9-19-2022

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Recommended Citation

Huang, Shidong, Chuanhe Huang, Dongfang Wu, Yabo Yin, M. Wasim Abbas Ashraf, and Bin Fu. 2022. "UAV-Assisted Sensor Data Dissemination in MmWave Vehicular Networks Based on Network Coding." Edited by Mu En Wu. Wireless Communications and Mobile Computing 2022 (September): 2576182. https://doi.org/10.1155/2022/2576182.

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Hindawi
Wireless Communications and Mobile Computing
Volume 2022, Article ID 2576182, 10 pages
https://doi.org/10.1155/2022/2576182

Research Article

UAV-Assisted Sensor Data Dissemination in mmWave Vehicular Networks Based on Network Coding

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Received 21 June 2022; Revised 22 August 2022; Accepted 24 August 2022; Published 19 September 2022

Academic Editor: Mu En Wu

Due to good maneuverability, UAVs and vehicles are often used for environment perception in smart cities. In order to improve the efficiency of sensor data sharing in UAV-assisted mmWave vehicular network (VN), this paper proposes a sensor data sharing method based on blockage effect identification and network coding. The concurrent sending vehicles selection method is proposed based on the availability of mmWave link, the number of target vehicles of sensor data packet, the distance between a sensor data packet and target vehicle, the number of concurrent sending vehicles, and the waiting time of sensor data packet. The construction method of the coded packet is put forward based on the status information about the existing packets of vehicles. Simulation results demonstrated that efficiency of the proposed method is superior to baseline solutions in terms of the packet loss ratio, transmission time, and packet dissemination ratio.

1. Introduction

With the development of 5G technology, the arrival of 6G communication technology will further promote the process of smart city. Application of smart transportation, smart logistics, smart medical care, and smart manufacturing and other related technologies have greatly changed people's lifestyles. The combination of 5G and related technologies such as remote control, remote operation, and machine vision [1, 2] will make digital workshops and smart factories a reality. 5G combined with unmanned vehicle transportation and intelligent robotics will enable unmanned monitoring and scheduling of the logistics process [3, 4], which will greatly improve current urban logistics efficiency. Application of 5G in intelligent traffic control and autonomous driving makes road condition monitoring, congestion guidance, intelligent parking, high-precision positioning, and emergency accident handling more efficient and convenient [5, 6]. With the aid of 5G communication technology, real-time monitoring of patient, remote surgery, and nursing guidance will become a reality [7, 8], and people can enjoy higher quality of medical services.

In various application scenarios of smart city, relevant sensing technologies play a very important role. In order to achieve efficient urban environmental data sensing, vehicle-based data sensing is a common solution; it plays an important role in the construction of smart city. Relevant equipment can be installed on the vehicle to sense the traffic information on the road, and an efficient traffic scheduling scheme can be made based on the current traffic information [9, 10]. Different sensors are installed on the vehicle to sense the current road and obstacles in real time [11, 12], which is the current implementation solution for autonomous driving. Sensors and corresponding devices installed on multiple vehicles can be applied to identify and locate the persons who owned the special identity [13, 14], which can make the urban life safer and more convenient.

Sensing technology based on vehicular networks plays an important role in the construction of smart city. Multiple vehicles cooperating with each other to accomplish a specific sensing task is very common, and the sharing of sensing data among multiple vehicles can achieve a larger range of environmental sensing and monitoring. Vehicles can take more effective control measures based on these sensing data. In order to improve the sharing efficiency of sensor data, the paper proposes a UAV-assisted sensor data sharing scheme for mmWave VN based on link availability identification and network coding technology to improve the data distribution efficiency. The main contributions of this paper are as follows.

(i) The paper proposes the concurrent sending vehicles selection method based on the availability of mmWave link, the number of target vehicles, the distance between sensor data packet and requested vehicles, and the waiting time of sensor data packet, which can improve the efficiency of sensor data sharing

(ii) To improve the efficiency of sensory data sharing, the paper designs a data distribution method based on network coding techniques. Construction method of coded packet is proposed, which can improve the efficiency of the multiple antennas in mmWave VN

(iii) Simulation results showed that the proposed method improves the efficiency of sensor data sharing of mmWave VN in term of time consumed and packet loss ratio

The rest of the paper is organized as follows. Section 2 introduces the related work; Section 3 introduces the system model. Section 4 introduces sensor data dissemination method based on network coding. Simulation and result discussion are presented in Section 5; Section 6 concludes this paper.

2. Related Work

2.1. Data Sensing Based on VN. Vehicles as a carrier of sensors for sensing the urban environment is a common solution. To accomplish the data collection from sensors deployed in different locations in urban, data forwarding schema based on the probability of a vehicle to reach a road side unit was proposed in the literature [15]; a distributed age-aware data collection scheme was proposed based on Lyapunov optimization technique in the literature [16], including a sampling method with a threshold at the source vehicle and a data forwarding strategy based on learning. For the traffic data collection in urban scene, P. Salvo et al. proposed a traffic data collection method based on LTE and V2V [17], and the way of data collection can switch between LTE and V2V according to the vehicle density.

