IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received July 30, 2018, accepted August 31, 2018, date of publication September 13, 2018, date of current version October 8, 2018.

Digital Object Identifier 10.1109/ACCESS.2018.2869380

A Delay Tolerant Network Routing Policy Based on Optimized Control Information Generation Method

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This work was supported in part by the National Natural Science Foundation of China under Grant 61502118, in part by the National Science and Technology Major Project of the Ministry of Science and Technology of China under Grant 2016ZX03001023-005, in part by the Natural Science Foundation of Heilongjiang Province in China under Grants F2016009 and F2015029, and in part by the Ph.D. Student Research and Innovation Fund of the Fundamental Research Funds for the Central Universities under Grant HEUGIP201809.

ABSTRACT Current research examining delay tolerant network (DTN) routing policies mostly focuses on network environments with relatively abundant resources and lacks consideration of resource-constrained special network environments. To overcome this limitation, a resource-constrained DTN routing policy (RC-RP) based on an optimized control information generation method is proposed. In contrast to traditional DTN routing policies, RC-RP can utilize local node resources to select the relay node and perform copy control according to the optimized control information to achieve a better overall network performance. The simulation results show that the performance of the RC-RP routing policy is clearly superior to that of the epidemic routing policy, SAW routing policy, and RBL routing policy.

INDEX TERMS DTN, opportunistic network, routing algorithm, optimal control.

I. INTRODUCTION

The architecture of traditional networks, such as the open systems interconnection (OSI) and transport control protocol/internet protocol (TCP/IP) architecture, mainly solves the problems of a small transmission delay, low error rate, and the presence of links between nodes [1], [2]. Therefore, these traditional architectures no longer apply in disaster scenarios, remote areas, and other network environments [3]–[5]. With the continuous development of network technology, network environments with large transmission delays, high error rate, and limited resources are becoming increasingly common [6], [7]. The advent of delay tolerant network (DTN) has solved these problems. DTN is a new type of network that differs from traditional networks, has features including high delay, high error rate, and low transmission rate, and may not have an end-to-end connection path [8].

Considering the many characteristics of DTN, the "storage-forward" method used by traditional networks cannot satisfy its communication; therefore, it adopts the "storage-carrying-forwarding" route mode for message forwarding [9]–[12]. The nodes in the network consistently search for the appropriate relay node or destination node until the message reaches the destination node or is dropped. Therefore, the communication of nodes in the DTN is based mainly on the movement of the nodes, the use of well-functioning connected branches in the network, and the delivery of messages to the destination node as quickly as possible [13]–[15]. To implement "storage-carry-forwarding", DTN constructs a bundle layer above the traditional network transport layer, thus converting the traditional "storage-forwarding" route mode to a "storage-carrying-forwarding" route mode to adapt to the network environment with high delay, high error rate, and no end-to-end connection path [16].

A reasonable DTN routing policy can utilize the limited resources in the DTN to forward messages according to specific forwarding rules to increase the probability of successful message delivery without increasing the network overhead [17]–[19]. However, current DTN routing policies have many shortcomings. They address mainly environments with unlimited network resources and do not consider the situation of constrained or unbalanced network resources [20]–[22]. Moreover, when a message is forwarded, the message forwarding success ratio is low, and the network overhead is large. Therefore, the proposal of a DTN routing policy for constrained resources is urgent so that the message can be efficiently forwarded when resources are limited or unevenly distributed. Considering the above problems, we propose a resource-constrained DTN routing policy based on the optimized control information generation method (OCIGM). This routing policy can use local node resources to select relay nodes and perform replica control based on optimized control information to achieve better overall network performance.

The remaining work presented in this paper is as follows. In the second section, related work is mainly introduced. In the third section, the OCIGM-based network model is mainly introduced. In the fourth section, the idea of the RC-RP routing policy is introduced. In the fifth section, the simulation experiment and analysis of the results are introduced. Finally, a conclusion is presented.

