Radio Resource Allocation Algorithm for Device to Device based on LTE-V2X Communications

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Abstract: Communication is important to regain transportation by accommodating real-time, easily reliable, and actionable information flows to allow safety, mobility and environmental applications. Device-to-Device (D2D) communication has become an emerging technology for wireless network engineers to optimize the network performance. It is considered as an enabler for Vehicle-to-everything (V2X) applications, with stringent reliability and latency requirements due to its ability to improve traffic efficiency, safety and comfort. In this paper, we investigate the radio resource management (RRM) for D2D-based V2X communications including both vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication. A new algorithm called Efficient Resources Allocation for V2X Communications (ERAVC) is proposed in order to maximize the sum rate of V2I users while guaranteeing the reliability requirement of V2Vusers. Simulation results indicate promising performance of the proposed ERAVC scheme compared with another existing method.

1 INTRODUCTION

Vehicle-to-everything (V2X), which includes vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), and vehicle-to-infrastructure/Network (V2I/N) communications, improves road safety, traffic efficiency, and the availability of infotainment services. The third Generation Partnership Project (3GPP) has finally deployed Long Term Evolution (LTE)-based V2X in Release 14 standard to provide solutions for V2X communications (3GPP TR 36.885 v.14.0.0, 2016). This latter have been greatly studied in recent years due to its potential to improve intelligent transport systems, effective driving assistance and traffic safety. This technology enables vehicles to communicate with vehicles, pedestrians, networks and infrastructures to perceive potential dangerous situations by collecting the information about the environment and exchange it in real time. These applications have small message size and strict requirements on reliability and latency (3GPP TR 22.185 v.14.3.0, 2017).

The main problem is that the current adhoc solutions for V2X communications over the Institute of Electrical and Electronics Engineers (IEEE) 802.11p standard are optimized for Wireless Local Area Network (WLAN) environment with very low mobility. So, this does not fulfil the requirement of V2X communications with high mobility. The device-to-device (D2D) communication based cellular networks is a promising enabler for V2X communications. 3GPP Release 12 and Release 13 provide D2D to proximity services (ProSe) where devices can directly communicate with each other over PC5 interface (Sidelink) without passing via a network infrastructure (3GPP TS 23.303 v.13.3.0, 2016). The D2D communications have been proposed to meet the requirements of diverse vehicular links with the benefits of proximity gain, reuse gain, and hop gain (Fodor et al., 2012).

The set of resources assigned to D2D communications is taken from the uplink resources due to their lower peak-to-average power ratio (PAPR) and because the uplink sub-frames are usually less occupied than the downlink (Laurent and Jérôme 2017). There are two resource allocation modes the underlay mode and the overlay mode. In the underlay mode, the cellular and vehicular users (V-UEs) can share the same resources, so they can achieve a best spectrum efficiency but, a strong interference could be generated among these users. In contrast, dedicated resources are allowed for V-UEs in the overlay mode. The advantage of this mode is

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that the eNodeB (eNB) does not need to handle interference among the cellular and V-UEs. In fact, radio resource management (RRM) plays a crucial role in the performance of V2X systems, and it faces many new challenges.

In this paper, we propose a resource allocation algorithm named ERAVC which aims at maximizing the sum rate of the V2I users (V2I-UEs) and guaranteeing reliability requirement of V2V users (V2V-UEs). The main focus is how V2V-UEs share resources with V2I-UEs.

This paper is organized as follows. Section 2 provides related works to the proposed resource allocation algorithm. In Section 3, we will present the system model of resources shared among vehicles. Section 4 introduces the proposed scheme algorithm. In section 5, we will discuss the results and evaluation of our proposed algorithm. Section 6 will conclude this paper.

2 RELATED WORKS

To address the RRM challenges, a number of recent works have proposed focusing on resource allocation based-D2D for V2X communications. Several works were discussed the resource allocation for V2V services where resource are shared only among V-UEs. Other works were considered resource allocation for both V2V and V2I services where resources are shared among V2V-UEs and V2I-UEs.