In order to meet the requirements of ITS applications for accuracy and timeliness of sensor data, while achieving efficient use of bandwidth resources, W. Nie et al. formalized the problem as the minimized communication overhead problem [18] and proposed two different solutions with mixed-integer linear programming and deviation-detection method. An adaptive vehicle clustering mechanism and online parameter adjustment method were designed in [19] to satisfy the ITS requirements for accuracy and timeliness of sensor data.

As to sensor data sharing in vehicular networks with the mmWave communication technology, X. Chen et al. proposed the graph-based routing selection mechanism [20], and heading vehicles are responsible for the selection of the transmission and receiving vehicles. To solve the problem that the communication performance is vulnerable to blocking and interference effects with the mmWave in VNs, a distributed dissemination mechanism was proposed with the consideration of blocking and interference effect to improve the efficiency of sensor data distribution [21]. For efficient data access in urban vehicle sensing networks, hybrid network architecture based on dedicated short-range communication and vehicular ad hoc network was proposed in the literature [22], and duplicated data suppression mechanism was designed based on signaling procedure and executed in distributed way among vehicles. As to UAV-assisted data dissemination in V2X networks, dynamic trajectory scheduling algorithm was designed for UAV to complete the data caching in the proactive caching phase, and relay selection method was proposed to improve the efficiency of data dissemination through V2V and V2I in the data dissemination phase [23]. Y. Meng et al. proposed a network architecture based on information-centric networking [24] and designed a distributed data caching strategy to alleviate the system pressure caused by user requests. Due to the good maneuverability, UAVs are often used in different IoT applications.

2.2. UAV-Assisted Sensor Data Collection and Dissemination. In UAV-assisted data collection scenarios, UAV deployment problem was studied in the literature [25] to maximize the available time of the user uplink in disaster relief scenarios; user devices were clustered and then each cluster was served by one UAV. The age of information and the power consumption of UAV are taken into consideration in the literature [26] and the data collection problem was formalized as a mixed-integer linear programming problem to be solved. To achieve efficient data collection in IoT, UAV-assisted data collection with NOMA was proposed in [27], and the location of UAV, sensor grouping, and power control are jointly considered in the solution. As to the scenario that sensors located on a straight line, the data collection intervals, the UAV's speed, and the sensors' transmit powers needed to be considered simultaneously to minimize flight time of the UAV to complete the data collection [28]. For UAV-assisted integrated sensing and communication system, a new sensing and communication mechanism was designed in the literature [29] to maximize the user available rate with the joint optimization of UAV trajectory, transmit precoder, and sensing start instant.

As to UAV-assisted sensor data distribution scenario, the flight track and speed, sending power, and data demand

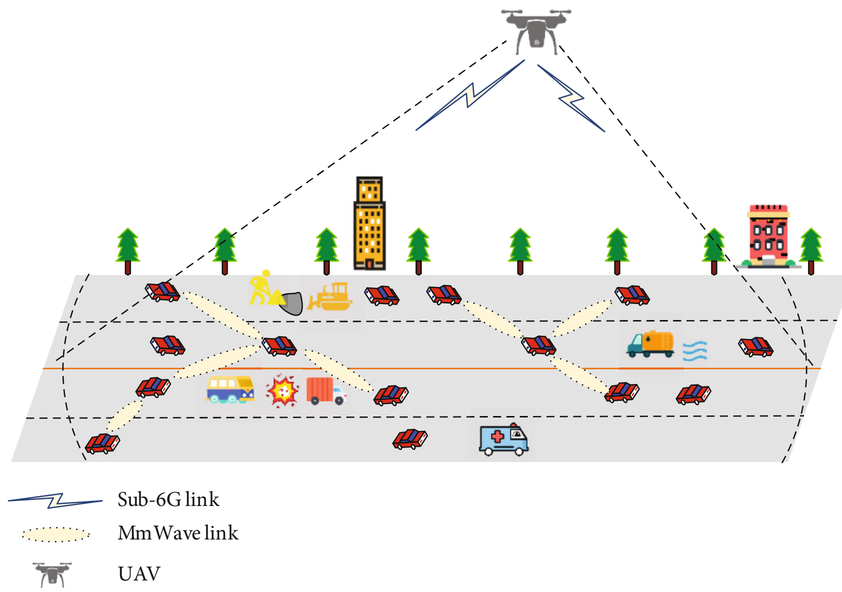

Figure 1: Scenario of UAV-assisted sensor data dissemination.

of sensors were needed to be considered simultaneously to minimize the data distribution time [30, 31]; the joint optimization problem was simplified into a convex optimization problem for solution. Multi-UAV-assisted data distribution for sensors in post-disaster areas was studied in the literature [31]. To realize the efficient data distribution to the receiving nodes within a specific region, file dispatching scheme based on graph theory with nonorthogonal multiple access (NOMA) was proposed in [32]; ground users and UAV can share the time-frequency resource block simultaneously. In the scenario where the UAV and the primer user shared the spectrum resources to distribute data to the sensors, to maximize the minimum number of bits of data received by the sensors while ensuring the communication quality of the primer user, the optimization problem was formalized as a mixed-integer non-linear program [33] and the corresponding convex approximation algorithm was designed to solve it.

