# Position-based MAC Forwarding Methods for Vehicular Networks

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***Abstract*—Finding and maintaining communication paths in vehicular networks is challenging because of node mobility. Packet routing in Vehicular Ad-hoc Networks (VANET) has been studied recently and many different protocols have been proposed. In particular, geo-routing methods, which do not require maintenance of routes, have been proved to be particularly suitable for VANETs. As usual, these methods use a forwarding mechanism to route packets through intermediate nodes until reaching the destination. In this paper we evaluate two forwarding schemes for vehicular networks that modify the Medium Access Control (MAC) layer contention mechanism in order to prioritize access according to nodes position. In particular, we consider two approaches that use a geometrically-increasing probability distribution for choosing the contention slots but, in the first case, the distribution is appropriately weighted, and in the second case, vehicles (nodes) select the window size according to their position. We analytically evaluate the considered mechanisms with respect to the performance metrics: success probability and access delay. Finally, a detailed study on how to choose the most appropriate parameters and their influence is also conducted.**

***Index Terms*—Vehicular networks, geo-routing, contention-based forwarding, MAC slot distribution**

## I. INTRODUCTION

Vehicular Ad-hoc Networks (VANETs) have become an extensive area of research, standardization, and development, which is bringing a total revolution to the driving experience. For several decades, researchers and engineers from all over the world have been interested in the idea of vehicles being "inter-connected" through wireless communications. Though the initial motivation behind inter-vehicle communications was to increase safety on the roads, more recently their use has been extended to a broader variety of applications, ranging from dynamic vehicle routing to downloading on-demand video.

In conventional networking, an application does not care about the geographic location of the physical devices with which it intends to communicate. Nevertheless, a large number of VANET applications are likely to involve the dissemination of information in a particular geographical region. The delivery of these geographically-addressed messages is performed by the GeoNetworking protocol [1], which is currently being specified by the European Telecommunications Standards Institute Technical Committee on Intelligent Transportation Systems (ETSI TC ITS). This protocol uses a forwarding mechanism to route packets through intermediate nodes until reaching the destination location (or geo-area), as depicted in Fig. 1. As basic forwarding algorithms, GeoNetworking defines a classical greedy forwarding and contention-based forwarding (CBF). The latter makes a receiver decide if it becomes the next forwarder, according to its position. Upon receiving a packet, all routers start a timer whose timeout depends on their specific positions, usually inversely proportional to the distance to the source node. The major advantage of CBF is that it provides an implicit reliability mechanism in case the most suitable router does not receive the packet, which in such a highly dynamic environment is quite likely. However, CBF still has some drawbacks, such as the larger forwarding delay and additional processing required.

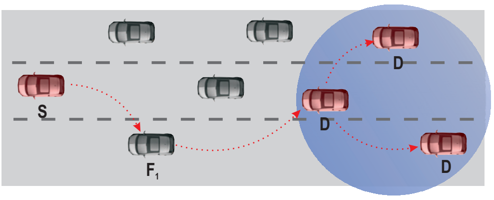

Fig. 1. Packet forwarding in a vehicular network. The source, destination and forwarder nodes are labeled with S, D and F, respectively. The geographical destination area is depicted as a blue circle.

As defined by the standard, CBF is completely implemented at the network layer. However, CBF might be also implemented directly at the Medium Access Control (MAC) layer, in order to optimize its operation. Implementing CBF at MAC layer should result in lower latency, since forwarding delay is removed and only access delay counts. Moreover, CSMA/CA medium access mechanisms can be controlled by means of several parameters, such as the contention window size and intervals, and the probability distribution for the slot selection, which result in multiple degrees of freedom to optimize MAC operation according to the most critical functionality offered by the network. For instance, such an optimization should benefit safety and emergency related applications, which rely and are built on top of the functionality of the geo-routing protocol. As drawback, implementation at the MAC layer may be potentially more complex, requiring at least firmware modification.

