Intelligent Vehicle Network Routing With Adaptive 3D Beam Alignment for mmWave 5G-Based V2X Communications

Iftikhar Rasheed, Fei Hu, Yang-Ki Hong, and Bharat Balasubramanian

***Abstract*— 5G-based millimeter Waves (mmWave) systems have the prospective of enabling > 1*Gbps* communications in the Intelligent Transportation Systems (ITS). ITS relies on vehicle-to-everything (V2X) communications to share information among vehicles. However, the V2X Communications via existing technologies such as DSRC, 3G, 4G and LTE, are not able to achieve such a high data rate. Although 5G-based mmWave can support ultra-low-delay V2X transmissions, it comes with beam alignment difficulties as well as the routing stability issues due to rapid mobility of vehicles. The dynamic vehicle traffic causes frequent beam misalignment which tends to degrade the quality-of-service (QoS) performance. In this paper, we first propose a 3D-based position detection scheme for beam alignment/selection purpose. Then a group-based routing algorithm is performed to select a secure path for achieving trustworthy data transmissions. The road traffic is automatically segmented to divide the vehicles into different groups, and each group head is selected and members are added. Group members are authenticated by the group head via elliptic curve algorithms. Huffman coding is performed to compress the data and encrypt the binary files. This proposed novel intelligent beam control and secure stable routing scheme have been verified in simulations to demonstrate much better performance than existing schemes.**

***Index Terms*— ITS, vehicle to everything communications (V2X), beamforming, routing, security, 5G millimeterWave (mmWave).**

I. Introduction

INTELLIGENT transportation system (ITS) desires a high-speed Vehicle-to-everything (V2X) network as the data infrastructure. The fifth-generation (5G) communication has been proposed to provide high data rates, minimize the latency and support Quality of Service (QoS) [1], [2]. Communication capacity of 5G can be significantly increased by using millimeterWave (mmWave) technique that is able to meet the increased traffic demands [3]–[5]. 5G mmWave supports $> 1Gbps$ of data rate. When using Multiple-Input-Multiple Output (MIMO) technique, it can achieve massive high-capacity communications. However, it is challenging to perform beam alignment in 5G mmWave systems [6]. Due to its high frequency (typically 30-60GHz), sharp beams with small angles are needed for directional transmissions (Tx) or receptions (Tx).

5G mmWave has been predicted for use in V2X applications [7], [8]. V2X often uses multi-hop communications to enable multiple vehicles to form a mesh network. Today V2X communication is typically achieved by means of Long Term Evolution (LTE) and Dedicated Short Range Communication (DSRC) [9], [10]. The LTE can cover a much larger area than DSRC.

Secure V2X data exchange is important before the social acceptance of mmWave-based communication method [11]. Some of the V2X safety applications include emergency stop, warning messages, emergency collision warning, pre-crash warning, pedestrian warning and others. General safe V2X communications via the graph-based encoding and joint belief encoding has been proposed in [12]. In [13] V2X network access probability has been computed. The distance between two vehicles is considered as a significant metric in such a probability derivation. So a lot of researchers looking into embed the security elements into V2X data exchange.

V2X routing with mmWave links requires carefully designed beamforming techniques [14]. Beamforming also helps to enlarge the overall network capacity. A Multimedia Broadcast Single-Frequency Network (MBSFN) that uses multiple antennas [15] has been proposed. This beamforming method enhances the Signal Interference Noise Ratio (SINR), reliability and decreases latency. Beamforming can be broadly classified into two types, i.e., switch beamforming and adaptive beamforming [16]. The turning-on of unnecessary beams can lead to inter-beam interference. By using the channel quality indicator, the beams can be dynamically controlled by switching to ON or OFF in the proper time instants. By running channel estimation algorithm, the network can achieve higher link rates. Channel parameters can then be computed by using two-dimensional discrete Fourier transform [17]. Those parameters help to align the mmWave beams properly.

Previous works suggested that routing quality-of-service (QoS) performance significantly relies on beam alignment effects in mmWave systems [18]. Our work aims to achieve high-throughput, secure routing by integrating

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path search scheme with adaptive mmWave beam alignment strategies. If the beams are not properly aligned, the standard communication protocols such as MAC and routing cannot be performed with sufficient link margin. The current mmWave systems do not have proper beam alignment schemes that enable a communication pair to maximize their channel capacity. mmWave propagation characteristics, together with the vehicle mobility, lead to performance degradation due to Doppler shifts and frequent beam misalignments.

Our V2X routing will include security support to prevent the unauthorized illegitimate vehicles from joining the routing process. Regarding V2X routing security, a Security Credential Management System (SCMS) is proposed. It uses Block chain-based message and revocation accountability [19]. The vehicles are clustered into groups with each group header being responsible for the prediction of the misbehavior. An anonymous group message authentication protocol is proposed in [20]. But those schemes did not integrate with V2X routing in mmWave environment.

Major Contributions: This work has the following 3 features:

- Optimal beam alignment in mmWave 5G for high-capacity V2X communications: Today Road Side Unit is fed with MIMO antennas to support multi-beam high-speed communications. We propose the concept of 3D representation and 3D-based position detection. Then rule-based method is created for the selection of the best beam with respect to channel capacity, Signal-to-Noise Ratio (SNR), and Reference Signal Received Quality (RSRQ).
- Dynamic vehicle routing scheme: Based on the above optimal beam selection results, we then propose a group-based secure V2X routing strategy. Groups are constructed based on the 3 important parameters: distance, vehicle's moving direction and speed. According to the vehicle amount of each group, the groups are split and merged if needed. The selected group head is responsible for the authentication of the group members by using the uniqueness of Elliptic Curve equation. Link-weight-based routing is designed by considering the distance between the neighbors, as well as the direct/indirect trust degree, for the selection of an optimal route to transmit vehicle data. The data is compressed by using Huffman coding technique and the header files are encrypted to achieve secure data transmissions.
- Comprehensive performance test: We then conducted comprehensive simulations and verified that our scheme has higher average data rate with respect to the number of vehicles and velocity of vehicles, compared with existing similar schemes. Particularly, the delivery rate and delay with respect to the number of delivered messages have been used to compare with the Smart Motion-prediction Beam Alignment (SAMBA) Algorithm and the Moving Zone Based Routing Protocol (MoZo).

Organization of the Paper: The rest of the paper is organized as follows: Section II summarizes the previous research works in this area; Section III elaborates the protocols and models of our proposed routing and beam alignment schemes. We then provide our performance analysis in section IV, followed by the conclusions in section V.

II. Related Works

A. mmWave Beam Alignment

mmWave often relies on the Space-Time (ST) alignment to eliminate the effect of beam sweeping [21]. The pilot arrival time is managed by using ST alignment, and then the channels are estimated from the received signals by applying temporal alignment. This method involves complex mathematical computations. Hierarchical Codebook design [22] was proposed for beam alignment with higher accuracy. Multiple-Input Single-Output (MISO)-based operation was the main feature in this work. Beam Alignment Error Rate (BAER) was also calculated by using tree search. However it decreases SNR, and the use of MISO is capable of providing good signals only for a single user. Location-aided beam alignment was performed for mmWave system [23]. Here the position matrix and gain matrix were computed from the input signals. The beams were sorted in descending order after the completion of computation. Position matrix is defined from two-dimensional coordinates.