(Xiguang et al., 2016) designed a two-location resource allocation algorithms (Centralized and Distributed Scheduling) V2V broadcast services. The main objective is to improve resource utilization efficiency, transmission accuracy and time delay. In the centralized scheduler, resources are allocated to V-UEs which have less relative distance than the distance of resource reuse. In the distributed scheduler, authors divided the highway into several areas and resource pool into several groups, where users in each area select resources from a specific group. Simulation results, show that the distributed scheduler performs slightly better than the centralized one.

(Shiyu et al., 2016) proposed a radio resource allocation based on (resource block) RB sharing to maximize the number of concurrent V2V transmissions instead of sum rate, where multiple V-UEs can access to one RB. The main objective is to allow non-orthogonal access for V-UEs, where the number of V-UEs to share the same RB is not limited. Firstly, they transform the reliability requirement into constraint of spectral radios matrix to limit the interference. Then, they utilize the theory of spectral radius estimation to improve the spectrum efficiency greatly.

(Ashraf et al., 2017) designed a novel Quality of Service (QoS) and proximity-aware resource allocation for V2V communication to minimize the total power transmission considering the queuing latency and reliability. They achieve that by exploiting the spatial-temporal aspects of V-UEs in terms of their traffic demands and physical proximity. First, a novel clustering mechanism is proposed to group V-UEs in zones based on their physical proximity. Then, RB are assigned to each zone based on their QoS requirements and traffic demands.

(Jihyung et al., 2018) proposed a resource allocation scheme based on vehicle direction, position, speed, and density for V2V communication. This scheme includes two resource allocation strategies according to vehicle location, the freeway case and the urban case. Specific resources pools are assigned for each geometric area. For the urban case, high vehicle density occurs in the intersection region, so a special resource was allocated in this region based on traffic density. For the freeway case, resources are allocated based on vehicle direction and position. Each zone of the freeway has a specific resources pool and when a vehicle enters a zone, it must allocate resources of this zone.

(Abanto-Leon et al., 2017) described a graph-based resource allocation algorithm for broadcast V2V communications in order to maximize the sum-rate capacity of the system. The area is grouped into several Broadcast Communication clusters where vehicles should transmit in orthogonal way. Whereas vehicles in different communications clusters can share the same RBs. So, a solution based on bipartite graph was introduced aims to assign every V-UE with a RBs that maximize sum rate.

(Liang et al., 2017) designed a spectrum sharing resources for both V2V and V2I links to guarantee the reliability for each V2V link while maximizing the ergodic capacity of the V2I connections. The resources sharing can take place between V2V and V2I users. So, they pair each V2V user with the corresponding V2I user that satisfy the minimum capacity requirement.

(Liang et al., 2018) proposed a graph based resources allocations for V2V and V2I communication. This scheme aims at maximizing the sum V2I communication while guaranteeing the reliability requirement of V2V communications. Firstly, V2V users are assigned into different clusters based on their mutual interference. Then, all V2V users in the same cluster are allowed to share the same

RB with one of the V2I users, while V2V users in different clusters cannot share RB.

These proposed algorithms do not consider the QoS requirement in totality such as delay, queuing length, buffer state, etc. In fact, most of these algorithms are interested only in maximizing sum rate without giving priority among users. In this work, we present a novel algorithm that gives priority to V-UE based on the buffer size, throughput, and packet delay in the time domain (TD) and maximize sum rate in the frequency domain (FD).

3 SYSTEM MODEL

We consider a cellular vehicular environment with M V2V and K V2I communications users. Orthogonal Frequency Division Multiple Access (OFDMA) can support multiple access for both V2X and cellular communications. The total uplink bandwidth is divided into F RBs for each scheduling unit (each RB).

