

QOS ANALYSIS FOR D2D ENABLED VEHICULAR COMMUNICATION

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Abstract : In this paper, we intend to allocate channel resources such as the sharing of the spectrum and allocation of power for different kinds of vehicular communication links. We focus on two kinds of links; for high capacity, we work with V2I (Vehicle to infrastructure) connections and for reliable connectivity we consider V2V (Vehicle to Vehicle) connections. We consider algorithms in order to maximize the capacity (Ergodic) and then we maximize the minimum ergodic capacity to ensure constant performance among V2V connections. D2D communication is the backbone for the vehicular system; therefore we implement another algorithm in order to reduce the interference to maximize the performance. We form a leader follower pair to maintain equilibrium between the cost charged by the leader and the resources bought by the follower. Furthermore, we perform detailed analysis using MATLAB to determine the working of the stated algorithms.

Keywords : Device to Device (D2D), Cellular communications, Power allocation, Sharing of spectrum, Interference reduction, Quality of Service (QoS)

1. Introduction

Vehicle communication is a dedicated branch of technology specifically designed for transferring information between road-vehicles. The whole concept of vehicle communication has its foundation drawn from the D2D communication complemented with the Cellular networks. As illustrated in figure 1, the vehicles can communicate either using V2V link (Vehicle to vehicle) or by V2I (Vehicle to infrastructure) link. The V2V link works with the help of D2D communication while the V2I links use the Base Station to transmit the information. Vehicular environment wireless access namely - IEEE 802.11p is considered conventional for vehicle communication but it suffers from major scalability issues and provides poor QoS and hence can provide only a short lasting vehicle to infrastructure links. Due to the aforementioned reasons, cellular

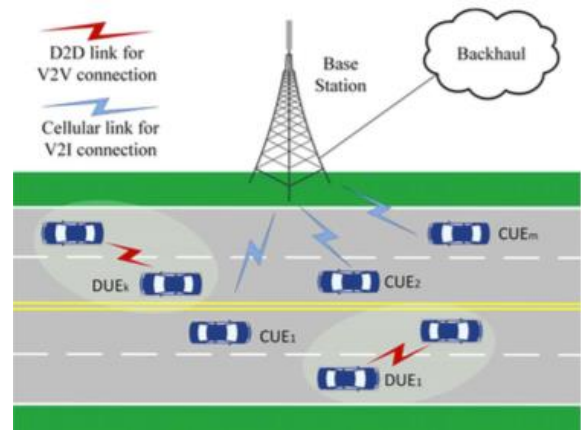
network working in coordination with D2D services can provide a legitimate solution and hence can create a high-performance and a reliable link for data transfer. In order to deploy a resource allocation scheme, we have to consider some key elements when working with algorithms. These key elements, which are the main constituents of our research, are Sum Ergodic capacity, optimal transmission power, and interference. First and second algorithms are designed to calculate Sum Ergodic capacity and

optimized Ergodic capacity respectively. Furthermore, in the third algorithm, we account for the interference between different communicating units by using Stackelberg equilibrium.

Fig. 1. V2V and V2I links in vehicular network

1.1. Background Literature

The D2D communications have been a recent topic of research enterprise [1], [2], [3]. Two different modes can be used to enable D2D communications: reuse mode and dedicated mode. In the reuse mode, DUEs use the CUE resources, whereas in the dedicated mode, DUEs make use of dedicated resources. The reuse mode improves spectral efficiency; on the other hand the dedicated mode eliminates interference to the existing CUEs. In the reuse



mode, D2D and Cellular communication requires precise systematization. Primary research has been done on aspects encompassing power allocation, spectrum sharing and selection of mode. The reduction of interference from D2D communications to the Cellular communications while assuring optimal D2D performance has been the objective of majority of the research. A scheme to control power has been studied in [4] that limits the SINR degeneration of the cellular network. In [5], authors have studied a control scheme to safeguard DUE receivers from cellular interference, where a CUE, located in an area where the SINR at the receiver of the DUE is higher than a preset threshold, is not allowed to allocate its resources to that particular DUE user. [6] Shows maximizing the sum rate of both DUE and CUE for a system consisting of one CUE-DUE pair, while guaranteeing minimum rate for the CUE.

