Research on Overlay D2D Resource Scheduling Algorithms for V2V Broadcast Service

Zhang Xiguang, Shang Yong, Li Xiaobo
School of Electrical Engineering and Computer Science
Peking University
Beijing, China
E-mail: shangyong@pku.edu.cn

Fang Jiayi
State Key Laboratory of Wireless Mobile Communications
Beijing, China
E-mail: fangjiayi@catt.cn

***Abstract*—In underlay D2D communications, cellular users share resource with D2D users, which may cause severe interference. When cellular cells have light loads, overlay D2D communications can be applied to avoid interference. In this paper, we adopted overlay D2D mode under which D2D resource is orthogonal to cellular user resource. We proposed two location-based D2D resource allocation algorithms for V2V (vehicle-to-vehicle) broadcast service, separately Location-based Centralized Scheduling Algorithm (LB-CSA) and Location-based Distributed Scheduling Algorithm (LB-DSA). Further, we researched transmission accuracy, time delay and resource utilization performances of the algorithms. Results show that LB-DSA has relatively lower demand on communication facilities, while LB-CSA performs slightly better in performances of time delay, transmission accuracy and resource reuse. Both of the two algorithms can realize resource spatial reuse and improve resource utilization efficiency, meanwhile controlling packet error rate at an acceptable level.**

Keywords—V2V, D2D, Broadcast Service, Resource Scheduling, Resource Reuse, Overlay

I. INTRODUCTION

In V2V (vehicle-to-vehicle) communications, vehicles share information with each other, which is applicable in services such as collision avoidance [1]. In traditional cellular communications, base stations relay information sent from transmitters, which incurs heavy loads to base stations and high consumption of spectral resource. D2D (device-to-device) communication, which establishes direct communication links between transmitters and receivers, can improve resource efficiency, lighten base station load and improve cellular coverage [2]. Due to these features, D2D is introduced to LTE in 3GPP in order to support V2V communication service [3].

In D2D communication, there are two resource allocation modes: 1. Underlay mode, in which D2D users use cellular uplink or downlink spectrum resource [2]-[6]. 2. Overlay mode, which means that D2D users are allocated with specified resource that is orthogonal to cellular user resource [7][8]. In [4] and [5], the authors researched on D2D underlay resource scheduling schemes in V2V broadcast scenario. In [4], a centralized resource scheduling algorithm based on interference cognition was proposed. In [5], the author proposed a new scheme to solve the problem of interference between D2D user groups. In [6], the author proposed D2D underlay resource scheduling schemes based on user locations. Although underlay mode improves resource utilization rate, it causes more severe spectrum interference between D2D users and cellular users. When there're light network load and high demand for communication quality, overlay mode has more advantages [8]. There are a few papers researching on D2D overlay communication. In [7], throughput performance of D2D overlay communication was evaluated. In [8], an overlay resource allocation scheme was proposed based on point-to-point D2D communication. Yet we haven't found published research on D2D overlay resource scheduling schemes for broadcast service. Broadcast communication enables a D2D user to share information with multiple other users, which is highly applicable to road services such as driving security service. In this paper, we designed two overlay resource scheduling algorithms for D2D broadcast service, which is a new research spot, to the authors' best knowledge .

The corresponding author of this paper is Shang Yong.

II. SYSTEM MODEL

We studied D2D resource scheduling algorithms for V2V broadcast service. The scenario consists of base stations and D2D users on a highway, which is illustrated in Fig. 1. D2D users work under overlay mode with spectrum resource orthogonal to cellular user resource. Each D2D user periodically broadcasts Cooperative Awareness Messages (CAM) in half-duplex way to other users located in its broadcast range. CAM Data packets contain traffic information such as location, velocity, etc. We suppose that data packets generated by D2D users are in the same size and they are broadcasted to other users at fixed time interval. Resource scheduling is under control of base stations. The whole process is described as follows. Firstly, D2D users send transmission request signals and location information to base stations. Secondly, base stations allocate resource to D2D users according to their locations and D2D users broadcast messages to other users in their broadcast range. In this paper, we mainly focus on the second process while the first process is not discussed.

