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***Abstract*—The Cellular Vehicle-to-Everything (C-V2X) is an emerging technology for vehicular networks in which resource allocation mechanisms play a crucial role in its overall performance. In C-V2X, there are two resource allocation modes known as mode 3 and mode 4. This study focuses on mode 3 where the resources are scheduled and allocated by the eNB to vehicles. Contrary to mode 4, the 3GPP has not standardized a specific resource allocation algorithm for mode 3. In this context, we propose in this paper, a new clustering-based resource allocation algorithm for mode 3, named Maximum Inter-Centroids Reuse Distance (MIRD). The main goal of our scheduling scheme is to efficiently allocate resources to vehicles with the application of a specific resource reuse mechanism between clusters. MIRD scheduling scheme is validated through simulations in realistic urban scenario, conducted using the LTEV2VSim simulator. The results demonstrate that our proposed algorithm outperforms another reference algorithm for mode 3 found in the literature.**

***Index Terms*—C-V2X, mode 3 scheduling, clustering, distance-based resource reuse approach**

I. Introduction

In the near future, the connected vehicles will revolutionize the transport sector and the automotive industry. Road safety remains the main objective of the automotive industry. For that, the integration of wireless communication technologies in this sector has given rise to a new paradigm known as Vehicle-to-Everything (V2X) communications. V2X communications aim to ensure road safety and traffic management services. Furthermore, they are also able to provide other types of services, such as entertainment applications.

The resource allocation in C-V2X has drawn the attention of the research community in the last few years. In fact, radio frequencies, which are scarce and precious resources, must be efficiently managed to avoid interferences and collisions. Besides, vehicular communications impose more challenges to the resource allocation problem due to constant changes in network topology caused by high mobility. Therefore, resource allocation in C-V2X is a key aspect to improve its performance and enable Internet-of-Vehicles (IoV) applications. C-V2X presents two modes of resource allocation: a centralized under-coverage mode and a distributed out-of-coverage mode. In LTE-V2X, these modes are respectively known as modes 3 and 4 as illustrated in Figure 1. In mode 3, the resources are scheduled and allocated by the evolved Node B (eNB) to vehicles. However, in mode 4, the vehicles autonomously select their radio resources using the sensing-based Semi-Persistent Scheduling (SPS) algorithm. Contrary to mode 4, the 3GPP has not standardized a specific resource allocation algorithm for mode 3.

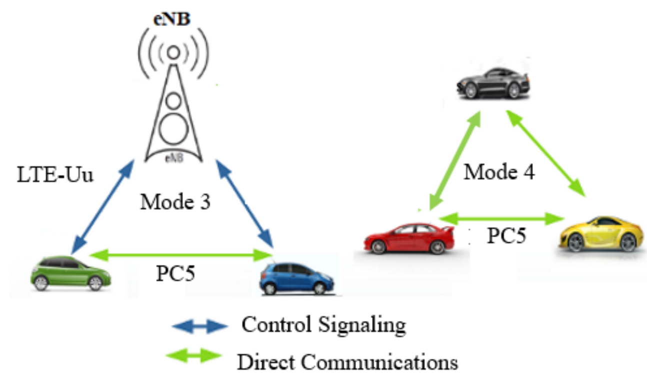

Fig. 1: Resource Allocation Modes in LTE-V2X

Several solutions have been already proposed for the LTE-V2X modes, and especially for mode 4. LTE-V2X mode 4 has a huge volume of research works compared to mode 3. This is explained by the fact that mode 3 is less challenging thanks to the control of the eNB while mode 4 presents different issues related to collision, interference and congestion control problems caused by its decentralized nature. However, even though mode 3 has to cope with a significant reduced set of problems, it remains very important to propose new resource allocation algorithms aiming to optimize the network capacity, the data rate of vehicles or the reuse of resources between vehicles.

Therefore, the novelty of this work is to propose a new scheduling algorithm for mode 3 named Maximum Inter-Centroids Reuse Distance (MIRD) based on vehicle clustering, resource clustering and resource reuse between clusters. The main idea of the MIRD algorithm relies on three steps. The first step is the clustering of vehicles according to their geographical positions and directions. The second step consists of dividing resources into multiple resource sets. The third step is the application of a specific resource reuse mechanism between clusters.

The present work is interested in the road safety applications in V2X communications. Road safety applications are based on the broadcasting of periodic basic safety messages. Here, it is relevant to highlight that the basic safety messages cannot admit the blocking of transmitters caused by the unavailability of radio resources. Therefore, we propose in this work a more practical resource reuse mechanism based on clustering. Generally, the resource reuse algorithms are based on the calculation of the distance between two vehicles in order to reuse resources between them. However, MIRD algorithm takes advantage of the clustering of vehicles and calculates the distance between the centroids of two clusters in order to enable the reuse of resources between all vehicles of both clusters. MIRD tries to maximize the distance between two clusters reusing the same resources to keep the interference under control. This solution makes the resource management task simpler since computing the inter-centroid distance between two clusters allows providing resource reuse between all vehicles of both clusters. As MIRD reduces the complexity of the resource reuse algorithm, it decreases the power consumption as well as the delay to make decisions for the resource reuse.