Another improved method on the selection of the best beam pair was suggested by [24] called Enhanced Binary Search Beamforming (EBSB). In this method the data packet was split into six parts which are sent individually. Stations choose the best sector and store the SNR values that are periodically updated by the station with respect to the sector ID. Although it has higher accuracy, the division of data becomes difficult if just a packet is lost. With the reduced complexity, a Hybrid Beam Forming (HBF) was proposed in [25]. This method involves the computations of SINR and Channel State Information (CSI).

In [26] mmWave based theoretical framework was proposed for highway vehicle communications. In this work the link budget was computed from the theoretical model which takes into account of the communication blockages under varying traffic densities. SINR outage probability and coverage rate play the key roles in this work. SINR outage probability is defined based on the parameters such as antenna gain, thermal noise power, interference and other parameters. Here the SINR threshold value was static, but the values of SINR vary at each location. The QoS performance was studied in multi-lane highway environment [27]. Only vehicle-to-infrastructure (V2I) communication was performed with multi-beam antennas. But the system complexity will be high as multiple base stations participate in the network.

B. V2X Routing

Routing in Vehicular communications is widely studied by many researchers. For example, Wagon Next Point Routing Protocol (WNPRP) was proposed for high-throughput data transmission in the selected route [28]. A next-hop vehicle was chosen through a filtration process. A time counter was set as the threshold by which the packets are either forwarded or dropped. Improper filtration process leads to the

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involvement of malicious vehicles. Therefore, vehicle routing scheme should have security in consideration. Security during data transmission was performed using ID-based signature scheme [29].

A secure network architecture could include RSUs, trusted authority, and vehicles, as assumed in [30]. In such a scheme it has the following phases: initial handshaking, message signing, batch verification, group key generation, group key signing, and verification. Both vehicle-to-vehicle (V2V) and V2I communications can be provided with the authentication by using this scheme. Generation of pseudo identity plays a major role in this authentication scheme. Cuckoo filter [30] can be used to add and remove items. The notification message includes the signature of vehicles, hereby it was known to every vehicle. A novel privacy-preserved authentication scheme was proposed to minimize the communication overhead [31]. This scheme begins with the mutual authentication among Vehicles, RSU and trusted authority. Each Vehicle was authenticated by RSU followed by the trusted authority. After authentication traffic information was transmitted and was also verified by RSU. The authentication process takes certain time and increases the delay in data transmissions.

Secure vehicle routing schemes have been studied in [32], [33]. In these trust-extended authentication mechanism the user was authenticated by their identity and password, hence the unique password can be extracted by advanced hacking technologies. In attribute-based authentication protocol a vehicle is validated by their identity and signature. Data security was achieved by time-efficient asymmetric cryptography which also includes a signature generation algorithm and a pseudo identity generation scheme [34]. However in this method, the receiving vehicle was not able to predict the sender vehicle's identity. All of the above schemes did not consider the mmWave beam alignment issue.

C. mmWave Beam Alignment in V2X Routing

Before our work a scheme called Smart Motion-prediction Beam Alignment (SAMBA) was designed for low-overhead beam alignment [8] in mmWave based V2X communication. The position and motion of the vehicle were predicted for fast beamforming. By estimating the distance and angle, the approximate position of vehicle was predicted. According to the received position the beamforming was aligned and the beam orientation was determined for each vehicle. Such a beamforming process is based on two-dimensional (2D) representation, and the polling channel access method is also used. Due to the use of polling the communication overhead increases. And this method also requires a centralized controller to perform each communication. In another method [35], it supports mmWave V2V communication based on Queue State Information and Channel State Information. This method also follows 2D model for position prediction. The formulation of 2D-based position detection is as follows,

$$P_{pos}(x, y) = \begin{cases} P_{pos}(x) = E_{pos}(x) + \overline{AB}_{pr}\sin(\beta_{pr}) \\ P_{pos}(y) = E_{pos}(y) + \overline{AB}_{pr}\cos(\beta_{pr}) \end{cases} \quad (1)$$

The position can be predicted from β_{pr} angle and AB_{pr} distance between any two vehicles. To perform data transmission, a communication link needs to be established. A radar-aided mmWave MIMO system was designed for V2I communication [36]. In this work the hybrid MIMO architecture was created to support two protocols for establishing the links (1) from a base station to a vehicle, or (2) from a vehicle to another vehicle. However, the link establishment process involves much overhead, and the V2I communications need complex protocols.

Another typical V2X routing scheme, Moving Zone (MoZo) based vehicle management architecture, was proposed for performing a reliable routing [37]. Similarity scores are provided with respect to the average distance at anticipated trajectory for a particular time period. The vehicle with the highest score is the captain vehicle. Captain vehicle creates Combined Location and Velocity Tree (CLV-tree) for the maintenance of information of zone members. If the distances between vehicles are increased then the zone splitting takes place. Furthermore, to avoid zone overlapping, the authors have used zone merging. The involvement of B+ tree requires periodic reorganization and increase of files, which tends to degrade the network performance. Dijkstra algorithm was also used in many works that include Zone-based routing, Beacon Information Independent geographic Routing (BIIR) algorithm and Traffic-aware routing protocol (TARCO) [38], [39]. but they all consumes much time for routing path selection, and fails if negative edges are present.

Location Error Resilient Geographical Routing (LER-GR), addressed the problem of inaccurate location detection [40]. For accurate location prediction and correction, Kalman filter is used in such a scheme. A modified beacon packet is used with the following fields: vehicle id, X and Y coordinates, velocity, timestamp and location error information. This work includes location prediction and correction algorithm. The velocity of vehicle was considered to be constant for a certain time interval. But in reality a vehicle's velocity may not be constant. Hence our solution will target the mmWave-based V2X routing with dynamic topology.

III. Secure mmWave-Based V2X Routing With Adaptive Beam Alignment

A. System Model

The proposed system model in Vehicular Ad hoc Network (VANET) consists of RSUs and vehicles to support both V2V and V2I communications. The major focus of our work is to design an adaptive mmWave beam alignment for high-throughput V2X routing, which uses group-based route selection to perform secure data transmission. The issues that exist in previous research works will be resolved in our work presented here.

