Optimized Ad-hoc Multi-hop Broadcast Protocol for Emergency Message Dissemination in Vehicular Ad-hoc Networks

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Abstract: Intelligent Transportation Systems and particularly vehicular adhoc networks (VANETs) play a key role in enabling Smart Cities as well as improving and maintaining road safety. VANETs are distributed networks built from moving vehicles on the road. Each vehicle of the network has an embedded IEEE 802.11p interface to support the interaction between the vehicles and their environment (V2X) and enable Inter Vehicular Communication (IVC). However, due to the instable nature of these networks caused by the high-speed mobility of the vehicles as well as frequent fragmentation and disconnection of the network, it is necessary to design and implement robust and fault tolerant communication protocols especially in the case of emergency situations on the road to rapidly alert the environment and the competent authorities. Moreover, the communication in these networks suffers from limited bandwidth spectrum making information dissemination time critical to achieve fairness toward all the nodes of the network. This paper proposes an optimization of the Ad-hoc Multi-hop Broadcast (AMB) protocol for the dissemination of information and particularly Emergency messages in vehicular ad-hoc networks (VANETs). The proposed solution aims to reduce the network traffic while optimizing the communication time and achieving high reliability for the emergency messages. The performance of the proposed protocol is evaluated on theoretical considerations and numerical calculations.

Keywords: Vehicular ad hoc networks; 802.11p; V2X; Data dissemination; Road safety

1 Introduction

Ensuring road safety is an important challenge for researchers in the automotive industry. New systems are continuously designed to improve safety on board of the vehicles and Inter-Vehicle Communication (IVC) is one of the promising solutions that aims to reduce dangerous events on the road and ensure the safety. To address these issues Vehicular Ad-hoc Networks (VANET) were designed to enhance road safety through the dissemination of emergency messages. The aim of information dissemination is to send information from one source to one or more destinations, ensuring short delivery time, high reliability, and best possible use of resources. Destinations targeted by the operation of dissemination can be characterized by their position, IP address, geographical place, or other features. In infrastructure-less wireless networks, routing protocols use flooding approach for the construction and maintenance of routes.

Flooding is the simplest protocol for broadcasting in ad-hoc networks where each node systematically rebroadcasts the packet received producing the Broadcast Storm Problem [5]. This systematic replay causes unnecessary and excessive bandwidth consumption; consequently, each node will receive several times the same information via the wireless channel. In addition, in the case of highly dense ad-hoc networks, flooding causes a significant number of collisions that cannot be fixed in the Medium Access Control (MAC) layer due to the absence of acknowledgment during the broadcast, reducing therefore the effectiveness and reliability of the broadcast. However, other types of distribution better adapted to IVC environments could include multicast [21] and geo-dissemination [22] as well. In the early studies, several methods were proposed to reduce message redundancy and collisions caused by naive flooding [23]. To ensure a rapid dissemination, several communication protocols have been designed to select the farthest relay vehicle for the emergency message. They can be classified into topology-, time-, cluster- and beacon-based algorithms [13] depending on the method used to select the next relay for the emergency message.

In this article, time-based [6] dissemination protocols, and particularly the Ad-Hoc Multi-hop Broadcast protocol (AMB) [18] [29] have been studied. This algorithm was designed to address the broadcast storm [19], hidden station [20] problems, as well as to enhance the reliability of the multi-hop spread in an urban environment [24]. The protocol relies on a modified version of the IEEE 802.11 [14] access layer adapted to the context of the networks of vehicles. However, it suffers from multiple problems such as a tremendous dissemination time and a considerable amount of redundant generated communication packets in high density traffic. To solve these issues, a new protocol called Optimized Ad-hoc Multi-hop Broadcast (OAMB) is proposed. This protocol relies on the physical characteristics of the transmission layer to address the shortcomings of the AMB protocol by significantly reducing the packet collisions, the number of transmitted messages as well as the duplication of messages resulting in an important reduction of dissemination time of emergency messages.

The rest of this paper is organized as follows. Section 2 gives a review of the main ideas and features of the AMB protocol. The new OAMB protocol is presented and analyzed in Section 3. A theoretical and numerical performance evaluation of the new protocol is presented in Section 4 while the conclusions are drawn in Section 5.

2 Review of the AMB Protocol

The Ad-Hoc Multi-hop Broadcast protocol (AMB) was designed for data dissemination across vehicular ad-hoc networks (VANETs), using channel jamming signal Black-Burst (BB) mechanism. BB was first used to broadcast channel-use information to neighbors located at one hop to limit and prevent collisions in wireless networks. It became later an important mechanism used in time-division multiple access (TDMA) based media access control (MAC) protocols [26]-[30]. In this article, we will focus on Directional Broadcasting (DB) side of the protocol. DB considers that cars drive only according to the known road axes. To broadcast a message in a certain direction, the transmitter vehicle loads the furthest vehicle in this direction to forward the message. To select this vehicle, the protocol divides the portion of road covered by its scope of transmission into segments of equal length. If there is more than one vehicle in the last segment in the direction of broadcasting, the process is renewed with a shorter segment length and so forth. If this is still insufficient after several iterations, a random choice is operated among all the vehicles of the last segment, and to address the problem of the hidden station [20], the Request To Send / Clear To Send (RTS/CTS) mechanism of the 802.11 wireless networking standard is adapted under the name of Request To Broadcast / Clear To Broadcast (RTB/CTB) [4] [8] for VANETs. This mechanism is described in Figure 1.