The rest of the paper is organized as follows.We first present an overview of the side-link resource allocation mode 3 in Section II. Section III presents the state-of-the-art of research works related to mode 3. Next, we present our contribution in Section IV. Then, we detail the MIRD algorithm in Section V. The simulation scenario and the analysis of results are presented in Section VI. Finally, we conclude our paper in Section VII.

II. Side-link Resource Allocation in mode 3

A. Resources in LTE-V2X

As in LTE, the LTE-V2X adopts Orthogonal Frequency Division Multiplexing (OFDM) in its physical layer and the Single-Carrier Frequency Division Multiple Access (SC-FDMA) at the Medium Access Control (MAC) layer. The available bandwidth, i.e. a 10 or 20 MHz channel, is subdivided in time and frequency domains into several orthogonal resources. In time domain, the signal is organized into frames of 10 ms. Thus, each frame is formed by 10 sub-frames of 1 ms and each sub-frame is formed by 2 time-slots (TS). In the frequency domain, the signal is formed by Resource Blocks Pairs (RBP), which is defined by 12 sub-carriers, spaced by 15 kHz and carrying 14 OFDM symbols. In LTE-V2X, a sub-channel is defined by a group of RBPs in the same sub-frame. A sub-channel is the smallest unit of resource that can be allocated to a vehicle to transmit a Cooperative Awareness Message (CAM). The Beacon Resource (BR) is defined by one or more sub-channels required to transmit the CAM packet. In LTE-V2X, Quadrature Phase-Shift Keying (QPSK) and 16-Quadrature Amplitude Modulation (QAM) modulations are used with the Turbo coding.

In LTE-V2X, a resource pool is formed by a set of sub-channels within a certain number of sub-frames. The number

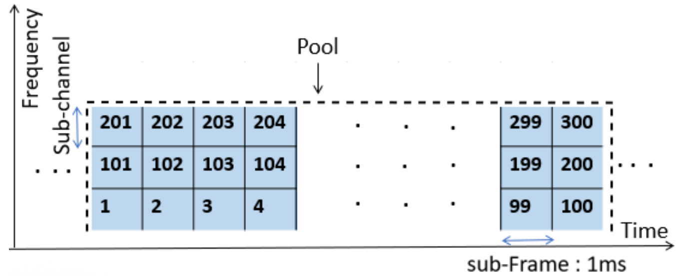

Fig. 2: Resource Pool with Nsf = 100 sub-frames and Nsc = 3 sub-channels

of sub-frames in the resource pool depends on the transmission interval of the beacon messages, and it is computed as 1,000 divided by the beacon transmission rate λ. For example, if the beacon transmission rate is λ = 10 pps, the number of sub-frames in the pool is then equal to Nsf = 1,000/10 = 100 sub-frames. Thus, if the number of sub-channels is set to $Nsch$ = 3 sub-channels, then the total number of available resources is $Nres$ = 300 resources as illustrated in Figure 2.

B. Mode 3

As previously pointed out, the 3GPP has not standardized a specific resource allocation algorithm for mode 3. Therefore, each operator can propose its own algorithm. However, there are two choices for resource allocation in this mode :

a) The dynamic allocation: in the dynamic allocation, each vehicle requests sub-channels from the eNB for each CAM packet transmission. The drawback of the dynamic allocation is the increase of the signaling overhead and the latency.

b) The Semi-Persistent Scheduling (SPS): in the SPS, the eNB reserves sub-channels for the periodic transmissions of vehicles. Each vehicle sends to the eNB the necessary information such as packet size, transmission frequency, and priority of packets. This information is refered to as the assistance information, which is used by the eNB to semi-persistently reserve the appropriate resources for each vehicle.

The main advantage of the SPS approach is the reduction of the signaling overhead and the delay introduced by the resource allocation mechanism. It is important here to note that the semi-persistent-scheduling approach is the more suitable approach for the LTE-V2V services. This is due to the fact that the basic safety messages, on which are based the primary use cases in LTE-V2V, are of periodic nature.

