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Improved Spectral Efficiency and Connectivity in RSMA based 5G V2X Systems

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Abstract

Vehicle to everything (V2X) faces several challenges including high data rate, low latency and stable connectivity requirements. Due to increased number of connected vehicles, Interference too appears to be a serious issue in V2X systems. Consequently, careful selection of multiple access techniques can lead to improved interference mitigation together with higher spectral efficiency and data rate. Vehicle mobility with growing traffic density is a demanding task that affects probability of vehicle connectivity, thereby resulting into requirement of sustained vehicle linkage for ongoing traffic safety. In this regard, our paper employs Rate Splitting Multiple Access (RSMA) technique, which considers change of both channel strength and direction for improved interference mitigation leading towards enhanced spectral efficiency. RSMA is optimized for weighted sum rate, further; it is integrated with mobility management to demonstrate sustained connectivity in the presence of increased traffic density. Presented results have been found promising, both in terms of spectral efficiency and stable connectivity. RSMA 5G V2X outperformed at higher Signal to noise ratio (SNR) values and on average achieved 25% better spectral efficiency compared to Non Orthogonal Multiple Access (NOMA) technique.

Keywords: Rate Splitting, Multiple Access, V2X, Spectral Efficiency, RSMA, Connectivity

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1. Introduction

5G allows higher data rate corresponding to enhanced mobile broadband (eMBB), low latency through ultra-reliable low latency communications (URLLC), and ability of good connectivity through massive machine type Communications (mMTC) features. In addition, 5G system offers many advanced services allowing greater safety on roads [1]. However, 5G V2X traffic is significantly variable due to continuous change in number of vehicles and their position. Accordingly, 5G V2X systems demand large spectrum to cater for huge density of connected vehicles to support rapid traffic growth. However, simultaneous usage of limited resources (spectrum) by large number of users pose significant issue, especially data loss due to increased collisions, and higher level of delays thereby hurting the key low latency requirements, etc. Resultantly, traditional orthogonal multiple access techniques (OMA) have shown their limitation especially in high mobility scenarios. To mitigate the detriments of OMA, Non Orthogonal Multiple Access (NOMA) approach which considered both unicast and broadcast transmission modes has been presented in [2]. NOMA benefitted from Power superposition technique to show its better performance compared to OMA, [3]. NOMA has also been applied in to 5G NR V2X through grouping of users in the manner to improve the spectral efficiency [4]. Research also employed Ergodic Rate criterion in to NOMA V2X context following a full duplex communication to reduce collisions and interference [5]. Rate splitting multiple access (RSMA) is a flexible and robust multiple access scheme which relies on rate splitting at the transmitter and successive interference cancellation (SIC) at the receiver [6, 7]. RSMA enables resource sharing in non-orthogonal way based on message division on the transmitter side against a decoding process performed by successive interference cancellation. RSMA is found to be a prominent multiple access technique for connectivity improvement through better spectrum exploitation. It has shown its flexibility with different technologies in which the transmitted symbol is split into common and private parts, whereas the later follows unicast transmission [8].

Mobility too is a challenging issue for resource allocation highlighted by a change of vehicles velocity through time. In addition, mobility leads to channel variance thereby resulting into issues of connectivity [9]. Apart from the fact that vehicles in V2X systems require reliable communication through efficient resource allocation with low level of latencies, vehicles connectivity issue is imminent at increased mobility [10]. In this paper, we incorporated RSMA into V2X in optimised way to improve weighted sum rate following a downlink transmission leading to interference mitigation, thereby resulting into improved spectral efficiency. We also aimed our research at connectivity improvement in downlink scenario using RSMA through efficient spectrum exploitation. The rest of the paper is structured as follows. Section II presents mobility and connectivity modelling in the context of RSMA based 5G V2X system. Section III provides brief overview of simulated environment followed by results and discussion before paper is finally concluded in section IV.

