An Effective Broadcast Scheme for Alert Message Propagation in Vehicular Ad hoc Networks

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Abstract— **In this paper, we focus on a vehicular ad hoc network (VANET) that makes use of 802.11–like wireless interfaces for Inter Vehicular Communication (IVC). We propose a distributed position–based broadcast protocol, named Smart Broadcast (SB), that aims at i) maximizing the progress of the message along the propagation line, and ii) minimizing the re–broadcast delay. The protocol is analyzed through a mathematical model that permits to determine the optimal parameter setting for a given scenario. Simulations are then used to validate the mathematical model and to compare SB with other broadcast algorithms.**

I. Introduction

The huge social and economical cost of road accidents makes research of proactive safety services a task of primary importance in the Intelligent Transport System (ITS) area. A fundamental application in this category is the fast and reliable propagation of warning messages to upcoming vehicles in case of hazardous driving situations, such as dangerous road surface conditions, accidents, unexpected fog banks, and so on [1], [2]. These applications require the definition of suitable broadcast mechanisms, capable of delivering alert messages to the highest number of upstream vehicles in the shortest possible time. In order to meet these requirements, the design of broadcast protocols should exploit the peculiar features that differentiate vehicular ad hoc networks (VANETs) from traditional wireless ad hoc networks.

In this study we propose and analyze a position–based broadcast algorithm, named *Smart Broadcast* (SB), which permits fast and reliable message propagation in a VANET scenario. We consider a VANET that relies upon MAC and PHY layers derived from the 802.11 specifications. Furthermore, we assume that nodes are capable of determining their own position, by means of a suitable localization system. The core of SB is the contention–resolution phase that determines the next relay node at each hop. The coverage area is subdivided in adjacent sectors and nodes in each sector randomly pick a backoff value in the contention window assigned to that sector. The contention windows are dimensioned in order to minimize the time to forward the message one hop further. The farther the sector from the message source, the shorter the backoff values. This strategy leads to better performance, in terms of message propagation speed, than that obtained by other position–based broadcast algorithms.

A first version of the SB protocol was presented in [3], where some preliminary results were obtained by means of computer simulations. In this paper, we propose a theoretical analysis of the protocol performance, which permits to derive the optimal parameter setting for a given scenario, enriched by an improved version of the protocol. Finally, we compare SB with the Minimum Connected Dominating Set (MCDS) broadcast algorithm [4], the *Urban Multihop Broadcast* protocol (UMB) [5] and the *Geographic Random Forwarding* protocol (GeRaF)[1] [6]. The comparison, performed by means of an extensive simulation campaign, shows that SB is able to guarantee high reliability, low propagation latency and reduced redundancy.

The paper is organized as follows. In Section II we give an overview of related work and, in particular, we describe the UMB and GeRaF broadcast protocols, used for performance comparison. In Section III we describe the Smart Broadcast Protocol in detail. Section IV provides the theoretical analysis of the protocol performance, while Section V derives the equations for the optimal parameter setting. In Section VI we validate the theoretical analysis by means of simulations, and in Section VII we compare the SB performance with the other position–based algorithms. Finally, Section VIII concludes the paper.

II. Related Work

The literature on broadcast algorithms for ad hoc networks is rather extensive [7]. For the sake of conciseness, we will focus our attention to a limited set of solutions that better comply with the specific features of VANETs.

As mentioned, road safety applications require fast and reliable propagation of the alert messages throughout the network. Optimal performance, in this case, can be obtained by assigning message–rebroadcast duties to the nodes in the *Minimum Connected Dominating Set* (MCDS) [4]. The MCDS is a set of nodes that satisfy the following properties: i) nodes in the set form a connected graph; ii) every other node in the

[1]GeRaF is a position–based MAC/routing scheme, designed for wireless sensor networks. Nevertheless, it has been considered in this study since it presents several similarities with SB and UMB.

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network is one–hop connected with a node in the set; iii) the set has the lowest cardinality over all the possible collections of nodes that fulfil the previous two requirements. In the MCDS–based broadcast algorithm, therefore, the message is forwarded only by the nodes in the MCDS, which achieve the largest progress along the propagation line, while guaranteeing the coverage of all nodes in the network. Unfortunately, the creation and maintenance of the MCDS structure in a highly mobile network is not practical, because of the continuous variation of the network topology [8], [9]. The same problem affects, in general, all the solutions that rely on a complete or partial knowledge of the network topology.