A more practical scenario comprising multiple CUEs and DUEs has been studied in [7] and [8]. In [7], D2D power regulation has been done by the BS in a way that guarantees maximization of the SINR of the Device-to-Device link while supporting an acceptable interference level at the link. In [8] a power control and spectrum allocation design has been proposed that maximizes the throughput of the system as well as guarantees minimum SINR for D2D and cellular links. Further, in [9] the authors have presented a price auction scheme for spectrum allocation to D2D communication with multiple DUE-CUE pairs. We also note that in [10], another resource allocation scheme was proposed based on reverse combinatorial auction.

1.2. Motivation and Contribution

Previous D2D communication schemes consider complete CSI at the Base Station that is not realistic in the contexts of vehicles because of fast channel fluctuations produced by movement.

In this research, we intend to utilize both kinds of connections for vehicles, that is, V2V as well as V2I connections. We work with cellular network complemented with D2D architecture, in which the V2I connectivity is permitted via the macrocellular network and the V2V connection is maintained by D2D

link in order to accomplish the twofold benefits. Also, we manage the resources based on slow fading parameters and channel's statistical information and not on the basis of instant CSI for approaching difficulties created due to the inadequacy to track channels that vary quickly.

To present a resolution we optimize relevant resources like Ergodic capacity, UE transmission rate, and transmission power. But, D2D communication can produce severe interference troubles because of the sharing of the channel's (cellular) resources. Therefore the D2D and cellular connection demand accurate cooperativeness. Therefore we deploy Stackelberg algorithm to construct leader-follower pair to form equilibrium via a utility function. The utility function helps us to examine the optimum price concerning the leader and the follower's optimum power.

2. System Model

We have considered a vehicular network which supports D2D communication as shown in Fig 1. It consists of K vehicle pairs which engages in V2V transfer of data through D2D communication, denoted as DUE, where each pair comprises a transmitter and a receiver and M vehicles that engages in cellular communication with the BS, denoted as CUE. We consider that every vehicle has the ability to perform V2V and V2I communications simultaneously. Let the CUE users be denoted as $\{1, \dots, M\}$ and DUE users be denoted as $\{1, \dots, K\}$. Efficiency of spectrum usage is ensured by DUEs reusing of spectrum of the CUEs in the uplink mode because of higher capability of BS to manage interference.

The power gain of the channel between the Base Station and the m th CUE, $h_{m,B}$, is given by:

$$h_{m,B} = g_{m,B} \beta_{m,B} A L_{m,B}^{-\gamma} = g_{m,B} \alpha_{m,B} \quad (1)$$

where $g_{m,B}$ is the exponentially fading power parameter, $\beta_{m,B}$ is a random variable representing shadow fading with ξ as the standard deviation, A is the loss constant incurred in the path, $L_{m,B}$ is the distance between the Base Station and the m th CUE, γ is decaying component. Similarly, h_k , $h_{k,B}$ and $h_{m,k}$, the power gain of channels between k th D2D pair, BS and k th DUE and the m th CUE and k th DUE respectively have been defined.

Further, the SINRs received from the m th CUE at the BS and at the k th DUE (D2D channel) has been defined respectively as:

$$\Upsilon_m^c = P_m^c h_{m,B} / \sigma^2 + \sum p_{m,k} P_k^d h_{k,B} \quad (2)$$

and

$$\Upsilon_k^d = P_k^d h_k / \sigma^2 + \sum p_{m,k} P_m^c h_{m,k} \quad (3)$$

where, P_k^d and P_m^c are the transmitting powers of DUE and CUE respectively, σ^2 is the power generated

by noise and $p_{m,k}$ indicates the status of spectrum allocation such $p_{m,k} = 1$ indicates that the spectrum of m^{th} CUE is reused by the k^{th} DUE and similarly $p_{m,k} = 0$ indicates no spectrum is being shared. Next, the ergodic capacity of a CUE is defined as:

$$C_m = E [\log_2 (1 + \gamma_m^c)] \quad (4)$$

where $E[.]$ is the expectation calculated over fast fading.