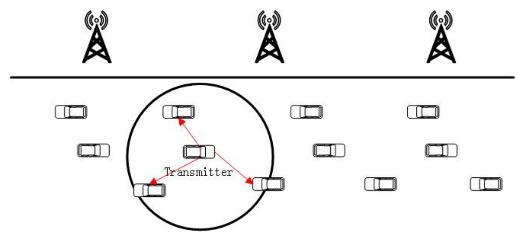


Fig. 1 System Model.

III. Resource Scheduling Algorithms

Base stations receive resource request signals from D2D users who need to broadcast information, and periodically allocate RBs to D2D users at fixed time interval. In each time interval, there're M RBs that can be allocated to D2D users. We designed two resource scheduling algorithms, separately Location-based Centralized Scheduling Algorithm (LB-CSA) and Location-based Distributed Scheduling Algorithm (LB-DSA). The main difference between the two algorithms is whether resource allocation of all D2D users is controlled by a centralized scheduler.

Assume that N D2D users send resource request signals to base stations. User group is defined as $U = \{u_1, u_2, u_3, ..., u_N\}$. The group of users located in the broadcast range of transmitter u_i ($1 \le i \le N$) is denoted as

$$\Phi_i = \{u_j \mid u_j \in U, \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \le r\}, \tag{1}$$

where (x_j, y_j) denotes two-dimensional coordinate position of users and r denotes radius of circular broadcast range.

A. Location-based Centralized Scheduling Algorithm(LB-CSA)

In LB-CSA, we assume that there's a centralized resource scheduler. The scheduler works as a super-power base station, orchestrating resource scheduling of all D2D users.

Firstly, since users broadcast information in half-duplex way, it should be guaranteed that no more than one user sends information at one time in a broadcast range, otherwise transmitters would miss information from each other. Secondly, in order to avoid co-frequency interference, orthogonal resource is allocated to users whose relative distance is less than resource reuse distance. The analysis to resource reuse distance will be discussed soon. Detailed scheduling process in a time interval is written as follows:

Algorithm 1 LB-CSA

```
Initialization: sequence all users by priority. Set i = 1.
Allocate a random consecutive RBs (resource blocks) to u_i.
while i < N do
    i = i + 1, traverse all users in broadcast range of u_i,
    check whether anyone has been allocated with RBs.
    if yes then
        Refuse allocating RBs to u_i in current interval.
    else
        Traverse users that have been allocated RBs in
        resource reuse range and check whether there're
        residual unused RBs.
        if yes then
            Allocate a group of residual RBs to u_i.
        else
            Refuse allocating RBs to u_i in current interval.
        end if
    end if
end while
```

Supposing M is the total number of RBs and Λ_l is the group of users which are allocated with the same resource block RB_l ($l = 1, 2, ..., M$), resource reuse distance can be defined as

$$R_l = \min_{\substack{u_i, u_j \in \Lambda_l \\ i \ne j}} \left(\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}\right) \tag{2}$$

The value constraint of R is related to broadcast distance r. Suppose that u_i and u_j send information simultaneously and they are allocated with same resource ($u_i, u_j \in \Lambda_l, i \ne j$, $1 \le i \le N, 1 \le j \le N$). If a receiver u_k is located in the broadcast ranges of both u_i and u_j, it needs to receive information from both u_i and u_j simultaneously. Therefore, u_k may mix the two information, resulting in co-frequency interference. In order to solve this problem, for $\forall u_k \in \Phi_i(\Phi_j)$, it should be guaranteed that $u_k \notin \Phi_j(\Phi_i)$, which is equal to,

$$\sqrt{(x_k - x_j)^2 + (y_k - y_j)^2} > r, \text{ for } u_k \in \Phi_i, \tag{3}$$

$$\sqrt{(x_k - x_i)^2 + (y_k - y_i)^2} > r, \text{ for } u_k \in \Phi_j, \tag{4}$$

where (x_i, y_i), (x_j, y_j) and (x_k, y_k) are location coordinates. Φ_i refers to the set of users in the communication range of u_i.

To fulfill the above inequality, It's obvious that R should be more than $2r$, as Fig. 2 illustrates.