In this paper we select optimal parameters for the two forwarding schemes for vehicular networks we proposed in [2], that modify the MAC layer contention mechanism in order to prioritize access according to nodes position. The

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main contribution of this paper is the development of a more elaborated evaluation framework than the one presented in [2], and the study of how to choose the most appropriate values for their different parameters.

The remainder of this paper is organized as follows. In Section II we briefly describe the two forwarding schemes proposed in [2]. In Section III we present the developed evaluation framework, which is then used to select the most appropriate values for the different parameters in the proposed distributions. The suitability of the values of choice for the parameters is studied in Section IV, and finally concluding remarks are given in Section V.

## II. MAC CONTENTION MODIFICATIONS FOR PRIORITIZED ACCESS

The techniques presented in [2] are two modifications of the Sift probability distribution, which was proposed in [3] for event-driven networks where a set of nodes tries to send a packet *simultaneously*. That is, when there are synchronized channel access attempts among many nodes. The key idea behind Sift is to use a non-uniform, geometrically-increasing probability distribution for choosing the contention slots within a fixed-size contention window ($CW$), rather than varying the window size as in many traditional MAC protocols. The resulting protocol performs well when the number of nodes attempting to send data is also large in relation to the $CW$ size, therefore it scales well when the number of contenders grows.

With the Sift protocol the probability of choosing the slot $j$ is given by:

$$g_{CW}(j) = \frac{(1-\alpha)\cdot\alpha^{CW+1}}{1-\alpha^{CW+1}}\cdot\alpha^{-(j+1)},\ j=0,\ldots,CW, \quad (1)$$

where $0<\alpha<1$ is a characteristic coefficient that determines the shape of the probability distribution, and it is adapted to the estimated number of contenders. The geometric distribution assigns low probability to the initial slots and high probability to the last few slots in the contention window, which greatly reduces the probability of packet collision.

Let us note that with the Sift mechanism all the vehicles use the same distribution for the slot selection, so all of them have the same probability of success in accessing the channel. However, for many applications in VANETs, especially for geo-routing, it is beneficial that vehicle position has an influence on the success probability. This is achieved by allowing that each vehicle uses a different probability distribution for the slot selection, based on its own position. Next, we briefly describe the Sift modifications proposed in [2] to this aim.

- **Weighted Sift**

  The first approach consists of weighting the Sift distribution according to the respective position of vehicles within the transmission range of the source node, assigning a higher success probability to the most distant nodes. For each contending vehicle $n_i$, the probability of choosing the slot $j$ is given by:

$$g(i,j) = \begin{cases} \gamma_i \cdot g_{CW}(j), & j=0,\ldots,CW-1,\\ 1-\gamma_i \displaystyle\sum_{k=0}^{CW-1} g_{CW}(k), & j=CW, \end{cases} \quad (2)$$

  where $g_{CW}$ is the Sift probability distribution over $CW$ slots, as defined in eq. (1), and $\gamma_i$ is given by the following expression (more details can be found in [2]):

$$\gamma_i = \left(1-\frac{F_\lambda(R-x_i)}{F_\lambda(R)}\right)\left(\sum_{k=0}^{CW-1} g_{CW}(k)\right)^{-1}, \quad (3)$$

  where $R$ denotes the transmission range, $x_i$ is the distance between the current node and the source node, and finally $F_\lambda$ refers to as the cumulative distribution function of an exponential distribution of mean $\lambda$.

  In the next section, we will study how to choose the best values for the parameters of interest $CW$ and $\lambda$.

- **Per Groups Sift**

  The second method consists of dividing the total number of vehicles into different groups, depending on their priorities. In particular, as we assume the priority is given by the position, we divide the transmission range into $C$ intervals. The group of vehicles located in each of these intervals select their contention slots by using the Sift probability distribution with different values for the contention window size (lower values for higher priorities).