3. Maximization design of CUE Sum Ergodic Capacity (Algorithm 1)

Here, we have developed a power and spectrum allocation scheme which depends on slow-varying channel parameters in order to improve V2V and V2I communication performances. The scheme maximizes the sum ergodic capacity of CUEs and ensuring each DUE receives minimum reliability. Furthermore to provide a minimum required QoS to all CUE, a minimum capacity has been set as a requisite for each CUE. The DUEs are assured reliability by keeping its received SINR γ_k^d below a preset threshold γ_0^d .

In vehicular communication, the resource allocation has been designed as:

Objective Function:

$$\text{Max} \sum_{m \in M} E [\log_2 (1 + \gamma_m^c)] \quad (5)$$

Constraints:

$$E [\log_2 (1 + \gamma_m^c)] > r_0^c, \quad \forall m \in M \quad (5a) \quad 0 \leq P_m^c \leq P_{\max}^c \quad \forall m \in M \quad (5b)$$

$$0 \leq P_k^d \leq P_{\max}^d \quad \forall k \in K \quad (5c)$$

$$\Pr\{\gamma_k^d \leq \gamma_0^d\} \leq P_0 \quad \forall k \in K \quad (5d)$$

Where γ_0^d is the minimum required SINR of each DUE to ensure reliability and r_0^c is the minimum capacity required for each CUE. P_{\max}^c and P_{\max}^d are the maximum transmitting powers of the V2V and V2I users. $\Pr\{.\}$ calculates probability of the input and P_0 denotes probability of the output at the V2V links. Our model assumes that only one DUE can use only one CUE's spectrum and one CUE can share its spectrum with only one DUE at a time. This assumption helps in complexity reduction of the network and is sufficient to prove our model.

3.1 Allocation of and examining feasible CUE-DUE pair

For one pair of CUE and DUE, optimal method of allocating power has been studied in order to maximize the sum of ergodic capacity of CUE while ensuring each DUE's minimum reliability.

Given, the m^{th} CUE band is being shared by the k^{th} DUE, and then the power allocated to a CUE-DUE pair is defined as

$$\text{Maximize } \sum_{m \in M} E [\log_2 (1 + \gamma_m^c)] \quad (6)$$

such that:

$$\Pr\{\gamma_d^k \leq \gamma_0^d\} \leq P_0 \quad (6a)$$

$$0 \leq P_m^c \leq P_{\max}^c \quad (6b)$$

$$0 \leq P_k^d \leq P_{\max}^d \quad (6c)$$

The constraint dealing with reliability of the k^{th} DUE in (6aa) have been evaluated and the optimal solution to (6a) gives:

$$P_m^{c*} = \min (P_{\max}^c, P_{d \max}^c) \quad (7)$$

and

$$P_k^{d*} = \min (P_{\max}^d, P_{c \max}^d) \quad (7a)$$

Equations (7) gives the optimal power allocation for one pair of CUE and DUE while guaranteeing minimum required capacity of each CUE and reliability of each DUE.

Moreover, the CUE-DUE pairs have been eliminated that failed to meet the minimum requirement of QoS of CUE (5aa) after optimal power (9) has been allocated to them. To this end, we have calculated $C_{m,k} (P_m^c, P_m^d)$, the ergodic capacity of the m^{th} CUE while k^{th} DUE is reusing its spectrum.

$$C_{m,k} (P_m^c, P_m^d) = (a / (a-b) \ln 2) [e^{1/a} E_1(1/a) - e^{1/b} E_2(1/b)] \quad \dots (8)$$

where $a = (P_m^c \alpha_{m,B}) / \sigma^2$, $b = (P_k^d \alpha_{k,B}) / \sigma^2$ and $E(.)$ is the exponential integral function.