As for user priority, we apply FIFO (first in first out) sequence, which is denoted as follows:

$$P_i = tw_i = t - tg_i, \tag{5}$$

where P_i is the priority of u_i, tw_i is the waiting time of u_i, t is current time. tg_i denotes the time when u_i generates data packet. The longer the user waits, the higher the priority would be. Therefore, time delay can be effectively reduced.

B. Location-based Distributed Scheduling Algorithm(LB-DSA)

LB-CSA poses high demand on capacity of centralized scheduler. In situations when the scheduler can't cover all D2D users, several base stations in different sites could be applied to schedule resource instead of a single centralized scheduler. Therefore we designed Location-based Distributed Scheduling Algorithm (LB-DSA). We assume that each base station only schedule resource for D2D users in specific cells, not knowing location information of users in other cells.

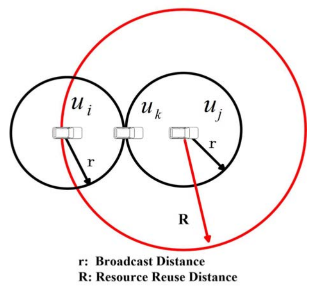


Fig. 2 Relationship between reuse distance and broadcast distance.

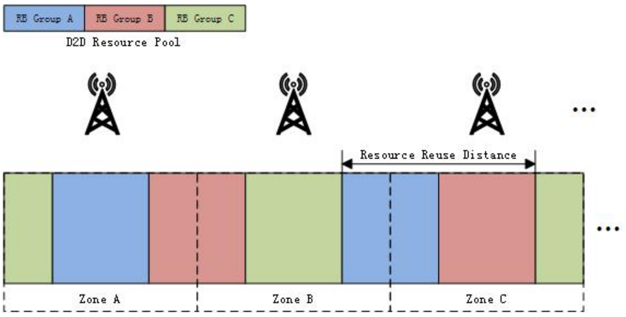


Fig. 3 Spatial allocation of spectrum resource for distributed algorithm.

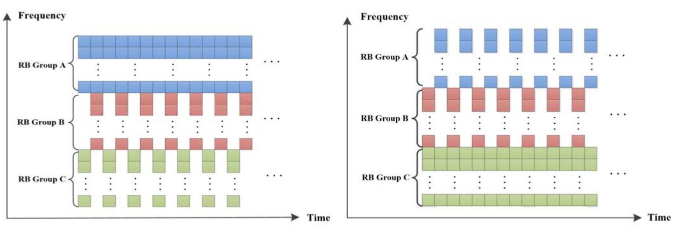
As Fig. 3 illustrates, we divide resource pool into several groups which are distinguished with different colors. The highway is also equally divided into several areas. Each base station covers a specific zone consisting of several colored areas. RBs in $RB\ \ GroupA$, $RB\ \ GroupB$ and $RB\ \ GroupC$ can only be used separately by D2D users in blue areas, red areas and green areas.

According to Fig. 3, there are colored areas spanning the borders of adjacent zones, which indicates that users in adjacent zones can use RBs from the same $RB\ Group$. Since each base station cannot get information of D2D users in other zones, there may exist conflicts and interference between users near the border of adjacent zones. In order to solve this problem, we designed a time-staggered scheme.

Fig. 4 illustrates time and frequency resource scheduling methods for adjacent zones: Zone A and Zone B. For Zone A, users in blue area can use $RB\ \ GroupA$ all the time. But users in red area (on the left side of border) can use $RB\ \ GroupB$ only in even-number time slots. For Zone B, users in green area can use $RB\ \ GroupC$ all the time. But users in red area (on the right side of border) can use $RB\ \ GroupB$ only in odd-number time slots. Allocation schemes for other areas are similarly designed. In this way, time conflicts between users in adjacent cells are avoided and therefore communication accuracy is improved.

Base stations allocate resource to D2D users in each time slot. In order to avoid conflicts, no more than one user should be allocated resource in any broadcast range, which is similar to LB-CSA. In this algorithm, we still use FIFO method to determine user priority.

Detailed algorithm process in n_{th} (n is an odd number) time interval is written as follows:



(a) (b)

Fig. 4 Spectrum resource allocation scheme for (a) Zone A and (b) Zone B.

