Channel And Power Allocation For Mm-Wave Device-To-Device-Enabled Vehicular Networks

Filbert Onkundi Ombongi, Heywood Ouma Absaloms, Philip Langat Kibet

Abstract: The demand for higher data rate services has led to the emergence of 5G wireless networks to offer the limitations of the current cellular communication technologies. The millimeter-wave (mm-wave) communication technologies have evolved into direct Device-to-Device (D2D) single-hop or multi-hop communications. Direct D2D communication can easily be integrated into vehicular communication networks such as vehicle-to-everything (V2X) to offer high-speed data connectivity, very low latency, and reliable services. However, the implementation of D2D enabled vehicular communication networks are characterized by an architecture that causes misalignment of the mm-wave beams from the vehicles thereby causing mutual interference. The mm-wave communication is also having a challenge of high propagation losses, sensitivity to blockage, and directivity. In this regard, the coexistence of cellular users, D2D users together with the vehicular users' calls for strict QoS requirements since there is the high mobility of the vehicles and the presence of mutual interference. This paper formulates a matching theory-based Hungarian algorithm to perform channel and power allocation that takes into consideration the high rate of channel fluctuations, interference, and latency constraints in the high mobility environment. The proposed Hungarian algorithm was simulated in MATLAB by applying 3GPP TR 37.885 and 38.901 specifications. The Hungarian algorithm is compared with the max-min algorithm. The Hungarian algorithm was found to have a 10.8% better performance than the max-min algorithm when the maximum spectrum efficiency was considered. When the minimum spectrum efficiency was considered the Hungarian algorithm was 17.35% better than the max-min algorithm.

Index Terms :mm-wave, D2D, vehicle-to-everything, 5G, Vehicle-to-Vehicle

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1.INTRODUCTION

The D2D communication which allows the users to interact directly without going through the base station has enabled the implementation of various bandwidth-intensive applications such as high definition video streaming [1], disaster relief services [2], smart cities [3] and internet of things [4]. D2D communication can also enable the implementation of vehicle-to-vehicle (V2V) communications for high spectral efficiency, fairness, and energy efficiency [5]. The vehicular communications require a high sum rate, very low latency, and accurate location determination for the deployed cases. Therefore, the mm-wave 5G technology which offers a high broadband bandwidth can support the D2D enabled vehicular communication. The channel sparsity and high temporal and angular resolution in the mm-wave band can be utilized for the accurate localization of the vehicles which is a very important feature for the provision of vehicular communication services. However, in the mm-wave band, there is a challenge of high propagation losses, atmospheric losses, sensitivity to blockage which requires proper directional transmissions [6]. The schemes used in D2D communication provide reduced latency and power consumption which are the key enablers for the delay-tolerant vehicular communications. Despite the benefits of D2D enabled vehicular communication, some challenges need to be addressed for better delay optimization, high reliability, and high system capacity. This includes the need for accurate sensing of the channel state information by the base station in a highly dynamic environment. In this paper, a resource allocation scheme is proposed that takes into consideration the mutual interference constraint an imperfect CSI scenario.