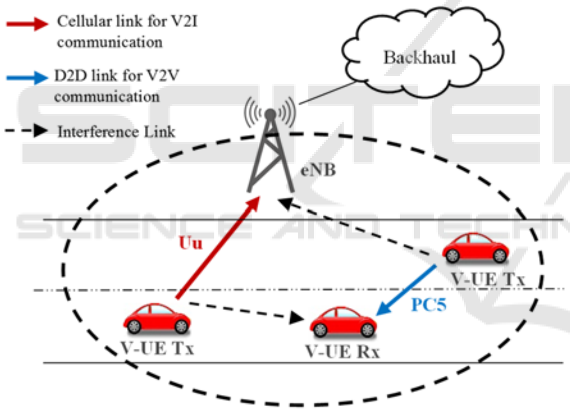

Figure 1: System Model.

As shown in figure 1, traffic efficiency messages and infotainment applications require generally frequent access to the remote servers or Internet for media streaming. Hence, it is ideally supported by high capacity V2I communication where V2I-UEs are considered as cellular users. Whereas, safety-critical information (e.g. cooperative awareness messages (CAMs) (ETSI EN Std 302 637-2, 2013), implies broadcast safety related messages among vehicles whether in event triggered or periodic way. Hence, it is supported by the D2D links, which impose strict latency and reliability requirements.

In this paper, we consider the uplink direction where orthogonal RBs are allocated to V2I-UEs to communicate with eNB and orthogonal RBs are used to communicate among V2V-UEs (Wanlu, 2016). However, the V2V-UEs share the uplink resources with V2I-UEs e.g. a RB can be shared by V2I-UE and V2V-UE. Therefore, interference exists among V2I-UEs and V2V-UEs. In order to allocate resources efficiently among V2I-UEs and V2V-UEs and reduce the complexity, a resource allocation will be proposed in section 4.2.

4 THE PROPOSED ALGORITHM

In this section, we introduce our proposed scheduling and resource allocation algorithm named "Efficient Resource Allocation for V2X Communication (ERVAC)". The main objective is to provide the QoS guarantees for each V-UEs, by maximizing the sum rate of all V2I-UEs and guaranteeing the reliability and latency requirement of V2V-UEs. For these reasons, our proposed scheduler is able to differentiate between these two V-UEs classes in the time domain (TD) and the frequency domain (FD).

The overall resource allocation algorithm is shown in figure 2. First, ERAVC classifies V-UEs in two classes the V2V-UEs class and the V2I-UEs class. After that, vehicles in each class are prioritized according to their QoS requirements in the TD scheduler (section 4.1). Then, in the FD scheduler, ERAVC allocates resources firstly for V2I-UEs and then for V2V-UEs (section 4.2).

4.1 TD Scheduler

V-UEs are picked from different QoS classes to be sorted during TD scheduler which is responsible for differentiating V-UEs according to their QoS requirements. TD scheduler selects limited number of V-UEs for scheduling during the next Transmission Time Interval (TTI), and determines the priority of V-UEs to be scheduled. As each service class has its specific requirements, each service class has its own metric. Then, it is necessary to study the performance metrics of both V2I-UEs and V2V-UEs.

4.1.1 V2V-UEs Metric

The proposed metric indicates that the V2V-UE packet with the longest delay time in the buffer achieves the higher priority compared to a short packet delay time. The weighted function of the m^{th} V2V-UE is calculated as follows:

