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UAV-assisted data dissemination based on network coding in vehicular networks

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Abstract

Efficient and emergency data dissemination service in vehicular networks (VN) is very important in some situations, such as earthquakes, maritime rescue, and serious traffic accidents. Data loss frequently occurs in the data transition due to the unreliability of the wireless channel and there are no enough available UAVs providing data dissemination service for the large disaster areas. UAV with an adjustable active antenna can be used in light of the situation. However, data dissemination assisted by UAV with the adjustable active antenna needs corresponding effective data dissemination framework. A UAV-assisted data dissemination method based on network coding is proposed. First, the graph theory to model the state of the data loss of the vehicles is used; the data dissemination problem is transformed as the maximum clique problem of the graph. With the coverage of the directional antenna being limited, a parallel method to find the maximum clique based on the region division is proposed. Lastly, the method's effectiveness is demonstrated by the simulation; the results show that the solution proposed can accelerate the solving process of finding the maximum clique and reduce the number of UAV broadcasts. This manuscript designs a novel scheme for the UAV-assisted data dissemination in vehicular networks based on network coding. The graph theory is used to model the state of the data loss of the vehicles. With the coverage of the directional antenna being limited, then a parallel method is proposed to find the maximum clique of the graph based on the region division. The effectiveness of the method is demonstrated by the simulation.

1 | INTRODUCTION

Transport commuting has become a ubiquitous part of daily life; vehicular networks (VNs) play a positive role and improve the living standards of the people. VN technologies can be useful in event-driven safety message broadcasting, information application, public safety, traffic coordination, automatic driving, automatic toll collection, and some other related applications. VNs access the location where a traffic accident occurs and timely inform the relevant vehicles to adopt safety measurements and provide quality of services of multimedia data for tourists in the course of a journey. With regard to information services, VN can be used for the remainder service about the carbon emissions, pollution levels of the haze, infectious diseases, etc., which can improve the living environment of human beings. Traffic flow coordination can also benefit from VN [1–4]. People can get current traffic information timely on the related road of the vehicle and then choose the optimal path. This information can be very fruitful to avoid congested sections and the best travel experience of the passengers. Intelligent transportation system benefits a lot from VN. It can provide information regarding petrol station, restaurants, services areas, weather information, navigation [5–8], and all desired information about the nearby environment. VN can be applied to automatic driving [9–12], such as the distance detection between vehicles, velocity estimation, location service, road condition perception and self-parking. VN can be used to realize automatic charging. In V2I communication, RSU can automatically sense the entrance

location, exit location and the journey mileage of a vehicle, and then realize the automatic charging of the vehicle, which can improve the charging efficiency and reduce the congestion at the charging place.

Data dissemination technology is widely used in various situations, such as traffic flow management [13, 14], emergency collision avoidance [15], and the data acquisition of public entertainment [16], which can reduce the number of the traffic accidents, relieve urban traffic congestion and promote the urban construction of a smart city. In some special scenarios, the timeliness of data distribution is essential. In order to achieve the goal, Unmanned Aerial Vehicle (UAV) is usually used to assist in data dissemination.Because of the UAV's good maneuverability, it is usually used to complete data dissemination tasks in some special scenarios. For example, in some natural disaster sites, when the communication infrastructure is damaged, the UAV can rapidly be deployed as the mobile base station to assist in the communication. Maybe in some scenarios, where the communication infrastructure cannot be deployed, such as the battlefield rescue and maritime rescue, the UAV can be deployed in time for the auxiliary communication to complete the data dissemination. Sometimes UAV can be deployed as a mobile base station to assist in the efficient distribution of data when the available communication resources are insufficient for many users, such as many users of different vehicles need to be informed immediately about the rescue information of the natural disaster or battlefield. UAV-assisted data dissemination can improve the efficiency of data access in these cases. Compared with the UAV with the ordinary antenna, the UAV with the adjustable active antenna can cover a larger area. It is suitable when the service area of the data dissemination is large and the available UAVs are insufficient.

Most of the existing solutions focus on the data dissemination assisted by UAV with the omni-directional static antenna and assume that the receivers are within the communication range of the UAV, and the direction of the antenna remains unchanged in the process of data dissemination. Because the wireless channel is easy to be interfered by the various factors and there are not enough available UAVs to provide service for the disaster area, UAV with the adjustable active antenna is usually used for data dissemination. To the best of our knowledge, the current research work does not involve the data distribution method of the UAV with the adjustable active antenna. In order to improve the efficiency of UAV-assisted data distribution, we propose a method of data dissemination based on network coding technology. Here, we enhance the applicability of the UAV; the adjustable antenna is installed on the UAV. The main purpose of directional antenna is to boost up the signal strength and the anti-interference ability. The direction of the antenna can be adjusted dynamically to extend the UAV's scope of services. The UAV with the function can be used for message broadcast in disaster relief and in the battlefield. We propose the data dissemination framework for the UAV with the adjustable active antenna.

The key contributions of this paper are summarized as follows:

- We use graph model to represent the data received status of the vehicles. UAV constructs the coded message and broadcasts it based on the IDNC according to the maximum clique of the graph. The proposed scheme reduces the number of broadcasts by the UAV and improves the data dissemination efficiency.
- We propose a parallel solution method based on region division to solve the maximum clique of the graph. The method improves the speed of finding the maximum clique and reduces the waiting time in the process of data dissemination.
- The simulation results show that the proposed method improves the efficiency of UAV-assisted data dissemination. To our best knowledge, our work is the first study about the data dissemination method of the UAV with an adjustable active antenna.

The rest of the paper is organized as follows: Part 2 surveys the related work. Part 3 introduces the system scenario, the modeling process and the specific algorithm of the problem in detail. Part 4 introduces the procedure of the simulation and the related results.

2 | RELATED WORK

Due to the mobility of vehicles, the data dissemination in the VANETs is mainly realized by wireless communication technology, such as the Wave, LTE and 5G et al. Data dissemination in the VN is mainly implemented by the way of self-organizing between the vehicles or the centralized mode assisted by the infrastructure such as the base station and RSU. It can also work by the hybrid mode of the two schemes. Data dissemination by the way of self-organizing is commonly implemented by the location of vehicles or the cluster of vehicles. The method based on location information selects the relay node according to the location of the neighboring nodes being responsible for the data dissemination [17–19]. The cluster-based data dissemination method divides vehicles into dissimilar clusters and the procedure of the data dissemination consists of two phases, intra cluster and inter cluster data dissemination [20–22]. Centralized data dissemination is to distribute the request data to the vehicles in a certain area through infrastructure, such as base station or road-side unit (RSU). The centralized dissemination method generally requires the deployment of multiple infrastructures to complete the data dissemination task among multiple vehicles geographically dispersed. In order to save the cost and expand the scope of data dissemination, the centralized method and self-organizing way frequently work together to get the data dissemination in VN. When the infrastructure is available, the data dissemination task is accomplished by the infrastructure. If the infrastructure of some road sections is not available, the data dissemination in the VN is grasped by the way of self-organizing mode.