III. Related Work

As previously mentioned, there are few research works, in the literature, interested in mode 3 compared to the huge mode 4 research interest. In **[1]**, Abanto-Leon *et al.* propose a new resource allocation solution for mode 3 in order to guarantee the Quality-of-Service (QoS) for each vehicle. In this context, the QoS refers to the number of sub-channels and the data rate that each vehicle needs for its transmission. This proposal also aims to avoid the conflicts that might occur between vehicles during transmissions. These conflicts are mainly related to the intra-cluster and inter-clusters interference problems, assuming that vehicles are grouped into clusters based on their geographical location. The intra-cluster problem is caused by the Half-Duplex (HD) nature of the sidelink interface PC5, where two vehicles on the V2V range cannot transmit simultaneously at the same time. The inter-clusters problem is related to the positioning of vehicles at the intersection of clusters. Those vehicles can receive messages broadcasted by other vehicles belonging to different clusters using the same sub-channel simultaneously, causing interference problems. The authors use a mathematical framework in order to propose a resource allocation solution that can avoid these conflicts. Then, the same authors have represented the centralized resource allocation in mode 3 by a weighted bipartite graph in **[2]** and **[3]**. In these solutions, vehicles and spectral resources are represented by the vertices of a graph and the edges represent the achievable data rate in each resource based on the Signal-to-Interference plus Noise Ratio (SINR) that the vehicles perceive. In **[2]**, the resource allocation solution aims to efficiently manage resources by avoiding the conflicts previously cited in **[1]** and also by enabling the reuse of resources between vehicles with an interference avoidance mechanism. Authors show mathematically and through simulations that this approach allows improving the performance in terms of the achieved data rate requested by vehicles. Then, in **[3]**, the proposed resource allocation algorithm is based on two approaches, namely bipartite graph matching-based successive allocation (BGM-SA) and bipartite graph matching-based parallel allocation (BGM-PA). The main objective of this algorithm is to find the optimal one-to-one vertex assignment in order to maximize the capacity of the system defined as the achieved data rate. The same authors propose in **[4]** two resource allocation schemes. The first scheme aims to minimize the perceived power of sub-channels. In this approach, it is assumed that vehicles send the channel conditions to the eNB. Then, the eNB schedules resources based on this information with a minimization of perceived power of allocated sub-channels. The suitable allocated sub-channels are non-occupied sub-channels or sub-channels experiencing a negligible interference. However, the second approach aims to maximize the distance for the reuse of sub-channels between vehicles in order to avoid the co-channel interference. The authors demonstrate through simulations that these two approaches outperform the decentralized approach, i.e mode 4, in terms of the Packet Reception Ratio (PRR), as the sub-channels are assigned in a more efficient manner with mitigated interference.

Authors of **[5]**, **[6]** and **[7]** focus on the geographical position-based resource allocation schemes and the distance-based resource reuse approaches. Cecchini *et al.* **[5]** propose a resource allocation mechanism based on the knowledge of vehicle position. The position of a vehicle is known through the Up-link Time Difference of Arrival (UTDOA) or the Global Navigation Satellite System (GNSS) positioning. They compare the effect of the positioning error on the system performance. They demonstrate that the localization accuracy is more important than the frequency of GNSS update, which leads to a low error rate. Besides, authors propose that a resource can be allocated for two vehicles if the distance between those vehicles is greater than a fixed resource reuse distance. Next, the same authors propose a new algorithm that aims to maximize the resource reuse distance between vehicles in order to control the probability of interference **[6]**. The authors prove that this last algorithm allows improving the PRR compared to its predecessor, presented in **[5]**.

The above-mentioned algorithms do not take into account the traffic density and channel conditions at the same time. Authors in **[8]** propose to use the geographical location of the vehicles and the environmental conditions, such as the channel load and the traffic density, to allocate resources to vehicles. This proposal is called aDaptive spatIal Reuse of rAdio resourCes (DIRAC). DIRAC defines 2 distances: the reuse distance and the HD distance. The reuse distance is the distance between 2 vehicles reusing the same resource while the HD distance is the distance between two vehicles transmitting in the same sub-frame but using different sub-channels. This proposal adapts the computed distances to the context conditions, such as the traffic density and the channel load. DIRAC aims to minimize the probability that two interfering vehicles are close to each other in order to minimize the QoS degradation. The simulation results show that DIRAC outperforms existing LTE-V2X Mode 3 and Mode 4 scheduling schemes in terms of the Packet Delivery Ratio (PDR) in both Line-Of-Sight (LOS) and Non-Line-Of-Sight (NLOS) conditions.

The novelty of our work is to propose a new resource allocation scheme based on the clustering. Grouping vehicles into clusters facilitates the resource allocation process by assigning a resource set to each cluster, which also facilitates the resource reuse between two clusters instead of reusing resources between only two vehicles.