The blocking effect in mmWave VN is considered in the above related work, but the network coding technique is not introduced in the solution. In this paper, we design a new UAV-assisted sensing data distribution scheme based on link availability identification and network coding techniques. Concurrent sending vehicles selection mechanism and coded packet construction method are proposed in this paper to improve the efficiency of sensor data sharing in mmWave VN.

3. UAV-Assisted Data Sensing Based on Vehicular Networks

3.1. System Model. Assuming that vehicles are equipped with sensing device and millimeter wave antenna, sensing device is used to sense the environment, such as road conditions, accident scene, and emergency vehicles, millimeter wave antenna is used to share the sensor data with other vehicles, and vehicles exchange the sensor data with each other to obtain complete information about surrounding environment information. The information can be used to make decisions, such as avoiding traffic accident and congested roadways. The vehicles use mmWave directional antenna in D2D communication. One data transmission, there are up to M receiving vehicles that can receive the transmitted data simultaneously, because vehicles use multiple antennas to send data through M RF chains [21].

Environment sensing procedure consists of two phases, sensing data acquisition and distribution. In the sensing stage, vehicle uses the sensors installed on the vehicle to sense the surrounding environment and then reports the sensor data to the UAV with the sub 6GHz link. In the stage of data dissemination, UAV gives the corresponding scheduling solution according to the sensor data owned by each vehicle located in its coverage and informs the vehicle with the scheduling solution, and then vehicles use mmWave communication technology to distribute or receive the sensor data in D2D at the corresponding time slot according to the scheduling solution distributed by UAV. The structure of the system is shown in Figure 1. After this round of data sharing is completed, then vehicles perform a new round of data sensing and then report the sensor data to UAV, then UAV distributes new scheduling solution to vehicles, and vehicles share the new sensor data with each other to realize the perception of the surrounding environment.

3.2. Link Availability Identification. In the stage of sharing sensor data, vehicles broadcast sensor data to neighbor vehicles with mmWave communication technology. The communication link is prone to blockage from the intermediate vehicles, which cause the failure of data transmission. So UAV needs to consider the link availability among the vehicles when make the scheduling decisions. As shown in

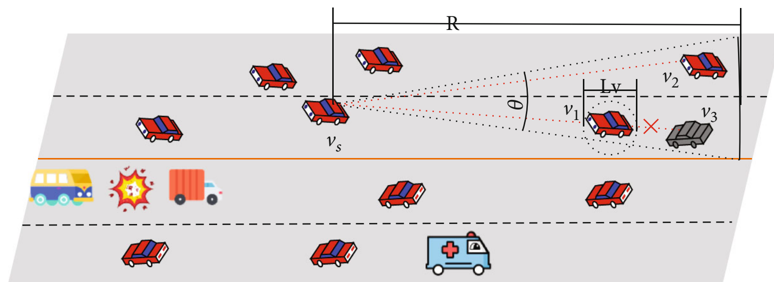

FIGURE 2: Link availability identification.

Figure 2, v_1, v_2, and v_3 are all neighboring nodes of v_s node, and the communication link between v_s and v_3 is blocked by vehicle v_1, which results in v_3 cannot receive the data sent by vehicle v_s successfully.

Suppose the length of vehicle v_1 is L_v, take the center position of vehicle v_1 as the center and make a circle with $L_v/2$ as the radius; if the LOS path between the sending node and the receiving node passes through the circular area, then the link between the sending node and the receiving node is blocked by vehicle node v_1; otherwise, the link is not blocked by vehicle v_1, as shown in Figure 2, and v_2 can successfully receive the data sent by v_s node, but v_3 cannot. Based on the coordinates of v_s, v_1, and v_3, and the length L_v of v_1, it can be determined whether the sending signal of v_s is blocked by v_1. Using this method, we can get the set of effective neighbor nodes and blocked neighbor nodes of any sending vehicle. During a time slot, multiple vehicles may send data simultaneously, vehicle may receive the data from multiple vehicles simultaneously, and the receiving noise of a vehicle can be got according to formula (1) [21]. P_j means the received power, P_i means the transmission power, G_i and G_i indicate the gain of transmit antenna and received antenna, respectively, L_0 denotes the reference path loss at 1 m, and r_{ij} is the distance between the transmitting vehicle and receiving vehicle. If the received noise strength is greater than a threshold, the vehicle cannot receive any data correctly; the vehicle is regarded as the interfered node.

3.3. Formalization of Problem. When a vehicle broadcasts data, at most M vehicles can receive the sent data. The data set consisting of sensed data of all vehicles is $L_{\text{total}} = \{p_1, p_2, \cdots, p_K\}$. In a certain time slot, sending vehicles are selected to send the corresponding coded data packets based on the existing data items located on vehicles and the link availability between vehicles. It is expected to spend the minimum number of time slots so that each vehicle gets all the data items in L_{total}, and the blockage and interference effects are needed to be considered during the schedule.