  Therefore, to each group of vehicles $c\in\{1,\ldots,C\}$, we associate a contention window size $CW_c$. Hence, the probability distribution used by all the vehicles in that group is the following:

$$h_c(r) = g_{CW_c}(r),\quad r\in\{0,\ldots,CW_c\}, \quad (4)$$

  where $g_{CW_c}$ is the Sift probability distribution over $CW_c$ slots, as defined in eq. (1).

  As in the previous case, in the next section, we will study how to choose the best values for the parameters $C$ and $CW_c$, $c\in\{1,\ldots,C\}$.

## III. PARAMETERS SELECTION

In order to figure out the most appropriate values for the different parameters in the proposed distributions, we first need to consider some performance metrics and study their influence on them.

Assuming that there are $N$ vehicles contending to be the next forwarder, and that the maximum size of the contention window is $CW$, for each protocol we construct a matrix $\mathbf{P}$ of dimension $N\times CW$, where $\mathbf{P}(i,j)$ is the probability of node $i$ selecting backoff value $j$. Then, by using this probability matrix we compute the probability of a successful transmission by the vehicle $i$ in the slot $r$, which is the probability of vehicle $i$ selecting slot $r$ multiplied by the probability of all the other vehicles selecting later slots:

$$\Pi_{V_i,S_r} = \mathbf{P}(i,r)\prod_{j=1,j\neq i}^{N}\left(1-\sum_{k=0}^{r}\mathbf{P}(j,k)\right). \quad (5)$$

Then, by addition of the corresponding probabilities we can obtain the success probability in a specific slot, the probability of a successful transmission by a particular vehicle and the total success probability.

With respect to the time required by a packet to be forwarded, we consider the *Mean Access Delay*:

$$T_{acc} = (E[A] - 1) \cdot (\sigma \cdot t_c + T_{Pkt}) + \sigma \cdot t_s, \qquad (6)$$

where $E[A]$ represents the expected number of attempts until a node wins the contention[1], $\sigma$ and $T_{Pkt}$ denote the time duration for a slot and a packet transmission respectively (expressed in seconds), and finally $t_s$ and $t_c$ represent respectively the mean slot number when the successful transmission starts or the collision occurs.

What we want is to maximize the success probability for the farthest vehicles while minimizing the *Mean Access Delay*. Therefore, we define the following objective function to be maximized:

$$f(x) = \frac{\Pi_{last}(x)}{\max\{\Pi_{last}\}} - \frac{T_{acc}(x)}{\max\{T_{acc}\}}, \qquad (8)$$

where $x$ represents a particular value for the parameters and $\Pi_{last}$ denotes the success probability of the last 10 vehicles. We divide by the maximum values of the performance metrics in the considered intervals in order to normalize the different measures.

### *A. Scenario*

Before discussing the parameter selection, we define here the scenario under study. We consider a transmission range of 300 meters, where 50 vehicles are equally spaced. Since the performance metrics studied in [2] were quite stable with respect to the number of vehicles, we keep it constant in this study. Nevertheless, later in Section IV we study the effect of a growing number of vehicles in the considered performance metrics with the selected parameters for the distributions.

Additionally, the slot time is assumed to be 9 $\mu s$ and the duration of a packet transmission is 768 $\mu s$ (500-byte network packet at 6 Mbps). Finally, the parameter $\alpha$ of Sift is computed as in [3]:

$$\alpha = M^{-1/(CW-1)} \qquad (9)$$

where $M$ is the maximum number of contenders, and it is assumed to be equal 150 vehicles.

### *B. Weighted Sift*

In this section we will study how to choose the best values of the parameters $CW$ and $\lambda$ for the Weighted Sift distribution. To this aim, we construct a grid varying both parameters over an extensive range of values, and then, for each pair of values, we compute the objective function defined in eq. (8). This function is depicted in Fig. 2, where $CW$ ranges from 8 to 64 slots and $\lambda$ from 6 to 60 meters.