IV. Motivation and contribution

The resource allocation solution proposed in this paper comprises three steps. The first step is the clustering of vehicles according to their geographical positions and directions. The second step consists of dividing the beacon resources into multiple resource sets. The third step relies on the application of a distance-based resource reuse approach for reusing resources between clusters. It is worth noting that the MIRD algorithm makes the resource reuse task easier. In fact, in the distance-based resource reuse algorithms, the distance-based approach is applied between vehicles which requires the computation of the distance between all pairs of vehicles to make decisions for the resource reuse. However, in our proposal, it is sufficient to compute the inter-centroid distance between two clusters in order to enable the reuse of resources between all vehicles of both clusters. For that, MIRD has the advantage of reducing the number of calculation operations

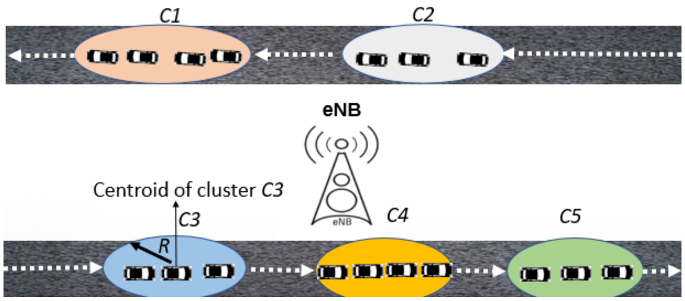

Fig. 3: (Geographical positions and directions)-based clustering architecture

required, the power consumption of computation resources and the time needed to make decisions for the resource reuse.

In the following, we present in detail and separately the clustering of vehicles, the clustering of resources and the distance-based resource reuse approach.

A. Clustering of vehicles

In the literature, there exist many clustering approaches for vehicular networks **[9] [10]**. In our approach, we assume that the eNB can group the vehicles into clusters according to their geographical positions and directions. Here, we define a cluster by its centroid, which refers to the central position of the cluster and its radius denoted as R, as illustrated in Figure 3. The eNB retrieves the geographical positions of vehicles either by the UTDOA technique or by the GNSS. The UTDOA is a technique based on the difference between the arrival times of two consecutive uplink packets.

B. Clustering of resources

After the clustering of vehicles, the eNB executes the second task which consists of dividing resources into multiple resource sets. In this context, we mean by resources the BR as already defined in **Section II-A**. In our scheduling scheme, MIRD, we take into account the HD nature of the sidelink interface PC5. To this aim, we propose to allocate sub-channels within different sub-frames to vehicles of the same cluster. Figure 4 illustrates an option when resources are divided into 3 time-orthogonal resource sets, denoted by $subset_1, subset_2$ and $subset_3$. In addition, we apply a specific resource reuse approach between clusters. In fact, two clusters can use the same resource set if the distance between their centroids is greater than a given threshold parameter RC_{reuse} that we will detail in the following.

C. MIRD-Resource Reuse Approach

While the previous algorithms presented in the literature **[5] [6]** apply the resource reuse distance approach between vehicles, MIRD applies it between clusters. We denote by Inter-Centroid Distance (ICD) the distance between the centroids of two clusters. In this approach, two clusters C_i and C_j can reuse the same resource set, if the ICD_{ij} of clusters C_i and C_j is greater than a fixed threshold, known as RC_{reuse} as computed in equation (1) and illustrated in Figure 4.

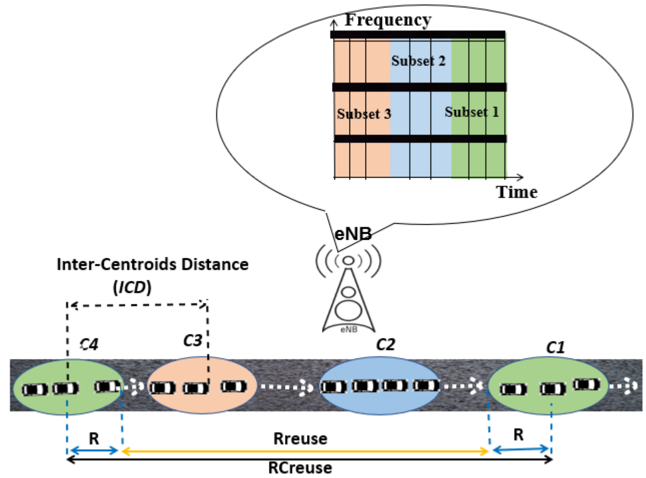

Fig. 4: Clustering-based resource allocation scheme under-cellular coverage

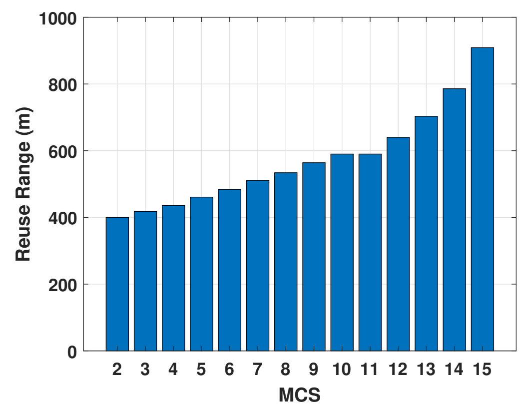

Fig. 5: R_{reuse} in function of MCS

$$RC_{reuse} = R_{reuse} + 2 * R \tag{1}$$

We note that the R_{reuse} is computed following the equations presented in **[11]** and it depends on the choice of the Modulation and Coding Scheme (MCS). The variation of R_{reuse} in function of MCS is presented in Figure 5.