Consider a general system model: there exists the participation of n vehicles $Vh = Vh_1,\ Vh_2, Vh_3, \ldots, Vh_n$ moving in opposite direction from West to East ($W \rightarrow E$) and East to West ($E \rightarrow W$). This road lane is segmented segments in accordance to equal distances of 100m, $Sg = s_1, s_2, \ldots, s_N$ into N. RSUs are deployed to support vehicles moving in

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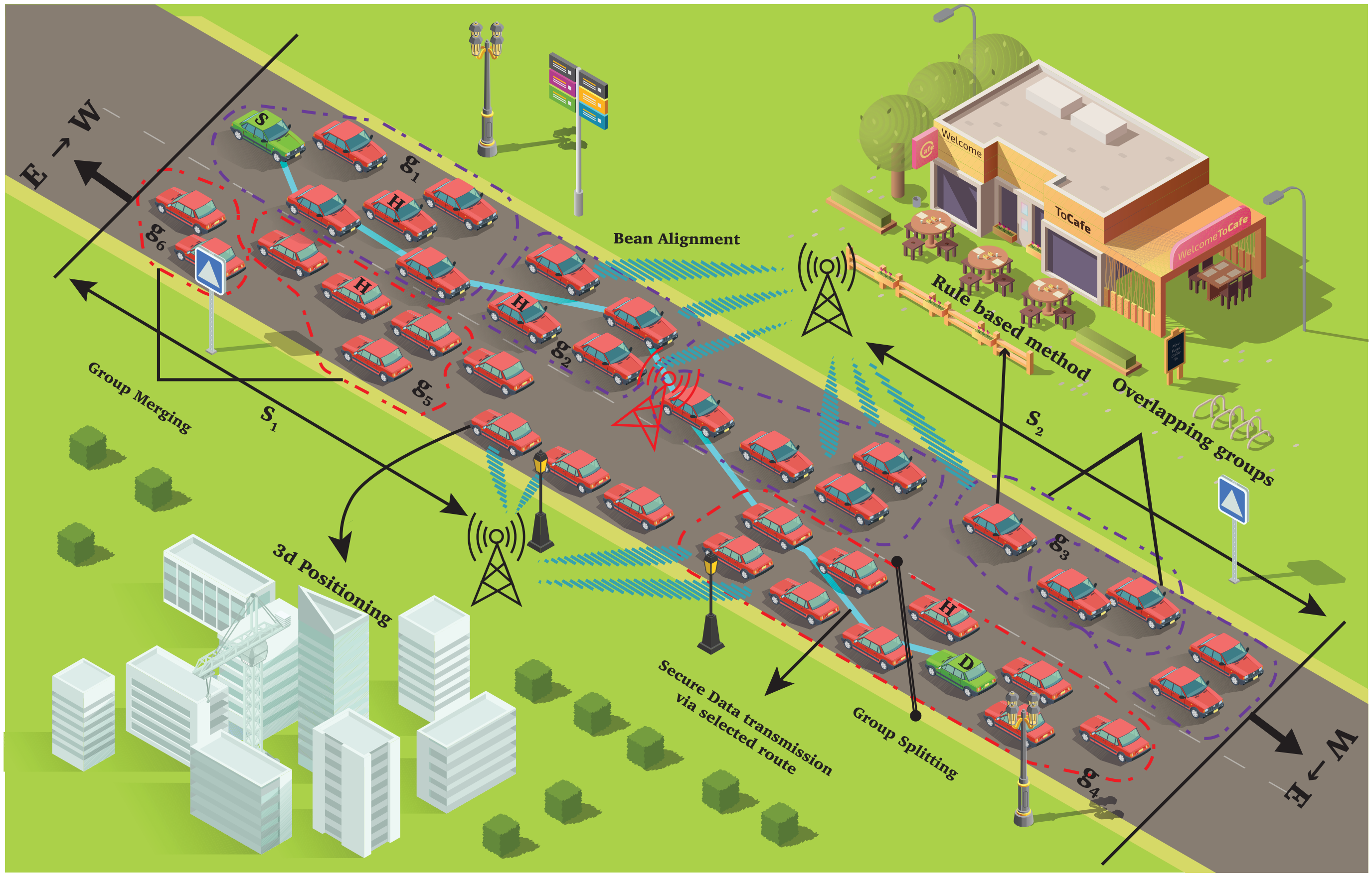

Fig. 1. Proposed system model.

both directions. RSUs are equipped with MIMO technology to provide wireless connectivity to multiple vehicles. We use 3D spherical objects based location prediction for beam alignment scheme.

Fig 1 depicts the proposed system model, which comprised of two segments s_1 and s_2, a set of groups created in two segments as $G = g_1, g_2, g_3, g_4, g_5,\ \ g_6$, each group head, and source (S)/ destination (D) vehicles. Here the group g_4 is comprised of a large number of vehicles. Hence it will be divided into two parts; whereas the two groups $g_5,\ \ g_6$ with small number of vehicles will be merged together. The deployment of MIMO-based RSU enables a vehicle to choose the best beam by using the rule-based method that includes channel capacity, SNR and RSRQ. The vehicles moving on road lane are divided into different groups based on those three parameters. The group(s) can be divided or merged based on the total number of vehicles in each group. Group headers are responsible for choosing a route for data transmission. Vehicles' link weight is used to determine the next-hop relay node. Huffman coding is used for data compression, and the cryptography is used to encrypt the header files. The beam alignment as well as routing scheme will be discussed in the following sections in details.

B. Beam Alignment

A high-throughput mmWave routing scheme requires an efficient beam alignment algorithm. Here we utilize the vehicular's position and velocity information for beam alignment. The position of a vehicle is defined by a 3D representation based on spherical object, which is comprised of three coordinates represented in Fig 2.

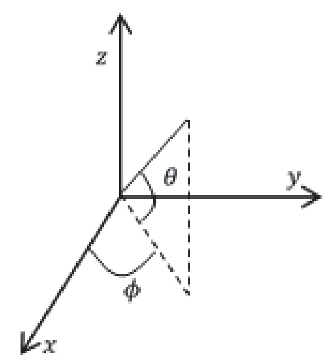

Fig. 2. Spherical coordinates.

To determine the vehicle's position, the distance between two vehicles is computed from the spherical coordinates. Two points of vehicle VP_1 and VP_2 are determined with respect to the latitude and longitude pairs of points, i.e., $VP_1(\theta_1, \phi_1)$ and $VP_2(\theta_2, \phi_2)$. Hereby we compute the spherical coordinates for each point from the following equation,

$$x = Rcos\theta cos\phi \tag{2}$$

$$y = Rcos\theta sin\phi \tag{3}$$

$$z = Rsin\theta \tag{4}$$

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TABLE I
RULES FOR BEAM SELECTION

Input			Output
Channel capacity (Mbit/sec)	SNR (dB)	RSRQ (dB)	
≥ 200	≥ 20	≥ -10	3
≥ 200	≥ 20	≤ -20	2
≥ 200	≤ 0	≥ -10	1
≥ 200	≤ 0	≤ -20	0
≤ 200	≥ 20	≥ -10	1
≤ 200	≥ 20	≤ -20	1
≤ 200	≤ 0	≥ -10	0
≤ 200	≤ 0	≤ -20	-1

Here R denotes the radius, θ defines the latitude over $-90^\circ \leq \theta \leq 90^\circ$, and ϕ represents the longitude between $0 \leq \phi \leq 360^\circ$. Once we determine the spherical coordinates, the distance can be estimated by applying Euclidean distance formula in 3D Pythagorean theorem. The distance is formulated as,

$$D_s = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \tag{5}$$

Based on the estimated distance D_s, a vehicle's position is identified and the predicated position is given as,

$$P_{pos}(x, y, z) = \begin{cases} P_{pos}(x) + D_s R cos\theta cos\phi \\ P_{pos}(y) + D_s R cos\theta sin\phi \\ P_{pos}(z) + D_s R sin\theta \end{cases} \tag{6}$$

After we obtain the predicted position $P_{pos}(x, y, z)$ of the vehicle, the beam orientation can be determined based on the directional antenna pattern by using the parameters of beamwidth and gain. The mathematical computations are illustrated as follows. Hereby the antenna pattern for main lobe is predicted from the determination of gain G_m (in dB) and the maximum beamwidth $\theta_{(max)}$. To extend 2D model to 3D case, the spherical radius of load is given as r, and the gain of the main lobe is formulated as,

$$G_m = \frac{4\pi r^2}{\pi\left(r^2 tan^2\left(\theta_{(max)}/2\right)\right)} \tag{7}$$

Here $\theta_{m(max)}$ represents the maximum beamwidth, which is formulated as,

$$\theta_{(max)} = 2tan^{-1}\sqrt{\frac{4}{G_m}} \tag{8}$$

Based on the detected position of the vehicle, the beams are established with the known lobe gain and beam width. The involvement of MIMO in RSU leads to the production of multiple beams from the antennas. We can then choose a particular beam for V2I communication by using rule-based method. A vehicle is required to communicate with a RSU first, and begins to validate the quality of each beam with respect to the rules defined. Three metrics, i.e., channel capacity, SNR and RSRQ, are used for beam validation. Table I shows some example rules.