II. RELATED WORK

DTN is currently a research hotspot as a new type of network with relatively wide application scenarios. Due to the unique characteristics of DTN, the selection of relay nodes plays an important role in improving the overall performance of the network. However, the routing policy is the basis of its relay node selection for each node in the network. Therefore, the design of a DTN routing policy is of great importance in DTN communication, especially for resource-constrained network environments, such as disaster scenarios and remote area networks. Existing routing algorithms are mainly given in [23]–[37]. In addition, Zhang *et al.* [38] proposed a hybrid routing algorithm that clusters nodes by predicting the probability of an encounter between nodes. In each cluster, the number of copies of the spray and wait routing is limited according to the encounter probability, and the messages are forwarded between clusters according to the characteristics of the nodes.

Wang *et al.* [39] clustered nodes based on the degree of node trajectory matching, used a semi-Markov model to predict the probability of an encounter between nodes, and used a path search policy to find the optimal path. Xu *et al.* [40] addressed the shortcomings of the current routing algorithms that rely mainly on the location of nodes when selecting relay nodes and proposed a controlled infection routing algorithm. The routing algorithm selects relay nodes by predicting the direction of the node movement. Huang *et al.* [41] proposed a routing policy based on the evolution of social characteristics for the large community problems caused by the detection of k communities in the opportunity social network. Cao *et al.* [42] proposed a routing policy based on bridging centrality, node activity, and community relations to solve the problem of the message delivery success ratio and message delay in the PSN cannot reach a well-balanced state.

Nishiyama *et al.* [43] noted that cooperative DTN can extend the coverage of other types of networks by transmitting messages generated by nodes far from the base station to the base station in a multi-hop manner. Consequently, they proposed a ring-distributed routing algorithm for cooperative DTN, controlling the number of message copies and message forwarding based on the surrounding environment of the source node. Zhang *et al.* [44] proposed a routing policy based on node spatial information and node connectivity transitivity to solve the existing routing algorithm does not consider the problem of node space information, in which the space information is a characteristic such as the dwell time at a location or the connection transitivity during the process of node encounter probability prediction. Wei *et al.* [45] designed a new type of message delivery metric to indicate the forwarding capability of the node and then designed a cost-based social-aware routing algorithm based on the node forwarding capability and relay node selection rules. Wu *et al.* [46] proposed a hop-constrained infectious routing algorithm to reduce the network overhead. The routing algorithm can effectively limit the number of nodes forwarding messages. To meet the needs of different network models, Mergenci and Korpeoglu [47] provided different routing mechanisms for different types of periodic connections to ensure the earliest delivery time and the minimum number of hops. Ayub *et al.* [48] proposed a probabilistic and replication based locking routing protocol which named RBL, the routing protocol based on the probability value of nodes and control message replication to improve network performance.

Based on existing researches, we propose a resource-constrained DTN routing policy based on OCIGM. This routing policy can use local node resources to select relay nodes and perform replica control based on optimized control information to achieve better overall network performance.

III. OCIGM-BASED DTN NETWORK MODEL

A. THE ROLE OF OCIGM

In [49], we proposed an OCIGM to be applied in the DTN. The role of OCIGM is to generate optimized control information for the routing policy of the mobile terminal. Based on the optimized control information, the mobile terminal adjusts the routing policy by limiting the number of copies of the message. According to the different types of optimized control information, the number of copies is limited to the following three types.

Assume that the numbers of copies of the message before and after receiving the optimal control information are *nrofCopies* and *nrofCopiesAfter* respectively, and the global network state NS is {message delivery ratio *mDelivery*, network overhead *mOverhead*, message drop ratio *mDrop*}.

Case 1: If optimal control information is used to improve the message delivery ratio, then equation (1) is used to control the number of copies.

$$nrofCopiesAfter = \frac{\alpha_1}{mDelivery} * nrofCopies \tag{1}$$

where α_1 is a threshold value, and $mDelivery < \alpha_1 < 1$.