Due to the flexibility of the UAV, it is mostly used to enhance the availability of the communication. In order to achieve the efficient data collection of disaster management systems, Ejaz et al. used the UAVs to collect the data of the IoT in the area

of the disaster zone and designed the energy-efficient data collection scheme by the UAVs [23]. For the efficiency of message delivery and QoS (quality of service) requirement of aerial ad hoc networks, Kumar et al. proposed route selection method based on the connectivity, latency and lifetime of the path with the neuro-fuzzy interference system [24, 25]. K. G. Panda proposed an UAV-assisted network architecture for the effectiveness of the post-disaster management. The proposed scheme guides the survivors to the nearest campsite, which can speed up the rescue operations [26]. Kaleem et al. used the UAVs to assist the function recovery of 3GPP-LTE and proposed a disaster resilient three-layered architecture consisted of SDN layer, UAV cloudlet layer, and a radio access layer, which get the low latency of communication in the disaster [27]. Adsadawut proposed a disaster-resilient communication framework for heterogeneous VN implemented through LTE and NerveNet and designed the corresponding selecting algorithm between the NerveNet and the LTE [28]. Zhao et al. proposed a network framework, which was composed of UAV, macro base station, micro base station and users [29]. When the user requested the data, UAV and micro base station provided users with the data cached which improved the efficiency of the data access. Oubbati et al. proposed an efficient routing solution based on flooding mechanism to make the data transmission more reliable and improve the robustness of the path [30, 31]. When the transmission path was interrupted between the vehicles, then vehicles temporarily cooperate with the UAV to transfer the data. In order to improve the efficiency of data offloading, Zheng et al. designed an optimal target vehicle selection scheme for UAV to complete the data offloading based on the reinforcement learning technology [32].

In the interest of improving the efficiency of the data distribution in the VN, network coding is adopted in many cases. Wang et al. proposed the solution to construct the set of the relay nodes by calculating the utility of the neighboring node [33, 34], then selecting the node with the largest utility as the relay node to broadcast the message by the instantly decodable network coding (IDNC) coding technology. Behnam et al. proposed a method for the periodic broadcasting of the VN based on the network coding technology, which is especially suitable for the broadcast of short messages [35]. Keshtkarjahromi et al. developed a network coding framework as to the coexistence of the D2D and the cellular and characterized the performance of the network coding framework from the perspective of time needed to recover all the packets [36]. Nawaz Ali et al. proposed a solution of the data acquisition in the VN based on the network coding and the timeliness of data acquisition was considered [37, 38], selecting one node according to the minimum slack time of the service and then constructing an encoded packet according to the maximum clique of the graph and broadcasting it. As to the data dissemination from the RSU to the vehicles, our research group proposed a data dissemination scheme based on network coding. The maximum flow theory was used to allocate users in RSU's overlapping areas, which improves the efficiency of data dissemination [39]. During the data transmission of vehicle networks, Tang et al. divided the vehicles into the backbone nodes and the ordinary nodes. When

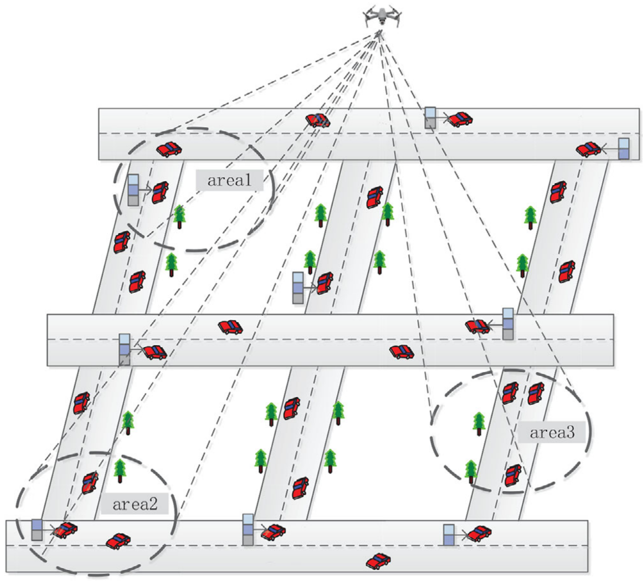

FIGURE 1 Scenario of the UAV-assisted data dissemination

the backbone node sent data to the ordinary nodes, network coding technology was adopted to reduce the packet loss rate of data transmission [40].

In some emergencies, such as earthquake or floods, the communication infrastructure is seriously damaged, so it is necessary to communicate with people and vehicles in the disaster area. Due to the maneuverability of UAV, it usually plays an important role in these scenarios. However, due to the large area of the disaster, there are not so many available UAVs. Therefore, UAV often carries one directional adjustable antenna to cover a broader region. As far as we know, there is no relevant literature on the efficient data dissemination mechanism of UAV with the directional adjustable antenna. Here, the data dissemination method for UAV with the directional adjustable antenna is studied. The graph model is used to model the data demand state of users in UAV's coverage. Based on the data requested state graph of users, UAV uses the network coding method to get the data dissemination, which improves the efficiency of the data distribution.

3 | UAV-ASSISTED DATA DISSEMINATION

3.1 | System model and assumptions

In some natural disasters or emergencies, there may not be enough UAVs to accomplish the relief efforts. We will use the UAV with adjustable antenna to realize the data dissemination. Assume that the UAV carries an adjustable antenna with a radius of d and is responsible for data dissemination in a larger region. When the UAV is broadcasting, its position remains unchanged and the direction of the antenna can be variable, which can cover different communication areas, such as the area1, area2 and area3, as shown in Figure 1, so that the UAV can send data

to the vehicles in the entire area covered by it when it adjusts the direction of the antenna. The proposed data dissemination scheme is not limited to this kind of road scene. It can be applicable to the other traffic network of different road scenarios. Coverage of UAV on the ground is approximated as one circle with radius d. In the course of the broadcasting, due to the unreliability of the wireless channel, it is impossible to ensure that all the data items are received correctly by every node. After receiving data items, vehicles will return a status message which indicates whether the data item was received successfully.

In order to improve efficiency of the data dissemination, the UAV broadcasts with IDNC. For example, assume that the UAV has broadcasted the data items f_1, f_2, and f_3. Vehicle v_1 has received the data items f_1, f_2 successfully and failed to receive the data item f_3; vehicle v_2 has received data items f_1, f_3 successfully and failed to receive data item f_2; then UAV broadcasts the encoded data item $f_2 \oplus f_3$. After receiving coded data item $f_2 \oplus f_3$, vehicle v_1 can decode data item f_3 with the existing data item f_2; vehicle v_2 can decode data item f_2 with the existing data item f_3. UAV can satisfy the requirements of the two vehicles by a broadcast which can improve the efficiency of the data dissemination.

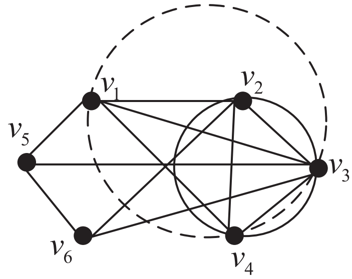

FIGURE 2 Geographical distribution of the vehicles

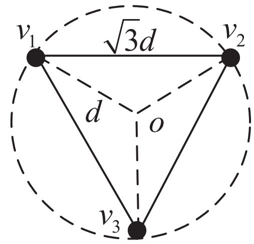

FIGURE 3 Circumcircle corresponding to the triangle

3.2 | Graph of the vehicles' data items requested

First, the UAV models the state of the data item requested by the vehicles as a graph; then UAV constructs the encoded message broadcast based on the maximum clique of the graph. Lastly, the vehicles accept the encoded message broadcasted by the UAV and decode the data item requested by itself. The solution can reduce the number of broadcasts by the UAV and improve data access efficiency of the vehicles. For the sake of simplicity, we use $v_1, v_2, \ldots, v_n$ to denote the vehicles; (x_i, y_i) represent the position coordinate of vehicle v_i; $f_1, f_2, \ldots, f_m$ represent the data items broadcasted by the UAV; d represents the communication radius of the UAV.