A set of rules are fed into the vehicle for beam selection that includes the estimation of the above metrics. The three metrics are formulated as,

$$C_c = B_t \log_2\left(1 + \frac{S}{N}\right) \tag{9}$$

$$SNR = 10\log_{10}\left(\frac{S_{pr}}{N_{pr}}\right) \tag{10}$$

$$RSRQ = R\left(\frac{RSRP}{r_i}\right) \tag{11}$$

The term C_c represents the channel capacity (in dB), B_t is the bandwidth (in Hz), $\frac{S}{N}$ denotes the signal-to-noise ratio, S_{pr} is signal power, N_{pr} represents the noise power, $RSRQ$ is Reference Signal Received Quality (dB), $RSRP$ is Reference Signal Received Power (dB) and R denotes the available resources. Then the beams are aligned based on the received signal strength that is given as,

$$r_i = T_p + G_m - P_l \tag{12}$$

Received signal strength r_i (in dB) computed in equation (12) is based on the transmission power T_p (in dB), antenna gain G_m (in dB) and path loss P_l (in dB). Hence the r_i (in dB) of each beam is arranged in increasing ascending order, and then the beam is aligned with respect to the vehicle's position.

C. Optimal mmWave Vehicle Routing

Routing in V2X networks plays a major role in performing QoS-oriented data transmissions. Due to the mobility of vehicles, the stable QoS performance is desired. To achieve higher throughput performance in routing, we determine the vehicle groups first. The road is segmented and each segment is comprised of vehicles that are grouped. A group example is: $G = g_1, g_2, g_3, g_4, g_5, \ g_6, \ldots$; each group is built with respect to the vehicle's direction D_c, speed S_p, and distance D_s.

Table II illustrates the procedure followed for the construction of groups in each segment. Proper construction of the groups helps to reduce the time consumed for route selection, and also increases the delivery rate. This procedure is performed in each segment to create different groups. In this grouping process the speed, direction and distance play the major role, according to which the vehicles are added to a forward or backward group. The group construction result is then used in the routing process.

In first step of this group construction algorithm the considered vehicle needed to exchange three main parameters for establishing whether that vehicle can be considered for joining certain group of vehicles. These three important parameters are the vehicle's direction D_c, speed S_p, and distance D_s. First of all the vehicle's speed S_p is compared with the minimum speed difference and if it meets this criteria next vehicle's direction $D_c$between the source vehicle and neighboring is found out. If the vehicle's direction D_c matches, further distance D_s between the vehicles is calculated. The distance D_s between source vehicle and neighboring vehicle is compared with the minimum distance difference to check whether the desired vehicles can be placed into the similar groups. If all of these three conditions are satisfied for a particular group a vehicle

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TABLE II
PROPOSED ROUTING ALGORITHM

Pseudo Code – Group Construction

Input - $Vh = Vh_1,\ Vh_2, Vh_3, \ldots, Vh_n$ // The main input to Group Construction algorithm are the vehicles which we are going to group them.
Output - $G = g_1, g_2, g_3, g_4, g_5,\ g_6, \ldots$ // The result of this algorithm is Constructed Group of input vehicles. Here each segment is comprised of vehicles that are grouped. Each group is built with respect to the vehicle's direction D_c, speed S_p and distance D_s.
1. Begin
2. $Vh \rightarrow$ Exchange S_p, D_c, D_s // Vehicles exchange required information needed for the construction of group i.e. S_p is vehicle's speed, D_c is vehicle's direction and D_s is vehicle's distance. Based upon these information Groups are constructed.
3. If
{
{
$(S\ (Vh_1) = S_{min})$ // Speed metric of a vehicle is compared with the minimum speed difference to find out whether the desire vehicles can be placed into the similar groups.
 	
$(D_c(Vh_1) = D_c(Vh_2))$ // Direction metric for two vehicles is compared and if that is in same direction then these vehicles can be added to the similar groups.
 	
$\left(D_s(Vh_1) = D_{s(min)}\right)$ // Distance between source vehicle and neighboring vehicle is calculated and minimum distance difference is found out to check whether the desire vehicles can be placed into the similar groups.
}
Add (Vh_1) in particular group // If all the above conditions are satisfied for a particular group a vehicle is placed in that group.
else
Add in other group which satisfies these conditions
}
end if
4. Construct $g_1 = Vh_1,\ Vh_2, Vh_3, \ldots$ // Constructed group with vehicles which have minimum speed and distance difference and are traveling in same direction.
5. For
{
Each Sg // Construction of groups in segments. Here we group the formed groups into similar segments i.e. road lane segments.
Repeat step 2
}
End for
6. $Sg = s_1, s_2, \ldots, s_N$ // Road lane with segments
7. $s_1 = \{g_1,\ g_2,\ g_3, \ldots\},\ s_2 = \{g_7,\ g_8,\ g_9, \ldots\}, \ldots$ // Each segment with constructed groups. The vehicles moving over the road lane are grouped in their segments for performing routing
8. End

is placed in that group. Otherwise vehicle is added to another group after repeating these previous steps.

Once various groups are formed, these groups are merged into similar segments based upon road lane segments. On these segments which contains various interrelated groups routing is performed.

Each group has a header vehicle that is chosen based on two qualities, i.e., node degree and successful packet rate. Node degree refers to how well a particular node stays connected with multiple neighboring vehicles. Then the successful packet rate SP_r is given as,

$$SP_r(t) = \frac{SP_{s(j,k)}(t)}{SP_{s(j,k)}(t) + RP_{(j,k)}(t)} \tag{13}$$

The successful packet rate at time t can thus be obtained in the above equation (13) by using the number of successful packets sent from vehicle j to vehicle k, during the time t that is represented as $SP_{s(j,k)}(t)$. The number of retransmitted packets from vehicle j to vehicle k at time t can then be represented as $RP_{(j,k)}(t)$. Once we evaluate these two metrics, the group head is chosen which is responsible for the authentication of the group members participating in its group. Assume that all the legitimate vehicles are registered and their information is maintained at the RSU. During registration each vehicle chooses a secret point from elliptic Curve equation which is used for authentication purpose. The curve equation can be written as,

$$y^2 = x^3 - x + 1 \tag{14}$$

Two points Pt_1 and Pt_2 are chosen by vehicles; each point is recommended to the group head by the RSU. Each group head requests the secret value for its group members. The secret value is generated by using *addition* operator as follows,

$$sc_e = (x_1, y_1) + (x_2, y_2) \tag{15}$$

The secret value sc_e is authenticated by the points $Pt_1 = (x_1, y_1)$ and $Pt_2 = (x_2, y_2)$. Once the group has validated the secrecy, it decides whether to include this member or not. Each member in the group is authenticated, and if they are legitimate they participate in that particular group. Furthermore the group head is also responsible for group splitting / merging operations.