Case 2: If optimal control information is used to reduce the network overhead, then equation (2) is used to control the

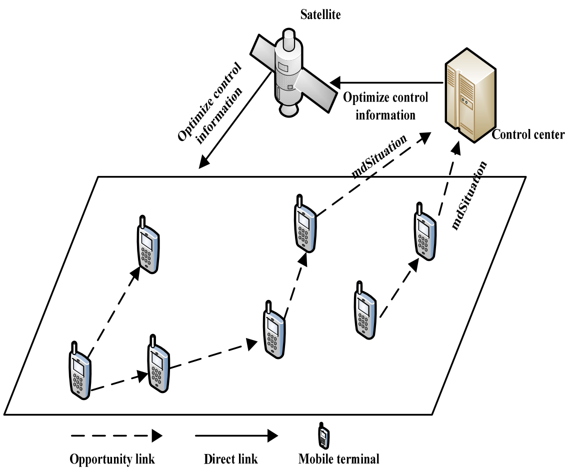

FIGURE 1. Network topology and weak feedback.

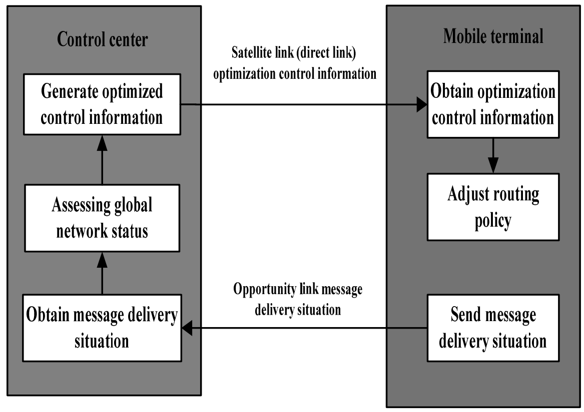

FIGURE 2. OCIGM optimized control information generation method function.

number of copies.

$$nrofCopiesAfter = \frac{\alpha_2}{mOverhead} * nrofCopies \qquad (2)$$

where α_2 is a threshold value, and $mOverhead > \alpha_2$.

Case 3: If optimal control information is used to reduce the message drop ratio, then equation (3) is used to control the number of copies.

$$nrofCopiesAfter = \frac{\alpha_3}{mDrop} * nrofCopies \qquad (3)$$

where α_3 is a threshold value, and $mDrop > \alpha_3$.

B. OCIGM-BASED DTN TOPOLOGY

The network topology mainly includes control center, satellite, and mobile terminals, and the mobile terminals have location sensing capabilities.

OCIGM-based network topology makes full use of the weak feedback characteristic of the hybrid topology. This weak feedback means that the mobile node can deliver messages to the control center through a weak connection (a mixed link consisting of a direct link and an opportunistic link), but the control center cannot directly contact all the nodes in the network. There is no way to know the current state of all mobile nodes. The OCIGM-based network topology and the weak feedback example are shown in Figure 1, and the functional module is shown in Figure 2.

The main function of the control center is to recieve message delivery situation *mdSituation* {message delivery ratio, message delivery overhead, message drop ratio} sent by mobile terminals through the opportunity link, and it evaluates the global network state NS of uncertainty based on the message delivery situation from the mobile terminals mt_1 to mt_N every time t_1:

$$mDelivery = \sum_{i=1}^{N} \frac{nrofDeliveryMessage_i}{N} \qquad (4)$$

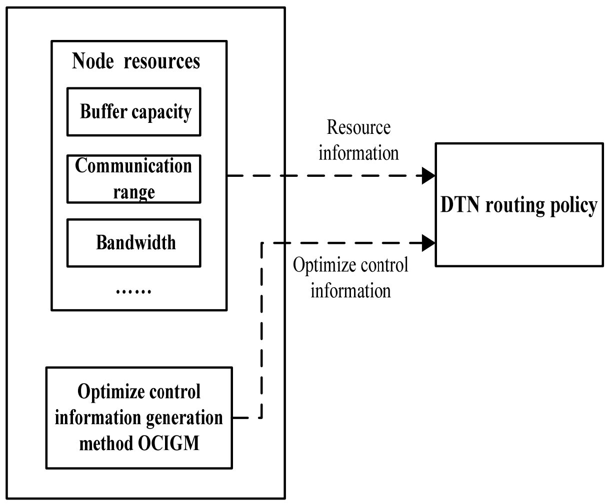

FIGURE 3. Resource-constrained DTN routing policy based on the OCIGM method.