2 RELATED WORK

In [7], a power control scheme to maximize sum-rate was studied for a D2D enabled vehicular network using successive convex approximation and Bernstein technique to determine its solution. The study considered the Gauss-Markov process to take care of the effect of the high mobility nature of the vehicular devices on the channel. The channel state information (CSI) at the transmitter and receiver was considered to reduce the delay and communication overhead. The D2D communication was being done in the reuse mode where the D2D devices reuse the spectrum allocated to the cellular users. An uplink resource block allocation scheme based on 3D graph matching and hyper-graph coloring was developed for cellular and vehicular users in [8] by considering the differentiated QOS needs and mobility of users to maximize their capacity. In [9], a power allocation and spectrum sharing scheme was studied for D2D vehicular networks to guarantee reliability by considering small changes of large scale fading to optimize the maximum and minimum sum capacity. In [10], a heuristic resource block and power allocation algorithm were developed for vehicle-to-vehicle users by considering the latency and reliability constraints to maximize the cellular users' sum rate and fairness. This study was extended in [11] by proposing a separate resource block and power allocation scheme that transformed reliability and latency constraints into optimization variables to maximize the sum rate of cellular users and the power per vehicular user. In [12], a statistical uplink spectrum sharing scheme based on massive MIMO was developed for a cellular network which consists of vehicular users by considering the networks' CSI to optimize spectrum efficiency. A resource allocation scheme was proposed for a V2V communication in [13] to maximize the sum-rate by considering reliability and delay constraints. The study in [14] formulated a power allocation algorithm based on the Stackelberg game for vehicle-to-everything (V2X) users under-laying the cellular users to maximize the packet error probability and ergodic capacity. It considered the interference between the base station and the vehicular user to maximize their utilities. In [15], a combination of successive convex optimization and Bernstein Approximation were used to solve a power allocation problem in a D2D enabled vehicular network to maximize sum throughput and outage probability. The study considered a round selection mode and the delay channel type for the multiple vehicles and cellular links to reduce interference between the users. The uplink channel allocated to the cellular users was reused by multiple V2V users which are having direct communication. The study was extended in [16] by applying the dual decomposition method to perform power control

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for sum rate and outage probability maximization in vehicular network with high mobility. The study considered multi-user interference and imperfect CSI presence with sub-optimal results obtained. All the aforementioned works have been implemented in the microwave band by applying technologies such as IEEE 802.11p and LTE-V2V which operate at 5.9GHz. However, this spectrum doesn't have sufficient radio resources for the evolving vehicular applications which need higher data rates as shown in [17, 18]. This implies that the vehicular networks can be implemented in the mm-wave band to offload traffic due to its huge bandwidth [19]. Some of the benefits offered by the mm-wave spectrum include the large bandwidth per channel [20] and the smaller wavelengths which can enable the design of highly directional beamforming antennas. With the high number of directional antennas, massive MIMO can be implemented so easily to reduce the out of cell interference [21] which enhances spectral efficiency which in turn attains high capacity of the network [22]. Some works have implemented cellular-based V2V and D2D based V2V communication to enhance performance in terms of capacity, latency, and packet error probability. This has been studied by applying resource allocation, power allocation, device association and beam selection, and interference management for V2V communications. A stable fixture many-to-many matching game was formulated in [23] for the vehicle links association to maximize obtained data rates per channel by considering the movement and position of the vehicle. In [24], a combination of matching game and particle swarm optimization was applied to pair the vehicle devices and maximize the communication beam widths. The study considered the queue state information and channel state information during the creation of V2V links. In [25], a V2V model was developed to consider the effect of beam misalignment and path losses in the mm-wave band for a vehicular communication network to maximize connectivity of the V2V devices. In [26], the interference analysis scheme that takes into consideration the co-channel interference was developed for a V2V network to optimize the ergodic capacity and packet error probability. The study also considers the diversity by looking at the channel non-linearity and the number of multipath clusters to minimize the packet error probability. In [27], a heuristic-based algorithm was proposed for a multi-channel diversity mechanism to improve diversity in vehicular networks. This was done to reduce the mutual interference resulting from the beam misalignment of the moving vehicles to maximize the SINR obtained between the communicating V2V pairs. The current study considers the Hungarian based algorithm to perform channel assignment and power allocation in a D2D based vehicular network in the mm-wave band. In this network scenario, there are three types of users namely, the cellular users whose uplink spectrum resources are reused by vehicular devices, the vehicle-to-base station communication users (V2I users), and the D2D based vehicle-to-vehicle users (V2V). The mm-wave path loss model used in this study follows the vehicular path loss modeling presentation in [28] and [29]. The objective of the study is to maximize the spectrum efficiency of the cellular users whose spectrum resources are reused by V2V users by considering reliability, transmit power, and minimum data rate constraints in the mm-wave band.