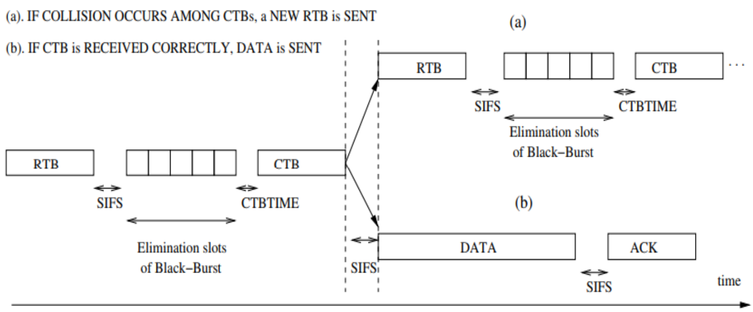

Figure 1
AMB Algorithm [18]

Figure 2 depicts the structure of the RTB, and CTB control frames as described in AMB; These frames are used in the process of channel reservation to allow the broadcast of a data frame. The RTB allows to claim the right to broadcast a data frame over the network. In the RTB frame structure, the RA is the receiver address of the next data or management frame while the TA is the address of the station transmitting the RTB frame. While in the CTB, the RA field corresponds to the address of the source station. The other fields (Frame Control, Duration, FCS) remain the same as for standard 802.11 MAC frames. Using these control frames, AMB is defined as follows: After observing the Network Allocation Vector [7] time, if the channel is idle, the carrier of the message transmits first an RTB packet.

Each vehicle receiver calculates its distance from the transmitter, and then transmits a strong interference signal (BB) during a discrete time corresponding to the number of time units (time slots) proportional to this distance.

RTB frame

	Frame control	Duration	RA	TA	Position	Brodcast direction	FCS
Bytes:	2	2	6	6	8	1	4

CTB frame

	Frame control	Duration	RA	FCS
Bytes:	2	2	6	4

Figure 2
The RTB/CTB Frame structure

At the end of this phase, each vehicle senses the communication channel. If the transmission channel is idle, i.e., the interference generated by the vehicle lasted the longest and it is one of the farthest from the transmitter of the RTB it responds by sending a CTB packet. If other less distant vehicles necessarily listened to the CTB of the furthest node, they would abstain from responding. If a collision occurs at the level of the source vehicle, it means that there are several CTBs sent by different vehicles in the last segment, the procedure is repeated using the same method of interference between the last vehicles with a random interference time. If the source vehicle receives a correctly decoded CTB, it transmits the message to the vehicle that issued the CTB. The latter must respond with an ACK packet to the source vehicle and become responsible for forwarding the message in the direction of the broadcast. If the vehicle source does not receive the ACK, it starts the procedure of the selection from the beginning.

However, the directional broadcasting of the AMB is ineffective as the next vehicle to retransmit the message must wait the longest before being able to send the package (CTB). This is due to that the longest BB is assigned to the farthest vehicle relay [8]. The selection of the farthest node based on the longest signal transmission implies a high latency and, limits its use in cases of emergency. Moreover, in the case of a dense network, several candidates can respond to the RTB, which will further delay the process of dissemination. Not to mention that the RTB/CTB sequence causes a loss of time before each transmission, which will increase delays, in the perfect case there is no packet loss or collision.

In order to improve AMB and overcome its shortcomings, a series of structural optimizations are proposed in the Optimized Ad-hoc Multi-hop Broadcast Protocol (OAMB), the new protocol is described in three distinct steps, each step is described by a specific algorithm. The purpose is to be able to select the most adaptable solution according to the road and traffic conditions. Moreover, each solution is evaluated and estimated according to a strong theoretical and numerical analysis.

3 Optimized AMB Protocol

The Optimized Ad-hoc Multi-hop Broadcast Protocol (OAMB) was designed to address the problems presented at the end of the previous section and to offer a better reliability of the dissemination process. In the proposed new protocol, only directional broadcasting is considered since several efficient solutions already exist for the dissemination at intersections [31] [32]. For this protocol, a vehicular network composed by mobile nodes communicating uses vehicle to vehicle (V2V) communication where the MAC layer of each vehicle integrates a service of independent neighborhood, containing a table of all the neighbors of a node in its communication range is assumed. Furthermore, each vehicle has an embedded GPS device and a digital roadmap. All messages sent over the network are sent in the broadcast mode, the antenna used in each vehicle is omnidirectional. The partitioning problem is corrected by one of the following methods: Carry and Forward [9], use of the Road-Side Units (RSUs) [25] as relays when available, Use of the opposite direction, Multiple Dissemination, etc.