$$mOverhead = \sum_{i=1}^{N} \frac{nrofOverheadMessage_i}{N} \qquad (5)$$

$$mDrop = \sum_{i=1}^{N} \frac{nrofDropMessage_i}{N} \qquad (6)$$

where t_1 is a threshold value, $nrofDeliveryMessage_i$ is the message delivery ratio of node mt_i, $nrofOverheadMessage_i$ is the message delivery overhead of mt_i, and $nrofDropMessage_i$ is the message drop ratio of node mt_i.

In process of evaluating the global network state, determine in sequence whether the message delivery ratio *mDelivery* in the global network state NS is greater than α_1, whether the network overhead *mOverhead* is smaller than α_2, and whether the message drop ratio *mDrop* is smaller than α_3, then the decision set of optimized control information is generated {improve message delivery ratio, reduce network overhead, reduce message drop ratio} according to the network states of uncertainty, and delivered to satellite. The satellite uses the direct link to send optimized control information to each mobile terminal.

If no mobile terminal sends *mdSituation* to the control center, the control center will send a self-control command to the mobile terminal.

The main function of the satellite is to provide a direct link between the control center and the mobile terminals and to send the message from the control center to each mobile terminal. The satellite receives the optimized control information from the control center and transmits it to each mobile terminal with a direct link.

The mobile terminal transmits the message delivery situation *mdSituation* of the mobile terminal in the period t_2 to the control center through the opportunity link in the period of time t_2, and receives the optimized control information from the satellite. The mobile terminal adjusts the routing policies based on optimized control information to optimize global network utility. The global network utility is defined as follows:

$$mDelivery/\alpha_1/(mOverhead/\alpha_2 + mDrop/\alpha_3)$$

IV. RESOURCE-CONSTRAINED DTN ROUTING POLICY BASED ON OCIGM

A. THE IDEA OF THE RC-RP ROUTING POLICY

The RC-RP routing policy is proposed to solve the problem of limited node mobility, node buffer capacity, communication range, node bandwidth and other node resource limitations and resource imbalances in the network. The RC-RP routing policy not only considers the local resources during message transmission but also is controlled by the generated optimized control information so that the limited resources in the network can be fully utilized and the purpose of optimizing the network transmission performance can finally be achieved.

In a resource-constrained DTN, to improve the network transmission performance, a single-copy and multiple-copy hybrid transmission method is used in this paper. In section 3, an optimized control information generation method OCIGM is introduced which feeds back optimized control information to each node in the network so that each node not only considers local resources (node buffer capacity, node communication range, node moving speed, node bandwidth, etc.) but also comprehensively considers the global situation of the network and then adaptively adjusts the node's own routing policy.

Communication between nodes primarily involves relaying messages between relay nodes. Its primary purpose is to increase the probability that messages are delivered; and communication between the node and the control center is mainly for the control center to evaluate the current global network state according to the message delivery situation of the nodes in the network. Therefore, to increase the message delivery ratio, reduce network overhead and message drop ratio, among others, the RC-RP routing policy separates communication between nodes and communication between nodes and control centers.

The RC-RP routing policy uses multiple copies for message transmissions between nodes (messages generated by a node), thus increasing the message delivery ratio. In contrast, to save node buffer resources, reduce network overhead and message drop ratio, the node sends its message delivery situation to the control center through the opportunity link via transmission in a single copy.