3 SYSTEM MODEL

2.1 Network Architecture

Consider a Device-to-Device (D2D) enabled V2V communication at the mm-wave band in a single cell network of radius, R. The macro base station (BS) is situated at the center of the cell and the road used by the vehicles is within the coverage radius of the BS as shown in Figure 1. The network has $\mathcal{I}$ vehicle devices which need vehicle-to-base station which can also be referred to as vehicle-to-infrastructure (V2I). The V2I links denoted as I-UEs with a set $\mathcal{I} = \{1,2\ldots,I\}$ should have a high capacity to enable V2V communications. The network consists of $\mathcal{D}$ device pairs that similarly allow local V2V communications as direct D2D communications. The V2V communication user devices are denoted as VUEs with a set given by $\mathcal{K} = \{1,2\ldots,K\}$. The orthogonal uplink resources allocated by the BS to the I-UEs are reused by the VUEs for a better spectrum deployment efficiency.

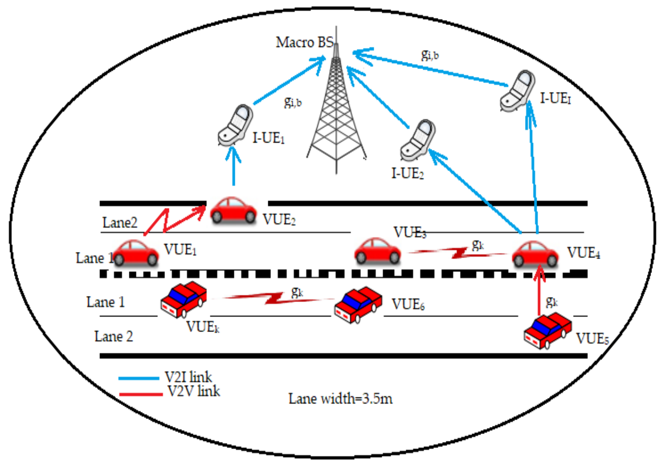

Figure 1: *D2D-enabled vehicular network model*

2.2 Problem Formulation

The channel power gain for the V2I links between the i[th] I-UE and the base station, $g_{i,b}$ can be given by;

$$g_{i,b} = |h_{i,b}|^2 \alpha_{i,b} \tag{1}$$

Where $h_{i,b}$ is the small scale fading and it is required to be independent and identically distributed and $\alpha_{i,b}$ denotes the large scale fading which can include mm-wave path loss and shadowing effects. The communication link between the k^{th} V2V pair has channel gain, g_k, the interfering link from the k^{th} VUE to the base station has a channel gain, $\widehat{g_k}$ and the interference link between the IUE device and the k^{th} VUE can be defined as $\widehat{g_\iota}$. When the range between two communicating V2V devices is beyond a safe communication distance of D2D communication, the V2V user pairs communicate through the BS as V2I links [30]. The CSI of all the links established with the base station are known but the vehicular links' CSI is sent to the base station with a period, T. The Gauss-Markov process can then be applied to model fast fading over this period. It can be defined as;

$$h = \epsilon\hat{h} + e \tag{2}$$

where $\hat{h}$ and h represent the channel responses in previous and current times respectively, e is the channel error that has a complex Gaussian distribution $\mathcal{CN}(0,1-\epsilon^2)$ and is independent of $\hat{h}$, ϵ $(0 \leq \epsilon \leq 1)$ is the channel correlation coefficient between two consecutive time slots. The parameter, ϵ can be determined by Jake's model and is expressed as; $\epsilon = J_0(2\pi f_d T)$ where the function $J_0(.)$ Is the Bessel function with a zero-order and $f_d = {}^{v f_c}/_{c}$ is the maximum Doppler frequency, c is the velocity of light in a vacuum, and f_c is the carrier frequency. Therefore, the channel gain for the VUE is given as;

$$g_k = \alpha_k(\epsilon_k^2|\hat{h}|^2 + |e_k|^2 \quad (3)$$

The SINR of the i^{th} I-UE and the k^{th} VUE can be expresses as;

$$\gamma_i^c = \frac{P_i^c g_{i,b}}{\sum_{k=1}^{K} \rho_{i,k} P_k^d \widehat{g_k} + N_o} \quad (4)$$

and

$$\gamma_k^d = \frac{P_k^d g_k}{\sum_{i=1}^{I} \rho_{i,k} P_i^c \widehat{g_\iota} + N_o} \quad (5)$$