Higher tolerance to nodesmobility is exhibited by the *Location–based Schemes*, which require nodes to be aware of their own position only. Hence, distributed contention mechanisms are used to select the relay nodes that maximize the additional area covered by each transmission [10], [11]. Examples of algorithms in this category are the Urban Multi-Hop Broadcast protocol [5], and the Geographic Random Forwarding algorithm [6], which are detailed in the following.

A. Urban Multi–hop broadcast (UMB)

The UMB protocol is explicitly designed for broadcast propagation in vehicular networks. The core of the algorithm is the contention scheme used to select the next relay node. For space constraints, here we give a brief overview of the algorithm, referring to [5] for further details. The coverage area of a node is equally partitioned in a given number of sectors. The relay node is selected in the furthest non–empty sector, so that the message progress is maximized. The node that holds the broadcast message (source) transmits a MAC–broadcast[2] control packet, called *Request–to–Broadcast* (RTB), which contains the geographical position of the source and the sector size. Upon receiving the RTB packet, nodes compute their distance from the source in number of sectors. Then, nodes transmit a channel jamming signal, called *black–burst*, that covers a number of time–slots equal to their distance from the source (in number of sectors): the further the distance, the longer the black–burst. Once a node has exhausted its black–burst transmission, it checks the channel status. If there are still ongoing transmissions, the node exits the contention phase. Conversely, if the channel is sensed idle, the node returns a *Clear–to–Broadcast* (CTB) control packet, containing its identifier (ID), to the source. Notice that all and only the nodes in the furthest non–empty sector will (simultaneously) transmit a CTB packet. If the source receives a single CTB packet, then it forwards the message to the node that has originated the CTB, which becomes the next relay. On the other hand, in case of collision, the process is iterated among the colliding nodes, over a finer space scale.

It is worth noticing that, according to the contention–resolution scheme, the potential relay nodes wait the longest time before retransmitting. This mechanism may lead to long latency, especially for high node densities.

[2]We use the term *MAC–broadcast* to denote one–hop broadcast transmissions. MAC–broadcast packets are never retransmitted by the receiving nodes.

B. Geographic Random Forwarding (GeRaF)

GeRaF is a position–based routing protocol that presents several analogies with UMB. Although GeRaF was developed for routing in wireless sensor networks [6], it can be easily adapted to the scenario here considered.

Similarly to UMB, GeRaF attempts to maximize the progress of the message along the propagation line. To this end, the coverage area is equally divided in adjacent sectors. The source node successively polls the sectors, starting from the farthest one, through *Request–to–Send* (RTS) messages. Upon receiving the RTS message, all the nodes in the polled region reply by transmitting a *Clear–to–Send* (CTS) packet. If a single node returns the CTS packet, then it becomes the next relay. If there are more nodes in the polled region, a collision occurs. In this case, the source issues a COLLISION message to start a collision–resolution scheme among the nodes involved. Nodes will reply to subsequent solicitations using a probabilistic bisection rule, that is, sending back control messages with a fixed probability of 0.5, until a node is finally elected as the next relay.

As UMB, GeRaF also attempts to maximize the per–hop message progress, but gives no specific provision for minimizing the delay.

III. Smart Broadcast protocol

The Smart Broadcast (SB) protocol has been designed to adhere as much as possible to the IEEE 802.11 specifications, so that its implementation in existing WiFi devices would require only marginal modifications of the firmware. SB is intended for almost–linear networks, which resemble VANET in highway scenarios. Similarly to UMB and GeRaF, SB still leverages on the assumption that the coverage area can be partitioned in adjacent sectors and that nodes are capable of estimating their own position and, therefore, the sector they belong to. Hence, a contention–resolution procedure is performed to elect the relay node. Conversely to the other schemes, though, the SB does not necessarily select the relay in the region that provides the largest progress, since it does not spend time to resolve collisions. The minimization of the *time* to perform a hop is, indeed, the main target of the Smart Broadcast (SB) protocol.