In order to ensure that two vehicles can receive the data item sent by the UAV at the same time, the distance between two vehicles should be less than or equal to $2d$, d meaning the coverage radius of UAV. If more than three vehicles can receive the data item sent by the UAV at the same time, the radius of the maximum circumcircle of these vehicles' locations must be less than or equal to the coverage radius d of the UAV. As shown in Figure 2, if four vehicles v_1, v_2, v_3, v_4 can receive the data item broadcasted by the UAV at the same time, the four vehicles must be in the coverage of the UAV. If the area of the maximum circumcircle of the four vehicles is less than or equal to the coverage of the UAV, then we can ensure that they can receive the data item sent by the UAV at the same time. The radius of the maximum circumcircle of multiple vehicles is determined by the locations of three vehicles among them; the result has been proved in mathematical theory. Given the radius d of the UAV's circular coverage, we can get the maximum area of its inscribed triangle. As shown in Figure 3, inscribed triangle area is maximum when its inscribed triangle is an equilateral triangle, which has been proved by mathematical theory. The length of the equilateral triangle side is $\sqrt{3}d$. If distance between any two vehicles is less than or equal to $\sqrt{3}d$, we can ensure that the clique consisted of these vehicles can be covered by the UAV.

Theorem 1. *If the length of the triangle side is less than or equal to $\sqrt{3}d$, the radius of the circumcircle of the triangle is less than or equal to d.*

Proof. If the length of the triangle side is less than or equal to $\sqrt{3}d$, the maximum distance between any two vertexes is $\sqrt{3}d$, which is shown as in Figure 3, the exterior radius of the triangle is d. In other situations, the exterior radius of the triangle is less than d. □

If vehicle v_i requests data item f_j, then UAV would add the vetex n_{ij} to the request state graph of the vehicles. By this way, UAV can determine all the vertexes of the graph. If node n_{ij} and node n_{kl} satisfy case1 or case2, then add an edge between the node n_{ij} and the node n_{kl}. By this way, UAV can construct the request state graph of the vehicles. Case1 means that $vehicle_i$ and $vehicle_k$ request the same data item and the distance between the two vehicles is less than or equal to $\sqrt{3}d$. The distance between $vehicle_i$ and $vehicle_k$ is less than or equal to $\sqrt{3}d$, meaning that the clique consisting of $vehicle_i$ and $vehicle_k$ can be within the communication scope of the UAV and they can accept the data items broadcasted by the UAV at the same time; otherwise they cannot receive the data item broadcasted by the UAV at the same time. Case2 means that data item f_j requested by $vehicle_i$ is available at $vehicle_k$ and data item f_l requested by $vehicle_k$ is available at $vehicle_i$. At the same time, the distance between $vehicle_i$ and $vehicle_k$ is less than or equal to $\sqrt{3}d$.

TABLE 1 Accepting status of the vehicles

	v_1	v_2	v_3	v_4
f_1	1	0	0	0
f_2	0	0	1	1
f_3	1	1	0	0

$$\text{case1}\begin{cases} distance(vehicle_i, vehicle_k) \leq \sqrt{3}d; \\ f_j \text{ requested by } vehicle_i; \\ f_l \text{ requested by } vehicle_k; \\ j = l; \end{cases}$$

$$\text{case2}\begin{cases} distance(vehicle_i, vehicle_k) \leq \sqrt{3}d; \\ f_j \text{ requested by } vehicle_i; \\ f_l \text{ requested by } vehicle_k; \\ f_j \text{ owned by } vehicle_k; \\ f_l \text{ owned by } vehicle_i; \\ j \neq l; \end{cases}$$

To give a more explicit picture on the construction process of the graph, we illustrate the details with an example. Now we assume that the receiving status of the vehicles v_1, v_2, v_3, v_4 are shown as in Table 1. 1 means that the data item was received successfully and 0 means that the data item was requested. f_1 is requested by v_2, v_3, and v_4. f_2 is requested by v_1 and v_2. f_3 is requested by v_3 and v_4. Vehicle v_2 and vehicle v_3 both request data item f_1 and the distance between vehicle v_2 and vehicle v_3 is less than or equal to $\sqrt{3}d$; add one edge between node n_{21} and node n_{31}. Vehicle v_2 requests data item f_2, vehicle v_3 requests data item f_3, the distance between vehicle v_2 and vehicle v_3 is less than or equal to $\sqrt{3}d$, vehicle v_2 owns data item f_3, vehicle v_3 owns data item f_2, then add one edge between node n_{22} and node n_{33}. By the same way, UAV can construct the request state graph of the vehicles based on the method which is shown in Figure 4. The maximum clique of the graph is $(n_{12}, n_{43}, n_{33}, n_{22})$. The UAV should give priority to the data items requested by the vehicles of the maximum clique; then UAV broadcasts message $f_3 \oplus f_2$, the procedure is shown as Algorithm1. Then these vehicles v_1, v_2, v_3 and v_4 receive the message and return the receiving state information whether they have received the message successfully; then the vehicles decode the message they requested. v_1 can decode the data item f_2 with data item f_3 owned; v_2 can decode data item f_2 with data item f_3 owned; v_3 can decode data item f_3 with data item f_2 owned; v_4 can decode data item f_3 with data item f_2 owned. Then UAV updates the request state graph of vehicles according to the receiving state information returned by the vehicles. UAV repeats the procedure until all the data items are received successfully by every vehicle. The method can reduce the number of the data disseminations. The maximum clique problem has been proved the NP-hard problem. When the area serviced by UAV is large and the vehicle density is high, the size of the request state graph becomes large and it is difficult to find the maximum clique of the graph.

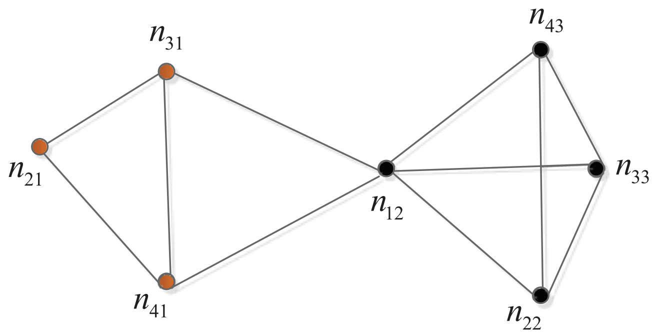

FIGURE 4 Graph of the vehicles' data items requested

ALGORITHM 1 Construct the RequestGraph algorithm executed by the UAV

Input: vehicle$_i$'s location (x_i, y_i); data items $f_1, f_2, \ldots, f_m$ broadcast by the UAV;
Output: RequestGraph//Construct the RequestGraph

while i<vehicleNum **do**
  while j<dataItemNum **do**
    if ($vehicle_i$ request the f_j) **then**
      Add $node_{ij}$ into the RequestGraph;
    end if
  end while
end while
while $\forall node_{ij}, \forall node_{kl} \in RequestGraph$ **do**
  distance($vehicle_i, vehicle_k$)= $\sqrt{(x_i - x_k)^2 + (y_i - y_k)^2}$;
  if (both $vehicle_i$ and $vehicle_k$ request the f_j & distance($vehicle_i, vehicle_k$) $< \sqrt{3}d$) **then**
    AddEdge($node_{ij}, node_{kj}$);
  end if
  if ($vehicle_i$ request the f_j & $vehicle_i$ have the f_l & $vehicle_k$ request the f_l & $vehicle_k$ have the f_j & distance($vehicle_i, vehicle_k$)$<\sqrt{3}d$) **then**
    AddEdge($node_{ij}, node_{kl}$);
  end if
end while
return RequestGraph;