We have then substituted optimal power from (7) into (8) and we get the maximum ergodic capacity of the m^{th} CUE while k^{th} DUE is reusing its spectrum., $C_{m,k}^*$ as:

$$C_{m,k}^* = C_{m,k}(P_m^{c*}, P_k^{d*}) \text{ if } C_{m,k}(P_m^{c*}, P_k^{d*}) > r_0^c \\ \text{--- } \infty, \text{ otherwise } \dots (9)$$

If the ergodic capacity of the CUE-DUE pair is less than r_0^c then it does not satisfy the minimum QoS requirement. Hence, the feasibility of the CUE-DUE pair is not optimal and therefore, we set $C_{m,k}^* = -\infty$

4. Maximization of minimum capacity of CUE (Algorithm 2)

In Section 3, a model is proposed for maximizing overall sum ergodic capacity. This leads to the improvement of the overall throughput and serves as an advantage from the network operator's side but it doesn't guarantee a improvement on the CUE's side. Although bad conditions might prevail at the CUE, its performance will be neglected in the view of overall performance. Here, we aim to maximize the minimum required capacity of the CUEs to produce a consistent performance among all CUEs.

The objective problem is defined as :

$$\max \min \sum_{m \in M} E [\log_2 (1 + Y_m^c)] \quad (10)$$

Constraints: (5a) - (5d)

For optimal resource allocation, we use the optimal power formula (7) and ergodic CUE capacity derived in (8), considering interference takes place between a single CUE-DUE pair. The proposed algorithm comprises of the following parts:

- Initialization a zero T matrix of MxK size. Then, initialize a random threshold value τ .
- Next, each element from the capacity matrix of (9) is examined to check whether it is less than τ or not and entries are made into the F matrix as follow:

$$T_{m,k} = 1, \text{ when } C_{m,k}^* < \tau \quad 0, \text{ otherwise} \quad (11)$$

- Then, Hungarian method has been applied to get the lowest cost, let it be c. If c is equal to zero, it mean τ is lesser or equal to the minimum required capacity and c greater than zero means τ is greater than the required minimum capacity.

- Last, bisection search method has been used to find the optimal minimum ergodic capacity.

5. Interference Reduction design (Algorithm 3)

A specific algorithm has been dedicated to counter the interference problem created by the DUE-CUE pair while DUE uses the resources of CUE to develop a channel for communication. In this algorithm, Leader-Follower pairs have been created. The leader is the CUE and follower being DUE. The leader i.e the CUE charges some cost from the follower i.e DUE in order to share resources. After that, joint scheduling has been performed. The leader-follower pair forms a queue on the basis of the respective utility function.

A single cell scenario has been considered with one common Base station and several user equipments. Both BS and UEs have one Omni-directional antenna. The D2Ds are equipped with one receiver and transmitter. The number of CUEs is represented by K while the DUEs are denoted by D (where $D > K$). The allocated channels for the CUEs are set to be fixed, while the DUEs share the channels with CUE. In every transmission time interval, scheduling happens. Channels are allotted between DUEs as per their priorities. A set of binary variables has been defined $\{x_{ik}\} (i \in D, k \in K)$ for stating the present pair of DUE pair in connection. If $x_{ik} = 1$ then i -th D2D pair is picked to utilize the k^{th} channel, and $x_{ik} = 0$ if not selected. Then we calculate the received signal at the BS and DUE by equation (12) and (13) respectively,

$$y_k^c = \sqrt{p_k g_{ke}} s_k + \sum x_{ik} \sqrt{p_i g_{ie}} s_i + n_k \quad (12)$$

$$y_i^d = \sqrt{p_i g_{ii}} s_i + \sum x_{ik} \sqrt{p_k g_{ki}} s_k + n_i \quad (13)$$

Where y_{ck} is the received signals at the BS, y_{di} is the received signals at the DUE, p_k is the power of transmission of the k^{th} CUE, p_k is the power of transmission of the k^{th} CUE, g_{ke} is the channel gain between k^{th} CUE and the BS, g_{ie} is the gain of the channel between i^{th} DUE transmitter and the base station, n_k and n_i are the representation of the white Gaussian noise, g_{ki} is the gain of the channel between the CUE - k^{th} and the receiver of i^{th} D2D, and g_{ii} is the gain of the channel between the transmitter of i^{th} D2D and the receiver of i^{th} D2D. Thereafter SNIR has been calculated at the i^{th} DUE, and at the BS corresponding to CUE k by equation (14) and (15) respectively,

$$\gamma_i^d = p_i g_{ii} / \sum_k x_{ik} p_k g_{ki} + N_0 \quad (14)$$

$$\gamma_k^c = p_k g_{ke} / \sum_i x_{ik} p_i g_{ie} + N_0 \quad (15)$$

Where N_0 is the noise power, γ_i^d and γ_k^c are the respective SNIRs. Channel rate of UEs has been obtained as follows,

$$r = \log_2(1 + \gamma) \quad (16)$$

The utility function is dependent on the charging price that leader demands from the follower and the power that follower acquires. This utility function is a key factor to reach a state of equilibrium i.e an optimal state in which the charging price is set such that the purchased optimal power does not cause interference yet is sufficient for transmission.