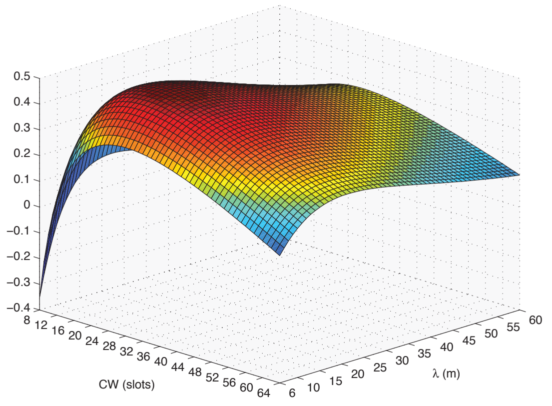

Fig. 2. Values of the objective function over the grid obtained for $CW$ taking values from 8 to 64 slots and $\lambda$ from 6 to 60 m.

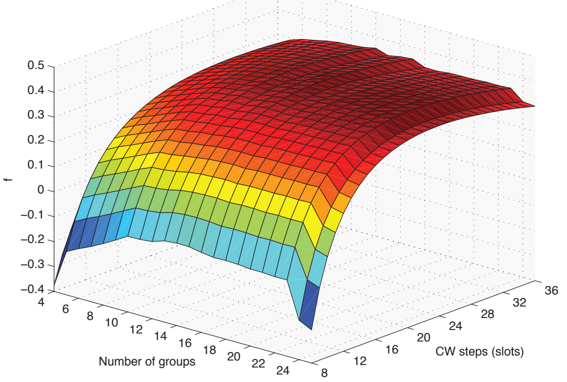

Fig. 3. Values of the objective function over the grid obtained for $CW_{step}$ takes values varying from 8 to 36 slots and $C$ from 4 to 25 groups.

The maximum value of the objective function inside this grid is reached when the parameters take the following values:

$$\begin{aligned} CW &= 25 \text{ slots}, \\ \lambda &= 18 \text{ m}. \end{aligned}$$

### *C. Per Groups Sift*

In this section we will study how to choose the best values of the parameters $C$ and $CW_c$, $c \in \{1, \ldots, C\}$, for the Per Groups Sift distribution. To simplify the computations, we assume here that the contention windows grow according to a fix number of slots (called $CW_{step}$) from one group to the next one. For example, if we have 3 groups and $CW_{step} = 6$, then $CW_1 = 6$, $CW_2 = 12$, and $CW_3 = 18$.

As in the previous section, we construct a grid varying the parameters $CW_{step}$ and $C$ over an extensive range of values. Then, for each pair of values, we compute the objective function defined in eq. (8). This function is represented in Fig. 3, when $CW_{step}$ takes values from 8 to 36 slots and $C$ from 4 to 25 groups.

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[1] Denoting by $\Pi_T$ the total success probability and applying the properties of the infinity sum of a geometric series, the expected number of attempts is computed as follows:

$$E[A] = \sum_{i=1}^{\infty} i\,(1 - \Pi_T)^{i-1}\,\Pi_T = \frac{1}{\Pi_T}. \qquad (7)$$

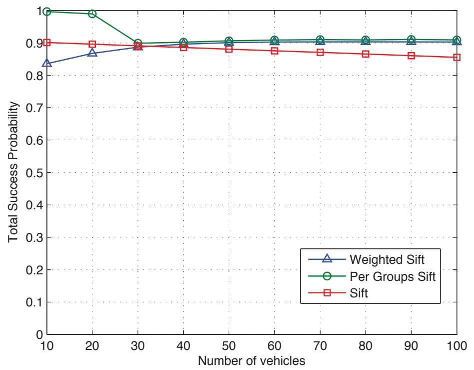

Fig. 4. Total probability of a successful transmission with respect to the number of contenders.