3.1 Deleting Black-Burst

There is an increasing research interest in neighborhood service or "Neighbor Discovery" [1]-[4], we assume that the neighborhood service is pre-existing within the MAC layer. Therefore, the mechanism of Black-Burst (BB) loses its necessity and becomes useless. In addition, the dissemination time is considerably reduced since the AMB protocol that is classified among the Time-based protocols due to the BB mechanism [10] changes category to the class of protocols known as Topology-based, Distance Based or Location-Based considering the neighborhood service. Since wireless networks cannot be controlled as securely as wired networks, collisions may be caused by a second transmitter out of the range of the first [20], and neither can recognize the attempts of others to send information. It becomes necessary, then, to reduce the probability of collisions. The CSMA/CA brings the back-off algorithm forward in the process and uses it even before the first delivery process, avoiding participants to simultaneously start a transmission and cause a collision. When a node has an urgent message to transmit; first, it, executes a waiting time called AIFS (Arbitrary Inter Frame Space)**,** if the channel is not idle, it executes a Binary exponential Back-off algorithm [33], then, a random value is set and decremented each time when the channel is found free until this value drops to zero. Then, an RTB control packet is transmitted on the transmission channel towards the farthest node in its communication range available in the neighborhood table [34]. Upon the reception of an RTB packet, if the destination ID specified in the message is different from the receiving node ID, it interrupts any dialogue on the network, and calculates its NAV (Network Allocation Vector) according to the duration field included in the received control packet, and it goes into the alert status as something is happening on the road and wait for the message that will contain more information about the situation. However, if the identity of the receiving node is specified in the RTB, it immediately responds to the source after observing a SIFS (Short Inter-frame Space) time, by sending a control packet CTB (clear to broadcast). When a CTB packet is received, if the node is not the recipient of the CTB, it interrupts any dialogues, calculates its NAV, and waits for the data message that contains more details about the emergency. If the node is the recipient, it is certain that it can send its message without any collisions or interferences and after a SIFS time it broadcasts the data packet. The following pseudo-algorithm describes the OAMB protocol after the BB suppression.

Algorithm 1: OAMB Protocol with BB suppression

```
Initialization:
∀ Vehicle v_k ∈ (1 ≤ k ≤ n)
                    Id_v = k ;
                    state_{v_k} := ∅ ;      //Idle
    At the reception of a new event_i
if (event_i == "accident") then
    if Id_v ≠ 0 then
        stop all the communications ;
        Backoff();
        state_{v_k} := "waiting for further instructions" ;
        Update NAV() ;
    else
        Select the farthest neighbor v_D
        From neighbors table
        Where v_D is in the opposite movement directio
        Create RTB() ;
        RTB().DestMACAddress == v_D .MACAddress
        RTB().SrcMACAddress == v_0 .MACAddress ;
        Wait(AIFS) ;
        Send (RTB()) to v_D ;
    end
else
    Handle the event according to the algorithm
end
At Reception of RTB() by v_i from v_s :
Open RTB() ;
if RTB().DestMACAddress ≠ v_i.DestMACAddress then
        state_{v_i} := "waiting for further instructions" ;
    Update NAV() ;
else
    Create CTB() ;
    RTB().DestMACAddress == v_s .MACAddress ;
    RTB().SrcMACAddress == v_i .MACAddress ;
    Wait(SIFS) ;
    Send ( CTB()) to v_s ;
end
At Reception of CTB() by v_i from v_s :
if CTB().DestMACAddress ≠ v_i.DestMACAddress then
        state_{v_i} := "waiting for further instructions" ;
    Update NAV() ;
else
    Create DATA() ;
    DATA().DestMACAddress == v_s .MACAddress ;
    DATA().SrcMACAddress == v_i .MACAddress ;
    Wait(SIFS) ;
    Send ( DATA()) to v_s ;
end
At Reception of DATA() by v_i from v_s :
if DATA().DestMACAddress ≠ v_i.DestMACAddress then
        state_{v_i} := "waiting for further instructions" ;
    Update NAV() ;
else
    Create ACK() ;
    ACK().DestMACAddress == v_s .MACAddress ;
    ACK().SrcMACAddress == v_i .MACAddress ;
    Wait(SIFS) ;
    Send ( ACK()) to v_s ;
end
At Reception of ACK() by v_i from v_s :
if ACK().DestMACAddress ≠ v_i.DestMACAddress then
        state_{v_i} := "waiting for further instructions" ;
    Update NAV() ;
else
        state_{v_i} := "Broadcast operation successful" ;
    Update NAV() ;
end
```

Upon receipt of the DATA packet, if the node is not designated as a relay of the data message, it calculates its NAV and processes the received packet. If the node is the relay of the message, it waits for a SIFS time and sends an acknowledgment to the sending node to inform it that the message has been well-received. Upon reception of an ACK packet, unconcerned nodes calculate their NAV while ignoring the message. The node concerned understands that the transmission is successful and stops its counter that is used to calculate the time necessary to retransmit in case of failure of the communication. Figure 4 shows the Lamport timestamp diagram [39] for the message exchange after the BB suppression. Since the nodes in VANETs are highly mobile and move at high speeds, disconnections are frequent, and one or more packets could be lost. To be able to detect the loss of these packets and retransmit them, the sending/receiving nodes must be synchronized as follows. In case of loss of the RTB packet the transmitter calculates a rebroadcast Time RTB_{rt} such as:

$$RTB_{rt} = T_{RTB} + T_{SIFS} + T_{CTB} + CTB_{rt} \tag{1}$$

The CTB rebroadcast time is considered in this equation in case the RTB has been successfully transmitted but the CTB has been lost, in which case a chance is given to receive the CTB for the second time, before retransmitting the RTB frame if the latter does not reach the transmitter after RTB_{rt}.