2. Mobility and Connectivity Modelling

V2X communication requires huge data rate for efficient execution of advanced services, accordingly high traffic density coupled with mobility impacts the connectivity and communication reliability. Mobility is an important criterion to evaluate the performance of vehicular network since it has an impact on resource assignment plus management too.

Since the alerting messages are time sensitive and should reach timely to all vehicles cooperating in the group to avoid occurrence of accidents, thus in our modelling RSMA is integrated as efficient multiple access technique followed by a multicast context. We consider a scenario where vehicles are randomly positioned and the transmitter is equipped with RSMA, which is applied in downlink scenario considering diverse mobility levels of the different users. The implementation actually integrates RSMA approach into an heterogeneous network including users with different mobility profiles considering Rician fading channel.

Figure 1 represents a multiple input single output (MISO) RSMA based 5G V2X System. Following a highway context, composed of one transmitter and two receivers. Accordingly, the received signal at the v_{th} vehicle can be represented by Equation 1:

$$Y_v = h_v^H x + n_v \tag{1}$$

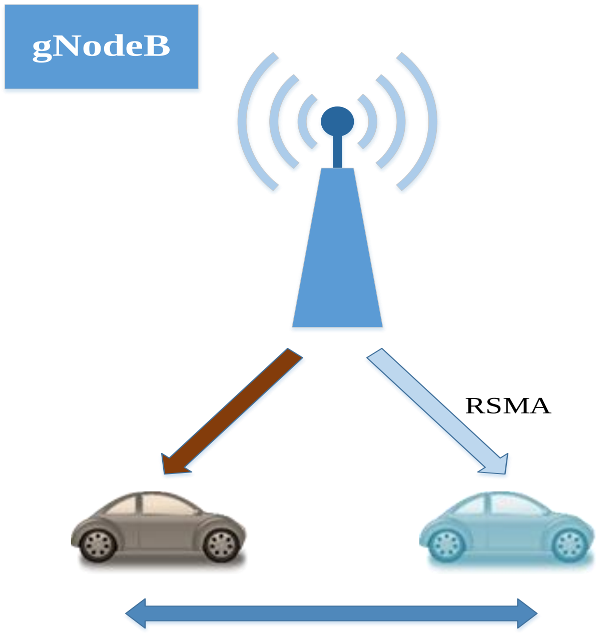

Figure 1. RSMA 5G V2X System

The set of vehicles is denoted by V ={1,…,v} distributed in random way. The noise experienced by the v_{th} vehicle is represented by n_v, and x stands for the transmitted signal; h_v^H corresponds to channel gain of the v_{th} vehicle. Since RSMA is based on dividing the transmitted signal into common and private parts, where later one is enabled by the linear precoding process [11], Equation 2.

$$X = p_c e_c + \sum_{v+1}^{V} p_v e_v \tag{2}$$

Where p in Equation 2 is the linear precoding matrix in which p_c relates to common part of the linear precoding process and p_v corresponds to the private one. On the same lines, e_c is the common transmitted message and e_v is the private one. At the receiver, the decoding process starts by decoding the common part under the assumption of private information as noise enabled by Successive Interference Cancellation. This allows a subtraction process towards the common information in the way to allow each user to decode corresponding message and eliminate the other under the assumption as noise [9]. Following on, the achievable data rate of the common information into the receiver side is represented by Equation 3.

$$R_c = \log_2\left(1 + \frac{|h_v^H p_c|^2}{\sum_{j=1}^{V} |h_j^H p_j|^2 + \sigma_{n,v}^2}\right) \tag{3}$$

Similarly, the data rate related to private information is represented by Equation 4.

$$R_v = \log_2\left(1 + \frac{|h_V^H p_v|^2}{\sum_{j=1}^{V} |h_j^H p_j|^2 + \sigma_{n,v}^2} \right) \quad (4)$$

The allocated data rate of the v_{th} vehicle thus is denoted by G_v, Equation 5 below.