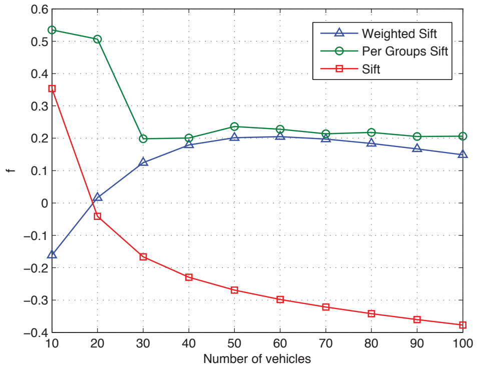

Fig. 5. Values for the objective function defined in eq. (8), with respect to the number of contenders.

The maximum value of the objective function inside this grid is achieved when the parameters take the values:

$$\begin{aligned} CW_{step} &= 24 \text{ slots}, \\ C &= 23 \text{ groups}. \end{aligned}$$

## IV. INFLUENCE OF THE NUMBER OF CONTENDERS

In this section, we verify that the selected values for the parameters improve the operation of the mechanisms and we also observe the influence of a growing number of contenders on the performance metrics under evaluation. Figures 4 and 5 show the total success probability and the values for the objective function defined in eq. (8), respectively, for the two proposals under consideration, as well as the original Sift, when the number of vehicles is varied between 10 and 100.

We can observe in Fig. 4 that the high success probability that characterizes Sift is retained (and even overcame) by the new proposals. Moreover, they scale well when the number of contenders increases, maintaining almost the same success probability. Compared to [2], the optimal selection of parameters only increases slightly the already high probability of success for Weighted Sift, which is positive, since it means that the good performance of the proposal is almost insensitive to parameter variation. On the other hand, Per Groups Sifts clearly increases the success probability, from 0.7 to 0.9, with the optimal parameters computed here. In both cases, the probability of success remains constant almost independently of the number of contenders.

Finally, when we consider the objective function to be maximized, we can observe in Fig. 5 that the two proposals clearly outperforms the original Sift when the number of contenders is high enough. Since the selection of the parameters was performed considering 50 vehicles, from the figure we can conclude that an overestimation of the number of contenders (see for instance in Fig. 5 the case with 30 vehicles when the best parameter were obtained in this paper for 50 vehicles) has a negative impact on the Weighted Sift distribution, while the Per Groups Sift benefits from this overestimation.

## V. CONCLUSIONS

In this paper we have evaluated two forwarding schemes for vehicular networks that modify the MAC-layer contention mechanisms in order to prioritize access according to nodes position. We have developed an evaluation framework which has been used to select the most appropriate values for some of the parameters in the forwarding schemes. In particular, we have defined an objective function to maximize the success probability for the farthest vehicles while minimizing the time required by a packet to be forwarded.

We have shown that with the selected parameters, both proposals outperform the original Sift. Weighted Sift is relatively insensitive to the selection of parameters. On the other hand, Per Groups Sift outperforms slightly the other two forwarding schemes. However, in this case, the overestimation of the number of contenders remarkably improves the Per Groups Sift performance (contrary to the Weighted Sift behavior). That is, it is in general sensitive to the selection of the parameters and the number of contenders. Therefore, additional tests should be performed to further tune its behavior for different number of vehicles.

## ACKNOWLEDGMENT

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## REFERENCES

[1] ETSI TS 102 636-4-1, “Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 4: Geographical addressing and forwarding for point-to-point and point-to-multipoint communications; Sub-part 1: Media-Independent Functionality,” V1.1.1, June 2011.

[2] García-Costa, C.; Egea-López, E.; García-Haro, J., “MAC Contention Distributions for Efficient Geo-routing in Vehicular Networks,” *Proc. 5th International Symposium on Wireless Vehicular Communications, WIVEC 2013*, June 2013.

[3] Tay, Y.C.; Jamieson, K.; Balakrishnan, H., “Collision-Minimizing CSMA and Its Applications to Wireless Sensor Networks,” *IEEE Journal on Selected Areas in Communications*, vol. 22, no. 6, pp. 1048-1057, Aug. 2004.