In Figure 6, we present the variation of RC_{reuse} in function of the cluster radius for different MCS values. When the MCS level increases, the R_{reuse} increases also as presented in Figure 5. Thus, the RC_{reuse} increases with the high MCS level values for the same cluster radius.

V. System Model and MIRD Algorithm

Let $\mathbb{V} = \{v_1, v_2, .., v_M\}$ designate the set of M vehicles present in the cell at a given time, when the cell starts the resource allocation procedure. For the sake of simplicity, we suppose that all vehicles in the cell follow the same direction. Based on the positions of the vehicles, the eNB runs the clustering algorithm to divide M vehicles into K clusters $\mathbb{C} =$

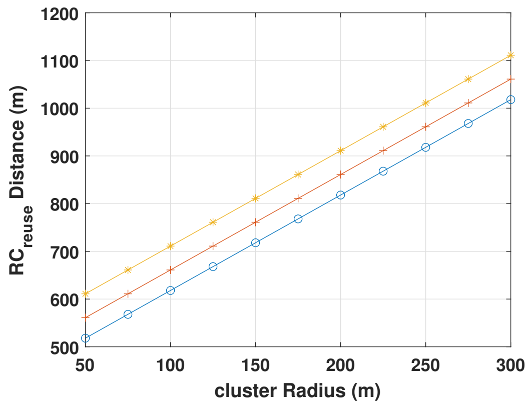

Fig. 6: RC_{reuse} in function of the cluster radius for different MCS values

$\{C_1, C_2, C_3, ..., C_K\}$ so that $\sum_{i=1}^{K} |C_i| = M$ and $\bigcap_{i=1}^{K} C_i = \emptyset$. If we denote the number of vehicles in cluster C_i by M_i, we also have $\sum_{i=1}^{K} M_i = M$. In this contribution, we have chosen the clustering algorithm presented in [12]. However, any clustering algorithm based on the geographical positions of vehicles can be chosen.

Let $\mathbb{R}$=$\{r_1, r_2, r_3, ..., r_N\}$ be the set of resources in the cell. Each resource corresponds to a BR which is a fixed number of sub-channels necessary to transmit a CAM message. We also suppose that each vehicle only needs one resource allocated by the eNB. Depending on the number of vehicles present in the cell, the number of resources can be greater than, equal to or smaller than the number of vehicles. When $M < N$, the eNB doesn't run out of resources and there are still unused resources in the cell. When $M = N$, each vehicle is allocated a distinct resource in the cell and there is no free resource available in the cell any more. When $M > N$, it is necessary to reuse resources in different clusters. The contribution of this paper is focused on the last case.

Let's consider in detail the resource reuse between clusters. We denote the set of resources allocated to cluster C_i by $\mathbb{R}_{C_i} = \{r_{C_i}^1, r_{C_i}^2, r_{C_i}^3 ..., r_{C_i}^{M_i}\}$. As each vehicle only needs one resource, we can consider $r_{C_i}^j$ as the resource that the eNB allocates to vehicle j in cluster C_i. For each cluster C_i, $i = 1, 2, ..., K$, the eNodeB executes Algorithm 1 and allocates a set of M_i resources. Algorithm 1 presents the first phase of resource allocation. In the case that $M > N$, the first phase of resource allocation in which each resource is allocated once ends with some cluster C_j so that the number of remaining resources is smaller than the number of vehicles of this cluster. That means $N - \sum_{i=1}^{j-1} M_i < M_j$.

After the first phase, there are $j-1$ clusters having resources allocated and $K-j+1$ clusters waiting for resource allocation. In phase two, we adopt a cluster-based resource allocation approach to reduce the complexity of the resource allocation algorithm. The whole number of resources allocated to a cluster in the first phase will be given to another cluster in the second phase. Algorithm 2 presents the second phase of resource allocation in which different clusters can use the same resources when they are sufficiently far from each other.

Let's call a cluster which has not received allocated resources and must reuse resources of another cluster a *requesting cluster*. The cluster which has already resource allocated in phase one and its resources can be given to a requesting cluster is called an *offering cluster*. To minimize the interference between two clusters using the same resources, the distance between them should be maximized. In order to allocate resources to a requesting cluster C_j, the eNB establishes a list of candidate clusters. The candidate clusters are the clusters which have been already allocated with resources in phase 1 and have the inter-centroid distance with cluster C_j greater than RC_{reuse}. This list is sorted by the inter-centroid distance with C_j in a decreasing order. The eNB traverses the list from one cluster to another and selects one or more clusters so that the number of total resources is greater than or equal to M_j. The selected resources may be already reused by another requesting cluster C_x but the inter-centroids distance ICD_{jx} between clusters C_j and C_x must be greater than the RC_{reuse} threshold.