Now assume that the existing data items on the vehicles are shown in Figure 3. An edge between two nodes indicates that a link between the two vehicles is available. v_1 owns the sensor data items set $L_1 = \{p_1, p_5\}$, v_2 owns the sensor data items set $L_2 = \{p_1, p_2, p_3\}$, v_3 owns the sensor data items set $L_3 = \{p_3, p_5\}$, v_4 owns the sensor data items set $L_4 = \{p_4\}$, v_5 owns the sensor data items set $L_5 = \{p_3, p_5\}$, v_6 owns the sensor data items set $L_6 = \{p_6\}$, v_7 owns the sensor data items set $L_7 = \{p_1, p_2\}$, and the total sensor data item set $L_{\text{total}} = \{p_1, p_2, p_3, p_4, p_5, p_6\}$.

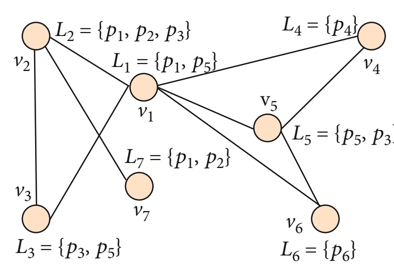

FIGURE 3: Request state graph of vehicles.

Assume that when a vehicle sends data, at most 3 vehicles can receive the sent data. In the current time slot, v_1 sends coded packet $p_1 \oplus p_5$, v_2, v_3, and v_5 are the receiving vehicles, and v_2 receives the coded packet $p_1 \oplus p_5$ and then can decode the required packet p_5 with the existing packets $\{p_1\}$; v_3 decode the required packet p_1 with the existing packet $\{p_5\}$; v_5 can decode the required packet p_1 with the existing packet $\{p_5\}$. Since v_1 being transmitting state, v_4 and v_6 are in the state of interference; there are no other optional vehicles as sending vehicles in this time slot. In the next time slot, the existing packets state of vehicles has changed, and then the new sending nodes and corresponding encoded packets are scheduled according to the updated state information with the expectation that all vehicles can get all the sensor data items in L_{total} with the minimum number of time slots spent.

$$P_j = \frac{P_i G_i G_j}{L_0 r_{ij}^{\alpha}}. \tag{1}$$

4. Sensor Data Dissemination Based on Network Coding

4.1. Selection of Concurrent Sending Vehicles. For the distribution of sensor data in each time slot, it is necessary to determine the concurrent sending vehicles and the corresponding packets to be sent. When selecting the sending vehicles, the distance to the vehicle which has the missing sensor packets, the generation time of sensor data, the number of valid receiving vehicles, and the number of concurrent sending vehicles need to be considered. $w_{n,i}$ is the weight corresponding to the v_n sending packet p_i calculated with formula (2). dis_{n,p_i} means the max shortest distance between v_n and the vehicles lacking of p_i, which can be achieved with Floyd's algorithm. $t_{p_i,n}$ means the waiting time of the packet p_i on vehicle v_n, curr_{n,p_i} means the number of the effective neighbor receiving vehicles when v_n sends the packet p_i, and ε_{n,p_i} means the number of concurrent sending vehicles when v_n sends the packet p_i. $n_w^{p_i}$ means the vehicle that is lacking of p_i and has the max shortest distance between itself and the vehicle v_n.

$$w_{n,i} = \mathrm{dis}_{n,p_i} + t_{p_i,n} + \mathrm{curr}_{n,p_i} + \varepsilon_{n,p_i}, \tag{2}$$

$$\mathrm{dis}_{n,p_i} = \mathrm{distance}\left(n, n_w^{p_i}\right), \tag{3}$$

$$w_n = \max\left(w_{n,i}\right), \tag{4}$$

$$w_n = \mathrm{sizeof}\left(Q_{v_n}^{\max}\right). \tag{5}$$

The selection process of concurrent transmitting nodes is shown in Algorithm 1. The vehicle with max weight w_n according to formula (4) is selected as the first sending node that is shown in lines 5 to 6. After the first sending vehicle is determined, its receiving vehicles and the corresponding interfered vehicles set are also determined which are denoted as InferenceSet. Remove selected sending vehicles, receiving vehicles, and interfered vehicles from the set of the current available vehicles to get the new available vehicle set AvaVelSet, which is shown in lines 15 to 16. Calculate new weight for the vehicle in the new available vehicle set AvaVelSet with formula (5), which is shown in line 8, $Q_{v_n}^{\max}$ is the maximum clique of decoding capability graph (DCG) of v_n. The construction process of decoding capability graph is discussed in Section 4.2. Select the vehicle with the maximum weight as the second sending node and then update the set of sending vehicle set SenderSet, the set of receiving vehicles, and the set of interfered vehicles InferenceSet. Lastly, the updated available vehicles set AvaVelSet can be achieved. Repeat the procedure to select the new concurrent sending vehicle until the set of available vehicles *AvaVelSet* is empty, and finally the set of concurrent sending vehicles SenderSet can be achieved; the details is shown as Algorithm 1.

