

17. F. Hrizi and F. Filali. On Congestion-Aware Broadcasting in V2X Networks. *in Proc. of the 2nd international workshop on communication technologies for vehicles (Nets4Cars'09)*, October 2009.
18. H. Jiang, H. Guo, and L. Chen. Reliable and efficient alarm message routing in vanet. *in Proc. of the 5th 28th International Conference on Distributed Computing Systems Workshops*, 2008.
19. S. Khakbaz and M. Fathy. A Reliable Method for Disseminating Safety Information in Vehicular Ad Hoc Networks Considering Fragmentation Problem. *in Proc. of the Fourth International Conference on Wireless and Mobile Communications (ICWMC'08)*, 2008.
20. G. Korkmaz and E. Ekici. Urban Multi-hop Broadcast Protocol for Inter-Vehicle Communication Systems. *in Proc. of the 1st ACM workshop on vehicular Ad Hoc networks (VANET'04)*, October 2004.
21. M. N. Mariyasagayam, T. Osafune, and M. Lenardi. Enhanced Multi-Hop Vehicular Broadcast (MHVB) for Active Safety Applications. *in Proc. of the 7th International Conference on ITS Telecommunications (ITST'07)*, 2007.
22. S.-Y. Ni, Y.-C. Tseng, Y.-S. Chen, and J.-P. Sheu. The Broadcast Storm Problem in a Mobile Ad Hoc Network. *in Proc. of the 5th annual ACM/IEEE international conference on Mobile computing and networking*, August 1999.
23. C. E. Palazzi, S. Ferretti, M. Roccetti, G. Pau, and M. Gerla. How Do You Quickly Choreograph Inter-Vehicular Communications? A Fast Vehicle-to-Vehicle Multi-Hop Broadcast Algorithm, Explained. *in Proc. of the 4th IEEE Consumer Communications and Networking Conference (CCNC'07)*, January.
24. F. J. Ros, P. M. Ruiz, and I. Stojmenovic. Reliable and efficient broadcasting in vehicular ad hoc networks. *in Proc. of the 69th Vehicular Technology Conference (VTC'2009)*, April 2009.
25. F. J. Ros, P. M. Ruiz, and I. Stojmenovic. Acknowledgment-based broadcast protocol for reliable and efficient data dissemination in vehicular ad-hoc network. *in Proc. of the the IEEE Transactions on Mobile Computing*, December 2010.
26. M. Torrent-Moreno. Inter-Vehicle Communications: Achieving Safety in a Distributed Wireless Environment - Challenges, Systems and Protocols. *Ph.D. thesis, University of Karlsruhe*, 2007.
27. M. Torrent-Moreno. Inter-Vehicle Communications: Assessing Information Dissemination under Safety Constraints. *in Proc. of the 4th Annual IEEE/IFIP Conference on Wireless On Demand Network Systems and Services (WONS)*, January 2007.