Group splitting – Vehicles moving in the same group will have the same direction but may not have the same speed during all time periods. Therefore their moving speed may lead to the enlargement of the distance between neighboring vehicles. Hence, the distantly moved vehicle may be out of the communication range from the particular group. Similarly, other vehicles from other group may join this group instantly. Due to this reason, the vehicles in a particular group are split into two parts. The group head keeps monitoring all the members and maintains the timestamps of the messages being transmitted. Timestamp is used to check whether the current transmission of the vehicles in that particular group has been completed. In case the timestamp is ignored, the vehicle requires the selection of a new route and performs transmission once again in the new route. If the number of vehicles increases to $N(Vh)_{max}$ then the group is split by the head, which itself chooses a new head for that group.

Group Merging – Vehicles differ in their mobility speeds, which may cause the overlap of two groups of vehicles. Such an overlap creates the ambiguity of the management for each group heads and also leads to the issue of communication overhead. If the groups overlap with each other, it becomes difficult for the group heads to provide routes and other requirements to members. Hence the overlapped groups and the group with small number of vehicles are grouped into one group. Once we merge those groups, it becomes more efficient to manage the group members. The numbers of vehicles that are traveling at a minimum distance (i.e. $N(Vh)_{min}$) from the members of neighboring groups, are required to be known before the group mergence. The distances between group members are monitored by the group head which initiates the mergence.

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A vehicle with data packets to transfer to its destination, can request for the available route to its group header, which checks whether the destination is present within the group; else, it searches route by using a neighboring group head. The route for transmission is selected by computing the vehicle's link weight based on the following metrics: distance, direct trust level, and indirect trust level. Direct trust level of a vehicle is computed as follows,

$$DT = \begin{cases} P_{Td}\ \ (j,k) + R_f \\ P_{Td}\ \ (j,k) + P_f \end{cases} \tag{16}$$

The terms $P_{Td}\ \ (j,k)$ is the previous trust level determined between vehicle j and vehicle k, R_f is the reward factor which is predicted based on the number of successful packet transmissions, P_f is the penalty factor which is given due to the unsuccessful packet transmissions. This is followed by the determination of indirect trust level as,

$$IDT = \frac{\sum_{nb} DT(nb,\ \ j) \times Sm(k, nb)}{\sum_{nb} Sm(k, nb)} \tag{17}$$

Hereby the indirect trust is defined by the neighboring vehicles; and $Sm()$ is the similarity between two vehicles. Indirect trust ensures higher security, since this trust value is provided by its neighboring nodes which travel closer for a longer time period. The link weight value between two vehicles j and k is given as,

$$W_{l(j,k)} = D_{s(j,k)} + DT_{(j,k)} + IDT_{(j,k)} \tag{18}$$

Given the estimated values, the link weight is estimated and a secure route is drawn for data transmission.

Furthermore the data are compressed by using Huffman coding technique from which the binary files and header files are generated. This coding technique uses lossless data compression of symbols and alphabets. Data compression is performed with variable-length codes. Consider a data packet to be compressed using this technique. The Huffman tree is constructed based on the occurrence frequency of the data present in the packets. Each character / string in the data packets is subjected to unique bit pattern encoding. Based on the bit pattern the Huffman tree is constructed, and the data is encoded. We can then retrieve the binary file and header file.

Huffman coding helps to create an optimal prefix code tree that is guaranteed to support m number of strings in a data packet. The header file is comprised of unique symbols as per the occurrence, whereas the binary files are comprised of codes for each symbol. The symbol defines the string present in the data packets. The generated binary file is based on the header file. Hence, without the header file, the binary file, i.e., the original data, cannot be retrieved. Table III illustrates the sample bit pattern used for the execution of Huffman coding technique. For the purpose of security, the header files are encrypted by using a session key. And binary files are retrieved only with the support of header files.

The session key is generated based on elliptic curve cryptography. Once the key is generated, the header files are encrypted. This encrypted data is transmitted in the path along with the timestamps. The session key is sent to the destination vehicle by the group head. The public and private keys are used for session keys, and the public key used for encryption is the session key for the source vehicle. The generated session keys are applicable only for a particular time period. In the next transmission period the vehicle should generate new session key. Consider a curve equation,

TABLE III
BIT PATTERN

String	Bit pattern
a	010
c	0011
e	110101
g	0001
f	11110

$$y^2 = x^3 + ax + b \tag{19}$$

From this curve we can define the point P, a prime number Pn, and choose a number g ranging over the selected Pn. The value of g should be equal to 1to $Pn-1$. The public key, i.e., the session key for the source vehicle sk_{SV}, is generated as follows,

$$sk_{SV} = g * P \tag{20}$$

The chosen value of g is the session key used at the destination vehicle sk_{DV}. The data are transmitted and the header files are decrypted by a destination vehicle to retrieve the original data. Hereby the data security is maintained.

IV. SIMULATION RESULTS

In this section, the proposed solutions are evaluated by implementing a V2X simulation tool. The use of mmWave 5G for V2X communication has two important properties, i.e., line-of-sight signal and initial reflection. We define the path loss as,

$$P_{loss} = 92.4 + 20\log f\ \ + 20\log R\ \ + E_{loss} \tag{21}$$

Path loss P_{loss} is determined by the carrier frequency f in Hz, environmental loss of the propagated signal power E_{loss} in dB, and the distance between the sender's transmitter antenna and receiver antenna R in $meters$. The propagation model considered for Highway and Urban model is same as suggested by [35] and [41].

A. Simulation Setup

The proposed architecture is implemented by using OMNeT++ integrated with SUMO traffic model. Such an integration is able to produce a real-world trace which visualizes realistic vehicle movement. This simulation environment supports different modules that are written in C++ language. The standard IEEE 802.11p is included to enable Wireless Access in Vehicular Environments (WAVE). The movement of vehicle with respect to their mobility speed is directed by the traffic simulation tool included in the network files.

The simulation of V2X communication in 5G allows the setup of several parameters listed in Table IV. We evaluate two different scenarios, i.e., urban and highway. According

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TABLE IV
SIMULATION PARAMETERS

Parameters	**Values/Ranges**
Simulation area	5000m×5000m
Road lane	Single lane
Number of vehicles	50 – 100
Number of RSUs	4
Number of MIMO antennas	10×10
Antenna gain	27 dB
Scenario	Urban
	Highway
Standard	IEEE 802.11p
Data time interval	5seconds
Mobility	5 – 50m/s
Packet size	1024 bytes
Simulation time	250 seconds

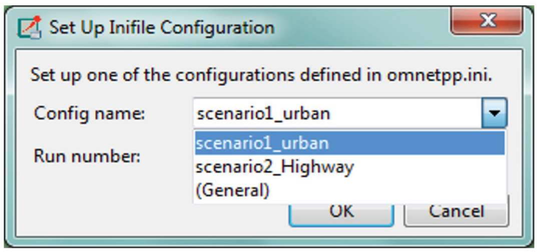

Fig. 3. OMNET++ configurations.

to this simulation, SUMO creates vehicle mobility and constructs road lane network. Then OMNeT++ is used to create configurations of vehicles (Fig.3). To connect SUMO and OMNeT++, we used Veins to define vehicle model in SUMO as a node in the OMNeT++.