Algorithm 1: Resource allocation in phase 1

Result: $\mathbb{R}_{C_i}, \forall C_i \in \mathbb{P}_1$
$\mathbb{P}_1$ = Null;
/* $\mathbb{P}_1$ is the set of clusters having resources allocated in phase 1 */
S = N;
/* S is the remaining resources */
i = 1;
while $(S >= M_i)$ && $(i <= K)$ **do**
  Add_cluster_into_$\mathbb{P}_1$ (C_i) ;
  for $x = 1$ **to** M_i **do**
    $r_{C_i}^x = r_x$;
  end
  S = S - M_i ;
  i++;
end

We present the main parameters of MIRD algorithm in **Table I**.

In this contribution, as we are interested in the basic safety messages, which are of periodic nature, the Semi-Persistent Scheduling (SPS) approach is the best choice. In this approach, a reselection time (T_{resel}), which is a multiple of the beacon period, is used in order to transmit with the same resource for a successive number of transmissions. The work in [6] has already demonstrated that a reselection time (T_{resel}) of 2 seconds is the best compromise between control signaling and performance. For this reason, the MIRD algorithm is executed every 2 seconds.

VI. Simulation Scenario and Result Analysis

In this section, we present the scenario of our simulation. We present also the reference algorithm which is used to compare the performance with the MIRD algorithm. Finally,

Algorithm 2: Resource allocation for a requesting cluster C_j in phase 2

Result: $\mathbb{R}_{C_j}$

$\mathbb{L}$= Distances_from_C$_j$_greater_than_$RC_{reuse}(\mathbb{P}_1)$;
Sort_by_Decreasing_Distance_from_C_j ($\mathbb{L}$);
$\mathbb{R}_{C_j}$ = Null;
$\mathbb{X}$ = Null ;
/* $\mathbb{X}$ is the set of resources already reused by requesting clusters */
resource_found = false;
p = 0;
while *(!resource_found) && ($\mathbb{L}$!= $\emptyset$)* **do**
    C_k = $\mathbb{L}$*[0];*
    p = p + M_k *;*
    $\mathbb{R}_{C_j} = \mathbb{R}_{C_j} \bigcup \mathbb{R}_{C_k}$ *;*
    if $p >= M_j$ **then**
        if *($\mathbb{R}_{C_k} \notin \mathbb{X}$) OR ($\mathbb{R}_{C_k} \in \mathbb{X}$ AND $ICD_{jx} \geq RC_{reuse}$)* **then**
            resource_found = true;
            $\mathbb{X} = \mathbb{X} \bigcup \mathbb{R}_{C_k}$ *;*
            /* ICD_{jx} is the inter-centroid distance between the cluster C_j and any cluster C_x which already reuses the resource set $\mathbb{R}_{C_k}$ */
        else
            $\mathbb{L} = \mathbb{L} \setminus C_k$ *;*
        end
    else
        $\mathbb{L} = \mathbb{L} \setminus C_k$ *;*
    end
end
if *resource_found == false* **then**
    $\mathbb{R}_{C_j}$ *= Null;*
end

TABLE I: Main parameters of MIRD algorithm

Parameter	**Description**
ICD	Inter-centroids distance: distance between the centroids of two clusters
R	Cluster radius
R_{reuse}	Minimum distance between two vehicles reusing the same resource as computed in **[11]**.
RC_{reuse}	Minimum distance between two clusters reusing the same resource set as computed in equation (1)

we analyse the simulation results and present the performance of our proposal.

A. Simulation Scenario

The simulation is conducted through the LTEV2VSim simulator **[13][14]**. LTEV2VSim is a Matlab-based open-source simulator dedicated for resource allocation in LTEV2V communications. The vehicle mobility is based on realistic traffic traces generated with PTVVISim simulator **[15]** of an urban scenario of Bologna. The propagation and NLOS modeling implemented by the simulator is the WINNER + B1 channel model as presented in **[16]**.

TABLE II: Simulation Parameters

Parameter	Value
Beacon Period	0.1 s
Beacon size	300 bytes
Channel Bandwidth	10 MHz
Frequency	5.9 GHz
Modulation and Coding Scheme (MCS)	5
Duplexing	HD
Equivalent Radiated Power (dBm)	20 dBm
Tx/Rx antenna Gain	3 dB
Antenna height	1.5 m
Path Loss model	WINNER +(B1)
Reselection time (T_{resel})	2s

In our simulations, we have chosen a scenario with M= 60 vehicles grouped into K= 9 clusters. The radius of the cluster is 200 m. The total number of available resources is N= 40 resources.

In order to demonstrate the performance of our algorithm, we compare it with the reference algorithm, denoted as $Algo_{ref}$, in which the eNB sorts the resources and assigns to each vehicle the first free BR.