In case of the loss of the CTB packet, the relay node calculates a rebroadcast time CTB_{rt} such as:

$$CTB_{rt} = T_{CTB} + T_{SIFS} + T_{DATA} + DATA_{rt} \tag{2}$$

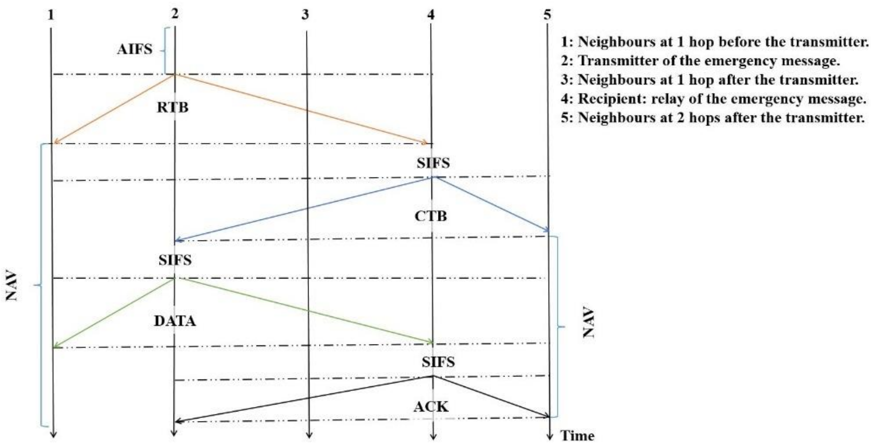

Figure 3
OAMB after Black-Burst suppression

The Rebroadcasting Time of the data is considered in this equation in case the CTB has been correctly transmitted, and the data packet has been lost. In this case, a second chance to receive the data is given, prior to rebroadcast the CTB frame if it does not reach the transmitter after CTB_{rt}.

In case of DATA packet loss the transmitter calculates a rebroadcast time $DATA_{rt}$. such as

$$DATA_{rt} = T_{DATA} + T_{SIFS} + T_{ACK} \tag{3}$$

In case of loss of the acknowledgment, the data is rebroadcasted to the relay, if after two attempts the node does not receive an acknowledgment, the reservation procedure is repeated by choosing a new relay, if the latter is aware that the dissemination was successful, it responds to the RTB packet received directly by an ACK but since time is a critical resource in the dissemination of emergency messages, an enhanced solution focused on the reduction of the number of control frames sent over the network will be presented in the next section.

3.2 Deleting Acknowledgment Control Frame

The main goal is to optimize the transmission time by reducing the number of control frames sent over the network during an urgent transmission, while maintaining reliability. Since the transmission medium is air, the broadcasting by the next relay of the RTB to the next hop is also received by the previous relay of the disseminated message. This can be considered as an ACK and a proof that the RTB was well received by the selected relay, which leads to the deletion of the explicit ACK. Figure 4. shows the Lamport timestamp diagram [39] for the message exchange in the network after the acknowledgement suppression.

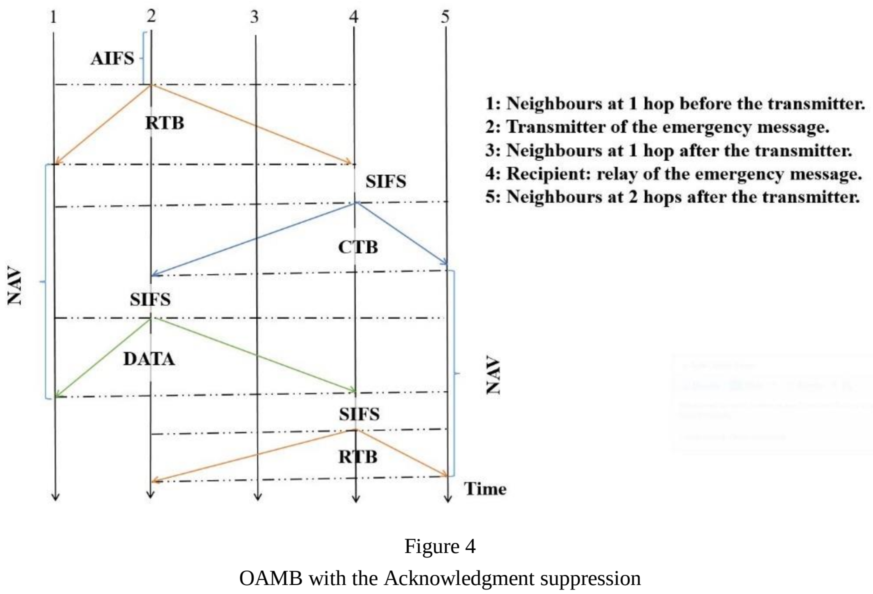

Figure 4
OAMB with the Acknowledgment suppression

The next pseudo-algorithm describes the acknowledgment suppression within the OAMB protocol. In the following section, an attempt to improve the performance based on the modification of the clear to broadcast structure modification and channel reservation mechanism in order to reduce the number of generated messages during the transmission of an urgent data frame will be presented.