$$\sum_{v=1}^{V} G_v = R_c \quad (5)$$

This gives the overall achievable data rate of the v_{th} vehicle R_v as follows, Equation 6:

$$R_v = G_v + R_c \quad (6)$$

Finally the connectivity condition is represented by Equation 7:

$$\sum_{v=1}^{V} G_v \leq \min \{R_{c,1}, \ldots R_{c,V}\} \quad (7)$$

Notably, vehicular connectivity is an important metric to ensure safety on roads. In our investigation, we integrate RSMA as efficient multiple access technique in a multicast context. Mobility and interference represents a serious and challenging issue for vehicular connectivity, especially because connectivity depends on vehicles' behavior such as directivity, localization and velocity. Mobility model impacts the communication efficiency ; although different mobility models could be implemented considering traffic status, however the movement behavior is determined by velocity which is further influenced by road status, including idle, sparsely occupied or busy etc. In our implementation, the mobility of vehicles follow a Random Way point (RWP) model taking into account velocity and pauses status [12]. Each user (vehicle in our scenario) in RWP initially selects one random point as a destination in the area before it starts moving towards destination at a given velocity. Upon arrival at the destination, user stops for time duration T_{Pause} and then selects another random point before it starts moving towards it. This process continues until the chosen mobility cycle is exhausted. RWP is exploited to characterise the mobilty of vehicles ranging between 0 and 2π considering a multiple input single output MISO context, and directivity is characterised by variance of channel gain following the velocity together with vehicles behaviour. Since connectivity depends upon the distance between vehicles, this places the component of distance an influencing parameter to assess vehicles connectivity.

The high mobility of Vehicles can lead to increasingly dynamic communication link. Our scenario is composed of V vehicles with the distance between vehicles denoted by e_v ; hence, the connectivity is established whenever $e_v \leq e_{threshold}$ which provides the probability of connectivity P_{Conn} expressed by :

$$P_{Conn} = \Pr(e_1 \leq e_{threshold} ; e_2 \leq e_{threshold} ; \ldots \; e_V \leq e_{threshold}) \quad (8)$$

In addition, since we assumed poisson distribution for vehicles interarrival, subsequently e_v is transformed into:

$$P = \prod_{v=1}^{V} \Pr(e_v \leq e_{threshold}) \quad (9)$$

3. Results and Discussion

MATLAB is used to perform simulations and results are obtained following a highway scenario with 11 Km of length which consists of one gNodeB equipped with four antennas and vehicles with each having one antenna. The gNodeB transmitted power is about 46 dBm compared to 26 dBm transmit power of vehicles. Vehicles, are randomly distributed, and they exchange alerting messages following 20m of separating distance among themselves. Implementation employs RWP, thus at each activity the Vehicles follow a random directivity between (0, 2π) together with a random localization (x, y). We consider 10.000 channel realizations following a Rician channel with the K factor value together with a noise variance of 1. Implementation is aimed towards results to highlight the efficiency of RSMA based 5G V2X in two ways, i.e. increased spectral efficiency compared to NOMA as well as sustained connectivity against varying velocity (40 – 80 km/h) in the presence of increased traffic density. System parameters are listed in Table 1 below.

Table 1. System Parameters

Parameter	Value
Road Length (Vehicles coverage area)	11 km [5]
Vehicle Velocity	40-80 km/h [6]
Transmit Power	46 dBm (gNodeB), 26 dBm (Vehicles) [5]
Average distance between vehicles	20 m [5]
Mobility model	RWP [12]
Vehicles InterArrival	Poisson distribution

Figure 2 shows the dominance of RSMA based 5G V2X over NOMA especially at high values of SNR. Clearly RSMA based 5G V2X provides a larger SNR working range than NOMA. RSMA compared to NOMA, provides better vehicular communication method due to the fact that the resources assigned to vehicles follow a splitting process at the transmitter, thereby enabling several vehicles to employ same sub channel to entertain communication. In our implementation, RSMA is further optimised in terms of weighted sum rate, thereby offering complexity minimization, reduced latency, better interference mitigation leading towards imrpoved spectral efficiency. RSMA 5G V2X outperformed NOMA and on average achieved 25% improved spectral efficiency compared to NOMA at higher SNR values (14-20 dB).