Where p_i^c and p_k^d are the transmit powers of the i^{th} I-UE and the k^{th} VUE respectively, $\widehat{g_k}$ is the interference to V2I link with channel gain given by $\widehat{g_k} = \widehat{\alpha_k}|\widehat{h_k}|^2$, $\widehat{g_\iota}$ is the interference to VUE link with a channel gain given by, $\widehat{g_\iota} = \alpha_{i,k}(\epsilon_{i,k}^2|\widehat{h_{\iota,k}}|^2 + |e_{i,k}|^2$ N_o is the noise power spectral density and $\rho_{i,k}$ is the resource reuse indicator where $\rho_{i,k} = 1$ if the k^{th} VUE reuses the channel allocated to the i^{th} I-UE user and $\rho_{i,k} = 1$ otherwise. The objective of this study is to meet the needs of the various V2V links which is the high capacity for the V2I users with a guarantee of high reliability of the V2V connecting links. Therefore, the optimization function involves the sum-rate maximization for all the I-UEs with minimum reliability of individual VUE guarantee. The optimization function for this study can be formulated as;

$$\max_{\{\rho_{i,k}\}\{p_i^c\}\{p_k^d\}} \sum_{i\epsilon\mathcal{I}} \log_2(1+\gamma_i^c) \quad (6)$$

$$\text{s.t} \log_2(1+\gamma_i^c) \geq r_{min}^c, \forall i \in \mathcal{I} \quad (6a)$$

$$0 \leq P_i^c \leq P_{max}^c, \forall i \in \mathcal{I} \quad (6b)$$

$$0 \leq P_k^d \leq P_{max}^d, \forall k \in \mathcal{K} \quad (6c)$$

$$\sum_{i\in\mathcal{I}} \rho_{i,k} \leq 1, \ \ \rho_{i,k} \in \{0,1\}, \ \ \forall i \in \mathcal{I} \quad (6d)$$

$$\sum_{k\in\mathcal{K}} \rho_{i,k} \leq 1, \ \ \rho_{i,k} \in \{0,1\}, \forall k \in \mathcal{K} \quad (6e)$$

$$p_r\{\gamma_l^d \leq \gamma_{min}^d\} \leq p_{min} \quad (6f)$$

Where r_{min}^c is the minimum data rate requirement for the I-UEs, γ_{min}^d is the minimum SINR required for a reliable link establishment for the VUEs, $p_r\{.\}$ determines the outage probability of the input, p_{min} is the minimum tolerable outage probability, P_{max}^c is the maximum transmit power of the I-UEs and P_{max}^d is the maximum transmit power of the VUEs. The constraint given in (4a) represents the minimum data rate for individual I-UE, (4b) and (4c) are the maximum transmit power thresholds for the I-UEs and VUEs respectively, (4d) and (4e) represent the I-UE resource reuse indicator with only one VUE allowed to reuse the channel bandwidth allocated to a single I-UE.

3 V2V Channel Modelling

The path loss is modeled according to [28] for V2V communication networks. The study considers the line of sight (LOS) and non-line of sight (NLOS) conditions to model the path losses.

3.1 Line of Sight Path Loss

This is the path that does not have blockage of the signal due to obstacles such as vehicles, buildings, and trees. This path loss has a dual-slope piecewise linear model which can better simulate the real propagation in vehicular networks. The LOS path loss for an urban scenario can be given as;

$$PL_{LOS}^u(\text{d}) = 38.77 + 16.7\log_{10}(d) + 18.2\log_{10} f_c + \mathcal{X} \quad (7)$$

Where d is the inter-vehicle Euclidean distance in meters, f_c, is the carrier frequency in GHz and $\mathcal{X}$ is the shadowing loss which can be defined as the signal power variations due to neighboring objects. The shadowing can be modeled as a log-normal random variable with a standard deviation in dB takes as 3 [29].