Calculation of the utility function is done by the following equation (17)

$$u_k(\alpha_k, p_i) = \log_2(1 + p_k g_{ke} / (p_i g_{ie} + N_0)) + \alpha_k \beta p_i g_{ie} \quad (17)$$

Where $u_k(\alpha_k, p_i)$ is the utility function, β is the scale factor (proportion of the gain of the leader's and the payment of the follower), and α_k is the charging price. The utility function is regulated as per the given constraints in equation(18) :

$$\max u_i(\alpha_k, p_i), \text{ such that } p_{\min} \leq p_i \leq p_{\max} \quad (18)$$

SINR threshold for DUE γ_0^d	5 dB
Carrier Frequency	2 GHz
Bandwidth	10 MHz
Cell radius	500 m
BS Antenna Height	25 m
BS antenna gain	8 dBi
Noise figure of Base Station	5 dB
Distance between BS and road	35 m
Vehicle antenna height	1.5 m
Vehicle antenna gain	3 dBi
Vehicle receiver noise figure	9 dB
vehicle speed , v	70 km/h
Number of Lanes	3 in each direction
Lane Width	4 m
Vehicle density	average vehicle-vehicle distance is 2.5 sec x vehicle speed

Minimum capacity of DUE r_0	0.5 bps/Hz
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The utility function is a logarithmic value with increases with increase in the P_i then reaches the maximum and thereafter starts to decrease with further increase in P_i . Therefore we differentiate to find the maximum of the utility function is stated by equation (19),

$$\partial u_i / \partial p_i = 1 / \ln_2 (g_{ii} / p_i g_{ii} + p_k g_{ki} + N_0) - \alpha_k g_{ie} = 0 \quad (19)$$

The solution (Max power) is given by equation (20),

$$p_i^* = (1 / \alpha_k g_{ie} \ln_2) - (p_k g_{ki} + N_0 / g_{ii}) \quad (20)$$

Optimal price is calculated by the following

$$a_k^* = (B / N_0 \beta) - (B / A) \quad (21)$$

Where $A = p_k g_{ke}$, and $B = 1 / \ln_2$.

6. Numerical Results

MATLAB simulations were performed to evaluate the performance of the aforementioned algorithms. We analyze a singular circular cell setting. The CUEs and DUEs combinations are evenly dispersed. The DUEs pair is sufficiently proximal to fulfill the greatest range requirement for communicating via D2D. Table (1) & (2) displays the parameters used in the MATLAB simulation to verify the algorithms used.

Table I:
Simulation parameters to calculate maximum sum Ergodic capacity algorithm [11], [12]

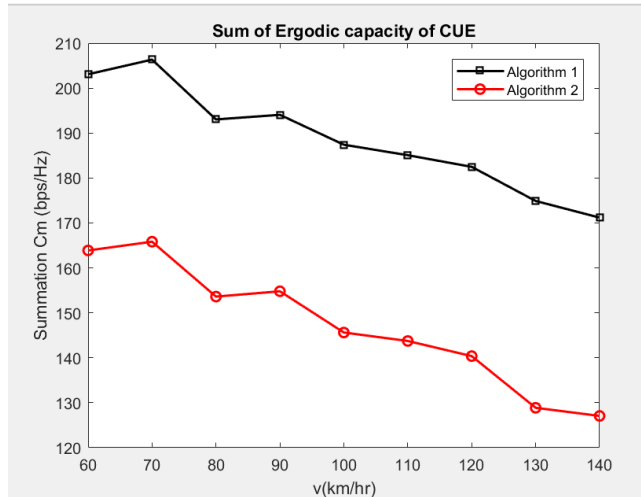
PARAMETERS	VALUES
Reliability for DUE p_0	0.001
Number of DUEs, K	20
Number of CUEs, M	20
Maximum transmitting power of CUE P_{\max}^c	1723 dBm
Max DUE trx power P_{\max}^d	1723 dBm

Noise power σ^2	-114 dBm
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Table II:

Table II:
Parameters for Interference reduction.