The contention mechanism for the election of the next relay is detailed below:

i) The source node transmits a *Request–to–Broadcast* (RTB) control message. The RTB is a MAC–broadcast packet that contains the geographical position of the sender node and other control information, such as the sector width, the message propagation direction and the contention window size cw.

ii) Only nodes that follow the RTB source along the message propagation direction can participate to the relay election. Upon receiving a RTB, nodes determine the sector they belong to by comparing their coordinates with those of the source. Let us number the N_S sectors from S_1 to S_{N_S}, starting from the

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sector at the edge of the coverage range and moving towards the source node. Each sector S_r is associated to a contention window W_r of size cw:

$$W_r = \{(r-1)cw, (r-1)cw+1, \dots, rcw-1\}, r = 1, 2, \dots, N_S\,.$$

Hence, nodes randomly pick a backoff time in the contention window associated to the sector they belong to. Thus, nodes in the outermost sector S_1 will pick a random backoff value in the set $W_1 = \{0, 1, \dots, cw-1\}$, nodes in S_2 will select their backoff in the set $W_2 = \{cw, cw+1, \dots, 2cw-1\}$ and so on. Notice that the contention windows $\{W_r\}_{r=1,2,\dots,N_S}$ provide a non–overlapping coverage of the set $\mathcal{W} = \{0, 1, \dots, cw\, N_S - 1\}$. Moreover, they guarantee that nodes in the further regions always transmit before the others.

iii) According to the CSMA/CA policy of IEEE 802.11, the backoff counters are decremented by 1 at each idle slot, while countdown is frozen when the medium is busy. The countdown process is, hence, resumed after the channel has been idle for a *Distributed Inter Frame Spacing* (DIFS).

iv) Whenever a node countdowns to zero, it sends a *Clear–to–Broadcast* (CTB) packet with its ID and coordinates and exits the contention phase (until a new RTB packet is received).

v) Upon receiving a valid CTB packet, nodes exit the contention phase (until a new RTB packet is received). On the contrary, nodes that overhear an unrecoverable signal (as in case of collision) remain in the contention phase and resume the backoff process as soon as the channel remains idle for a DIFS.

vi) The contention phase is concluded when a valid CTB packet is received by the source node, i.e., the node that holds the message. In this case, the source transmits a MAC-broadcast frame which contains a header, which carries the next relay ID, and the message body. The transmission occurs after a Short Inter Frame Spacing (SIFS), in order to gain priority over the still contending nodes. Therefore, all the nodes that receive the MAC-broadcast frame are required to pass the message body to the upper layers, but only the relay node is allowed to forward the message along the propagation direction. The relay, hence, becomes the message source for the next contention phase and the algorithm is repeated.

Notice that, in order to reduce the one–hop latency, the algorithm does not provide any collision resolution scheme. According to this strategy, the broadcast propagation can exhaust itself if no successful transmissions occur in any of the N_S sectors or the broadcast message is not received by the elected relay node. To increase the robustness of the protocol, we assume that, after sending the RTB, the source node sets its own backoff counter to $\max\{W_{N_S}\} + 1 = cwN_S$. If such a backoff is cleared before a valid CTB is received, the procedure is repeated anew after an extra time delay Δ. Analogously, after broadcasting the message, the source node expects to hear a RTB broadcast message sent by the relay node, which would acknowledge the success of the forwarding phase. If such a RTB message is not received in a time Δ, the source repeats anew the contention procedure. This makes the algorithm robust in case of node mobility and channel errors.

IV. Theoretical Analysis

In this section we derive the analytical expressions of the average per–hop latency and message progress. Moreover, we will derive the message propagation speed.

Before presenting the mathematical analysis, we need to fix hypotheses and assumptions. We consider that the broadcast message is propagated along a strip–shaped area, representing a highway scenario. We assume a circlar reception model, so that a transmission is correctly received only by nodes within a distance R from the source. For the sake of normalization, we assume $R = 1$. Generally we can assume that the road section is much smaller than the transmission range R. Hence, the forward road area covered by each transmission is approximately rectangular, with side R. Such an area is considered the reference area unit (AU).