Algorithm 2 LB-DSA (for odd-number time interval)

1: Initialization: sequence all users by priority. Set $i=1$.
2: Judge which zone u_i belongs to.
3: **if** $(x_i, y_i) \in Zone\ \ A$ **then**
4: Allocate a section of resource from $RB\ \ Group\ \ A$ to u_i if it locates in blue area, allocate a section of resource from $RB\ \ Group\ \ C$ to u_i if it locates in green area, refuse allocating resource to u_i if it locates in red area.
5: **else if** $(x_i, y_i) \in Zone\ \ B$ **then**
6: Allocate a section of resource from $RB\ \ Group\ \ B$ to u_i if it locates in red area, allocate a section of resource from $RB\ \ Group\ \ C$ to u_i if it locates in green area, refuse allocating resource to u_i if it locates in blue area.
7: **else if** $(x_i, y_i) \in other\ \ zones$ **then**
8 Allocation rule is similar to $Zone\ \ A$ and $Zone\ \ B$.
9: **end if**
10: **while** $i < N$ **do**
11: $i = i+1$, traverse all other users in Φ_i , check whether anyone has been allocated with RBs .
12: **if** yes **then**
13: Refuse allocating RBs to u_i in current interval.
14: **else**
15: Judge which zone u_i belongs to and allocate resource according to Fig. 4, similar to line 2-8.
16: **end if**
17: **end while**

When n is an even number, resource allocation schemes for Zone A and Zone B should be accordingly adjusted. The adjusted rules are as follows:

- If $(x_i, y_i) \in Zone\ \ A$, select RBs from $RB\ \ Group\ \ A$ and $RB\ \ Group\ \ B$.
- else if $(x_i, y_i) \in Zone\ \ B$, select RBs from $RB\ \ Group\ \ A$ and $RB\ \ Group\ \ C$.

Similar adjustments should also be made to other zones.

According to Fig. 3, RBs allocated to users in adjacent areas become orthogonal and spatial reuse of spectrum resource is realized. In this algorithm, spatial resource reuse distance is approximately equal to the length between two areas with the same color, which is labeled in Fig. 3. As long as the resource reuse distance is larger than $2r$, co-frequency interference can be avoided (deducted in LB-CSA). By allocating RBs discontinuously in time slots illustrated in Fig. 4, users in adjacent zones can take turns to utilize the same RB and therefore conflicts between users near zone borders can be effectively alleviated.

An obvious advantage of LB-DSA relative to LB-CSA is that it has low demand on communication facilities because a high-capacity centralized scheduler is not needed.

IV. System Simulation

A. Selection of MCS and Performance Parameters

In order to reduce algorithm complexity, packet division is not considered in this paper. Therefore data quantity supported by *RBs* allocated to each user at one time must be larger than 300Byte, which is the size of CAM data packet in this paper. Size of SU (Scheduling Unit, number of *RBs* needed by one user in a single scheduling interval) is determined by MCS (Modulation and Coding Scheme) index value. The quantitative relationship is listed in Table I.

Supposing that there're totally 50 *RBs* in each scheduling time interval. According to Table I, when $MCS = 3,4,5$, at most one user can be supported in each time interval. When $MCS = 6,7,8$, two users can be supported in each time interval. When $MCS = 9,10$, three users can be supported.

Under the condition that number of served users is the same, the smaller MCS index value is, the lower packet error rate would be. Therefore, we use *MCS* values of 3,6,9 to perform simulations.

In this paper, we focus on interference avoidance and improvement of resource reuse rate in V2V broadcast service. We use comprehensive packet error rate, time delay and resource utilization rate to evaluate the system.

a. Comprehensive Packet Error Rate

Data packets are generated at the interval of 100ms, therefore when the waiting time of a data packet is longer than 100ms, we treat it as packet dropout situation. Comprehensive packet error rate can be denoted as

$$R = r_e + r_l, \tag{6}$$

where r_e is packet error rate and r_l is packet loss rate.

Theoretically, packet error rate changes with distance. We calculated the average packet error rate at different communication distances.

b. Time Delay

Since scheduling latency and RLC delay are small enough to be neglected, time delay can be denoted as

$$t_w = t_s - t_g, \tag{7}$$

where t_s is total transmission time of data packet and t_g is packet generation time.