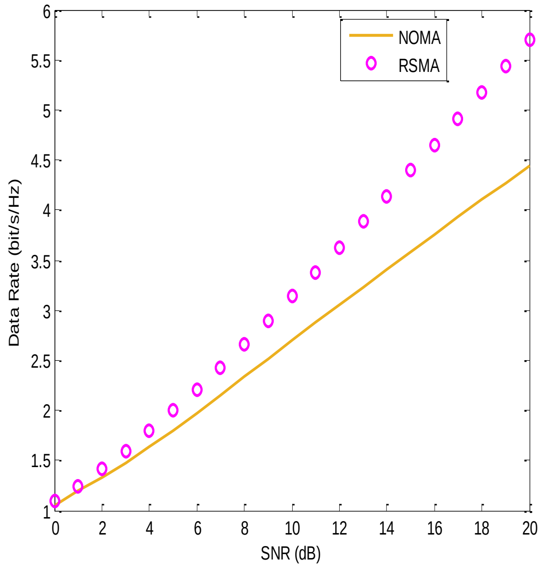

Figure 2. Spectral Efficiency comparison

Due to high vehicular mobility, the changing velocity leads to change in Doppler frequency which impact vehicles' communication as well as connectivity. Traffic safety can suffer due to any sort of data latency and lack of seamless connection. It usually requires stable connectivity to enable vehicles exchange awareness messages in almost real time. To accomplish the same, RSMA is found to be an heuristic solution towards subtle vehicular connectivity. RSMA based 5G V2X system allows vehicles to benefit from efficient utilisation of spectrum together with better connectivity and increased spectral efficiency; consequently, the probability of connectivity in RSMA based 5G V2X system increases with increased traffic density, Figure 3.

4. Conclusion

Interference among vehicles in V2X system is inevitable due to increased traffic mobility and density. Varying vehicles' velocity and increased mobility further generates the issue of sustained vehiclular connectivity. Vehicles in 5G V2X systems must communicate reliably without loss of data, and timely to share their position as well as location related information for road safety applications. Traditional orthogonal and non orthogonal multiple access techniques have demonstrated their limitations to ensure quality of service and reliable communication among connected vehicles, thereby harming the very requirements of road safety. Rate splitting mutliple access technqiue has emerged to be a promising technqiue due to its complexity minimization, reduced latency and improved interference mitigation. RSMA is flexible access solution to be able to manage dynamic conditions in V2X setting. This paper implements optimised RSMA in the context of weighted data sum rate thereby providing significantly improved data rate (spectral efficiency) compared to NOMA. RSMA on average has resulted into 25% better spectral efficiency at higher SNR values. Paper also models RSMA with the random way point mobility and presents that the probability of connectivity in RSMA based 5G V2X systems is sublte and increases with increased traffic density. This somehow sustantiates RSMA as a viable technique for 5G based V2X systems in terms of improved spectral efficiency and better connectivity.

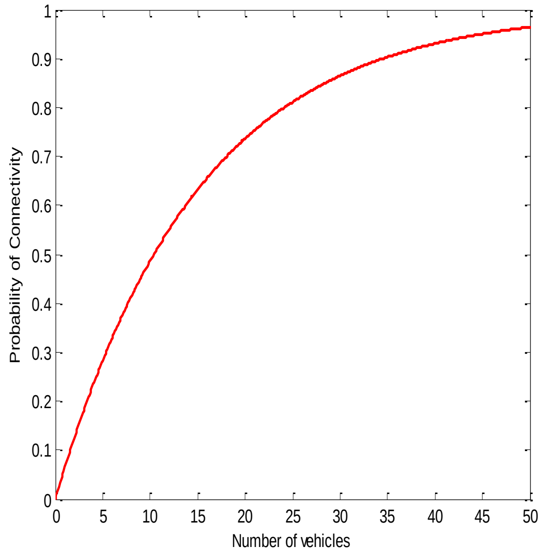

Figure 3. RSMA based 5G V2X Connectivity

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