Algorithm 2: OAMB with ACK suppression

```
Initialization:
∀ Vehicle v_k ∈ (1 ≤ k ≤ n)
        Id_v = k ;
        state_{v_k} := ∅ ;    //Idle
    At the reception of a new event_i
if (event_i == "accident") then
    if Id_v ≠ 0 then
        stop all the communications ;
        Backoff();
        state_{v_k}:= "waiting for further instructions" ;
        Update NAV() ;
    else
        Select the farthest neighbor v_D
        From neighbors table
        Where v_D is in the opposite direction of the movement ;
        Create RTB() ;
        RTB().DestMACAddress := v_D .MACAddress ;
        RTB().SrcMACAddress := v_0 .MACAddress ;
        RTBwait := 1 ;
        Wait(AIFS) ;
        Send (RTB()) to v_D ;
    end
else
    Handle the event according to the algorithm
end
At Reception of RTB() by v_i from v_s :
Open RTB() ;
if (RTB().DestMACAddress == v_i.DestMACAddress) ) then
    Create CTB() ;
    RTB().DestMACAddress := v_s .MACAddress ;
    RTB().SrcMACAddress := v_i .MACAddress ;
    Wait(SIFS) ;
    Send ( CTB()) to v_s ;
else if ((RTBwait==1) & (RTB().BroadcastDirection==1)) then
        state_{v_i}:= "Broadcast operation successful" ;
    Update NAV() ;
else
    if (RTBwait==0) then
            state_{v_i}:= "waiting for further instructions" ;
        Update NAV() ;
end
At Reception of CTB() by v_i from v_s :
if CTB().DestMACAddress ≠ v_i.DestMACAddress then
        state_{v_i}:= "waiting for further instructions" ;
    Update NAV() ;
else
    Create DATA() ;
    DATA().DestMACAddress := v_s .MACAddress ;
    DATA().SrcMACAddress := v_i .MACAddress ;
    Wait(SIFS) ;
    Send ( DATA()) to v_s ;
end
At Reception of DATA() by v_i from v_s :
if DATA().DestMACAddress ≠ v_i.DestMACAddress then
        state_{v_i}:= "waiting for further instructions" ;
    Update NAV() ;
else
    Select the farthest neighbor v_D
    From neighbors table
    Where v_D is in the opposite movement direction;
    Create RTB() ;
    RTB().DestMACAddress := v_D .MACAddress ;
    RTB().SrcMACAddress := v_i .MACAddress ;
    Wait(SIFS) ;
    Send ( RTB()) to v_s ;
end
```

3.3 Modification of the Clear to Broadcast Control Frame

In this solution, the structure of the CTB control frame is modified to make a transmission channel reservation prior to the data arriving in a certain communication area. This has the advantage of informing the vehicles that something is happening on the road and being cautious, waiting for the details of the events that will arrive instantly after. Instead of sending a new RTB packet on each hop, the characteristics of the wireless broadcast are used again. Indeed, when sending a CTB packet to the transmitter, it can also reach the next relay of the message and therefore, it serves somehow as an RTB packet. It is enough to modify the structure of the CTB frame to adapt it to this new solution. The idea behind is to add a field where the address of the next relay is inserted. The new structure of the CTB frame is depicted in Figure 5. A 6-byte Intermediate relay (IR) address field has been added, which corresponds to the node that will be the next relay of the message, and a transmitter address (TA) field to specify the current transmitter of the control frame for the next relay.

	Frame Control	Duration	Receiver Address **RA**	Transmitter Address **TA**	Intermediate Relay Address **IR**	FCS
Bytes:	2	2	6	6	6	4

Figure 5
proposed structure for the new CTB frame

While studying the conventional IEEE 802.11p MAC header [12]; it was noticed that it contains four address fields, i.e. two additional address fields of the original frame could be exploited without having to change the standard of the 802 .11 frame at the MAC level essentially as far as the size of the control frame is concerned. Figure 6 shows the Lamport timestamp diagram [39] after the introduction of the new CTB design. When an emergency event has occurred on the road, after executing a random Back-Off plus AIFS time, if the communication channel is free, a vehicle sends an RTB frame to the farthest neighbor in its communication range.