The AU is equally divided into N_S sectors, so that each sector covers a fraction $A = 1/N_S$ of an AU. Nodes are distributed on the strip according to a (bi–dimensional) Poisson process of intensity λ nodes per AU. Therefore, the number of nodes within the generic sector S_r will be a Poisson random variable of parameter $\lambda_r = \lambda A$.

Finally, we assume that nodes do not move significantly during the time taken by the contention procedure to be completed. Since the one–hop time is of the order of milliseconds (as we will see in the next sections) and the relative speed between vehicles proceeding in the same direction is not expected to be very large (typically less than 100 km/h), the variation of the relative distance in a hop time is negligible.

A. One–hop latency

In the following we derive the average re–broadcast latency, τ, defined as the mean time required before the broadcast message is successfully forwarded to the next relay node.

Upon receiving a RTB packet, the nodes enter the contention phase and randomly pick a backoff value in their contention windows, W_r, $r = 1, 2, \dots, N_S$. As noticed, the contention windows form a partition of the set $\mathcal{W} = \{0, 1, \dots, N_S cw-1\}$. Let us denote by q_h the number of nodes that pick the same backoff value $h \in \mathcal{W}$. Under the considered hypotheses (Poisson nodes distribution and independent backoff selection), $\{q_h\}_{h\in\mathcal{W}}$ are independent and identically distributed Poisson random variables, with parameter $\tilde{\lambda} = \lambda A/cw = \lambda/(cwN_S)$. Since contending nodes are mutually in range, their countdown processes occur synchronously. Therefore, at the h–th countdown step, one of the following events occurs.

- $q_h = 0$: No node transmits, and the channel remains *Idle* (I) for the entire slot.
- $q_h > 1$: Multiple nodes send the CTB simultaneously, thus incurring into a *Collision* (C).
- $q_h = 1$: A single node transmits the CTB packet, thus winning the contention and becoming the next relay. After a SIFS, the node will receive the *Broadcast* message (B) to be relayed and the procedure will be concluded.[3]

[3] In the theoretical analysis, we neglect channel errors.

The events I, C and B occur independently with probabilities

$$\begin{aligned} P_I &= e^{-\tilde{\lambda}} ; \\ P_C &= 1 - e^{-\tilde{\lambda}} \left(\tilde{\lambda} + 1 \right) ; \\ P_B &= \tilde{\lambda} e^{-\tilde{\lambda}} ; \end{aligned} \tag{1}$$

respectively. The number of unsuccessful events before the completion of the procedure is, hence, a geometrically distributed random variable, with average value n_U given by:

$$n_U = \frac{1 - P_B}{P_B} . \tag{2}$$

Now, the event I takes a time T_I, equal to a single time–slot. A collision event C takes a time T_C, given by the transmission time of a CTB packets, followed by a DIFS. Therefore, the average duration T_U of an unsuccessful countdown step is given by

$$T_U = T_I \frac{P_I}{1 - P_B} + T_C \frac{P_C}{1 - P_B} . \tag{3}$$

Finally, the event B, which concludes the contention phase, takes a time T_B that accounts for the CTB reception time, the SIFS and the message transmission time. The average re–broadcast time τ can, hence, be expressed as:

$$\tau = T_0 + T_B + n_U T_U + T_\Delta ; \tag{4}$$

where T_0 is the *contention starting time*, equal to a DIFS plus the RTB transmission time. The term T_Δ accounts for the extra time spent to restart the procedure, whenever no nodes in the coverage area win the contention, as explained in Section III. Under the simplifying assumption that successive iterations of the contention procedure are statistically independent, we easily get

$$T_\Delta = \left\lfloor \frac{n_U}{cwN_S} \right\rfloor (T_0 + \Delta) ;$$

where $\lfloor x \rfloor$ denotes the integer part of x. Notice that, in typical operating condition, the contention procedure is successfully completed within a maximum contention window, so that T_Δ can be generally neglected.

Replacing (2) into (4) (and neglecting T_Δ) we finally get

$$\tau \simeq T_0 + T_B + T_I \frac{P_I + K P_C}{P_B} ; \tag{5}$$

where the factor K is defined as $K = T_C / T_I$.