$$\text{case1}\begin{cases} p_j \text{ requested by } v_i \\ p_l \text{ requested by } v_k \\ i \neq k \\ l = j \end{cases},$$

```
Require: VehicleSet
Ensure: SenderSet
1: Set AvaVelSet = VehicleSet;
2: while (AvaVelSet ≠ Null)
3:    W_max = 0;
4:    for (v_i ∈ AvaVelSet.)
5:      if (AvaVelSet == VehicleSet)
6:        Calculate W_i of v_i according to formula (4);
7:      else
8:        Calculate W_i of v_i according to formula (5);
9:      end if
10:     if (W_i > W_max)
11:       W_max = W_i;
12:     end if
13:   end for
14:   Select v_k with the W_max and add v_k in SenderSet;
15:   Calculate InferenceSet with the current SenderSet;
16:   AvaVelSet = AvaVelSet − SenderSet − InferenceSet;
17: end while
18: return SenderSet;
```

Algorithm 1: Concurrent sending vehicles selection.

$$\text{case2}\begin{cases} p_j \text{ requested by } v_i \\ p_l \text{ requested by } v_k \\ p_l \text{ owned by } v_i \\ p_j \text{ owned by } v_k \\ i \neq k \\ l \neq j \end{cases}. \tag{6}$$

4.2. Construction of Decoding Capability Graph. Decoding Capability Graph of $v_n(DCG_{v_n})$ is constructed based on the existing packets and its valid neighbor nodes. Firstly, the vertex of DCG_{v_n} are generated. If a valid neighbor vehicle v_i missing the packet p_j which cached on v_n, then the vertex ϑ_{ij} is generated, all vertexs in DCG_{v_n} are produced with the same way. Then, edges of DCG_{v_n} are produced. For any two vertices ϑ_{ij} and ϑ_{kl}, if they satisfy the *cases*1 or *case*2, an edge is added between ϑ_{ij} and ϑ_{kl}, all edges in DCG_{v_n} are obtained by this way. *case*1 means that vehicle v_i and vehicle v_k miss the same packet p_j which exists on v_n; *case*2 means that vehicle v_i and vehicle v_k each has the missing packet of the other. Vehicle v_i has packet p_l requested by vehicle v_k, vehicle v_k has packet p_j requested by vehicle v_i, and both p_j and p_l exist on vehicle v_n.

An example is given to illustrate the procedure of creating *DCG* for a vehicle. Suppose that vehicle v_2 has valid neighbors v_1, v_3 and v_7, as shown in Figure 3. The set of existing sensor packets of vehicle v_2, v_1, v_3, v_7 are $L_2 = \{p_1, p_2, p_3\}$, $L_1 = \{p_1, p_5\}$, $L_3 = \{p_3, p_5\}$, $L_7 = \{p_1, p_2\}$ separately. Construct the *DCG* for v_2 with the above method, we can get DCG_{v_2} shown as Figure 4. Maximum clique of a graph can be achieved with the heuristic algorithm in [34]. Maximum clique of DCG_{v_2} is $Q_{v_2}^{\max} = \{\vartheta_{13}, \vartheta_{31}, \vartheta_{73}\}$ which locating in dashed line, the weight of v_2 is 3 according to formula (5). Packets requested of $Q_{v_n}^{\max}$ is $\{p_1, p_3\}$. If v_2 broadcast the coded packet $P_{coded} = p_1 \oplus p_3$, v_7 can decode the packet p_3 with the existing packet p_1, v_3 can decode the packet p_1 with the existing packet p_3, v_1 can decode the packet p_3 with the existing packet p_1.

4.3. Data Dissemination of Selected Vehicles. Once the concurrent sending nodes in the system are identified, the packets to be sent by each sending node need to be determined in order to achieve efficient sharing of sensor data. Based on the current identified sending vehicles, receiving vehicles, and interfered vehicles, UAV can get the effective neighbor nodes set Neigh_{v_n} of any vehicle v_n. Then, the DCG of any vehicle v_n can be constructed based on the existing packets and missing packets of its effective neighbor nodes and the existing packets set of v_n.

When vehicle disseminates sending sensor data, the first selected vehicle will broadcast the packet p_i with the maximum weight according to formula (2) that is shown in lines 1 to 4. If it is not the first selected vehicle, for any existing packet p_i of v_n, calculate the number of neighbor vehicles that lack the packet p_i among its effective neighbor vehicles; if the number of neighbor vehicles that lack the packet p_i is greater than or equal to M, then v_n broadcasts the packet p_i directly to M neighbor nodes among effective neighbor nodes which lack the packet p_i, which is shown in lines 5 to 11. For every packet p_i owned by v_n, if the number of effective neighboring nodes lacking it is less than M, and then find the maximum clique $Q_{v_n}^{\max}$ of DCG_{v_n}; if the number of vertices of $Q_{v_n}^{\max}$ is greater or equal to M, choose any M vertices from $Q_{v_n}^{\max}$, and the requested packets of the selected M vertices from $Q_{v_n}^{\max}$ are used to construct the coded packet P_{coded}; and lastly, v_n broadcasts the coded packet P_{coded} to the neighbor vehicles associated with the selected M vertices from the maximum clique $Q_{v_n}^{\max}$, as thown in lines 12 to 16. If the number of vertices of $Q_{v_n}^{\max}$ is less than M, construct the coded packet P_{coded} with the requested packets of the M vertices in the maximum clique $Q_{v_n}^{\max}$, and lastly, v_n broadcasts the coded packet P_{coded}, which is shown in lines 17 to 21. The procedure of vehicle broadcast is described as Algorithm 2. After the data sharing of the current time slot, update the data state of vehicles; and then the new set of sending nodes is determined based on the updated data state information to complete the sensor data distribution for the next time slot. Repeat the procedure until each vehicle gets all the sensor data.