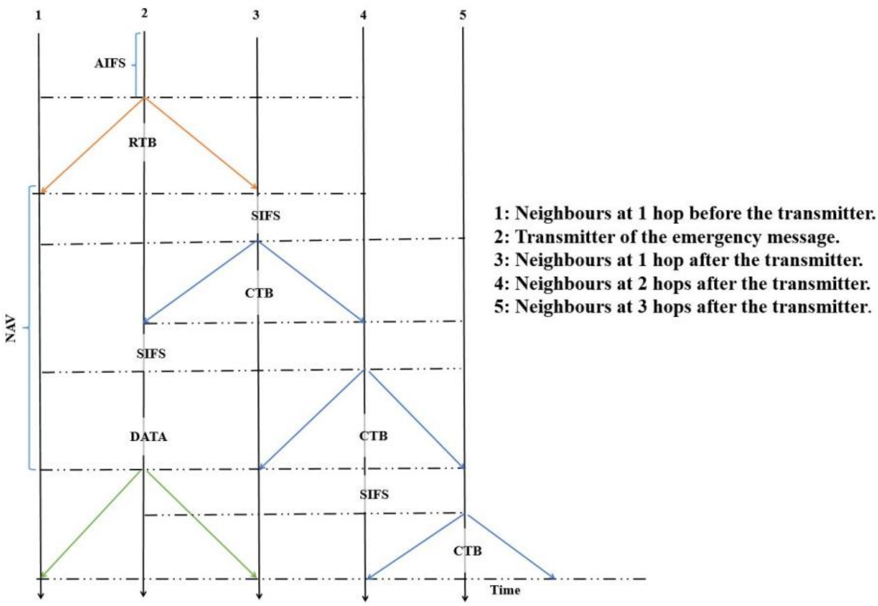

Figure 6
The OAMB execution trace with the CTB proposed design

After receiving an RTB message, the relay responds after a SIFS time to the transmitter and sends a CTB frame containing the identity of the node that is selected as the next relay, while the other non-selected nodes compute their NAV time and stay alert about what is happening on the road. The next relay having received a CTB frame responds to its transmitter after a SIFS time by a new CTB frame after selecting the next relay and so on. At the same moment, the initiating node of the message has received the CTB and has been synchronized by waiting for a SIFS + transmission time of the frame CTB time before transmitting the data packet, avoiding the generation of a collision at the level of the next relay.

Algorithm 3: OAMB with CTB structure modification

```
Initialization:
∀ Vehicle v_k ∈ (1 ≤ k ≤ n)
        Id_v = k ;
        state_{v_k} := ∅ ;      //Idle
        ID_{v_D2} := ∅ ;        //Idle
    At the reception of a new event_i
if (event_i == "accident") then
    if Id_v ≠ 0 then
        stop all the communications ;
        Backoff();
        state_{v_k} := "waiting for further instructions" ;
        Update NAV() ;
    else
        Select the farthest neighbor v_D
        From neighbors table
        Where v_D is in the opposite movement direction;
        Create RTB() ;
        RTB().DestMACAddress := v_D .MACAddress ;
        RTB().SrcMACAddress := v_0 .MACAddress ;
        Wait(AIFS) ;
        Send (RTB()) to v_D ;
    end
else
    Handle the event according to the algorithm
end

At Reception of RTB() by v_i from v_s :
Open RTB() ;
if (RTB().DestMACAddress == v_i.DestMACAddress) ) then
    Select the farthest neighbor v_D2
    From neighbors table
    Where v_D2 is in the opposite movement direction;
    Create CTB() ;
    RTB().Dest1MACAddress := v_s .MACAddress ;
    RTB().SrcMACAddress := v_i .MACAddress ;
    RTB().Dest2MACAddress := v_D2 .MACAddress ;
    Wait(SIFS) ;
    Send ( CTB()) to v_s and v_D2 ;
else
        state_{v_i} := "waiting for further instructions" ;
    Update NAV() ;
end

At Reception of CTB() by v_i from v_s :
if (CTB().Dest1MACAddress = v_i.MACAddress) then
    Create DATA() ;
    DATA().DestMACAddress := v_s .MACAddress ;
    DATA().SrcMACAddress := v_i .MACAddress ;
    Wait(SIFS) ;
    Send ( DATA()) to v_s ;
    DATAwait := 1 ;
else if (CTB().Dest2MACAddress == v_i.MACAddress) then
    Select the farthest neighbor v_D2
    From neighbors table
    Where v_D2 is in the opposite movement direction;
    Create CTB() ;
    RTB().Dest1MACAddress := v_s .MACAddress ;
    RTB().SrcMACAddress := v_i .MACAddress ;
    RTB().Dest2MACAddress := v_D2 .MACAddress ;
    Wait(SIFS) ;
    Send ( CTB()) to v_s and v_D2 ;
    ID_{v_D2} := v_D2
else
        state_{v_i} := "waiting for further instructions" ;
    Update NAV() ;
end

At Reception of DATA() by v_i from v_s :
if DATAwait==1 then
        state_{v_i} := "Broadcast operation successful" ;
    DATAwait=0;
    Update NAV() ;
else if (DATA().DestMACAddress == v_i.MACAddress then
    DATA().DestMACAddress := ID_{v_D2} .MACAddress ;
    Send ( DATA()) to ID_{v_D2} ;
else
        state_{v_i} := "waiting for further instructions" ;
    Update NAV() ;
end
```

The relay node retransmits the data packet immediately after it receives it. In fact, there is no longer need to observe an additional waiting time because it is less likely to cause collisions on the level of the next relay, due to the ongoing reservation process happening one hop far from the transmission process of the data packet. It is also noticed that, in this case receiving the data for a second time works as an ACK, the OAMB protocol with the new CTB design is described in the above pseudo-algorithm. The next section offers a performance evaluation is proposed in order to estimate the OAMB protocol.