3.3 | Maximum clique algorithm based on region division

When the UAV uses the adjustable antenna for the data dissemination, its current coverage region is a local region; there is a constraint condition that the distance between any two

ALGORITHM 2 Maximum Clique algorithm based on region division and constructing coded message executed by the UAV

Input: RequestGraph of the data items requested by vehicles;

Output: Message coded;//Divide the RequestGraph//Find the MaxClique of the the RequestGraph

Divide the RequestGraph into multiple Subgraph$_i$ with the square with side length $2\sqrt{3}d$;
for (*direction* $\in$ {*current*; *left*; *lowerleft*; *down*;*lowerright*; *right*; *upperright*; *upward*, *upperleft*}) **do**//*k* threads find the maximum clique of subgraph$_i$ parallelly
  for (i=0;i<subgraphNum;) **do**
    for (k=0;k<threadNum;k++) **do**
      MaxClique$_k$=Thread$_k$(Subgraph$_i$);
      i=i+1;
    end for
    MaxClique=Max(MaxClique$_k$);
  end for
  Each square moves $\sqrt{3}d$ in the *direction* to get new Subgraph$_i$;
end for//Construct the message coded
Find the request data items $p_1, p_2, \dots, p_n$ of the MaxClique;
return message $p_1 \oplus p_2 \oplus \dots \oplus p_n$;

vehicles should be less than or equal to $\sqrt{3}d$ when UAV constructs the request state graph of the vehicles. UAV should make full use of this feature in the process of finding the maximum clique of the graph. The method based on region division is designed to find the maximum clique. Use the square shape with $2\sqrt{3}d$ side length to divide the entire service region into multiple subregions. Then UAV finds the maximum clique of the subgraph in each subregion and selects the largest one as the maximum clique of the graph; the UAV gives priority to the vehicles in the maximum clique and broadcasts data items to them. The number of vehicles in the subregion may be much less than that of the entire service region. The maximum clique of the request state graph is transformed into the maximum clique of the subgraph. At the same time, the computational procedure of finding the maximum clique of the subgraph can be executed by the way of parallel computing, which further accelerates the calculation process.

Suppose that a vertex of a clique is inside the square area with $2\sqrt{3}d$ side length, and there are some neighboring nodes locate outside the square, such as the neighboring nodes $\{n_{s1}, n_{s2}, n_{s3}, n_{s4}, n_{s5}\}$ of the node s, which is shown as in Figure 5a. The maximum distance between arbitrary two nodes of the graph is less than $\sqrt{3}d$, because the distance between any two nodes of the graph must be less than or equal to $\sqrt{3}d$ when the graph is constructed. Two squares being adjacent is defined as definition 1. If node s can form one clique with nodes $\{n_{s1}, n_{s2}, \dots, n_{sm}\}$, then any two nodes of the $\{s, n_{s1}, n_{s2}, \dots, n_{sm}\}$ must fall into at most two adjacent squares with side length $\sqrt{3}d$, which is proved as theorem 2.

Definition 1. *Two squares are adjacent if the two squares have at least a common vertex or a common edge.*

Theorem 2. *If node s can form one clique with these nodes $\{n_{s1}, n_{s2}, \dots, n_{sm}\}$ and the distance between any two nodes of the clique is less than or equal to $\sqrt{3}d$, then any two nodes n_{sk} and $n_{sl} \in \{s, n_{s1}, n_{s2}, \dots, n_{sm}\}$ must fall into at most two adjacent squares with side length $\sqrt{3}d$.*

Proof. Assume that the existence of the two nodes n_{sk} and $n_{sl} \in \{s, n_{s1}, n_{s2}, \dots, n_{sm}\}$ belong to non-adjacent squares with side length $\sqrt{3}d$; the two nodes n_{sk} and n_{sl} must fall into two non-adjacent squares with side length $\sqrt{3}d$; then the distance between n_{sk} and n_{sl} must be more than $\sqrt{3}d$, which is shown as node n_{s1} and node n_{s3} of Figure 5a. According to the constraint, the distance between any two nodes from one clique should not exceed $\sqrt{3}d$ when the graph is constructed, and no two such nodes exist. So any two nodes in $\{s, n_{s1}, n_{s2}, \dots, n_{sm}\}$ from one clique must fall into at most two adjacent squares with side length $\sqrt{3}d$. Based on the fact, we can conclude Lemma 1. □

Lemma 1. *If nodes $\{s, n_{s1}, n_{s2}, \dots, n_{sm}\}$ can form one clique, these nodes must belong to at most four adjacent squares with side length $\sqrt{3}d$; that means, any clique of the graph must fall into four adjacent squares with side length $\sqrt{3}d$. In other words, any clique must fall into one square with side length $2\sqrt{3}d$.*

Proof. We assume that nodes $\{s, n_{s1}, n_{s2}, \dots, n_{sm}\}$ can form one clique and these nodes fall into more than four squares with side length $\sqrt{3}d$. According to the definition of neighbor relation among the squares, there are at most four squares which are neighbors with each other. So there must be two nodes in $\{s, n_{s1}, n_{s2}, \dots, n_{sm}\}$ locating at two non-adjacent squares with side length $\sqrt{3}d$. Then we can derive that the distance between the two nodes is above $\sqrt{3}d$ which is in contradiction with the distance we assumed when the graph is constructed, so Lemma 1 is proved. □

The service area of the UAV is divided into multi-quare subregions with side length $2\sqrt{3}d$; the graph is also divided into multiple subgraphs belonging to multi-square subregions with side length $2\sqrt{3}d$. The nodes of the subgraph can be located anywhere in the square region with side length $2\sqrt{3}d$. The square region is further divided into four smaller square regions (SSR) with side length $\sqrt{3}d$, which is shown as in Figure 5a. If node s falls into one SSR with side length $\sqrt{3}d$ shown as in Figure 5a, its neighboring nodes must belong to the eight neighboring SSRs of the current SSR in which node s is currently located in. The square subregion with $2\sqrt{3}d$ side length only needs to move three times to cover all the cliques that node s can form with its neighboring nodes. From *Lemma*1, we know that any clique that contains node s must belong to one square