The maps are generated based on the two scenarios as shown in Fig 4 and Fig 5, respectively. These scenarios vary in terms of the number of turns in the road lane and the major assumptions followed here are:

1) Highway model used does not include path losses from buildings or any infrastructure loss present in Urban scenario.Thus propagation loss for Highway model is lesser as compare to Urban model.
2) Urban model consists of propagation losses that includes buildings etc. that are presents in the Urban scenario.
3) Channel propagation model used follows the same characteristics defined in [35] and [41]. Path loss is calculated from equation (21). Further simulation parameters can be seen in Table IV.

The proposed beam alignment and secure routing algorithm are tested in those two scenarios. The overall performance shows the variations due to the changes in vehicle densities of each scenario. In the highway scenario, the vehicles mostly have straightforward moving direction, whereas in urban scenario the vehicle density and mobility are more dynamic.

B. Performance Analysis

Conventional schemes such as SAMBA algorithm and MoZo architecture, have some drawbacks mentioned before. SAMBA algorithm was used for beam alignment and MoZo

Fig. 4. Urban scenario.

Fig. 5. Highway scenario.

architecture was designed for performing routing between two vehicles. Here we compare our mmWave routing scheme with those two schemes and investigate the three performance metrics: data rate, delivery rate and delivery time.

We also performed complexity analysis in terms of Delay Time for Number of association Beamforming Training(A-BFT), as the number of non-trained beams (because of collisions etc.) and the Beamforming delay can have adverse effect on the performance of vehicular communications network [35].Therefore we have also tried to analyzed how our proposed method overcome this computational complexity issue present in SAMBA algorithm.

1) Data Rate: Data rate defines the transfer rate of data via the mmWave beams. A collision-free beam alignment helps to achieve higher data rate. To outperform the previous SAMBA algorithm, we have proposed 3D-beam alignment and beam formation as discussed before.

mmWave date rate can be enlarged if using an QoS-oriented routing with proper beam alignment scheme. A comparison on this metric is depicted in Fig. 6, in which the proposed

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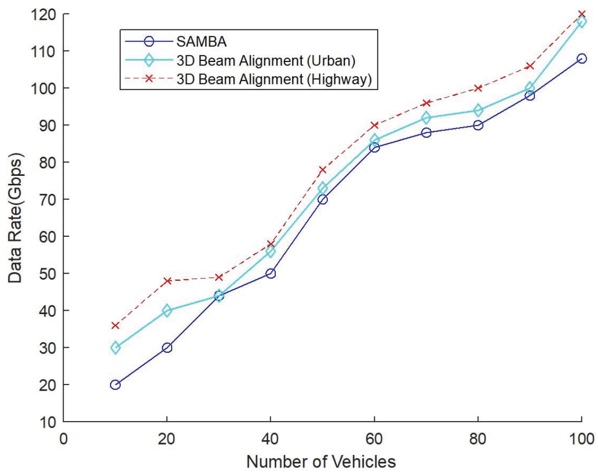

Fig. 6. Comparative results on data rate.

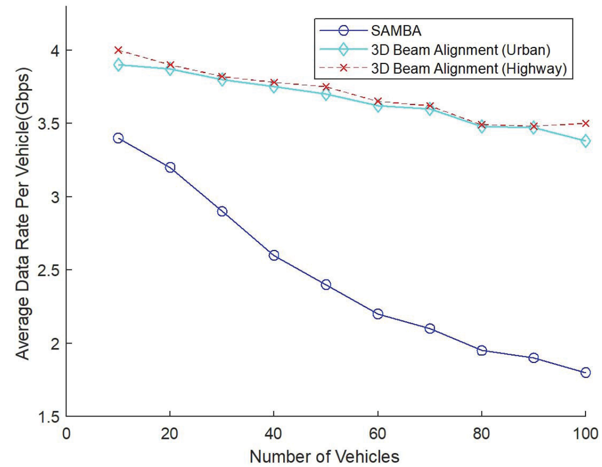

Fig. 7. Comparison on Average data rate per vehicle with respect to number of vehicles.

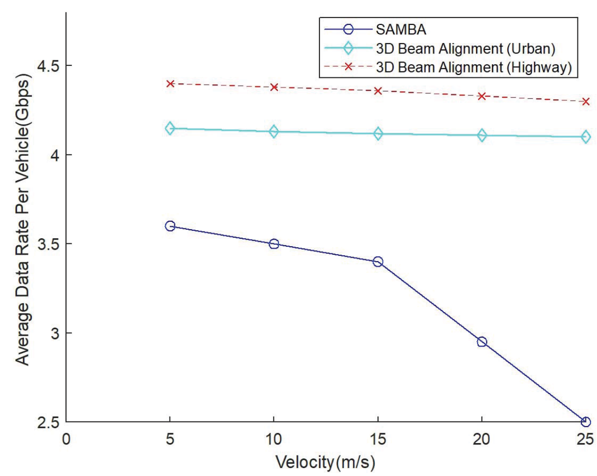

Fig. 8. Comparison on average data rate per vehicle with respect to velocity.

3D beam alignment shows higher data rate. And the highway scenario shows a higher data rate than the urban scenario, since the vehicles move in same direction for relatively long time periods and thus their positions are easier to estimate. Comparing with SAMBA algorithm, our proposed 3D beam alignment is approximately 15 to 20 percent better in terms of data rate. With the increase of the number of vehicles, the data rate also increases gradually. But our scheme always outperforms the SAMBA method.

For better understanding of these results we introduce the metric known as the Average Data rate per vehicle. As its name suggests it shows the average data rate achieved per vehicle. By observing the the Average Data rate per vehicle we can clearly distinguish between the performance of our proposed work with SAMBA algorithm. Fig.7 shows the comparison of average data rate per vehicle with respect to the number of vehicles. In previous SAMBA algorithm the average data rate shows serious decrease with the increase of the number of vehicles. Hence SAMBA does not have good scalability. This result shows very low rate when over 100 vehicles are participating in the network. Our proposed 3D beam alignment brings higher data rate and there is less drop in average data rate per vehicle as number of vehicles are being increased (Fig. 7). The involvement of MIMO technology in RSUs is necessary to achieve high data rate. But our beam alignment scheme is the main reason of maintaining the high data rate. Initially, for the small participation with only 10 vehicles, the average data rate achieved is around 3.4 Gbps in SAMBA and 3.9 Gbps in our proposed 3D-Beam alignment - with 0.5 Gbps of improvement here. And with the increase of the number of vehicles the enhancement gets greater. With the participation of 100 vehicles, 1.8 Gbps is reached in SAMBA whereas 3.38 Gbps can be achieved by our proposed 3D beam alignment scheme.