4 Theoretical and Numerical Performance Evaluation

Given that the directional broadcasting of AMB being ineffective, and that topology-based protocols have proven their efficiency compared to time-based protocols [13], in this section we entirely focus on the evaluation of the OAMB protocol on both theoritical and numerical levels.

4.1 After Deleting Black-Burst

To determine the performance of the OAMB protocol in case of the BB suppression, the theoretical time required for the dissemination of an emergency message is estimated. For this purpose, the following hypotheses are considered:

- The transmission channel is reliable (no loss of message due to signal attenuation);
- No partitioning of the network;
- The broadcasting antennas are omni-directional;
- The road is directional (no intersections);
- The neighbor tables are preexistent within the IEEE 802.11p MAC layer;

The measurement metrics for the waiting times in VANETs are decisive for the synchronization of the developed protocol, to avoid packet collisions and errors during network communication. Table 1 presents the notations used in the main formulas.

Table 1

principal abbreviations used in the formulas.

Abbreviation	Signification
L	Size (Length)
T	Transmission time
H nb	Hops number

AIFSN	Arbitrary Inter Frame Spacing Number
Rphy	Bit rate
AC	Access Category

In order to estimate the time needed to transmit a frame; the following equation is applied:

$$T_{frame} = \frac{8 \times \mathrm{L_{frame}}}{\mathrm{R_{phy}}} \tag{4}$$

The time required to broadcast an emergency message to the next hop is calculated as follows:

$$T_{hop} \approx AIFS + \left\{ 4\, SIFS + 4\, T_{PHY} + \frac{L_{[RTB+CTB+MAC+DATA+ACK]}}{R_{phy}} \right\} \tag{5}$$

The time required to broadcast an emergency message on a road segment:

$$T_{Segment} \approx (T_{hop} \times H_{nb}) - SIFS \tag{6}$$

With

$$H_{nb} \geq \frac{Dissemination\ distance(m)}{communication\ range\ (m)} \tag{7}$$

Due to its randomness, the time of the back-off has not been considered in (5). Chosen in the following contention window interval CW = 3, ..., 511, making it impossible to guess; therefore, the sign ≈ is used instead of equality in the above equations. In (6), on the last hop of the transmission, when the message reaches its last destination, there is no longer need to spread the message any further. Thus, there is no need to wait for the last SIFS.

Table 2
EDCA default setting in 802.11p [11]

	Queue 1	Queue 2	Queue 3	Queue 4
Priority	Highest	-	-	Lowest
AIFS	58 µs	58 µs	71 µs	123 µs
CW min	3	7	15	15
CW max	511	1023	1023	1023

Moreover, the AIFS is only observed at the first hop because the reservation of the channel is done at the same time thanks to the control packets CTB, which are diffused to answer the transmitter that the route is reserved, reaching the nodes located in the area behind the relay.

To compute the value of the AIFS according to the access category (AC) and based on Table 2. parameters, the following formula is applied [16]

$$AIFS\ [AC] = AIFSN\ [AC]\ \times\ 1\ Time\ slot + SIFS \tag{8}$$

To estimate the performances of the OAMB protocol, the parameters in Table 3 are considered:

Table 3
Parameters for calculating the transmission time of an emergency message [13]-[15]

Parameter	Values
AIFS Time	58 µs
SIFS Time	32 µs
Transmission Time of the physical header	64 µs
Data flow Rate	27 Mbps
Dissemination distance	10 000 m
transmission range	250 m
Size of RTB	29 bytes
Size of CTB and ACK	14 bytes
Size of MAC header	34 bytes
Size of MAC data frame	500 bytes

A previous work [13] presented a comparison of two naive Topology-based and Time-based Emergency Dissemination Protocols. The simulation showed that the investigated Topology-based protocols are more efficient than the Time-based or Delay-based protocols during the dissemination of messages across the network. The topology-based protocols are faster and generate fewer messages during the dissemination across the network. For a naive Topology-based protocol using the same assumptions and parameters and by varying the vehicles density over the network gives a transmission time of approximatively 98 *ms* for higher density traffic while it grows exponentially and reaches over 40 *s* for the same scenario in the time-based protocols.

After the numerical application of the equation (6) using upper parameters, the following results are obtained:

$$T_{segement} = 16.26\, ms$$

These results outperform those obtained during the simulation of the naive Topology-based protocol in terms of propagation delay, which is promising and encourages the implementation of this protocol. This solution has the advantage of reducing the time of the dissemination of the emergency message along the road, indeed by removing the calculation procedure of the most distant node which itself calculates the longest Black-Burst time. The time saved is approximately:

$$T_{saved} \approx T_{longest_{BB}} \times H_{nb} \tag{9}$$

Although the time is considerably reduced, the problem of the number of control frames sent over the network and the additional time generated during their sending still arises, as well as the number of the Inter Frame Space (IFS) between sending each frame to route a single release package.