During the process of multiple-copy transmission, the RC-RP routing policy performs copy control according to optimized control information and uses the local resources of the surrounding nodes to select the relay nodes. The RC-RP routing policy defines a successful delivery probability for each node of the network as a basis for the selection of relay nodes. The RC-RP routing policy sets two queues for each node: message queues and message delivery situation queues. The message queue stores communication messages between nodes (source nodes and destination nodes are all mobile terminals in the network); the message delivery situation queue stores the message delivery situation sent from the node to the control center in the time interval t_2, and the time to live of the message delivery situation is t_2. The resource-constrained DTN routing policy framework based on the OCIGM method is shown in Figure 3.

B. COMMUNICATION BETWEEN NODES AND THE CONTROL CENTER

Communication between the node and the control center consists of two parts: the control center sends optimized control information to the node, and the node sends the message delivery situation to the control center.

(a) Control center sends optimized control information to nodes

The manner in which the control center sends optimized control information to the nodes, as mentioned in section 3, is through the use of satellites as relay nodes for broadcasts, such that no specific routing policies are involved.

(b) The node sends the message delivery situation to the control center

The node sends the message delivery situation to the control center, which is relays messages through the opportunity link formed by node movement. The manner in which the node sends messages to the control center is shown in Figure 4.

As shown in Figure 4, a timer is set for the control center, and the global network state in the time interval t_1 is sent to each node in the network every t_1. Concurrently, a timer is set for each node in the network. For any node i, the message delivery situation of the node is calculated every t_2 and forwarded to relay node j in a single-copy manner. The condition that node i selects node j as the relay node for forwarding the message delivery situation is that the probability of successful delivery of node j is greater than the probability of successful delivery of node i, where the calculation of the probability of successful delivery of any node i is given by equation (7).

$$dpro_i = \frac{ql * speed_i}{distance_i} * transmitRange_i \tag{7}$$

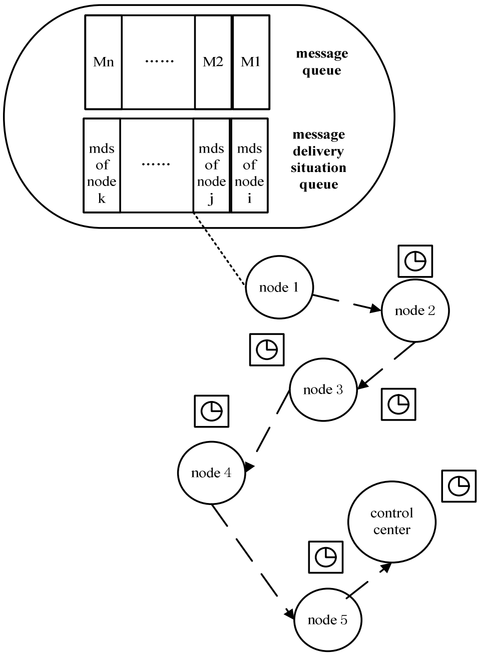

FIGURE 4. The manner in which the node sends messages to the control center.

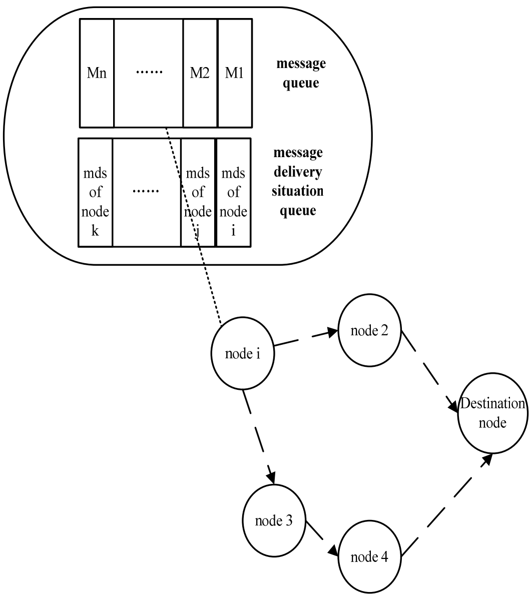

FIGURE 5. Communication between nodes.