TABLE I. MCS and Number of Users Served

MCS Index Value	RB Number Needed by One Single User	Number of Served Users (in one scheduling interval)
3	41	1
4	34	1
5	28	1
6	23	2
7	20	2
8	18	2
9	16	3
10	16	3

c. Resource Utilization Ratio

In this paper, we define resource utilization ratio as

$$\eta = \frac{N_{used}}{N_{all}} = \frac{N_{used}}{n \times t}, \tag{8}$$

where N_{used} refers to the number of all *RBs* used during scheduling and N_{all} refers to the total number of *RBs* in resource pool in all time. n denotes the number of *RBs* in the resource pool in each interval which is 50 in this paper and t indicates the total number of time intervals.

B. Simulation Results and Analysis

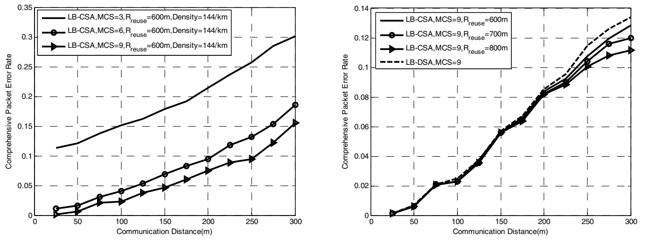
We simulated communication performances of LB-CSA and LB-DSA. Main simulation parameters are listed in Table II.

We simulated LB-CSA scheme setting MCS index value at 3, 6 and 9 when traffic density is 144/kilometer and reuse distance is 600m. The relationship between comprehensive packet error rate and communication distance under LB-CSA is presented in Fig. 5(a). It is clear from the curves that MCS index value has large effect on comprehensive packet error rate. As MCS index decreases, comprehensive packet error becomes higher. With the decrease of MCS index value, the number of users supported in each time interval becomes less, resulting in higher packet dropout rate and higher comprehensive packet error rate.

We compared comprehensive packet error performances of LB-CSA and LB-DSA schemes setting reuse distance of LB-CSA at 600m, 700m and 800m. Traffic density is 144 users per kilometer. According to the curves shown in Fig. 5(b), communication accuracy performance of LB-CSA is slightly better than that of LB-DSA. For LB-DSA, since *RBs* are allocated in discontinuous time slots, usable *RBs* are less and probability of packet dropout is higher. Therefore, the packet loss rate of LB-DSA is higher than that of LB-CSA, resulting in higher comprehensive packet error rate. As resource reuse distance increases, comprehensive packet error rate decreases, which is obviously in accordance with theoretical analysis.

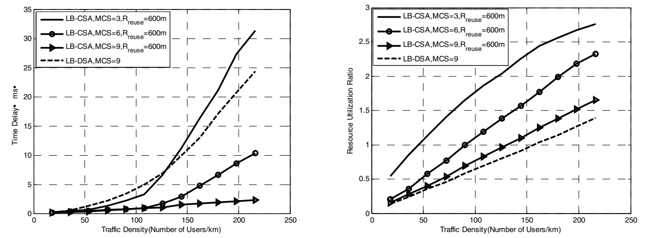
TABLE II. Simulation Parameters and Values

Resource Scheduling Interval	1ms
Number of *RBs* in Each Scheduling Time Interval (M)	50
Inter-site Distance (ISD)	800m
Highway Length (l)	2.4km
Broadcast Distance (r)	300m
Zone Numbers of Highway (for LB-DSA)	3
Service Model	CAM (300 byte /data-packet with fixed interval of 100ms)
MCS Index Value	3, 6, 9



(a) (b)

Fig. 5 Comprehensive packet error rate performances of (a) LB-CSA, (b) comparison between LB-CSA and LB-DSA.



(a) (b)

Fig. 6 Simulation results of (a) time delay performance, (b) resource utilization ratio performance.

We also simulated time delay performance of LB-CSA and LB-DSA. Time delay performances are presented in Fig. 6(a). It can be seen from the curves that traffic density and MCS index value have obvious effect on time delay. Higher MCS index value enables more users to be allocated with resource in a time slot and therefore average time delay is reduced. When MCS index value is 9, time delay of LB-CSA is obviously lower than LB-DSA. The main reason is that discontinuous time allocation of LB-DSA prolongs waiting time of users and thus increases packet loss rate.