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PARAMETERS	VALUES
Radius of the cell	500m
Layout of the cell	1 (nos) – Shape circular
Estimate number of D2D pairs	10
Estimate number of CUEs	5
CUE Power for transmission	23 dBm
Maximum distance of communication for D2D	50 meter
DUEs power for transmission	0dBm to 23dBm
Thermal noise power density	-174dBm/Hz
Bandwidth	180kHz
Transmission time interval (TTI)	1 millisecond

2: Sum Ergodic capacity of CUE

Figure 2 shows that the algorithm 1 proves to be efficient as the Sum Ergodic capacity for CUE-DUE pair formulated by using algorithm 1 is higher than algorithm 2. Also, the nature of the graph depicts that as speed increases, distance between vehicles increases so capacity decreases. This explains the negative slope of the graph.

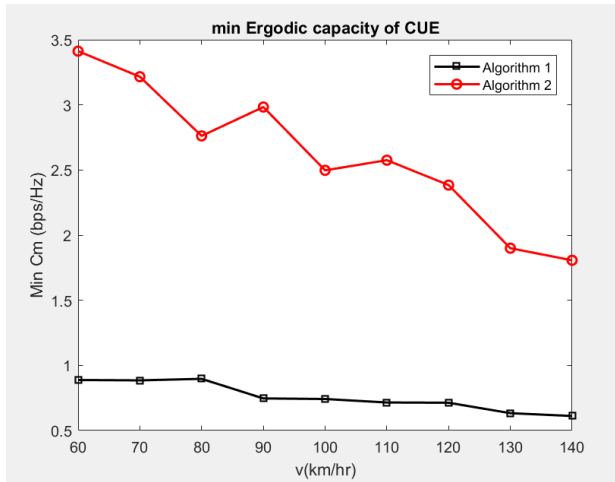


Fig 3: Minimum Ergodic capacity

Figure 3 shows that algorithm 2 proves to be much more efficient as the minimum Ergodic capacity of CUE-DUE pair formulated as per algorithm 2 is higher than algorithm 1.

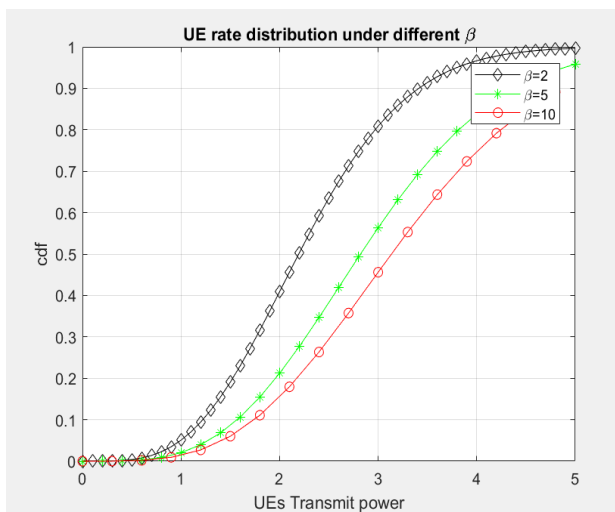


Fig 4: CDF vs. UE transmission power

Figure 4 presents the relationship between the cumulative distribution function and the Transmitted power. β is defined as the proportion of the gain of the leader's and the payment of the follower. Concerning a greater β , there will be less payment for the follower, and therefore, the follower will prefer higher power of transmission.