In equation (7), ql is the adjustment factor, $speed_i$ is the moving speed of node i, $distance_i$ is the distance between the current node i and the control center, and $transmitRange_i$ is the communication range of node i. The speed of node movement and the range of communication can be used to characterize the possibility of node transmitting their messages to the control center.

C. COMMUNICATION BETWEEN NODES AND NODES

The primary purpose of communication between nodes is to increase the probability of successful message delivery. Therefore, RC-RP routing policies use multi-copy methods for message transmission when communicating between nodes. The communication between nodes is shown in Figure 5. Any node i in the network schedules messages in the message queue in multiple copies. To save network resources and reduce node load, the number of message copies is limited according to optimization control information. Simultaneously, to improve network performance, relay nodes are selected based on local node resources (node communication range, node buffer capacity).

In resource-constrained DTN, not only is each node in the network limited in node mobility, node communication, node buffer resources, communication range, node bandwidth, but also there is a problem of an unbalanced distribution of node resources is encountered. To solve the problem of unbalanced distribution of resources to some extent, communicating between nodes is done, not only to limit the number of message copies based on optimized control information (enhancing the success ratio of message forwarding, reducing network overhead, and reducing the number of message copies), but also to introduce the node communication range and node buffer capacity to select relay nodes. The communication range of a node can indicate the probability that the node can establish a connection with other nodes to a certain extent. The greater the communication range of the node, the higher is the probability of a connection with other nodes. Concomitantly, the node's buffer capacity can be used to characterize the its ability to store messages. The larger the capacity, the more messages can be stored.

The condition that any node i in the network selects node j as the message relay node is that the probability of successful delivery of node j is greater than the probability of successful delivery of node i, and the successfully delivered probability of any node i can be shown in equation (8):

$$dPro_i = \beta_1 * transmitRange_i + \beta_2 * buffer_i \tag{8}$$

In equation (8), $transmitRange_i$ is the communication range of node i, $buffer_i$ is the capacity of node i, and $\beta_1 + \beta_2 = 1$.

D. RC-RP ROUTING POLICY PROCESS

1) COMMUNICATION BETWEEN NODES AND THE CONTROL CENTER

During communication between nodes and the control center, the control center sends optimized control information to the nodes by broadcasting the messages to each node through the direct link provided by the satellite, such that there is no corresponding routing policy. Due to the limitation of the power of the mobile node itself, the uplink satellite link does not apply to it. Therefore, when a node sends a message delivery situation to the control center, it can only forward the message delivery situation via the node's movement through the opportunity link. To save network resources, the node sends a message delivery situation to the control center in the form of a single copy.

At any time t, for any node i, the specific process of the RC-RP routing policy for sending a message delivery situation to control center is as follows:

(a) Determine whether time t is a multiple of period t_2 at which the node sends a message delivery situation; if so, it goes to (b); otherwise, it goes to (e);

(b) Node i calculates its message delivery situation *mdSituation* {message delivery ratio, message delivery overhead, message drop ratio} from time $t - t_2$ to time t;

(c) Node i sets the TTL of the message delivery situation *mdSituation* to t_2;

(d) Determine whether node i can directly deliver the message delivery situation *mdSituation* to the control center. If it can be delivered directly, deliver the *mdSituation* to the control center and go to (h); otherwise, go to (e);

(e) Determine whether node i establishes a connection with any node j in the network; if yes, go to (f); otherwise, go to (h);

(f) After node i establishes a connection with any node j in the network, it obtains the probability of successful delivery $dpro_j$ of node j, and compares it with its own probability of successful delivery $dpro_i$, if $dpro_j$ is smaller, the node i continues carrying its message delivery situation until it encounters a node that meets the relay condition and goes to (g); otherwise it goes to (h);

(g) The message delivery situation *mdSituation* of node i and the message delivery situations of other nodes it carries to node j are forwarded, and the message delivery queue of node i is updated after the relay is successful;

(h) Determine if the simulation time has been reached; if so, end; otherwise, go to (a).