3.2 Non-Line of Sight (NLOS) Path Loss

This occurs when the LOS is blocked by blockages such as trees, buildings. The NLOS equation for the urban vehicular environment can be given by;

$$PL_{NLOS}^u(\text{d}) = 36.85 + 30\log_{10}(d) + 18.9\log_{10} f_c + \mathcal{X} \quad (8)$$

The shadowing loss which is modeled as a log-normal random variable, in this case, it is 4dB [29].

4 Resource Allocation Optimization

3.1 Power Allocation for each I-UE and V2V pair

Consider a single I-UE and VUE pair to maximize the I-UEs data rate. The I-UE data rate is given by;

$$R_{i,k} = \log_2\left(1 + \frac{P_i^c g_{i,b}}{\sum_{k=1}^{K} \rho_{i,k} P_k^d \widehat{g_k} + N_o}\right) \quad (9)$$

The equation given in (5) must satisfy the constraints and it can be reformulated as;

$$\max_{p_k^d, p_i^c} R_{i,k} \quad (10)$$

$$\text{s.t } p_r\{\gamma_l^d \leq \gamma_{min}^d\} \leq p_{min} \quad (10a)$$

$$0 \leq P_i^c \leq P_{max}^c, \forall i \in \mathcal{I} \quad (10b)$$

$$0 \leq P_k^d \leq P_{max}^d, \forall k \in \mathcal{K} \quad (10c)$$

Lemma: The equation (11) has a feasible region which can be defined as;

$$\left\{(p_k^d, p_i^c): \exp\left(\frac{C\gamma_{min}^d}{B}\right)\left(1 + \frac{D}{B}\gamma_{min}^d\right) \leq \frac{\exp\left(\frac{A}{B}\right)}{1 - p_{min}}, \quad C\gamma_{min}^d \geq A, \quad 0 \leq P_i^c \leq P_{max}^c, \quad 0 \leq P_k^d \leq P_{max}^d\right\} \quad (11)$$

Alternatively, it can be defined as;

$$\left\{(p_k^d, p_i^c): \left(1 + \frac{B}{\gamma_{min}^d D}\right)\exp\left(\frac{A - C\gamma_{min}^d}{\gamma_{min}^d D}\right) \geq {}^1/_{p_{min}}, C\gamma_{min}^d < A, \quad 0 \leq P_i^c \leq P_{max}^c, \quad 0 \leq P_k^d \leq P_{max}^d\right\} \quad (12)$$

where $A = P_k^d \alpha_k(\epsilon_k^2|\hat{h}|^2$, $B = P_k^d \alpha_k(1 - \epsilon_k^2)$, $C = N_o + P_i^c \alpha_i \epsilon_{i,k}^2 |\hat{h}_{i,k}|^2$, $D = P_i^c \alpha_{i,k}(1 - \epsilon_{i,k}^2)$

Theorem: The optimal power allocation for the optimization function given in (10) can be determined for the VUE and I-UE users as follows;

$$P_k^{d^*} = \begin{cases} \min\{P_{max}^d \;\; P_{c,max}^{d_1}\} & if\ P_{max}^d \leq P_{min}^d \\ \min\{P_{max}^d \;\; P_{c,max}^{d_2}\} if\ P_{max}^d > P_{min}^d\ and\ P_{max}^c > P_{min}^c & \\ P_{c,max}^{d_1} & Otherwise \end{cases} \quad (13)$$

$$P_i^{c^*} = \begin{cases} \min\{P_{max}^c \;\; P_{d,max}^{c_1}\} & if\ P_{max}^d \leq P_{min}^d \\ \min\{P_{max}^c \;\; P_{d,max}^{c_2}\} if\ P_{max}^d > P_{min}^d\ and\ P_{max}^c > P_{min}^c & \\ P_{c,max}^c & Otherwise \end{cases} \quad (14)$$