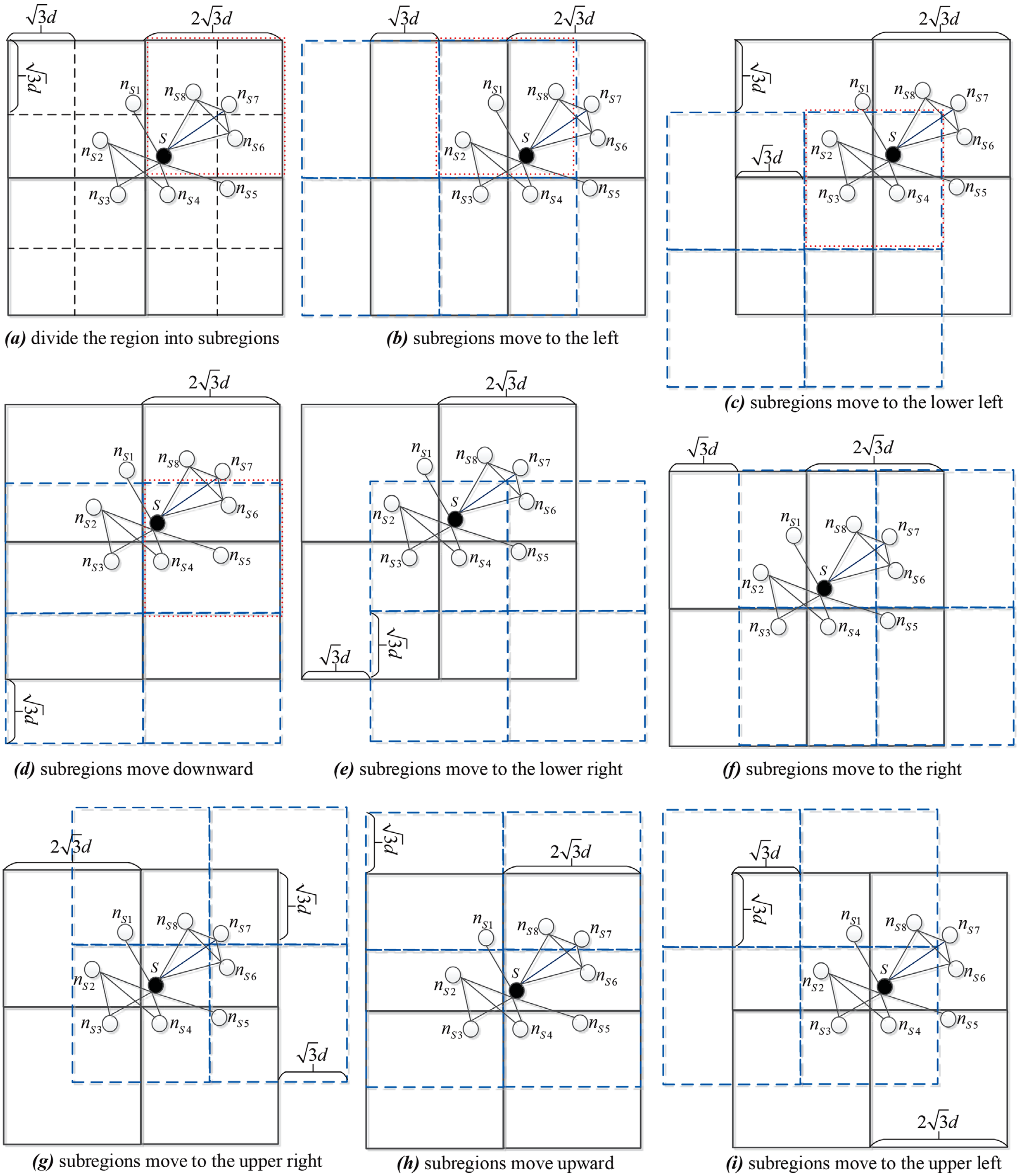

FIGURE 5 The movement of the subregions

region with side length $2\sqrt{3}d$.Based on the above statement, any clique that contains node s must belong to four square subregions with side length $2\sqrt{3}d$, which are shown as the red dashed squares in Figure 5a–d. The four squares have one common SSR with side length $\sqrt{3}d$, in which node s is currently located in.

In order to calculate the maximum clique that s can form after adding neighboring nodes n_{s1} and n_{s2}, the subregion with side

TABLE 2 Maximum cliques corresponding to the sub-graphs

	Square1	Square2	Square3	Square4
(a)	$(S, n_{s6}, n_{s7}, n_{s8})$	(n_{s1})	(n_{s3})	(n_{s4})
(b)	(S, n_{s1})	$(\emptyset)$	$(\emptyset)$	(n_{s3})
(c)	(S, n_{s2}, n_{s3})	$(\emptyset)$	$(\emptyset)$	$(\emptyset)$
(d)	(S, n_{s4})	(n_{s2}, n_{s3})	$(\emptyset)$	$(\emptyset)$
(e)	(n_{s5})	(S, n_{s2}, n_{s3})	$(\emptyset)$	$(\emptyset)$
(f)	(n_{s6}, n_{s7})	(S, n_{s1})	(n_{s3})	(n_{s5})
(g)	(n_{s7})	(n_{s8})	(S, n_{s2}, n_{s3})	(n_{s5})
(h)	(n_{s7}, n_{s8})	(n_{s1})	(n_{s2}, n_{s3})	(S, n_{s4})
(i)	(n_{s1})	$(\emptyset)$	$(\emptyset)$	(S, n_{s2}, n_{s3})

length $2\sqrt{3}d$ move $\sqrt{3}d$ to the left which is shown as the red dashed square of Figure 5b; in order to calculate the maximum clique that s can form after adding nodes n_{s2}, n_{s3} and n_{s4}, the subregion moves down $\sqrt{3}d$ which is shown as the red dashed square of Figure 5c. In order to calculate the maximum clique formed by s after adding the neighboring nodes n_{s4} and n_{s5}, the subregion moves $\sqrt{3}d$ to the right which is shown as the red dashed square of Figure 5d. After the above procedure, all the neighboring nodes of node s can be covered. Find the maximum clique of the subgraph in every subregion with side length $2\sqrt{3}d$, we can get the maximum clique $(s, n_{s6}, n_{s7}, n_{s8})$ of the graph in Figure 5a.

We use the square shape with $2\sqrt{3}d$ side length to divide the entire service area into multiple subregions. Subregions just need to move eight times to cover all the neighboring nodes being outside the squares with $2\sqrt{3}d$ side length, detailed method of the squares' movement is shown in Figure 5. Subregions move $\sqrt{3}d$ in these directions {*letf, lowerleft, down, lowerright, right, upper right, upward, upperleft*}. When these squares with side length $2\sqrt{3}d$ move to a new location, we find the maximum clique of the subgraph located into each subregion with $2\sqrt{3}d$ side length parallel by the multi-thread technology; details are shown as in Algorithm 2.

The graph is divided into four sub-graphs with four squares with side length $2\sqrt{3}d$, as shown in Figure 5a. The four maximum cliques are $(S, n_{s6}, n_{s7}, n_{s8})$, (n_{s1}), (n_{s3}), (n_{s4}) corresponding to the four sub-graphs belonging to the four squares. When the squares move $\sqrt{3}d$ to the left, shown as in Figure 5b with the blue dotted line, we can also get the four maximum cliques (S, n_{s1}), $(\emptyset)$, $(\emptyset)$, (n_{s3}) of the four sub-graphs divided by the four squares. The maximum cliques of subgraphs are shown in Table 2 corresponding to the different locations of the squares. Finally, the maximum clique of the whole graph can be obtained by selecting the max one among the maximum cliques of the sub-graphs. Then, we can get the maximum clique $(s, n_{s6}, n_{s7}, n_{s8})$ of the entire graph. Then, the UAV constructs the coded message according to data items requested by the vehicles of the maximum clique and broadcasts it to the vehicles. After receiving the message broadcast by the UAV, the vehicles return the status information about whether they receive the coded data item successfully. According to the receiving status information returned by the vehicles, the UAV updates the request state graph of data items and finds the maximum clique of the graph updated by the same method. The UAV repeats the procedure until all the data items are received by every vehicle.