2) COMMUNICATION BETWEEN NODES

Because the primary purpose of communication between nodes is to increase the probability of successful message delivery, RC-RP routing policies use multiple copies for message transmission when communicating between nodes. To reduce the blindness of node relay node selection and to solve the resource wasting problem caused by a large number of duplicate copies of the same message in the network, the RC-RP routing policy selectes relay nodes based on the node communication range and node buffer capacity when communicating between nodes (shown in equation (8)). Simultaneously, uses the optimized control information used to perform copy restrictions.

At any time t, the specific steps of the RC-RP routing policy for communication between nodes are as follows:

(a) Determine whether any node i in the network receives optimized control information at time t; if yes, go to (b); otherwise, go to (c);

(b) Execute OCIGM for copy restriction;

(c) Determine whether node i establishes a connection with any node j in the network; if yes, go to (d); otherwise, go to (f);

(d) After node i establishes a connection with any node j in the network, it obtains the probability of successful delivery $dPro_j$ of node j and compares it with its own probability of successful delivery $dPro_i$. If $dPro_j$ is smaller, then node i continues carrying the message delivery situation until it encounters a node that meets the relay conditions and go to (e); otherwise go to (f);

(e) If the number of message copies in node i is greater than 1, the message carried by node i is relayed to node j in a binary manner; otherwise it is directly delivered. After the relay succeeds, the message queue of node i is updated;

(f) Determine if the simulation time has been reached. If yes, then it will end; otherwise, go to (a).

TABLE 1. Simulation parameters.

Parameter	Settings
Scene size	4500 m×3400 m
Simulation time	43200 s
Number of node groups	4
Number of nodes	14
Initial message copy number	100
Node buffer size	5 M
TTL	300 min
Message generation interval	25s
Message size	500 k~1 M

V. SIMULATION EXPERIMENTS AND ANALYSIS

A. SIMULATION ENVIRONMENT SETTINGS

In this paper, we simulate the RC-RP routing policy through the ONE [50], and compare the RC-RP routing with the Epidemic routing policy [51], SAW routing policy [52] and RBL routing policy [48] by changing the simulation parameters. The specific simulation parameter settings are shown in Table 1 and Table 2.

In the simulation, two sets of nodes were positioned to simulate pedestrians and trams, and two fixed nodes were simulated concurrently to simulate control centers and satellites. To simulate the above-mentioned network environment, the following limitations were imposed during the simulation: nodes (pedestrians, trams) can rely on only opportunistic links to the send message delivery situation to the control center, and messages cannot be sent to the satellite; the control center does not serve as a relay node for communication between nodes, and the control center cannot directly send information to the nodes. During the simulation, the time interval for the message delivery situation for the group 1 and group 2 nodes was 1000 s, and the lifetime of message delivery situation was 1000 s. The initial settings were $\alpha_1 = 0.5$, $\alpha_2 = 3$, and $\alpha_3 = 2$.

B. EVALUATION METRICS

We will use the following metrics to evaluate the performance of policy:

TABLE 2. Node parameters.

	Group 1	Group 2	Group 3	Group 4
Node type	Pedestrians	Trams	Control center	Satellite
Number of nodes	10	2	1	1
Node transmission speed	250 kBps	10 MBps	10 MBps	10 MBps
Communication range	10 m	1000 m	1000 m	entire space
Node movement model	ShortestPath Map	MapRoute	fixed	fixed
Node movement speed	0.5~1.5 m/s	7~10 m/s	0	0