The values of P_{min}^d and P_{min}^c can be given by;

$$P_{min}^d = \frac{P_{min}^c \gamma_{min}^d \alpha_{i,k}(1-\epsilon_{i,k}^2)(1-p_{min})}{\alpha_k(1-\epsilon_k^2)p_{min}} \quad (15)$$

$$P_{min}^c = \frac{N_o}{\frac{1-\epsilon_{i,k}^2}{1-\epsilon_k^2}\left(\frac{1}{p_{min}}-1\right)\alpha_{i,k}\,\epsilon_k^2|\hat{h}_k|^2 - \alpha_{i,k}\,\epsilon_{i,k}^2|\hat{h}_{i,k}|^2} \quad (16)$$

3.2 Channel Allocation and Hungarian Algorithm

The resource allocation formulated in this study comprises of power allocation and channel assignment problem. The channel assignment problem is an optimization function used to determine the optimal assignment of resources to a given set of wireless users. The assignment problem is aimed at optimizing the sum utility such as maximize the channel sum rate. Assuming there are I I-UEs denoted by $\mathcal{I} = \{1,2 \ldots, I\}$ and N Resource Blocks (RBs) which is represented by $\mathcal{N} = \{1, 2, \ldots, N\}$ in a D2D vehicular network. Let $I \times N$ matrix W be an assignment matrix where the element $\rho_{i,k} = 1$ shows that a RB N_i has been assigned to I-UE, i and $\rho_{i,k} = 0$, otherwise.

A matrix Ψ can be defined as the utility matrix with the elements, $\Psi_{i,n}$ showing the data rate of I-UE, i at the RB, n. The RB assignment can then be formulated as;

$$\Pi^* = \underset{\Pi}{\operatorname{argmax}} \sum_{i=0}^{I}\sum_{n=0}^{N} \rho_{i,k}\Psi_{i,n} \quad (17)$$

$$\text{s.t} \sum_{n=0}^{N} \rho_{i,k} \leq 1\ \forall i \in \{1,2, \ldots, I\} \quad (18)$$

$$\sum_{i=0}^{I} \rho_{i,k} \leq 1\ \forall\ n \in \{1,2, \ldots, N\} \quad (19)$$

The optimal assignment for this function can be found by the Hungarian Algorithm [31]. Assuming the same number of I-UEs and RBs i.e. $I = N = m$ for the formulated channels assignment problem and given Ψ as the utility matrix. The Hungarian algorithm can be applied in the following steps to determine an optimal assignment solution.

- The row minimum is identified in each row and subtracted from each element in a row.
- The column minimum is identified for each column and subtracted from each element in a column.
- All the zeros are covered with a minimal number of horizontal and vertical lines.
- The number of vertical and horizontal lines is then checked. If the number of lines is found to be greater or equal to the number of columns or rows, then the algorithm terminates. The output of a set of zeros is displayed as the output with each column or row having one zero, this is chosen as the optimal assignment, otherwise go to step 5
- The smallest element in the matrix that was not covered in step 3 is determined. This value is subtracted from each of the uncovered rows and added to each of the covered columns. Steps (3) and (4) are then repeated.

The combined power allocation and the Hungarian based channel allocation algorithm is given in Algorithm 1.

Algorithm 1: Hungarian based Power and Channel Allocation Algorithm
1. for $i = 1{:}I, do$ 2. for $k = 1{:}K$ 3. determine optimal power allocation values $(P_k^{d^*}, P_i^{c^*})$ using (13) and (14) for each I-UE and VUE pair 4. Using (10) and values of $(P_k^{d^*}, P_i^{c^*})$, determine data rate, $R_{i,k}^*$ 5. If $R_{i,k}^* < r_{min}^c$, then set $R_{i,k}^* = -\infty$ 6. end if 7. end for 8. end for 9. Using the Hungarian Algorithm, determine optimal channel reuse pattern $\rho_{i,k}^*$ based on $R_{i,k}^*$ 10. return values of $\rho_{i,k}^*$ and $(P_k^{d^*}, P_i^{c^*})$

4 Results And Discussion

This section presents the simulation results for the developed D2D-enabled vehicular network model in the mm-wave band and validates the algorithm proposed in this study. The I-UEs and VUEs are randomly selected among the generated vehicles where the VUE pairs are established form the proximity vehicles and the I-UEs have equal shares of the system bandwidth. The study follows the urban grid simulation set up

a scenario in 3GPP TR 37.885 [28].