The average data rate per vehicle with respect to the vehicle's velocity is plotted in the Fig. 8. In vehicular communications, the velocity of vehicle plays a key role, since it impacts on the QoS performance metrics. The vehicle's position varies with respect to the change of the velocity of the vehicle. In highway scenario the vehicle speed is higher than the that of the urban scenario. The SAMBA algorithm shows more drop in average data rate, especially when the vehicles are moving between 15 m/s to 25 m/s. The proposed 3D beam alignment achieves higher data rate with respect to the number of vehicles and velocity. Decrease of average data rate per vehicle intimates the poor design of beam alignment in SAMBA algorithm. Therefore it is notable that the increase of average data rate per vehicle enhances the system performance and it eventually decreases the communication overhead and coordination collisions in beamforming process. The involvement of 3D representation that fits spherical objects tends to have accurate result with different vehicle positions. The errors in vehicle's position also leads to the degradation of data rate, since the beams are formed based on the position of vehicles.

Overall, the data rate shows improvement in both scenarios when compared with previous schemes. The increase of data rate also impacts on other system performance metrics such as throughput, delivery ratio, etc., as discussed below.

2) Delivery Rate: Delivery rate indicates how many packets are successfully received without bit errors or packet loss.

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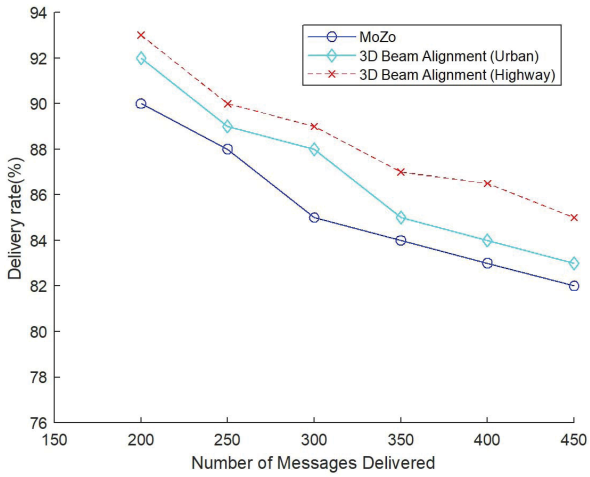

Fig. 9. Comparison on delivery rate with respect to number of messages delivered.

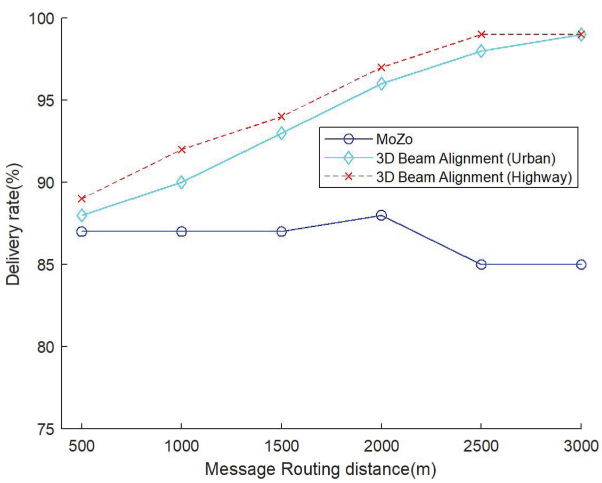

Fig. 10. Comparison on delivery rate with respect to message routing distance.

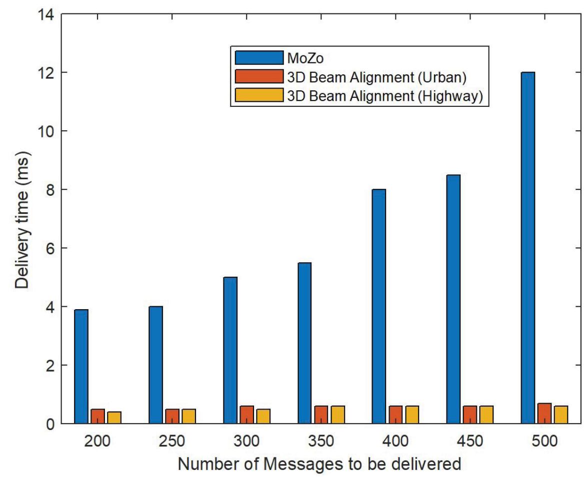

Fig. 11. Comparison on delivery time with respect to number of messages to be delivered.

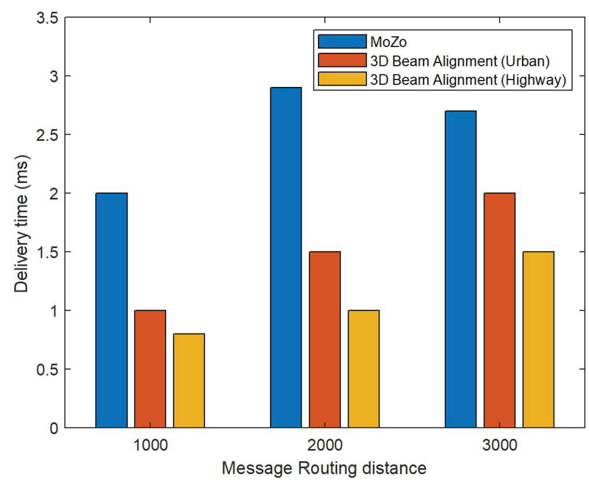

Fig. 12. Comparison on delivery time with respect to number of messages to be delivered.

The bit errors often come from link noise or medium access collisions. Packet loss is typically due to network congestion. We have generated deliver rate results as shown in Fig.9 and Fig.10.

In Fig. 9, the delivery rate is plotted in terms of the number of messages delivered to the destination vehicle without errors. Highway scenario shows better delivery rate after using our 3D beam alignment and secure routing scheme, due to the straightforward movement (i.e., without much direction changes) of the vehicles in this scenario.

Delivery rate is also plotted against message routing distance in Fig. 10. Due to the use of optimal mmWave routing, the data from the source vehicle is successfully delivered to the destination vehicle without packet drops. Such a low packet loss rate is also due to our efficient grouping scheme which chooses optimal route through the direct communication between the group heads.

3) Routing Delay: End-to-end delivery delay is an important routing metric. The packet transmission delay is often due to long routing path (i.e., too many hops), long queuing delay in each node's buffer, and node mobility which makes the link become broken from time to time (thus new routing path needs to be established). If there is a network attack, the transmission can also get delayed.

Fig. 11 shows the reduction of delivery time, due to the perfect selection of the route by using our secure mmWave routing scheme. Our routing scheme still has low delay even if the distance between the neighboring vehicles increases. The delivery time is less than other schemes in both highway and urban scenarios.

Message routing distance refers to the total distance covered from the source to destination vehicle which receives the data packets. With the increase of the distance between the source and destination, the delivery time also increases since the data packets needs to cross more number of intermediate vehicles before reaching the destination. Fig. 12 illustrates the lower delivery time compared with other schemes. Here we use security-based routing path selection. Thus no attackers change the routing paths, which helps to maintain the best routing path.