B. Result Analysis

In our simulations, we evaluate the performance of the proposed algorithm with the following Key Performance Indicators (KPI):

- The Packet Reception Ratio (PRR) is defined as the ratio between the number of successfully received beacons and the total number of neighbors.
- The Average Error Rate (AER) is defined as the ratio between the number of not correctly decoded beacons and the total number of beacons expected to be received.
- The Average Blocking Rate (ABR) is defined as the ratio between the number of blocked vehicles due to the unavailability of resources and the total number of vehicles.
- The resource reuse rate (λ) is defined as the ratio between the number of clusters reusing the resource sets and the total number of clusters in the scenario.
- The complexity gain ($G_{N_{co}}$) is computed as the difference between the number of needed operations to make resource reuse decision in the standard Resource Reuse Distance (RRD)-based approach and the number of needed operations to make resource reuse decision in the MIRD algorithm.

The comparison between the performance of MIRD algorithm and the reference algorithm is made by analyzing the PRR, AER and ABR as shown in Figures 7, 8 and 9 respectively. These parameters indicate the reliability level which is one of the most important requirements of the V2X applications in order to ensure the basic safety service. Figures

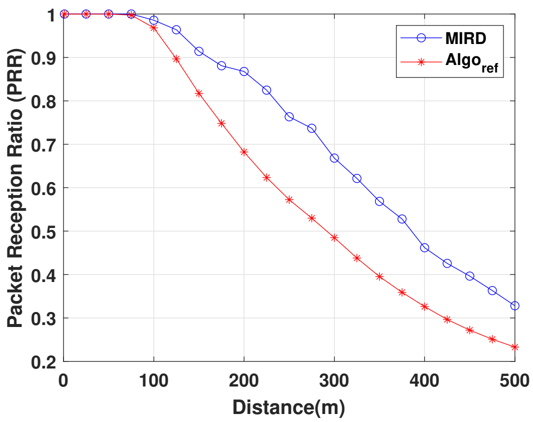

Fig. 7: The Packet Reception Ratio (PRR) for MIRD and $Algo_{ref}$ in an urban scenario of Bologna.

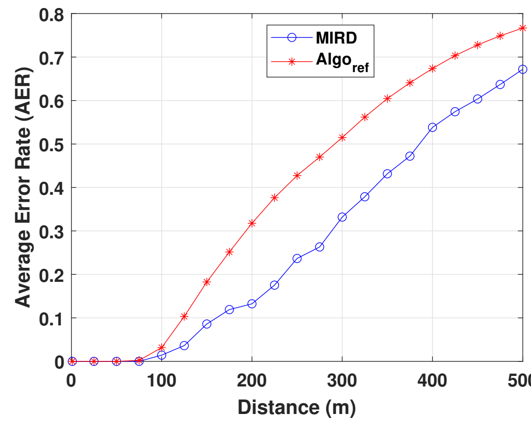

Fig. 8: The Average Error Rate (AER) for MIRD and $Algo_{ref}$ in an urban scenario of Bologna

7 and 8 show the variation of the PRR and the AER, respectively, in function of the distance between transmitter T_x and receiver R_x for MIRD algorithm compared to the reference algorithm $Algo_{ref}$. The PRR decreases when the distance between transmitter and receiver increases. On the contrary, the AER increases when the distance between transmitter and receiver increases. The difference between MIRD and $Algo_{ref}$ is very clear in the figures for the distances higher than 100 m. For example, for the same distance of 150 m, the PRR of MIRD is about 92%, while the PRRs of $Algo_{ref}$ is about 81%. Also, for the same distance, the AER of MIRD is about 0.09 while the AER of $Algo_{ref}$ is about 0.19. We conclude that MIRD algorithm achieves better performance than the reference algorithm in terms of PRR and AER.

Figure 9 illustrates the ABR of MIRD compared to the reference algorithm. As shown in the figure, MIRD presents an ABR equal to 0% thanks to the resource reuse approach, while the ABR of $Algo_{ref}$ is not null. This is explained by the blocking of transmitters when there are no resource available. As already explained, the blocking of transmitters is very dangerous in the context of the basic safety messages because the blocked vehicle is not detected by its neighbors.

Figure 10 shows the values of the resource reuse rate for three traffic scenarios with a fixed number of resources $N = 40$ resources, as presented in Table III. As shown in the figure, the resource reuse rate increases with the increase of the number of vehicles. For M = 80 vehicles, the resource reuse rate is T = 50% which increases also the resource allocation capacity. Here, we define the resource allocation capacity as the total number of resources that can be allocated to vehicles without collision. Assuming for example that we have 100 resources, so 100 vehicles can be allocated without collision. However, when we apply the resource reuse approach with a resource reuse rate of 50%, the resource allocation capacity will be of 150 resources which is more beneficial in case of high vehicle density areas.