Figure 2 shows the cumulative density function for different values of V2I users (I-UEs) and V2V users (VUEs) by considering the SINR of the received signal in a mm-wave path loss model and Rayleigh fading. The study considered a minimum SINR level of 5dB for every VUE. The latency constraint in the form of the outage probability for the VUEs SINR was taken as $p_{min} = 10^{-4}$. This shows that by increasing the number of VUEs, the outage probability improves. This shows that reliability can be improved by the densification of the users as this offers more user alternatives which can share spectrum with the VUEs.

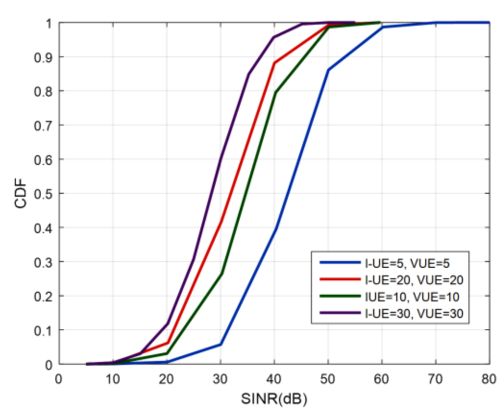

Figure 2: *CDF for a varying number of users*

Table 1*: Simulation Parameters*

Parameter	Value
Cell radius, R	500m
Carrier frequency, f_c	30GHz
Bandwidth, W	200MHz
Number of VUEs, K	{10,20,30}
Number of I-UEs, I	(10,20,30}
Maximum VUE transmit power, P_{max}^{d}	23dBm
Maximum I-UE transmit power, P_{max}^{c}	23dBm
Macro BS antenna height	25m
Macro BS antenna gain	8dBi
Micro BS receiver noise figure	7dB
Distance between BS and highway	25m
Vehicle antenna height	1.6m
Vehicle antenna gain	5dBi
Vehicle receiver noise figure	13dB
Average vehicle speed, v	100km/h
Number of lanes	2x2
Lane width	3.5m
Noise power, N_o	-174dBm
Minimum data rate of I-UE, r_{min}^{c}	0.5bps/Hz
Minimum SINR threshold, γ_{min}^{d}	5dB
Bisection search accuracy, ε	10^{-6}
Reliability of VUE	10^{-4}

The shadowing standard deviation for V2V and V2I links is given as 3dB and 4dB respectively. The V2I path loss parameters are derived from 3GPP TR 38.901 ([32].