4) Average Delay Introduced From BF Training: Here we have tried to perform the complexity analysis in terms

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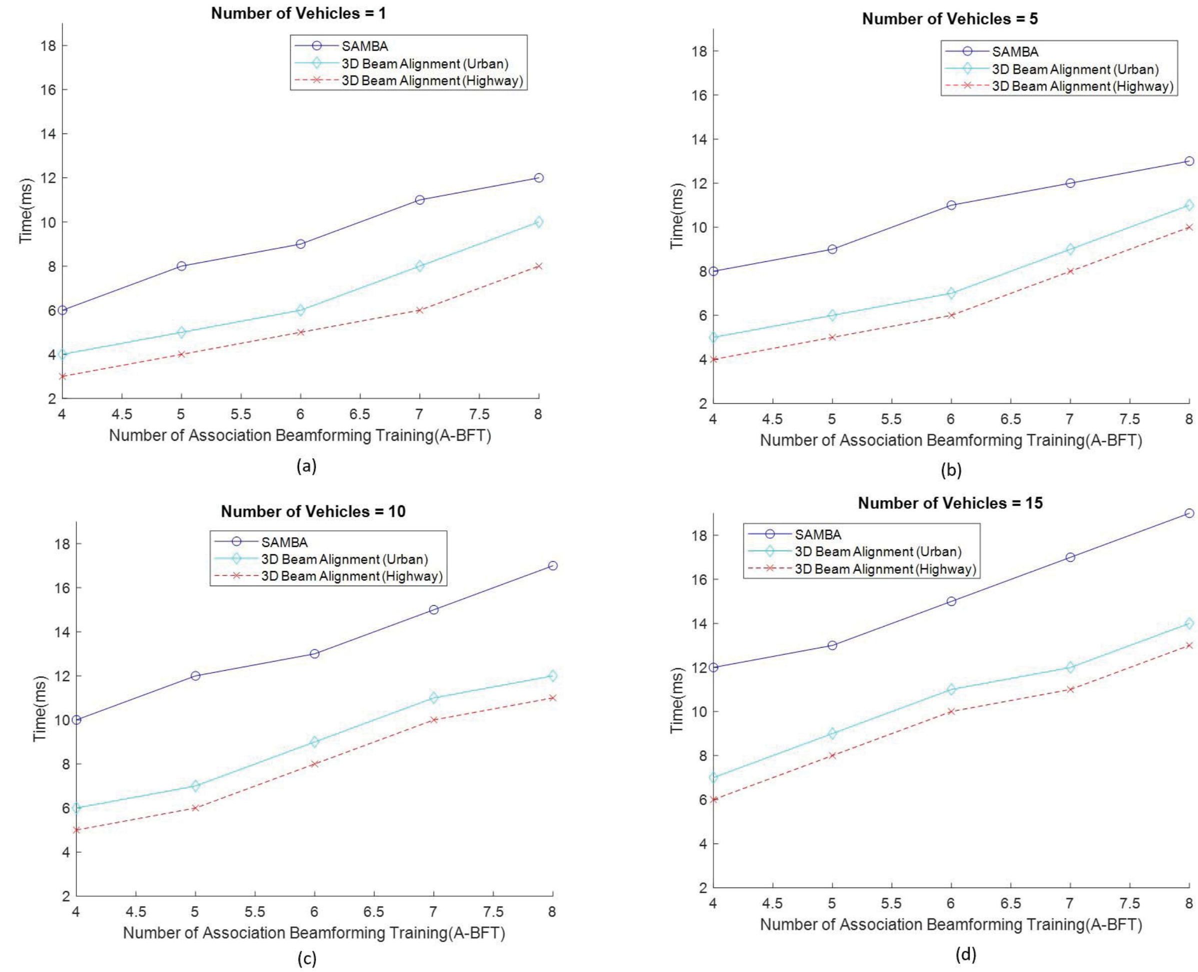

Fig. 13. The Number of non-trained beams vs the BF Delay for Number of Vehicles: (a)1 (b)5 (c)10 (d)15.

of delay Time for Number of Association Beamforming Training(A-BFT) as the number of non-trained beams (because of collisions etc.) and the Beamforming delay can have adverse effect on the performance of vehicular communications network.

As from the Fig. 13 it can be deduced that when number of vehicles are increased the overall Time (delay) increases. Similarly more A-BFT would also means higher delays. Thus this higher delay would have a great impact upon the performance of vehicular network i.e. latency would increase and there would be compromise on the desired data rate. From Fig. 13 it is clearly seen that our proposed work has shown better performance in terms of BF delay. Both highway and urban model are able to show lower time delay as number of vehicles are being increased. Likewise when A-BFT are increase still our method has lesser increase in time delay as compare to SAMBA algorithm.

V. Conclusion

In this paper, a mmWave routing with beam alignment has been designed for V2X communications. The beam alignment is based on 3D-based position detection and beam alignment. According to the alignment result of beams, V2I routing performance is optimized. MIMO technology is used to establish the communications among a large number of vehicles. For the selection of the best beam, a rule-based method is used which takes into account the channel capacity, signal-to-noise ratio and reference signal received quality. To achieve efficient routing, the road lane is segmented with the grouping of vehicles in each segment. The modeled grouping procedure also has group splitting/merging functions. The selected group header evaluates each group members by means of elliptic curve equation. Routing path for packet transmission from the source vehicle is chosen based on the link weight, and then the data is compressed by using Huffman coding. Elliptic curve cryptography (ECC)-based session key is generated for both sender and receiver vehicle. Our entire mmWave routing approach was then extensively compared with SAMBA and MoZo algorithms. The performance metrics used for evaluations are average data rate, delivery rate and routing delay. Our results showed that our scheme has much better QoS performance.

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Bharat Balasubramanian is currently a Professor and the Executive Director of the Center for Advanced Vehicle Technologies, a cross-disciplinary research center focused on automotive innovation at The University of Alabama. He worked for nearly 40 years as a Research and Development Engineer for the Mercedes-Benz brand, and also in Stuttgart. In 2012, he retired as the Vice President of the Group Research and Advanced Engineering at Daimler, Stuttgart, Germany, where he was responsible for product innovations and process technologies. He began his career in the automotive industry after graduating from the Indian Institute of Technology. In 1974, he began working with Daimler and earned both his master's and Ph.D. degrees while employed there. He began as a Computational Analysis Engineer with the Department for Automatic Transmissions and Power Steering Systems. In 1988, he was named the Chief Engineer and became the Vice President for engineering technologies at the Mercedes-Benz Passenger Car Research and Development in 1997. Nine years later, he was named the Vice President of the Daimler/Mercedes-Benz Research and Advanced Engineering, where he was responsible for 1,300 engineers in Germany and 1,000 more in international research and development locations. He has been at the forefront of most of the major advances that have occurred in automotive technology over the past 20 years. Recently, he helped developing Magic Body Control, an innovative feature of the current series of the Mercedes-Benz S-Class that uses cameras to scan the road profile ahead. He also led research in innovations for advanced driver assistance systems and active safety. Besides his work at Daimler, he taught for 20 years at the School of Automotive Engineering and Railway Technology, Technical University of Berlin. In 1998, he was named as an honorary professor.

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