B. One–hop message progress

Let us now focus on the one–hop message progress δ, defined as the additional distance covered by the message in a re–broadcast phase, on average. The message progress is defined as the distance between the actual source and the next relay node.

Let us recall that sectors are numbered from N_S to 1, starting from the closest to the source node. Furthermore, let us assume that the next relay belongs to the sector J. Under this condition, the average message progress, normalized to R, is given by

$$\delta(J) = (N_S - J)A + A/2 ; \tag{6}$$

where we recall that $A = 1/N_S$ is the (normalized) length of each sector. Notice that, the sector J contributes to the message progress only for half of its spatial extension since the relay node, on average, will be positioned in the middle of the sector.

Now, it remains to determine the statistics of J. From the message–progress perspective, each repetition of the contention phase represents a renewal epoch. Hence, we can focus on the contention phase where the relay is elected. The probability that the next relay node belongs to the sector $J = r$ is equal to the probability that the successful event B occurs at the backoff slot $s \in W_r$, given that B occurs within the cwN_S steps. In formula, we have

$$P_J(r) = P[s \in W_r | s \in \mathcal{W}] , \ r = 1, 2, \ldots, N_S . \tag{7}$$

Denoting by $P_s(h)$ the conditioned probability that $s = h$, given that $s \in \mathcal{W}$, we have

$$P_s(h) = \begin{cases} \dfrac{(1 - P_B)^h P_B}{1 - (1 - P_B)^{cwN_S}} & h = 0, 1, \ldots, cwN_S - 1 ; \\ 0, & \text{otherwise.} \end{cases} \tag{8}$$

Putting (8) in (7), we easily get

$$P_J(r) = \sum_{h=(r-1)cw}^{r\,cw-1} P_s(h) = \frac{(1 - P_B)^{(r-1)cw} (1 - (1 - P_B)^{cw})}{1 - (1 - P_B)^{cwN_S}} . \tag{9}$$

Hence, from (9) we get the average value of J:

$$m_J = \sum_{r=1}^{N_S} r P_J(r) = \frac{1}{1 - (1 - P_B)^{cw}} - \frac{N_S (1 - P_B)^{cwN_S}}{1 - (1 - P_B)^{cwN_S}} . \tag{10}$$

Finally, taking the expectation of both sides of (6), we get the final expression of the average per–hop progress:

$$\delta = (N_S - m_J)A + A/2 . \tag{11}$$

C. Message propagation speed

We define the message propagation speed as the (normalized) distance covered by the message in a second. In general, the process that describes the propagation of the message along a direction is correlated [4]. For the sake of simplicity, though, we neglect such a correlation and compute the average message propagation speed, v, as the ratio between the one–hop message progress δ and the average one–hop latency τ:

$$v = \frac{\delta}{\tau} . \tag{12}$$

V. Optimal parameter setting

In this section we determine the setting of the protocol parameters that minimizes the message propagation latency.

The one–hop latency τ given in (5) is a function of the parameter $\tilde{\lambda} = \lambda / (cwN_S)$, through the probabilities P_I, P_B and P_C. The nodes density λ is given by the scenario and, hence, cannot be decided. Hence, the two protocol parameters that can be tuned are N_S and cw. The tradeoff in the choice

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of N_S is between the probability that a sector is empty and the speed of the broadcast propagation. Furthermore, the precision of the node position estimation also limits the sector size and, in turn, the maximum value of N_S.[4] Hence, the only remaining parameter to optimize is the contention window size cw.

In the following, therefore, we derive the value of cw that minimizes the average re–broadcast latency τ given in (5). Since T_0 and T_B do not depend on cw, the cost function to minimize is $C(\tilde{\lambda}) = T_I(P_I + KP_C)/P_B$. Replacing P_C with $1 - P_I - P_B$, we have

$$C(\tilde{\lambda}) = -T_I K + T_I \frac{K - (K-1)P_I}{P_B} \,. \tag{13}$$

Setting to zero the derivative of $C(\tilde{\lambda})$ in $\tilde{\lambda}$ we get, after some algebra, the following transcendent equation

$$\tilde{\lambda} = 1 - \frac{K-1}{K} e^{-\tilde{\lambda}} \,. \tag{14}$$

Eq (14) admits a single solution $\tilde{\lambda}_{opt}$ in the interval $(1/K, 1)$, which can be easily found with standard numerical methods. The optimal cw value is, hence, obtained as

$$cw_{opt} = \text{round}\left(\frac{\lambda}{N_S \tilde{\lambda}_{opt}}\right) \,; \tag{15}$$

where round(x) denotes the rounding function.[5]

VI. Validation of the Theoretical Analysis

In this section, we compare the mathematical results obtained in the previous sections with simulation outcomes (obtained with MATLAB), in order to validate the theoretical analysis.