3.4 | Algorithm complexity analysis

Suppose there are m vehicles distributed in the area covered by the UAV, and a file consisting of n data items needs to be distributed. At worst, there are $m \times n$ nodes in the data request state graph of the vehicles constructed by Algorithm 1. When constructing the data request state graph of the vehicles, it needs to determine whether there is an edge between any two nodes. The complexity of Algorithm 1 is $O(m^2 \times n^2)$. Using the conventional method, we need to search the largest clique in the large area. If the branch and bound method is used, the algorithmic complexity is $O(m \times n \times 2^{m \times n})$ [34]. Here, according to the coverage radius of UAV's directional antenna, the large region is divided into k sub-regions, and then the maximum clique is found in each sub-region. Then the number of nodes falling into the small region is approximately mn/k. The branch and bound method is used in each sub region. The complexity of Algorithm 2 is $O(m \times n/k * 2^{m \times n/k})$ to find the maximum clique. The calculation process of the k sub-regions can be carried out in parallel and then the maximum clique of the whole region can be obtained. In the data distribution process, a single file can be divided into multiple sub-files for distribution, which can ensure the effectiveness of the proposed framework.

4 | PERFORMANCE EVALUATION

4.1 | Simulation environment

First, we compare the time consumed of the method proposed in this paper with the method without region division to find the maximum clique of the request state graph with different number of nodes. The computing procedures of the two methods are executed on the platform Win10 OS, 16G RAM and Intel(R) Core(TM) i5-4570 CPU @ 3.2GHz. Then we compare the number of broadcasts needed and the time consumed to finish the data dissemination in different scenarios. The data dissemination procedure of the UAV to vehicles is conducted by the network simulator NS-3; the parameters of the simulation are shown in Table 2.

4.2 | Simulation results and discussions

In order to verify the effectiveness of the method proposed in the paper, we compare the performance of the proposed method with other methods based on network coding without region division [34] and non-coding method [41] in different scenarios, which are named CDDB and NCDC, respectively.

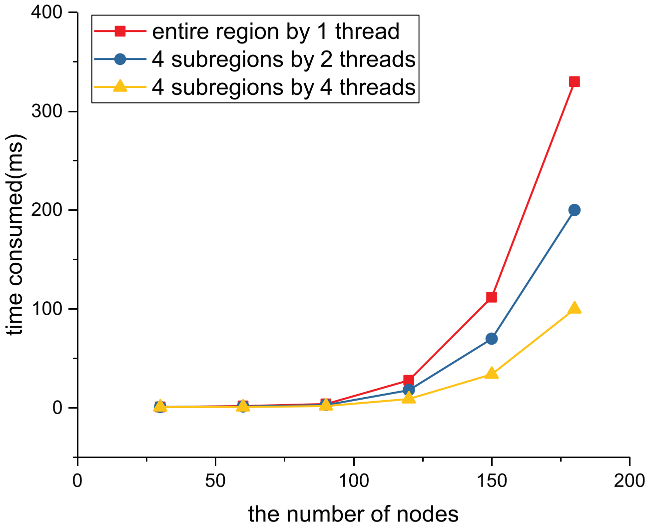

FIGURE 6 Time consumed to find the maximum clique

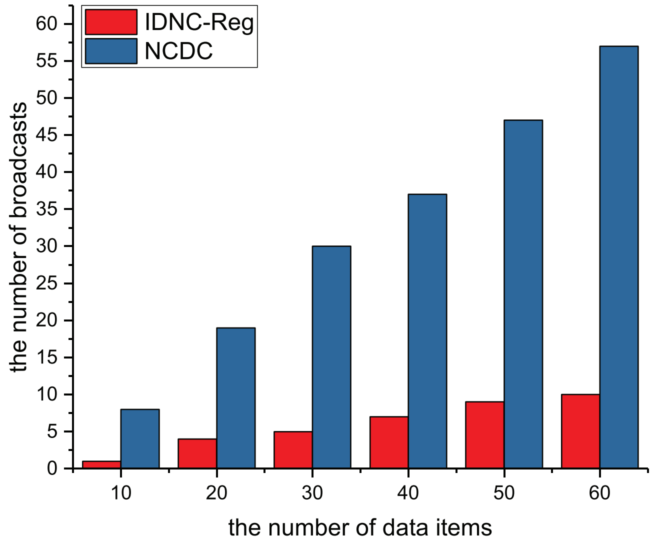

FIGURE 7 Data dissemination with fixed number of vehicles

UAV uses the omnidirectional antenna to realize the data dissemination based on network coding and the service area is not divided into multiple sub-regions in [34]. Network coding technology is not selected in [41] and the omnidirectional antenna is used for data dissemination.

Scenario 1 is that UAV is responsible for the data dissemination for the $4\sqrt{3}d * 4\sqrt{3}d$ square region. With the change of the number of data items lost and the vehicles, the number of nodes in the graph of the vehicles' data items requested will also change. The method of the region division is to divide the entire region into four subregions with side length of $2\sqrt{3}d$, then use the method proposed in the paper to find the maximum clique run by multiple threads in parallel; the method is run with 2 threads and 4 threads, respectively. The method of CDDB is to find the maximum clique in the entire square region which is run with a single thread. The simulation compares the time consumed of the three methods to find the maximum clique of the graph with the number of nodes being 40, 80, 120, 160 and 200. From the simulation results of Figure 6, the calculating speed of the method based on the region division is much faster than the method without region division; the advantage is gradually strengthened with the increase of the number of nodes in the graph. Because the complexity of the maximum clique problem changes exponentially with the number of the nodes, the time consumed also verifies the fact. The time consumed by the 4 threads is much less than the 2 threads, because the more threads run parallel which can speed up the calculating speed. It can be seen from the results that IDNC-Reg has an advantage over CDDB in the perspective of finding the maximum clique.

Scenario 2 is that the number of vehicles is kept at a constant 30 and the number of data items broadcasted by the UAV increases gradually, which is 10, 20, 30, 40, 50 and 60. The UAV has broadcasted the data items and the vehicles received the data items with a data item loss rate of 10% and it needs to continue to broadcast these lost data items to ensure that every vehicle gets all the data items. We compare the number of broadcasting needed to disseminate the lost data items with the way of IDNC coding and non-coding. It can be seen from Figure 7 that the number of broadcasts by IDNC-Reg and NCDC both increases with the increment of the number of the data items; the number of broadcasts needed by IDNC-Reg is much less than NCDC. The number of broadcasts needed are becoming increasingly differentiated with the increase of the data items. With the increase of the data items, the number of lost data items continues to increase. This will lead to the increase of the encoding opportunities and eventually strengthen the advantage of broadcasting by network coding proposed in the paper.