Finally, we simulated spectrum resource utilization ratio of two LB-CSA and LB-DSA, which is illustrated in Fig. 6(b). As MCS index value becomes higher, number of *RBs* needed to support each user becomes smaller and therefore resource utilization ratio decreases. Since *RBs* can only be used in some specific time intervals in LB-DSA, resource utilization ratio of LB-DSA is lower than LB-CSA. It can be seen that most resource utilization ratios are larger than one, which indicates that the algorithms can realize resource spatial reuse.

According to simulation results, we can conclude that although LB-DSA does not demand a high-capacity centralized scheduler, it performs slightly worse in communication performances than LB-CSA. The communication performances of LB-DSA are still at an acceptable level.

V. Conclusion

In this paper, overlay D2D communication is applied to V2V broadcast service, in which D2D users send CAM (Cooperative Awareness Messages) packets periodically to other users. In this process, base stations don't need to relay information, therefore network load is lightened and resource utilization is improved. Besides, since the resource for D2D users is orthogonal to that of cellular users, interference between D2D users and cellular users can be alleviated. In order to schedule D2D resource and improve resource utilization efficiency, we designed location-based resource scheduling algorithms. In LB-CSA, a centralized scheduler is applied and all users can be coordinated promptly. LB-CSA performs well in communication accuracy, resource utilization and time delay performances. Considering project realization and computing complexity, we further designed Location-based Distributed Scheduling Algorithm (LB-DSA). LB-DSA applies distributed base stations instead of a centralized scheduler and realizes resource spatial reuse through spatial allocation of resource, meanwhile avoiding conflicts by adopting a time-staggered allocation scheme. Although LB-DSA performs slightly worse than LB-CSA, it lightens the load of scheduler and has lower demand on communication facilities. Results show that both of the two algorithms can realize resource reuse while controlling packet error rate and time delay at acceptable levels.

References

[1] Wanlu Sun, Erik G. Strom, Yutai Sui and Kin Cheong Sou, "D2D-based V2V communications with latency and reliability constraints." Globecom Workshops (GC Wkshps), Austin, 2014, pp. 1414-1419.

[2] Nandish P. Kuruvatti, Andreas Klein, Lianghai Ji, "Robustness of Location based D2D resource allocation against positioning errors," Vehicular Technology Conference (VTC Spring), Glasgow, United Kingdom, 2015, pp. 1-6.

[3] Xingqin Lin, Rapeepat Ratasuk and Amitava Ghosh, "Network-Assisted Device-to-Device Scheduling in LTE," Vehicular Technology Conference (VTC Spring), Glasgow, United Kingdom, 2015, pp. 1-5.

[4] Che-Wei Yeh, Guan-Yu Lin, Mei-Ju Shih and Hung-Yu Wei, "Centralized Interference-Aware Resource Allocation for Device-to-Device Broadcast Communications," Internet of Things (iThings), IEEE International Conference. Taipei, 2014, pp. 304-307.

[5] Yuxin Zhao, Benoit Pelletier and Diana Pani, "Resource allocation achemes for D2D communications," Systems, Applications and Technology Conference (LISAT), Farmingdale, 2014, pp.1-5.

[6] Weijun Xing, Ning Wang, Chao Wang and Fuqiang Liu, "Resource allocation schemes for D2D communication used in VANETs," Vehicular Technology Conference (VTC Fall), Vancouver, 2014, pp. 1-6.

[7] Philippe Sartori, Hossein Bagheri, Vip Desai, Brian Classon, Weimin Xiao, Deping Liu, "Design of a D2D overlay for next generation LTE," Vehicular Technology Conference (VTC Fall), Vancouver, 2014, pp. 1-5.

[8] Siba Narayan Swain, Sudeepta Mishra and C. Siva Murthy, "A novel spectrum reuse scheme for interference mitigation in a dense overlay D2D Network," Personal, Indoor, and Mobile Radio Communications (PIMRC), Hong Kong, 2015, pp. 1201-1205.