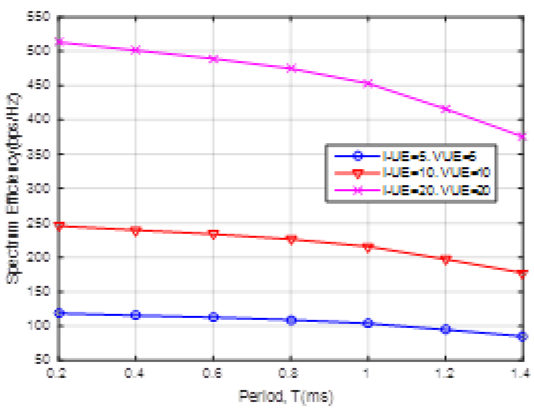

***Figure 3**: Spectrum Efficiency versus feedback period, T(ms)*

Figure 3 shows a plot of maximum spectrum efficiency obtained versus the feedback period of the channel state information. The feedback period is used to show the latency constraint considered in this study. The spectrum efficiency decreases as the period, T increases. The increase of the period leads to some uncertainty in the V2V links at the BS. This prompts the BS to start managing the transmit power of the I-UEs so that the reliability of the V2V links affected by the I-UEs interference can be guaranteed. The reduction of the I-UE interference due to the satisfaction of the maximum transmit power constraints of the VUES, there will be low power allocation to the I-UEs which results in lower spectrum efficiency of the I-UEs. The I-UEs have less interference and due to the maximum power constraint of the VUEs, less power is allocated to the CUEs which reduces both the maximum and minimum spectrum efficiency obtained.

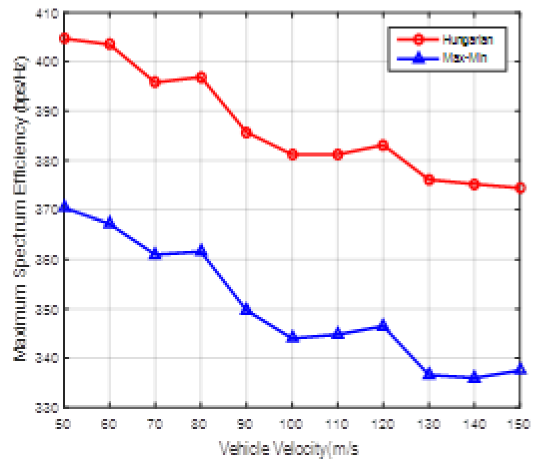

***Figure 4:** Spectrum efficiency versus vehicle velocity*

Figure 4 shows the maximum spectrum efficiency for all I-UEs was considered for varying velocity of the VUEs along the road. The performance of the proposed matching theory-based Hungarian algorithm and the max-min algorithm were compared. It was found that the proposed Hungarian algorithm has a 10.8% better performance than the max-min algorithm when the maximum sum rate was considered. The spectrum efficiency was found to decrease when the vehicle velocity was increased. This is due to the rise in the distance between the vehicles which introduced sparse traffic. This led to lower reliability of the V2V links due to the reduced received signal power.

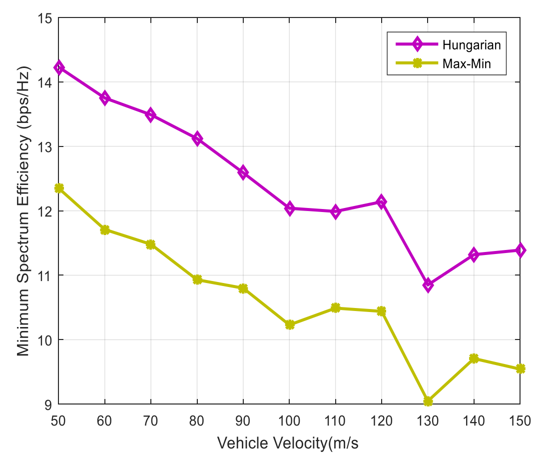

***Figure 5:** Spectrum efficiency for varying vehicle velocity*

Figure 5 shows the minimum spectrum efficiency obtained by varying the vehicle velocity. The proposed Hungarian algorithm was again found to have a 17.35% better performance compared to the max-min algorithm.

5 CONCLUSION

In this paper, the channel and power allocation problem were formulated for a mm-wave D2D-enabled vehicular network undelaying cellular network to optimize the outage probability and spectrum efficiency. The cumulative density function of I-UEs by considering the SINR of the VUE received signal showed that increasing the number of I-UEs and VUEs improved the outage probability. This implies that the densification of users can enhance the reliability of a vehicular network. Besides, the Hungarian algorithm was proposed to solve the formulated resource allocation problem. It was shown that when the maximum spectrum efficiency was considered, the Hungarian algorithm had a 10.8% better performance than the max-min algorithm. When the minimum spectrum efficiency obtained for the I-UEs was considered, the Hungarian algorithm showed a 17.35% better performance than the max-min algorithm.

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