We can also highlight another advantage of the MIRD algorithm which is related to the algorithm complexity. For

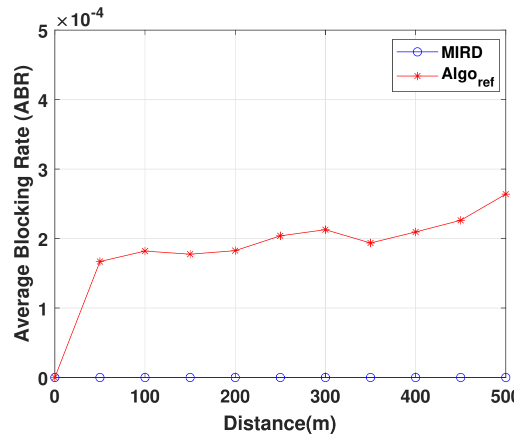

Fig. 9: The Average Blocking Rate (ABR) for MIRD and $Algo_{ref}$ in an urban scenario of Bologna

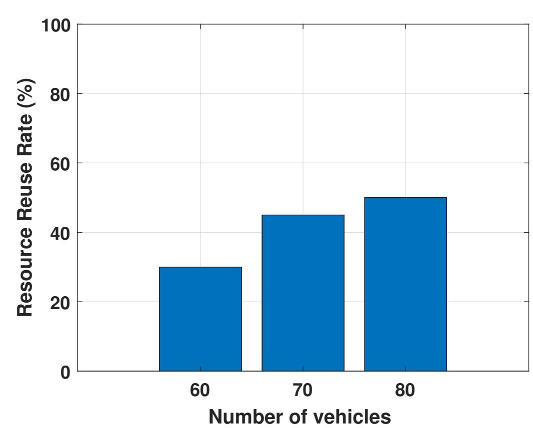

Fig. 10: The Resource Reuse Rate (λ) for MIRD in 3 traffic scenarios.

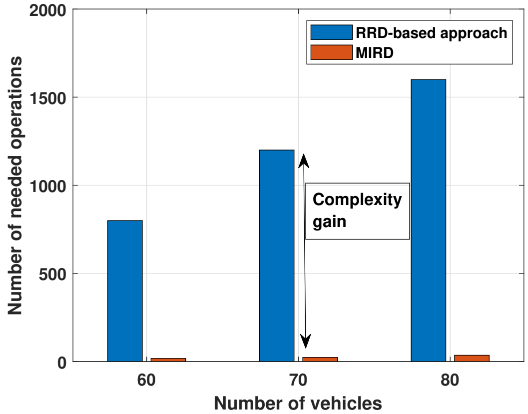

Fig. 11: The complexity gain for MIRD in 3 traffic scenarios

TABLE III: traffic scenarios

Number of vehicles	Number of resources	Total number of clusters	Number of offering clusters	Number of requesting clusters
Scenario (a): 60	40	9	6	3
Scenario (b): 70	40	11	6	5
Scenario (c): 80	40	12	6	6

that, we define another parameter, referred to the gain in the number of computation operations needed, denoted by $G_{N_{co}}$ as already explained in VI-B. We remind that in the standard RRD-based approach, the resource reuse for a given vehicle v_i is applied after the computation of the distance between this vehicle and all other vehicles in the scenario. Let us suppose that we have 60 vehicles grouped into 9 clusters and 40 resources. Among those clusters, there are 6 offering clusters and 3 requesting clusters. The total number of vehicles in the offering clusters is 40 vehicles and the total number of vehicles in the requesting clusters is 20 vehicles. Here, we compare the resource reuse mechanism for both approaches. In the standard approach, for each requesting vehicle v_i, we need the computation of the distance between v_i and all other offering vehicles. In our scenario, each vehicle needs 40 operations and thus we need $40 \times 20 = 800$ operations for all requesting vehicles. However, when we apply the MIRD approach, we need for each requesting cluster 6 operations and thus we only need $6 \times 3 = 18$ operations for all requesting clusters. So, the gain in the number of computation operations is very high and it is of $G_{N_{co}}$ = 800 - 18 = 782 operations, which reduces the complexity of the MIRD algorithm. We illustrate the complexity gain in Figure 11 for three traffic scenarios as presented in Table III. As shown in the figure, the number of computation operations increases with the increase of the total number of vehicles in the scenario. So, the gain achieved by the MIRD algorithm is very important in the congested traffic scenarios.

VII. Conclusion and perspectives

In this paper, we propose a new clustering-based resource allocation algorithm for mode 3, named Maximum Inter-Centroids Reuse Distance (MIRD). The main idea of MIRD algorithm is firstly the clustering of vehicles according to their geographical positions and directions. Secondly, the resources are divided into orthogonal resource sets and each resource set is assigned to a cluster. Finally, MIRD applies a specific resource reuse approach between clusters by computing the inter-centroids distance between clusters. The MIRD is validated through simulations conducted using the LTEV2V simulator. The obtained results show that MIRD algorithm outperforms the reference algorithm for mode 3 found in the literature in terms of PRR, AER and ABR. In addition, the MIRD reaches a very high complexity gain compared to the standard RRD-based approach. In our future work, we will apply this proposal in the 5G-V2X context taking into account different propagation conditions and mixed traffic circumstances.

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