Fig. 1 shows the one–hop latency τ versus λ, for different values of cw. Lines refer to the theoretical results given by (5), while marks refer to the simulation outcomes. Such values have been obtained by dividing the simulated time over the number of times the broadcast message has been forwarded (*number of hops*, in the following). Hence, the τ obtained by simulation is affected by the correlation in the message propagation process that, on the contrary, is neglected in the theoretical model. Nevertheless, the good match of analytical and simulation results confirms the validity of the model.

Fig. 1 also proves the validity of the optimization proposed in Section V. The dashed bold curve that interpolates the minimum values of the other curves in the figure, indeed, has been obtained by plugging cw_{opt} in (5), for each λ. We can see that, by using the optimal contention window value, we always get the lowest delay over all the possible cw values. This curve also reveals another important result: the per–hop latency obtained by using cw_{opt} is approximately constant when varying the node density λ.

Fig. 2 shows the average one–hop progress δ versus the node density λ. Curves have been obtained by assuming cw_{opt} for

[4] Curves shown in the rest of the paper have been obtained with $N_S = 10$, the same value used for UMB and GeRaF

[5] To avoid pathological cases, it is wiser to set cw_{opt} as the maximum between (15) and 2.

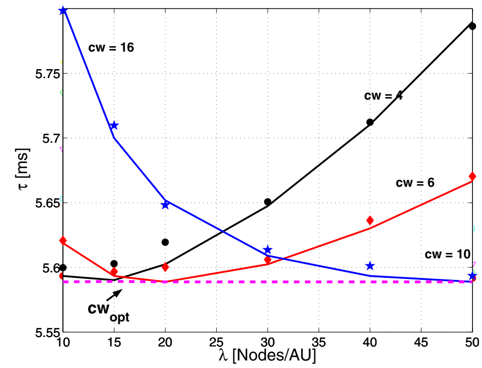

Fig. 1. One–hop latency τ.

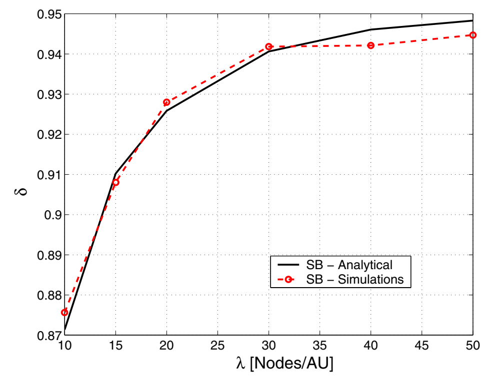

Fig. 2. One–hop message progress δ with optimal parameters setting.

each λ. The continuous curve refers to the theoretical results, given by (11), while the dashed line interpolates the simulation outcomes. The simulated δ is given by the ratio between a reference distance (normalized with respect to R) and the mean number of hops that the message takes to cover such a distance. The figure reveals that (11) captures rather closely the actual protocol performance. Moreover, we can observe that, as expected, the higher the node density, the closer the per–hop progress to the maximum possible.

Finally, Fig. 3 reports the propagation speed, v, versus the nodes density λ. Once again, curves have been obtained by considering the optimal cw setting for each λ. The theoretical curve (continuous line) is given by (12). The simulation values, instead, are obtained as the ratio of the distance covered by the broadcast message in a time T over T. Once more, the match of the two curves is rather good, thus confirming the validity of the theoretical model.

VII. Experimental Results

In this section we compare the performance of SB against that of UMB and GeRaF by means of simulations. Furthermore, we show also the limiting performance achieved by the ideal MCDS–based broadcast algorithm.