$$Metric_{m}^{M} = \frac{d_m^t}{D_m} \quad (1)$$

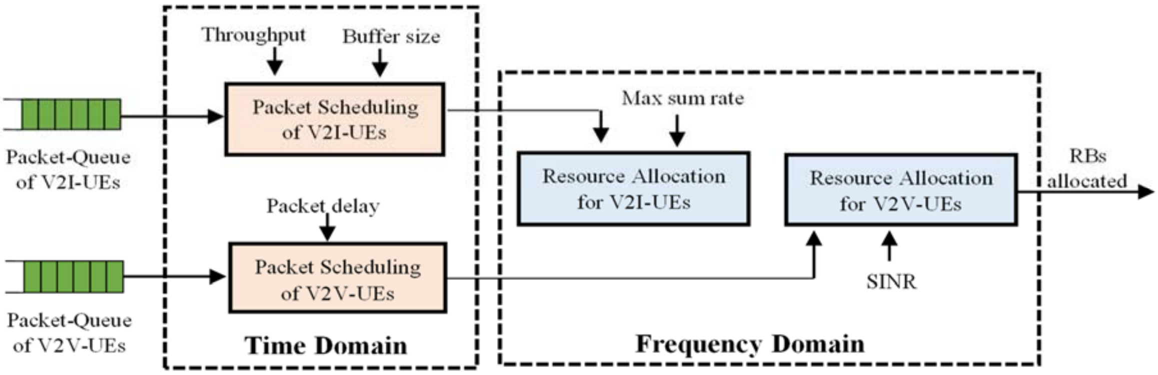

Figure 2: Overview resource allocation algorithm.

Where d_m^t is the largest delay time of the packet in the buffer of the m^{th} V2V-UE, where, d_m^t of a packet is the difference between the actual time and the packet arrival time at the buffer, and D_m represents the delay tolerance of the m^{th} V2V-UE.

4.1.2 V2I-UEs Metric

The weighted function of the k^{th} V2I-UE is calculated in (2) in order to include a certain fairness level and to minimize packets waiting:

$$Metric_k^K = \frac{r_k(t)}{R_k(t-1)} \times \frac{Q_k(t)}{\Delta_c(t)} \tag{2}$$

$$r_k(t) = log(1 + SINR_k) \tag{3}$$

$$R_k(t-1) = \left(1 - \frac{1}{\tau}\right) R_k(t-1) + \frac{1}{\tau} r_k(t) \tag{4}$$

Where:

- $r_k(t)$represents the throughput of the k^{th} V2I-UE calculated in (3) using the Shannon theorem,
- $R_k(t-1)$is the average throughput for the k^{th} V2I-UE at time (t – 1) as shown in (4),
- τ is a constant value for averaging the k^{th} V2I-UE data rate,
- $Q_k\ (t)$:is the queue buffer size of the k^{th} V2I-UE,
- $\Delta_c(t)$: is the sum of all V2I-UEs queue buffer.
- $\frac{r_k(t)}{R_k(t-1)}$: is the PF metric (Kais et al., 2014).
- $\frac{Q_k}{\Delta_c(t)}$: aims to prioritize V2I-UE that has several waiting packets.

4.2 FD Scheduler

The FD scheduler is responsible for allocating RBs to each V2I-UEs and V2V-UEs classes, which are selected by the TD scheduler for data transmission. In this section, we introduce a resource allocation scheme that fulfils the QoS requirements for each class. We consider resource allocation based D2D link for V2V-UE and cellular link for V2I-UE, where one V2V link can share spectrum with one V2I link. To do that, the set of RBs are allocated in two steps as presented in Table 1.

The first step of the FD scheduler is responsible for allocating RBs only for V2I-UEs. Whereas, the second step is responsible for allocating RBs already assigned to V2I-UEs from the first step to V2V-UEs. In the latter allocation, RBs are shared with V2V-UEs only if they don't interfere with V2I-UEs.

In the first step, RBs are allocated in order to maximize the sum rate for V2I-UEs using Shannon capacity as follows:

$$max \sum_{k=1}^{K} \sum_{f=1}^{F} log_2(1 + \delta_k^f) \tag{5}$$

Where δ_k^f is the SINR of the k^{th} V2I-UEs over the f^{th} RB.

