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Power Optimization for Spectrum Sharing in Vehicular Networks

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Abstract: ***The main goal of vehicular communication is to provide a more safe and efficient vehicular operation. The challenge in a Vehicle-to-Everything (V2X) network is to provide reliable connectivity for the Vehicle-to-Vehicle (V2V) links and high data rate connectivity for the Vehicle-to-Infrastructure (V2I) links at the same time. This requirement leads to spectrum sharing in vehicular communication. As the vehicular systems increases, the transmit power levels increases in the environment which in turn causes harmful effects on the atmosphere. The objective of this paper is to analyze the graph-based spectrum sharing algorithms that are available for vehicular communication and to develop a power optimization algorithm based on Hidden Markov Model (HMM) and to incorporate it into these algorithms in such a way to achieve better sum capacity for the V2I links along with a guaranteed reliability for the V2V links.***

Keywords: ***V2V, V2I, resource allocation, power optimization.***

I. INTRODUCTION

Vehicular communication is a technology using which vehicles can communicate with the moving parts of the traffic around them. The main purpose of V2X technology is improving road safety, energy saving and traffic efficiency on the roads. While using this technology, the V2X systems can convey important information to the driver like information regarding inclement weather, accidents that has happened in nearby places, road condition in which the vehicle is travelling and various other dangerous activities of the nearby vehicles.

The physical and medium access control (MAC) layers of the vehicular networks were originally made for low mobility networks. This leads to various issues in the network [8], [9]. These issues are addressed by recent projects of 3GPP which uses long-term evolution (LTE) networks for the vehicular communication. For management of the radio resources in vehicular networks, algorithms that adapt to the large-scale fading of the vehicular channels has to be considered [7]. The sum capacity of the V2I links and the reliability of the V2V links can be maximized by considering the channel state information (CSI) that is feedback periodically [6]. To reduce the signalling overhead in the vehicular networks, slow fading CSI based resource allocation scheme has been developed in [1]. To make maximum use of the available spectrum and to improve the wireless networking, spectrum sharing with cognitive radios can be used [10]. Vehicular communication can also be supported by macro cellular links and localized D2D links [2]. To meet the demands of the upcoming wireless scenario, optimization of resource allocation is an important criterion [3], [4], [5]. This paper mainly concentrates on optimization of the graph-based resource allocation algorithms for vehicular communication.

II. SYSTEM MODEL

The system model considered for this paper is shown in Fig.1. This figure represents a D2D based network consisting of several V2I and V2V links. The V2I links are commenced by the antenna in the vehicles with the infrastructure around it. These V2I links are used for high data rate applications which includes cloud access, media streaming and social networking. To assist these applications, the V2I links requires large capacity uplink connection with the base station. The V2V links are commenced in between different vehicles in a vehicular network to exchange the safety messages. Hence the reliability of these links is important.

A group of V2I and V2V links are considered and the total bandwidth available is split into L number of resources blocks (RB). The number of V2I links and V2V links are taken as M and K. For simplification, the number of RBs and the number of V2I links are considered to be equal. So that each V2I link can use a single resource block. The spectrum is orthogonally allocated for the V2I links. Since the V2V links are less intensive, the spectrum allocated for the V2I links can be shared with the V2V links. This spectrum sharing would enhance the spectrum utilization and the interference caused due to this spectrum sharing will be manageable.

In practical scenario, the V2V links will be more than the V2I links in a vehicular network. Taking this into consideration, we can reuse a single resource block that is allocated for a V2I link among multiple V2V links. Another consideration taken into account is that the channel state information of the links which come in contact with the BS are estimated fully at BS. The CSI of the V2V links will be estimated by the mobile receivers and then periodically transmitted to the BS. This will lead to signaling overhead and tracking the instantaneous CSI will become infeasible. Hence to overcome this issue, another consideration is made where only the slowly varying large-scale fading of the mobile channels are accessible by the BS.