4.4. Complexity Analysis. Assuming that there are N vehicles and K sensory packets, concurrent sending nodes are selected based on the weight of vehicle. The distance between vehicle where the sensory packet is located to the vehicles lacking of the packet needs to be obtained, which can be resolved by Floyd's algorithms, and the computational complexity is $O(N^3)$. The subsequent sending nodes are determined according to the maximum clique of DCG, which can be achieved by heuristic algorithm in [35], and its computational complexity is $O(N^2K)$.

In the sensor data dissemination phase, if the sending node is the first one chosen, the sending packet is determined according to formula (2), and the computation complexity of it is $O(N^3)$, which is same as above. If the sending node is not the first one chosen, the sending packet is constructed based on the maximum clique of DCG, and the computation complexity of the procedure is $O(N^2K)$.

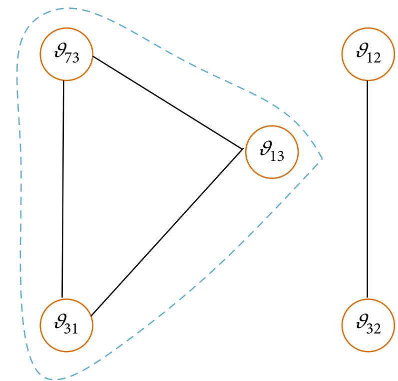

Figure 4: Decoding capability graph of v_2.

5. Performance Evaluation

The simulation scenario is a 16 m × 500 m road consisting of 4 lanes, and the number of vehicles on each lane follows Poisson's distribution with density of λ_v. Control signals between UAV and vehicles are transmitted using sub-6GHz omni-directional antenna, the inter-vehicle communication is carried out using mmWave directional antennas, the data plane is based on 802.11ad implementation in literature [36], and the simulation parameters are shown in Table 1. The proposed method BADDNC in this paper is compared with methods BAMD [21], w/o LAD [21], and GBRS [20] in terms of packet loss rate, transmission time, and packet distribution ratio. BAMD considers millimeter wave blocking effect but does not use coded distribution technology; w/o LAD is a simplification of BAMD, in which there is no link availability identification process; sending vehicle selection of GBRS is based on the utility value of vehicle nodes, which takes into account vehicle distance, number of neighbors, and packet queue.

Packet loss rate (PLR) is the ratio of the number of users who unsuccessfully received the sent packet to the number of target users, shown as formula (7). $\text{Num}_i^{\text{tar}}$ is the number of target users of ith transmission. $\text{Num}_i^{\text{succ}}$ is the number of users who received the packet successfully of ith transmission.

$$\text{PLR} = 1 - \frac{\sum_{i=1}^{K} \text{Num}_i^{\text{succ}}}{\sum_{i=1}^{K} \text{Num}_i^{\text{tar}}}. \tag{7}$$

Require: Sending vehicle *SenderSet*;
Ensure: Void;
while $v_n \in SenderSet$ **do**
  if (v_n is the first selected sending vehicle) **then**
    v_n broadcasts p_i with the maximum weight according to formula (2);
  else
    Calculate $Neigh_{v_n}$ of v_n according to available link identification and interference threshold;
    while Any packet p_i cached on v_n **do**
      if $(|Neigh_{v_n}^{p_i}| >= M)$ **then**
        v_n broadcasts the packet p_i to any M vehicles from $Neigh_{v_n}^{p_i}$;
        Return;
      end if
    end while
    v_n finds the maxclique $Q_{v_n}^{\max}$ from DCG_{v_n};
    if $(Size(Q_{v_n}^{\max}) >= M)$ **then**
      Select any M vetexex from $Q_{v_n}^{\max}$;
      Construct P_{coded} with the packets requested by the selected M vertex;
      v_n broadcasts P_{coded};
    else
      Construct P_{coded} with the packets requested by every vertex from $Q_{v_n}^{\max}$;
      v_n broadcasts P_{coded};
    end if
  end if
end while

ALGORITHM 2: Vehicle broadcast.

TABLE 1: Simulation parameters.