The protocol parameters of UMB and GeRaF algorithms have been set as suggested in [5] and [6], respectively. In particular, the number of sectors N_S has been set to 10, as

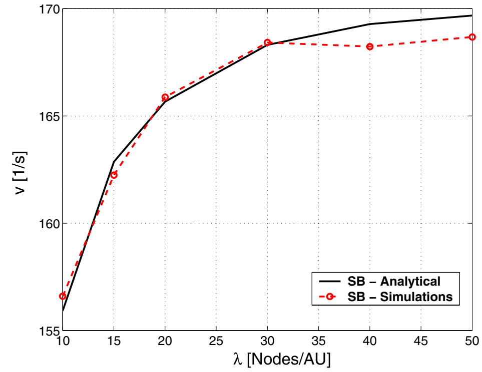

Fig. 3. Message propagation speed v with optimal parameters setting

suggested in [5]. For the sake of fairness, we assume that all the schemes have equal transmission rate (1 Mbps) and coverage range. Also, we assume that RTB/RTS is 20 bytes, CTB/CTS is 14 bytes, and data is 512 bytes.

Fig. 4 shows the average propagation speed, v, for each scheme. In order to evaluate the dependency of the SB performance on the setting of the contention window parameter, we considered two set of results: the first, represented with a continuous line, has been obtained by fixing $cw = 6$, while the other, plotted with a dashed line, has been obtained by adopting the cw_{opt} for each λ. From the figure we can observe that the propagation speed achieved by SB is almost constant when varying the node density. On the contrary, the propagation speed obtained by UMB and GeRaF decreases as the node density increases. The reason is that, in UMB and GeRaF, higher nodes densities determine a greater number of collisions during the contention phase and, consequently, an increase of the wasted time. It is also worth noticing that SB experiments only 20% performance loss with respect to the MCDS protocol, which leverages on the ideal assumption that the optimal relay node is always known in advance.

So far as SB is concerned, we can also observe that setting $cw = 6$ leads to a marginal loss of performance with respect to the optimal case, thus proving that the SB scheme is robust to the variations of the scenario, provided that cw is appropriately set.

Fig. 5 shows the average one–hop progress δ versus the node density λ obtained by the different schemes. As we can see, SB may lead to a slightly lower advancement than the other schemes. This is due to the fact that SB balances both the message progress and the latency. Therefore, SB might prefer to slightly extend the path rather than trying to resolve collisions.

VIII. Conclusion

In this paper we have presented an analysis of a novel position–aware protocol, named Smart Broadcast, for fast and reliable message propagation in VANETs. A mathematical model of the protocol performance has permitted the optimization of a protocol parameter, namely the contention window size cw, as a function of the node density. Finally, the protocol has

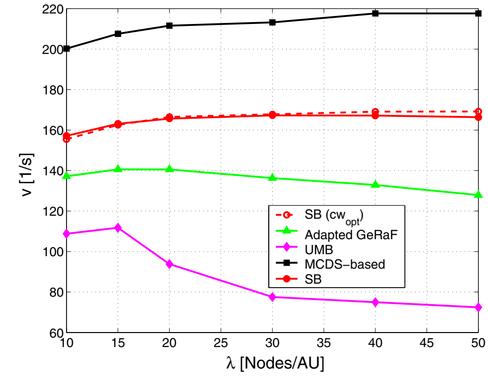

Fig. 4. Message propagation speed: protocols comparison

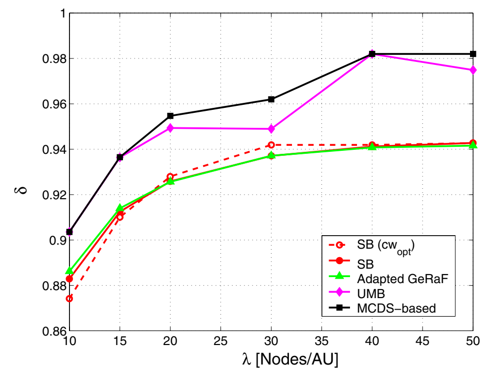

Fig. 5. One–hop message progress δ: protocols comparison

been compared with other well–known position based schemes, revealing good performance in different operating conditions.

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