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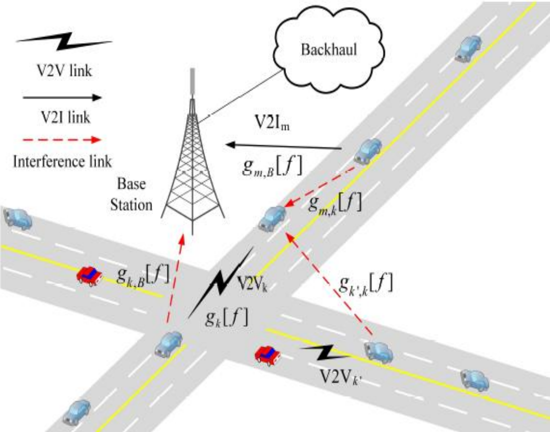

Fig.1. D2D based vehicular network

III. SPECTRUM ALLOCATION

A. Baseline graph-based resource allocation

The baseline resource allocation algorithm involves in partitioning the V2V links into various clusters based on mutual interference. The interference caused in between the V2V sets are minimum. The links in each cluster share the same spectrum but V2V links in different cluster cannot share the spectrum. The resource allocation is formulated as a weighted 3-D matching problem where the V2I links, V2V links and resource blocks are considered as the vertices and the edge weights of the graph are formed by the capacity of the V2I links.

The Fig.2 represents the interference management among the vehicular links. Each vertex represents a V2V link and the edges joining the vertices represent the mutual interference in between them. The weight of the edge is set based on the level of interference which is determined by the large-scale fading CSI of the interfering channels. The main aim of the V2V partitioning is to divide the stringently interfering links into different groups and allow the remaining links to share the resources so that the intra-cluster interference is minimized.

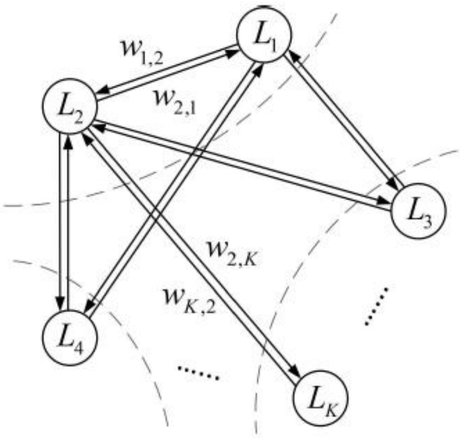

Fig.2. Graph representation of interfering links

B. Greedy resource allocation

The greedy resource allocation algorithm in based on the baseline resource allocation algorithm which will improve the system performance. In the greedy resource allocation algorithm, the initializations are made same as the before algorithm and then for each V2V link, the best cluster is chosen sequentially in such a way that the sum V2I capacity is maximized. This is repeated for several times until the time bound or convergence is achieved.

C. Randomized resource allocation

The resource allocation is formulated as a combinatorial problem. When solving the greedy resource allocation algorithm, it tends to get trapped at the local optimum, which might be far away from the global optimum due to the combinatorial nature. This problem can be sorted by the randomized algorithm. In the randomized resource allocation algorithm, based on the probability related to the achieved sum capacity, the V2V links will be allowed to join a suboptimal cluster. In the randomized approach, each entry (W) is amplified by some factor T as

$$W = \exp(T.w) \qquad (1)$$

This is done in order to achieve large entries such that when it is transformed into probability distributions, these large entries will lead to large probabilities. A change in the parameter T will take place for each sweep of the V2V links. This will avoid being trapped at the local optimum and will make the process more stable. Hence this algorithm might lead to a local optimum and works well in practice. To reduce the signaling overhead the resource allocation with slow fading CSI can be considered. Though the fast fading CSI of the links are available such information is not considered for resource allocation.

IV. POWER OPTIMIZATION

This section describes the proposed optimum power allocation scheme using Hidden Markov Model for resource allocation in vehicular communication.

Power Optimization has gained a major concern in the upcoming technological scenario as there are many health hazards that are caused due to the increased power levels in the environment. This also disturbs the ecological balance of the atmosphere. Spectrum sharing along with power optimization can increase the spectrum efficiency of the network. Hidden Markov Model (HMM) is a probabilistic method in which the system being modeled is considered to be a Markov process with hidden states. The objective of the HMM model is to learn about the hidden Markov process by observing the other process which is dependent on it.

The Hidden Markov Model is based on the maximum likelihood criterion. The maximum likelihood criterion can be evaluated by:

- Count all possible states
- For given each state sequence the probability of the observed data is calculated.
- Based on the probability of the state sequence, find the average of the weights of the results.