4.2 After Deleting the Acknowledgment Control Frame

Due to the omni-directional nature of the broadcasting antenna, when an RTB packet is sent by the emergency message relay, it is received by the previous relay/transmitter as well, which is considered an acknowledgment. Thus, the transmission of a new ACK message becomes unnecessary. The ACK is deleted, the SIFS time that precedes its sending is also deleted, saving additional time during the transmission, which can be expressed in the following form:

$$T_{saved} \approx (T_{[PHY+ACK]} + SIFS) \times H_{nb} \tag{10}$$

Thus, the equation that allows to compute the transmission time of an emergency message on the route segment becomes as follows:

$$T_{segment} \approx AIFS + \left[\left\{3\,SIFS + 3\,T_{PHY} + \frac{L_{[RTB+CTB+MAC+DATA]}}{R_{phy}}\right\} \times H_{nb}\right] - SIFS \tag{11}$$

In order to compare the two previous solutions, calculations considering the same parameters and their values are performed, noticing considerable improvement.

$$T_{segement} = 12.4\,ms$$

Since time is the main performance criterion in emergency situations, this solution has the advantage of improving the performance of the first solution by exploiting wireless broadcast characteristics. But the channel reservation process always takes a lot longer with the RTB/CTB mechanism as presented in this method. This operation is done on each hop.

4.3 After Modifying the CTB Packet Structure

In this solution, after the first jump, only the data dissemination time, the MAC header and the physical header are counted because the reservation process takes place at the same time with the dissemination of the data and ends even before it reaches the last vehicle in the network. Moreover, the data transfer time is much greater than the transmission time of the CTB. This leads to the fact that the time of the canal reservation becomes invisible compared to the time of the dissemination of the data. The dissemination time of the emergency message is estimated as follow:

$$T_{segment} \approx AIFS + \left[\left\{SIFS + 3\,T_{PHY} + \frac{L_{[RTB+2CTB+MAC+DATA]}}{R_{phy}}\right\} + \{(H_{nb} - 1) \times \left(T_{phy} + \frac{L_{MAC+DATA}}{R_{phy}}\right)\right] \tag{12}$$

In order to compare the two previous solutions against the third proposed one, calculations considering the same parameters and their values are performed except for the size of the new CTB frame:

$$T_{segement} = 3.57\,ms$$

This solution has a clear advantage over the previous two; it improves the dissemination time of about 78%. However, this solution presents the same problems inherent to those protocols based on the topology of the network. These problems are not related to the OAMB protocol itself, but to the high mobility of the vehicles, and a lot of research are currently carried to help solve them [9] [25].

5 Optimized AMB Protocol Summary and Discussion

In this article we proposed an optimization of the Ad-hoc Multi-hop Broadcast (AMB) protocol aiming shorter communication time and high reliability for the emergency messages. While designing the OAMB protocol, the dissemination time was considered a critical parameter. It is an essential factor in the broadcasting of urgent messages through the network.

Table 4
The OAMB Protocol summary

OAMB	Description	Advantages	Inconvenient	Estimated time	Expected problems	Proposed solutions
(1)	Origin: AMB protocol. BB deletion. Topology-based.	Diffusion time improved	Many control frames are sent, leading to additional delay due to inter frame segments.	16.26 ms	Additional delay due to the loss of control frames	Synchronize communication using timers starting each time a new packet is sent
(2)	Origin: (1). ACK deletion. RTB works as an ACK.	Diffusion time improved and reduced latency.	Similar to the previous solution but reduced	12.4 ms	Chanel reservation is done at each diffusion, leading to unnecessary additional traffic	Use the physical characteristics of the channel to reduce the number of control frames sent over the network.
(3)	Origin: (2). Uses the RTB only once. CTB works as an RTB. DATA plays the role of an ACK as well.	Diffusion time improved by about 75% compared to the first solution.	reliability problems due to the communication with a unique most distant node	3.57 ms	The expected problems are those related to Topology based protocols	These problems could be solved with the help of new hybrid solutions to offer higher reliability to this class of protocols.

The proposed protocol includes three different optimization solutions to improve the directional part of the AMB protocol, and so its estimated performance is better than the results of its predecessor. Table 4. Shows a summary of the performance estimation for the three solutions in term of transmission time. It can be noticed that OAMB at the last proposed solution highly improves the performance of the first optimization. After ACK suppression, the performance is improved by about 23.7%, Whilst, after the new CTB with channel reservation, the performance is improved by about 71.2% when compared to the results with ACK suppression, and by about 78% when compared to the BB suppression solution. Further research plans include the investigation of the applicability of different different fuzzy methods (e.g. [35]-[38]) for the improvement of the emergency message dissemination as well as a simulation based comparison of the AMB protocol and the proposed new solutions.

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