After allocating each RB to the corresponding V2I-UE in the first step, we will follow the RB already allocated to V2I-UEs, for each V2V-UEs, in the second step. If the condition (6) is verified, this user can share this RB with V2I-UEs. So, the V2V-UE will share RBs with the corresponding V2I-UE if the SINR of the k^{th} V2V-UE ($\delta_{m,f}$) is higher than the SINR threshold (δ_{th}^m) as shown in (6):

$$\delta_{m,f} = \frac{p_{m,f}\, g_m}{\sigma^2 + p_{k,f}\, g_{k,m}} \geq \delta_{th}^m \tag{6}$$

Where $p_{m,f}$ and $p_{k,f}$ denote the transmit power of the m^{th} V2V-UE transmitter and the k^{th} V2I-UE transmitter over f^{th} RB, respectively,g_m and $g_{k,m}$ are the desired channel power gain of the m^{th} V2V-UE and the interference channel power gain from the k^{th} V2I-UE to the m^{th} V2V-UE, respectively, and σ^2 is the noise power.

Table 1: ERAVC Algorithm.

Algorithm 1: ERAVC

K ← total number of V2I-UEs
M ← total number of V2V-UEs
F ← total number of RBs
δ_{th}^{m}: % SINR threshold of V2V-UEs
// TD Scheduling
Sort V2V queue buffer according to (1)
Sort V2I queue buffer according to (2)
// FD Scheduling
Step 1: RBs allocation for V2I-UEs
For k:= 1 to K **do**
For f:=1 to F **do**
Calculate C(k,f); % capacity of the k^{th} V2I-UE on the f^{th} RB
End for
// selecting the RB that maximize sum rate of the k^{th} V2I-UE according to (5)
Find (k,f) = max C(k,f), with (k,n) ∈ K*F
Assign the f^{th}RB to the k^{th} V2I-UE
End for
Step 2: RBs allocation for V2V-UEs
For f:= 1 to F **do**
For m:=1 to M **do**
//Find the RB already assigned for V2I-UE to be share with V2V-UE.
If $\delta_{m,f} > \delta_{th}^{m}$ **then**
Assign the f^{th} RB to the m^{th} V2V-UE
//V2V-UE share the f^{th} RB with V2I-UE.
End If
End for
End for

5 SIMULATION RESULTS

In this section, we present the simulation result to validate our proposed resource allocation algorithm ERAVC. We consider a simulation model composed of a single cell of the radius equal to 1.5 km, one eNB carrier frequency of 2 GHz, a system bandwidth of 5MHz. The number of V2V-UEs and V2I-UEs varying between 50 and 500. We consider the simulation of freeway case as detailed by (3GPP TR 36.885 v.14.0.0, 2016). The path loss model for V2V-UEs links is calculated according to WINNER model (WINNER II, 2007). Whereas the path loss for V2I-UEs links is computed as follows:

$$PL(d) = 128.1 + 37.6\ \log_{10}(d) \tag{7}$$

Where d is the distance of the communication link (in km). The simulation and configuration parameters are presented in Table 2.

Table 2: Simulation parameters.

Parameter	Value
Cell Radius	1.5 km
Number of eNB	1
Bandwidth	5 MHz
Number of RBs	25 RBs
OFDM symbols per slot	7
Shadow fading standard deviation	9 dB
Carrier frequency	2 GHz
Maximum V2V-UE transmit power	23 dBm
Maximum V2I-UE transmit power	23 dBm
SINR threshold of V2V-UEs	5 dB
V2V and V2I-UEs speed	Random (5, 150) km/h
TTI	1 ms
Number of V2V-UEs / V2I-UEs	50 -500
Simulation length	5000 slot
Scheduling/Allocation resource	slot
Average Packet size for V2V-UEs	50-300 Bytes
Average Packet size for V2I-UEs	1200 bytes
Noise power σ^2	-114 dbm
Path loss model	LOS in Winner + B1 (WINNER II, 2007)

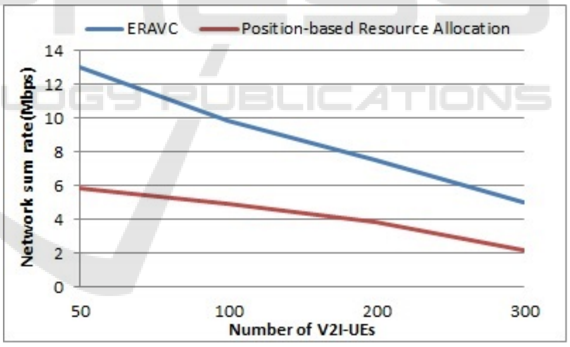

Figure 3: Average throughput for V2I-UEs.