Scenario 3 is that the number of data items broadcasted by the UAV is kept at a constant 30 and the number of the vehicles increases gradually, which is 10, 20, 30, 40, 50 and 60. The UAV has broadcasted 30 data items and the vehicles received the data items with a data item loss rate of 10% and it needs to continue broadcasting these data items to ensure that every vehicle gets all the data items. We compare the number of broadcasting needed to disseminate the lost data items with IDCN-Reg and NCDC. It can be seen from Figure 8 that both the number of broadcasts by IDNC-Reg and NCDC increases with the number of the vehicles; the number of broadcasts needed by network coding is much less than the non-coding. The number of broadcasts needed are becoming increasingly differentiated with the increase of the vehicles. Along with the increase of vehicles, the number of the lost data items also increases. This work will lead to the increase of the encoding opportunities and eventually reduce the number of broadcasts by network coding. The number of broadcasts needed by NCDC does not change with the continuous increase of the vehicles later because the number of the lost data items has reached the number of the total data items broadcasted by the UAV.

Scenario 4 is that the number of data items broadcasted by the UAV and the number of vehicles are kept at a constant 30. The UAV has broadcasted 30 data items, the vehicles received the data items with different data item loss rate and it needs

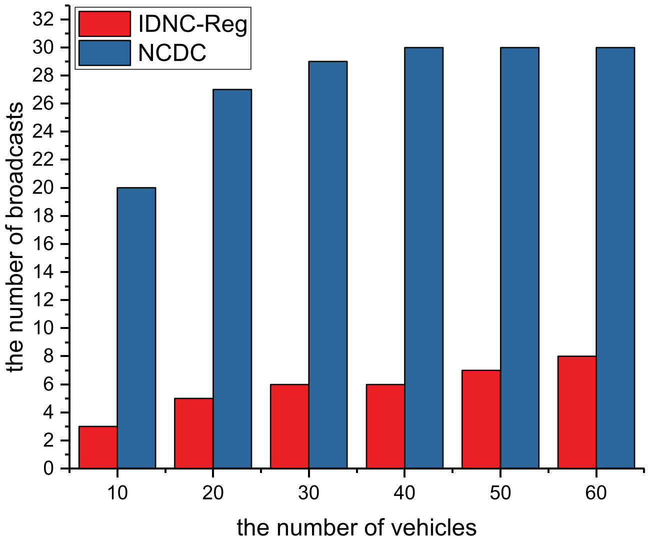

FIGURE 8 Data dissemination with fixed number of data items

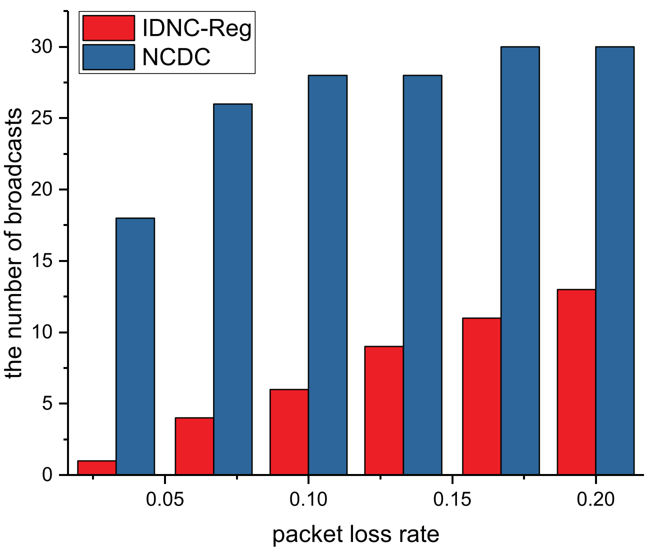

FIGURE 9 Data dissemination with fixed number of data items and vehicles

to continue broadcasting these data items to ensure that every vehicle gets all the data items. We compare the number of the broadcasting needed to disseminate the lost data items with the way of NCDC. It can be seen from Figure 9 that both the number of broadcasts by IDNC-Reg and NCDC increase with the data item loss rate; the number of broadcasts needed by IDNC-Reg is much less than the NCDC. The difference of the number of broadcasts needed is becoming smaller and smaller with the increment of the data item loss rate. Along with the increase of the data item loss rate, the number of the lost data items of the vehicles also increases. This work will lead to the decrease of the decoding capability of the vehicles and eventually increase the number of broadcasts by IDNC-Reg. The number of broadcasts needed by NCDC does not change with the continuous increase of the data item loss rate because

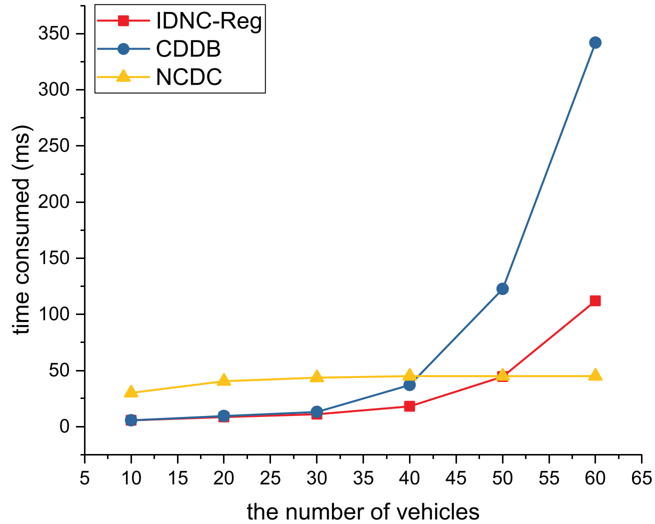

FIGURE 10 Time consumed to accomplish the data dissemination

TABLE 3 Simulation parameters

Parameter	Value
Radius of UAV	$d = 30$ m
Servent area of UAV	$4\sqrt{3}d * 4\sqrt{3}d$
Area of subregion	$2\sqrt{3}d * 2\sqrt{3}d$
MAC protocol	802.11p
Mobility model	Static
Packet size	1024 bytes
Packet loss rate	10%

the number of the lost data items has reached the number of the total data items broadcasted by the UAV.

Scenario 5 is that the number of data items broadcasted by the UAV is kept at a constant 30 and the number of the vehicles increases gradually, which is 10, 20, 30, 40, 50 and 60. The UAV has broadcasted 30 data items and the vehicles received the data items with a data item loss rate of 10% and it needs to continue to broadcast these data items to ensure that every vehicle gets all the data items. We compare the time consumed by the broadcast needed to accomplish the dissemination of the lost data items with the way of IDNC-Reg, CDDB and NCDC. It can be seen from Figure 10 that the time consumed for broadcasts by IDNC-Reg and CDDB is much less than NCDC when there are few vehicles; the time consumed by IDNC-Reg is shortest when there are few vehicles. Time consumed by the three methods and the performance improvement of IDNC-Reg compared with CDDB are shown inTable 4, when the number of vehicles are 10, 20, 30 and 40. When the number of vehicles reaches 60, the time consumed by the IDNC-Reg and CDDB is more than NCDC. Finding the maximum clique of the two methods takes too much time, but the time consumed by the IDNC-Reg is still less than CDDB because the method IDNC-Reg divides the entire region into multiple subregions to find the maximum clique, which is more efficient than the method CDDB. The

TABLE 4 Performance under different number of vehicles

Solution	10	20	30	40
NCDC	30 ms	40.5 ms	43.5 ms	45 ms
CDDB	5.5 ms	9.5 ms	13 ms	37 ms
IDNC-Reg	5.5 ms	8.5 ms	11 ms	18 ms
Performance improved	0%	10.5%	15.4%	51.3%