In the optimum power allocation design, it is attempted to find the optimum power control for both the V2I and V2V links. To implement power optimization using hidden Markov model, we consider a general Markov model with *n* distinct states such as *n1*, *n2*, *n3*, *n4*. The change in state of the system occurs when there is a change in the transition probabilities associated with it.

To know about the power allocation at a particular instant, the statistics of the preceding states must be known.

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So, the conditional probabilities of the past events are given as:

$$P\,(Pt|Pt\text{-}1, Pt\text{-}2, \ldots, P1) \quad (2)$$

The assumption considered for the first-order Markov model is that the probability of an event at a particular instant depends only on the immediately preceding state. The conditional probability is given as:

$$P\,(Pt|Pt\text{-}1) \quad (3)$$

In the power allocation design, the parameters considered for the system model are SINR, noise power and the channel from V2I to V2V links. These parameters are considered as stochastic processes. At a particular instant t, for a particular observation Qt, the conditional probability is given as:

$$P\,(Pt|Qt) = \frac{P\,(Qt|Pt)\,P\,(Pt)}{P\,(Qt)} \quad (4)$$

The likelihood is determined by neglecting the probability in the denominator P(Qt).

V. RESULT AND DISCUSSION

This section presents the simulation results of the various graph-based algorithms for resource allocation in vehicular networks. The simulation results are obtained using MATLAB software. The system model considered has a BS located at the center of the cell and the vehicles are placed on the road based on the Spatial Poisson process and the vehicle speed is used to determine the vehicle density in the network. The major parameters for the simulation are listed in Table-I.

Table- I: Simulation Parameters

Parameters	Value
Carrier frequency	2 GHz
Bandwidth	10 MHz
Cell radius	500 m
Distance from BS to Highway	35 m
Absolute vehicle speed	70 km/h
Number of lanes	6
Lane width	4 m
SINR threshold	5 dB
Reliability for V2V, p0	0.01
Number of V2I links, M	10
Number of V2V links, K	30
Noise power	-114 dBm
Maximum power of V2I and V2V	23 dBm
Shadowing standard deviation for V2I	8 dB
Shadowing standard deviation for V2V	3 dB

A comparison of CDF of the instantaneous sum V2I capacity achieved by all the three graph-based algorithms is presented in Fig.3. This describes the capacity of the V2I links without power optimization. We can observe the capacities of the sum V2I links for various algorithms from the Fig. 3.

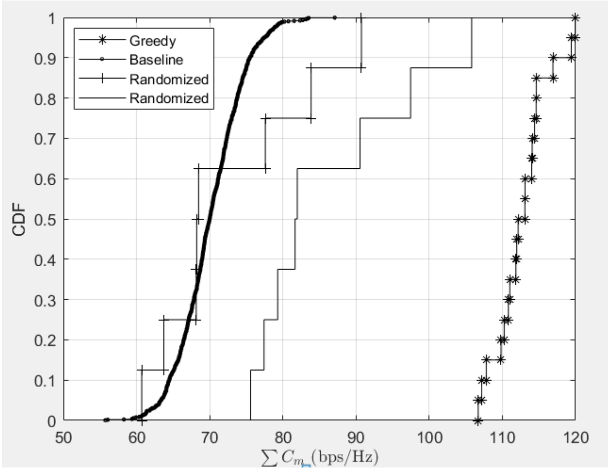

Fig.3. CDF of instantaneous sum V2I capacity

The benchmark considered for the sum V2I capacity is the CROWN scheme which provides a sum V2I capacity of 50 bps/Hz. When comparing the results obtained with the benchmark scheme, a maximized capacity of the V2I links is observed. The greedy algorithm which was built on the baseline algorithm shows a maximized capacity than the baseline algorithm. The randomized algorithm also has an improved capacity than the baseline scheme but not as the greedy algorithm. The Fig.4 demonstrates the comparison of the sum V2I capacity with power optimization. When comparing this graph with the Fig.3 which represents the sum V2I capacity without optimization, it is observed that even after optimizing the power the capacity of the V2I links has not varied drastically. The capacity of the V2I links are maximized when compared with the benchmark scheme.