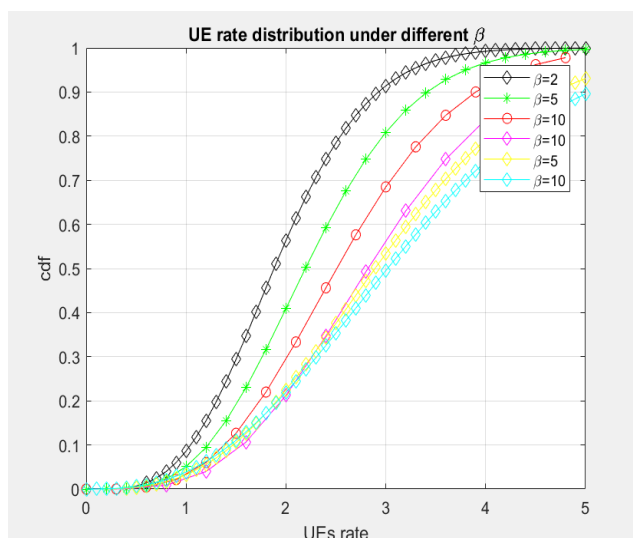


Fig 5: CDF vs. UE rate

Figure 5 shows the relation between the cumulative distribution function and the Transmission rate. For every higher β the amount for the follower is comparatively inexpensive, and hence, the follower will retain large transmission power. With higher DUE's power of transmission, the rate of DUEs is also more.

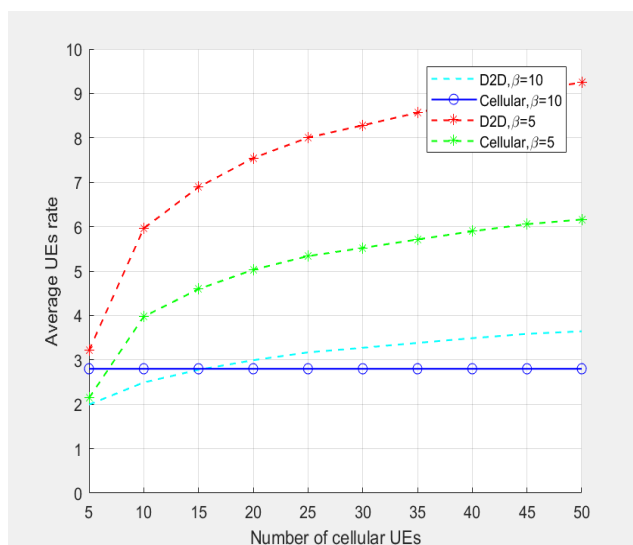


Fig 6: Avg UE rate vs No. of CUE

Figure 6 shows the relation between the average transmission rate and no. of UEs. The graph explains that with an increase in the number of CUEs, DUE's rate is also improved. Aforementioned is due to the fact that DUEs have extra resources to utilize.

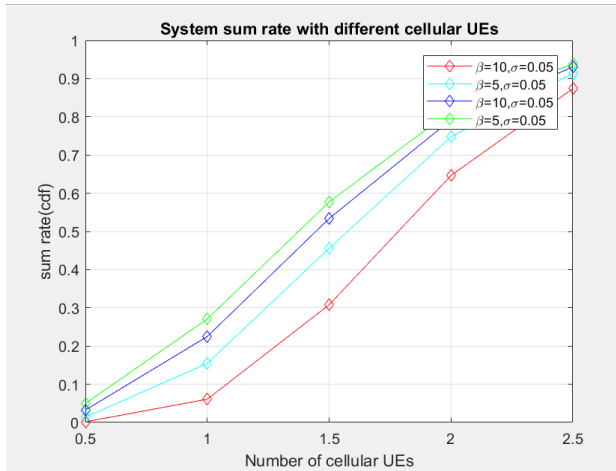


Fig 7: Sum rate vs No. of CUE

The fairness coefficient - which influences the queue priority (σ) and scale factor's (β) outcomes are displayed prominently in figure 7. It can be noted that there is proper management of interference and the transmission rate achieved by CUEs is fairly high.

7. Conclusion

In this paper, we have proposed algorithms to allocate power and spectrum between CUEs and DUEs to enable D2D enabled vehicular communication. Our scheme is focused on differentiated QoS requirements for vehicular communication since CSI is hard to track due to fast movement of vehicles on road. This paper proposes robust algorithms to maximize the total ergodic capacity of CUEs and guaranteeing the minimum optimal capacity of CUE and DUE's reliability. The present output is restricted to resource distribution between a single unit of CUE and DUE but further work can be carried out to extend our research to a more practical scenario with sharing possible among multiple CUEs and DUEs.

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