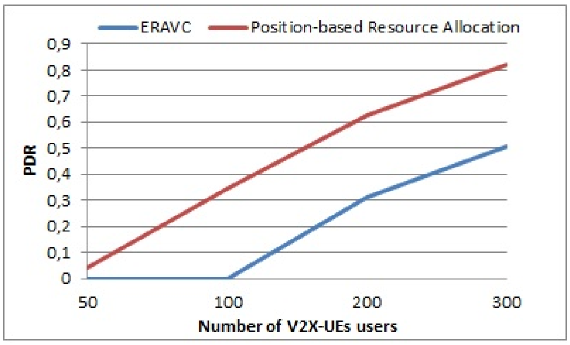

Figure 4: Packet Drop Rate for all V2X-UEs.

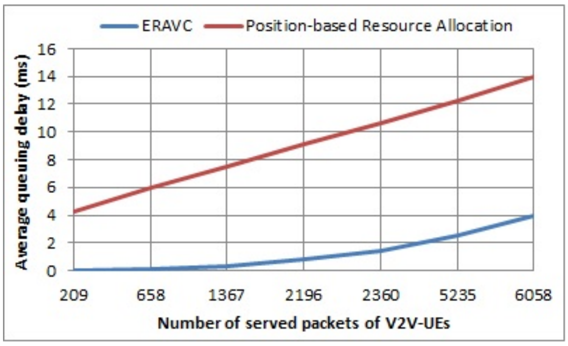

Figure 5: Average Queuing Delay for V2V-UEs.

To evaluate our proposed ERAVC algorithm and demonstrate its effectiveness, we compare it with the “Position-based resource allocation” (Jihyung, 2018). It can be noted that the “Position-based resource allocation” algorithm gives the worst performance in terms of throughput, delay, and Packet Drop Rate (PDR). This is achieved by RBs sharing among V2I-UEs and V2V-UEs.

Figure 3 demonstrates the average throughput of the system for V2I-UEs. The proposed algorithm (ERAVC) gives the highest rate as it selects the users having the maximum reported SNIR value in order to improve network efficiency and cell performance. Therefore, ERAVC utilizes efficiently the radio resources since it selects packets of users with the best channel conditions. Whenever the network is more congested, ERAVC algorithm becomes more efficient, since it gives priority to V2I-UEs that have several waiting packets, and reaches the best rate.

Figure 4 presents the PDR of all V2X-UEs where our ERAVC algorithm offers the best rate compared with the “Position-based Resource Allocation”. For this latter, the average PDR performance becomes worse as it does not take in consideration the buffer size as in our ERAVC scheme. Indeed, each zone has its specific RBs, which are selected based on vehicles position and direction, which may result resource starvation.

Figure 5 illustrates the average queuing delay versus the number of V2V-UEs. It can be seen that our ERAVC algorithm achieves a queuing delay reduction for V2V-UEs as compared to the “Position-based Resource Allocation”. This is achieved by the TD scheduler that favours packets with the longest delay time in the buffer and reduces the number of miss deadline packets.

6 CONCLUSION

In this paper, we have investigated the resource allocation for D2D-based V2X networks. In this type of networks, both V2V-UE and V2I-UE communication links coexist and each V2V-UE can share spectrum with one V2I-UE. Indeed, we proposed a new algorithm called “Efficient Resources Allocation for V2X Communications (ERAVC)” that aims at maximizing the sum rate of V2I-UEs while guaranteeing the reliability and latency requirement of V2V-UEs. Compared to an existing algorithm “Position-based resource allocation”, our proposed algorithm can achieve best performance in term of throughput, delay and PDR since it takes into consideration the buffer size, throughput, and packet delay.

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