Parameters	Value
Transmission power of vehicles	30 dBm
Carrier frequency	28 GHz
Size of sensor data packet	1600B
Bandwidth of mmWave	2.16GHz
Transmission rate of mmWave link	1Gbps
Antenna gains of vehicles	$G_t = G_r = 1$
Half-power beamwidth of antenna	$\theta = 45^\circ$
Number of RF chains for transmission antenna	$M = 4$
Path loss exponents of channel	$\alpha = 2.7$(LOS)
SNR threshold	$P_{th} = 10$dB
SINR threshold	$\gamma = 5$dB
Noise power of vehicles	$N_0 = -174$dBm
Interference threshold	$\sigma = -54$dBm
Time slot interval	$\Delta t = 0.0625$ms

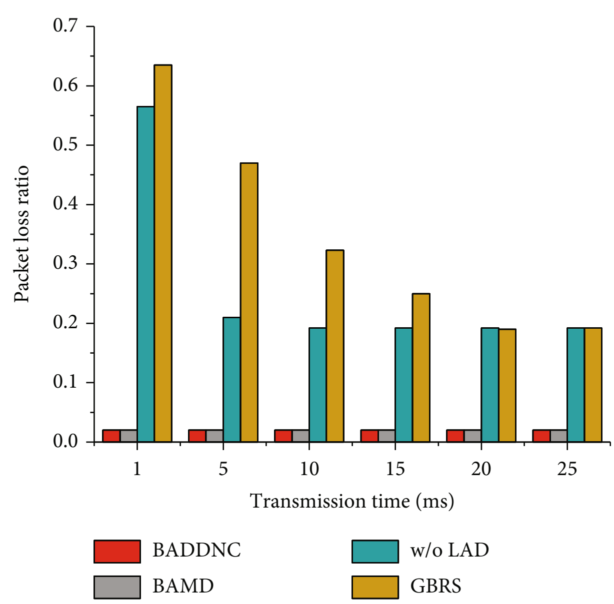

FIGURE 5: Packet loss ratio when $\lambda_v = 0.01$.

Transmission time (TT) means the time consumed that each vehicle gets all the sensor data packets, shown as formula (8). Num_{Diss} is the number of concurrent

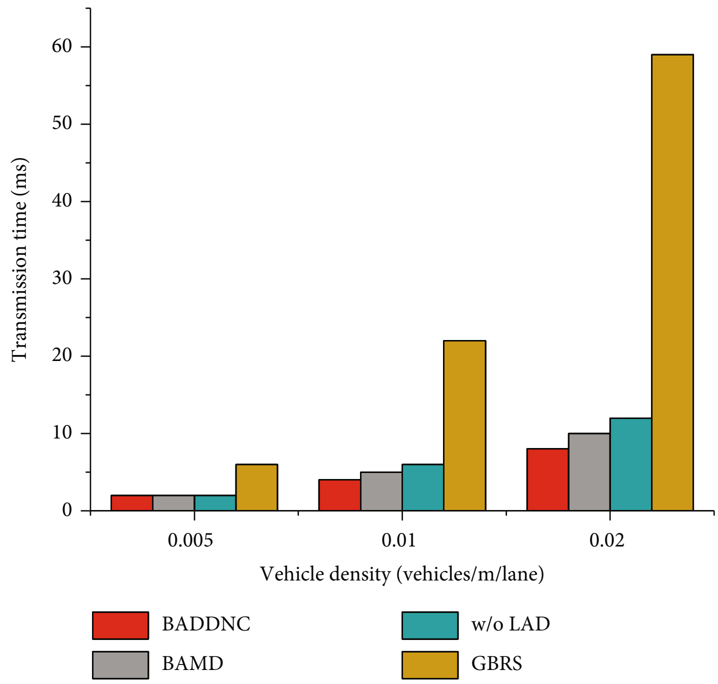

FIGURE 6: Transmission delay vs. vehicle density.

transmissions; Δt is the time consumed to complete a transmission.

$$TT = \mathrm{Num}_{\mathrm{Diss}} \cdot \Delta t. \quad (8)$$

Packet dissemination ratio (PDR) denotes the ratio of the number of missing packets that all vehicles have got and the sum of missing packets of all vehicles, shown as formula (9). $\mathrm{Num}_{v_i}^{t_{\mathrm{cur}}}$ is the number of missing packets of vehicle v_i at time t_{cur}. $\mathrm{Num}_{v_i}^{w}$ is the number of missing packets of vehicle v_i.

$$\mathrm{PDR} = 1 - \frac{\sum_{v_i \in V} \mathrm{Num}_{v_i}^{t_{\mathrm{cur}}}}{\sum_{v_i \in V} \mathrm{Num}_{v_i}^{w}}. \quad (9)$$

In Figure 5, packet loss ratio of four methods is given when λ_v=0.01. During the distribution of sensor data, the feedback information of link availability will be used for the next sensor data dissemination. It can be seen from Figure 5 that both BADDNC and BAMD have a lower packet loss ratio, because the sending vehicles perform link availability identification before they disseminate sensor data with BADDNC and BAMD. In comparison with BAMD and BADDNC, BGRS and w/o LAD do not perform link availability identification during the data dissemination process and have a higher packet loss rate. As the transmission process proceeds, more link feedback information is collected and then the packet loss rate of BGRS and w/o LAD finally remains at a relatively stable state.