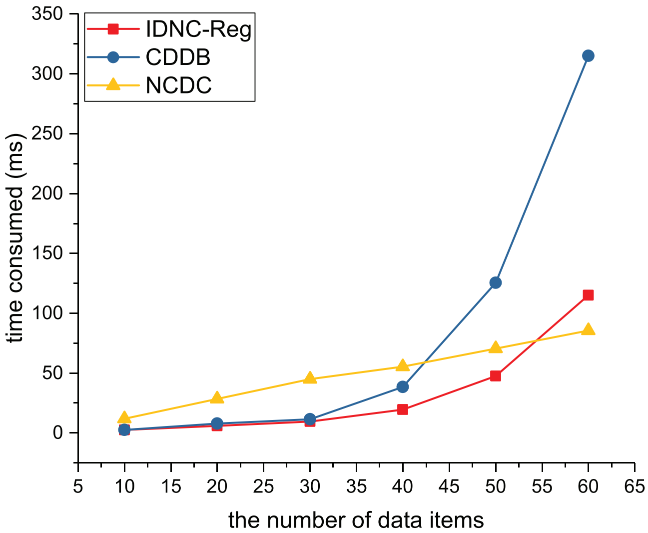

FIGURE 11 Time consumed to accomplish the data dissemination

method proposed in the paper is more suitable than the other two methods when there are not many vehicles.

Scenario 6 is that the number of vehicles is kept at a constant 30 and the number of the data items broadcasted by the UAV increases gradually, which is 10, 20, 30, 40, 50 and 60. The UAV has broadcasted the data items with a certain number and the vehicles received the data items with a data item loss rate of 10% and it needs to continue to broadcast these data items to ensure that every vehicle gets all the data items. We compare time consumed for the broadcast needed to disseminate the lost data items by IDNC-Reg, CDDB and NCDC. It can be seen from Figure 11 that the time consumed for broadcasts by IDNC-Reg and CDDB is much less than that of NCDC when there are few data items, the time consumed by IDNC-Reg is shortest when there are few data items. Time consumed by the three methods and the performance improvement of IDNC-Reg compared with CDDB are shown in Table 5, when the number of data items are 10, 20, 30 and 40. When the number

TABLE 5 Performance under different number of data items

Solution	10	20	30	40
NCDC	12 ms	28.5 ms	45 ms	55.5 ms
CDDB	2.5 ms	8 ms	11.5 ms	38.5 ms
IDNC-Reg	2.5 ms	6 ms	8.5 ms	19.5 ms
Performance improved	0%	25%	26.3%	49.3%

TABLE 6 Performance under different data-item loss rate

Solution	3.3%	6.7%	10%	13.3%
NCDC	27 ms	39 ms	42 ms	42 ms
CDDB	2.5 ms	8 ms	13 ms	41.5 ms
IDNC-Reg	2.5 ms	7 ms	11 ms	22.5 ms
Performance improved	0%	12.5%	15.4%	45.8%

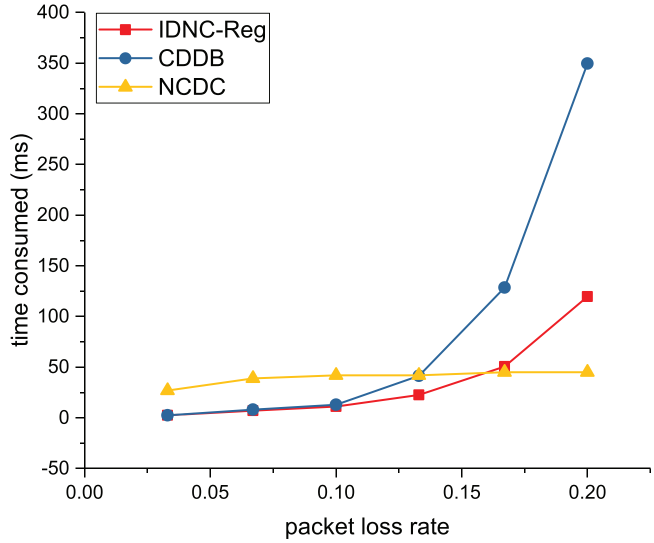

FIGURE 12 Time consumed to accomplish the data dissemination

of the vehicles reaches 60, the time consumed of the IDNC-Reg and CDDB is more than NCDC. Because finding the maximum clique of the two methods takes too much time, the time consumed of the IDNC-Reg is still less than the CDDB because the method IDNC-Reg divides the entire region into multiple subregions to find the maximum clique which is more efficient than the method CDDB. The method proposed in the paper is more suitable than the other two methods when the scale of the data items is not so large. When a large file is disseminated, it can be divided into multiple sub-files. When all the vehicles receive all the packets of the current sub-file disseminated by UAV, the next sub-file will be distributed, so that the number of nodes in the graph model can be controlled in an appropriate scale.

Scenario 7 is that the number of data items broadcasted by the UAV and the number of vehicles is kept at a constant 30. The UAV has broadcasted 30 data items, and the vehicles received the data items with the different data item loss rate and the UAV needs to continue broadcast these data items to ensure that every vehicle can get all the data items. We compare the time consumed of the broadcasting needed to accomplish the dissemination of the lost data items by IDNC-Reg, CDDB and NCDC. It can be seen from the Figure 12 that the time consumed of broadcasts by IDNC-Reg, CDDB and NCDC all increase with the data item loss rate. The time consumed of broadcasts by IDNC-Reg and the CDDB is much less than NCDC when there are few data items; the time consumed of the

IDNC-Reg is fewest when there are few data items. Time consumed by the three methods and the performance improvement of IDNC-Reg compared with CDDB are shown in Table 1, when the data-item loss rate are 3.3%, 6.7%, 10% and 13.3%. When the data item loss rate reaches 0.2, the time consumed of the IDNC-Reg and CDDB is more than NCDC method. Because finding the maximum clique of the two methods takes too much time, but the time consumed of the IDNC-Reg is still less than the CDDB because the method IDNC-Reg divides the entire region into multiple subregions to find the maximum clique which is more efficient than the method CDDB. The method proposed in the paper is more suitable than the other two methods when there are not many data items.

Based on the simulation and the results, UAV assisted data dissemination with a directional adjustable antenna is necessary when wireless channel is unstable and the available UAVs are not sufficient. Especially, there are lots of nodes distributed over a large area waiting to receive the data disseminated because the directional adjustable antenna can expand the service coverage of UAV and improve the communication quality. Meanwhile, network coding technology can improve the efficiency of the data dissemination. When there is a large file to be distributed, dividing it into multiple small files for distribution can ensure the efficiency of the data dissemination based on the network coding.

5 | CONCLUSION

This paper designs a UAV-assisted data dissemination scheme based on network coding to improve the efficiency of data dissemination. Divides the data dissemination area into multi-sub regions to solve the maximum clique problem in the process of the data dissemination. The maximum cliques of the sub-regions are solved parallel with the multiple threads by the UAV. Here, simulation results prove that the proposed scheme improves the computational efficiency and reduce the number of data dissemination. The future work will focus on exploring the efficient heuristic algorithm to find the maximum clique of the sub-graph of requested data items by the vehicles.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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