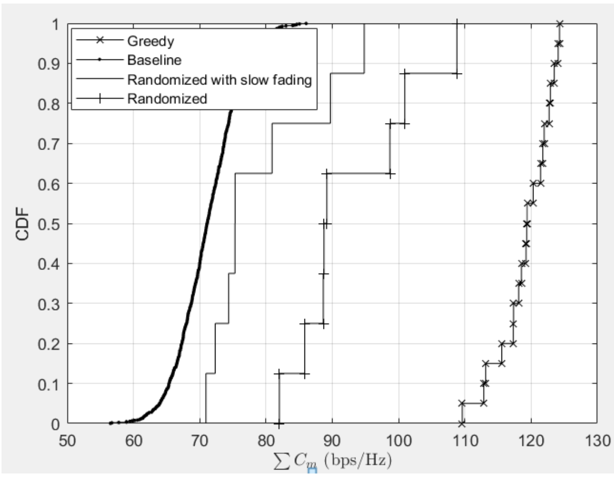

Fig.4. CDF of instantaneous sum V2I capacity with power optimization

The Fig.5 demonstrates the CDF of the instantaneous SINR of the V2V links. From this figure the reliability of the V2V links can be observed. Since the V2V links are used to transfer the safety messages between vehicles, examining the reliability of these links are very important. To ensure the reliability of the V2V links, a threshold value for the SINR is considered.

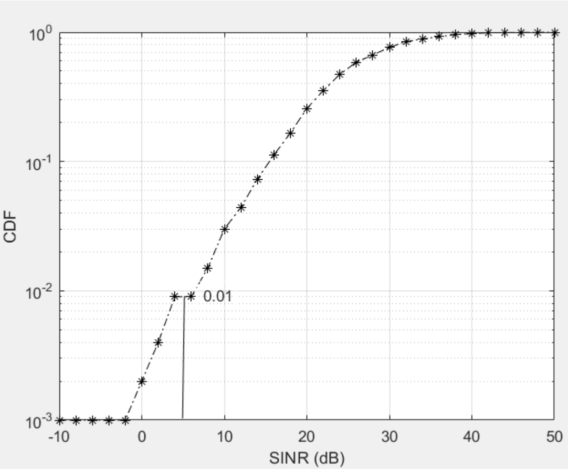

Fig.5. CDF of instantaneous SINR for V2V links with power optimization

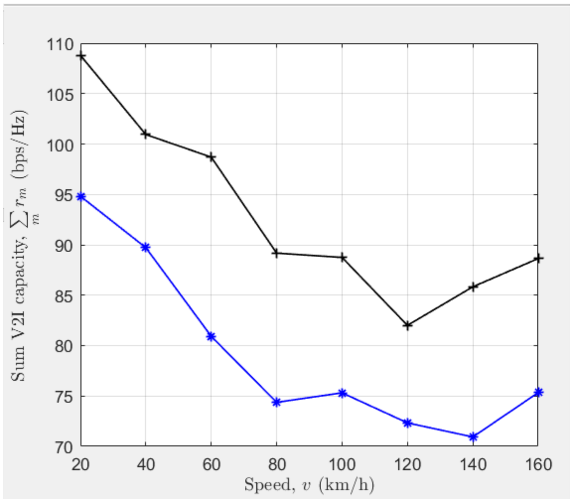

Fig.6. Sum V2I capacity with varying vehicle speed

The SINR threshold is 5db at the targeted outage probability of p0=0.01. All the analysed algorithms have achieved this consideration and guarantees the reliability of the V2V links. The Fig.6 represents the sum V2I capacity with varying vehicle speed for the randomized algorithm and randomized algorithm with slow fading CSI. From this graph we can observe that the capacity of the V2I links decreases as the speed increases. This is because the vehicle speed is related with the traffic in the highway.

VI. CONCLUSION

The power optimization using HMM model for the resource allocation schemes in a D2D based vehicular network has been studied and implemented in this paper using MATLAB software. The graph-based resource allocation schemes such as baseline algorithm, greedy algorithm and randomized algorithm which divides the V2V links into spectrum sharing clusters with minimum interference were analyzed and HMM model-based power optimization scheme has been developed for these algorithms. The parameters such as sum V2I capacity and the reliability of the V2V links were analysed for baseline algorithm, greedy algorithm and randomized algorithm. The performance of the three algorithms along with power optimization was also observed. From the results obtained it is obsreved that the reliability of the V2V links is guaranteed since it achieves the targeted outage probability of po=0.01 at the SINR threshold of 5dB. And the sum V2I capacity of the graph-based algorithms along with power optimization has a maximized capacity when compared with the benchmark CROWN scheme.

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