In Figure 6, transmission delay of four methods is given at different vehicle densities. As can be seen in Figure 6, the transmission delay of several schemes increases as the vehicle density increases; because as the vehicle density increases, the amount of sensor data by the vehicles increases, then the time required to distribute the sensor data increases accordingly. The transmission delay of BADDNC, BAMD, and w/o LAD is significantly less than BGRS, because these three methods are able to schedule more concurrent transmission at each time slot. BADDNC has the smallest data transmission delay compared to the other three methods because BADDNC performs an available link identification to discover available receiving vehicles before each transmission and also uses a network coding method during data distribution, which can improve the data distribution efficiency to some extent. BAMD has shorter distribution delay than w/o LAD because BAMD performs the available link identification process before data distribution to select the neighboring nodes with better link status as the receiving nodes.

Packet dissemination ratio of several schemes increases as the transmission time increases, as can be seen in Figure 7. This is because the number of sensor packets received by vehicles increases with the transmission time. The packet dissemination ratio of BADDNC, BAMD, and w/o LAD is higher than BGRS because these three methods are able to schedule more concurrent transmissions at each time slot. BADDNC has the highest packet dissemination ratio compared to the other three methods because BADDNC performs an available link identification process to discover available receiving vehicles before each transmission and also uses network coding technology during data distribution, which can increase the number of receiving vehicles that can successfully receive packets. By this way, it can improve the efficiency of sensor data distribution. BAMD has a higher packet dissemination ratio than w/o LAD because BAMD performs the available link identification process before data distribution and selects the

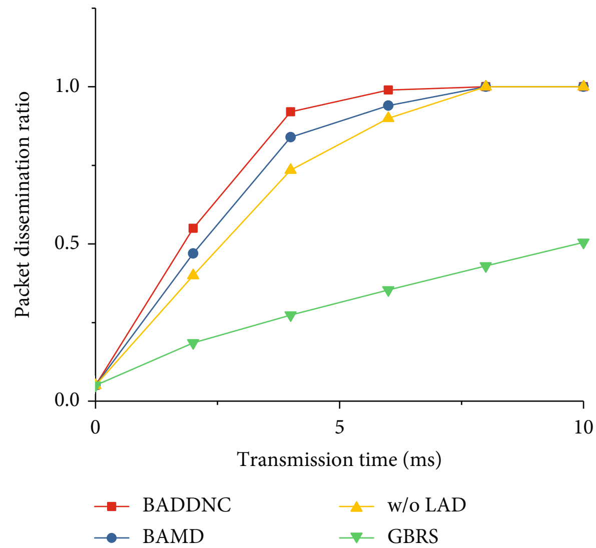

FIGURE 7: Packet dissemination ratio when $\lambda_v = 0.01$.

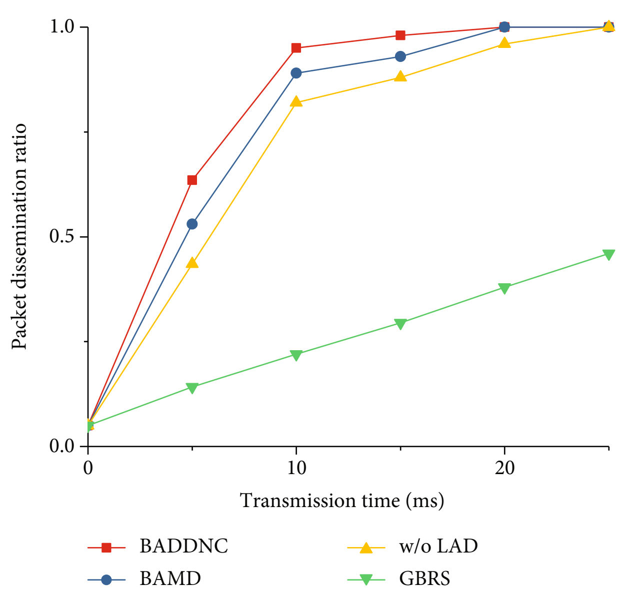

FIGURE 8: Packet dissemination ratio when $\lambda_v = 0.02$.

neighboring nodes without the link blockage. The comparison between Figures 7 and 8 illustrates that as the number of vehicle increases, more transmission time is required to complete the distribution of sensor data. In the case of different vehicle densities, the proposed method BADDNC has a higher packet dissemination ratio and can improve the efficiency of sensor data packet dissemination.

6. Conclusion

The paper proposed a sensor data dissemination method based on available link identification and network coding to improve the sensor data sharing efficiency in mmWave VN. Concurrent sending vehicles selection method are proposed based on the availability of mmWave link, the number of target vehicles, the distance between sensor data packet and requested vehicles, the number of concurrent sending vehicles, and the waiting time of sensor data packet. Construction method of coded packet is put forward based on the status information about the existing packets of vehicles. The proposed method can speed up the sensor data sharing in mmWave VN. The simulation results indicate that our proposed sensor data dissemination solution is best when the efficiency of sensor data dissemination is a real concern in VN. In the future, the new network coding method will be explored to facilitate the sensor data dissemination.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (No. 61772385).

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