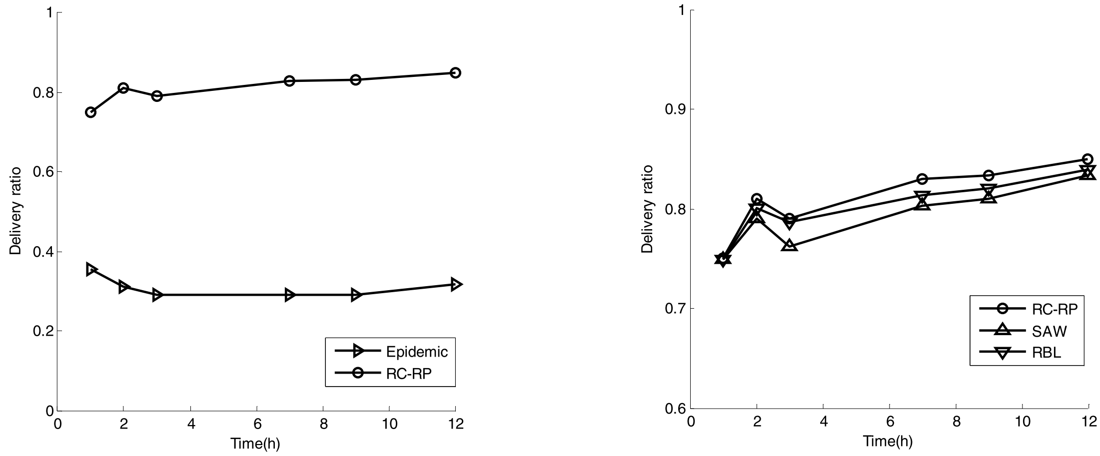

FIGURE 6. comparison of delivery ratio.

1) *Message delivery ratio:* the number of messages successfully delivered to the destination node/the total number of generated messages;
2) *Network overhead:* (the number of messages relayed—the number of successfully delivered messages)/ the number of successfully delivered messages;
3) *Message drop ratio:* the number of discarded messages/the total number of generated messages;
4) *Network utility:* (message delivery ratio/α_1)/(network overhead/α_2+ network message drop ratio/α_3).

C. ANALYSIS OF EXPERIMENTAL RESULTS

1) IMPACT OF SIMULATION TIME CHANGES ON EACH ROUTING POLICY

The remaining parameters in the simulation parameter table are unchanged, and the performance evaluation of each routing policy was performed by changing the simulation time. The simulation time was increased from 1 h to 12 h. Figure 6 shows a comparison of the delivery ratio, Figure 7 shows a comparison of the network overhead, Figure 8 shows a comparison of the message drop ratio, and Figure 9 shows a comparison of the network utility.

As shown in Figures 6a, 7a, 8a, and 9a, the RC-RP routing policy significantly improved the message delivery ratio and network utility and reduced the network overhead and message drop ratio compared with the Epidemic routing policy. The most notable changes were observed in the network overhead, message drop ratio and network utility. Compared with the Epidemic routing policy, the RC-RP routing policy increased the average delivery ratio 1.7 times, reduced the average network overhead 184.7 times, reduced the average message drop ratio 365.2 times, and increased the average network utility 595.3 times. As shown in Figures 6b, 7b, 8b, and 9b, compared with the SAW routing policy and RBL policy, the RC-RP routing policy clearly improved the message delivery ratio and network utility, and reduced the network overhead and message drop ratio. Compared with the SAW routing policy, the RC-RP routing policy increased the average delivery ratio by 2.5%, reduced the average network overhead by 80.7%, reduced the average message drop ratio 3.79 times, and increased the average network utility 2.13 times. In comparison to the RBL routing policy, the RC-RP routing policy increased the average message delivery ratio by 1.16%, reduced the average network overhead by 18.9%, reduced the average message drop ratio 2.84 times, and increased the average network utility by 0.69 %.

2) IMPACT OF THE MESSAGE GENERATION INTERVAL CHANGES ON EACH ROUTING POLICY

The remaining parameters in the simulation parameter table were unchanged, and the simulation time was set to 43200 s. The performance of each routing policy was evaluated by

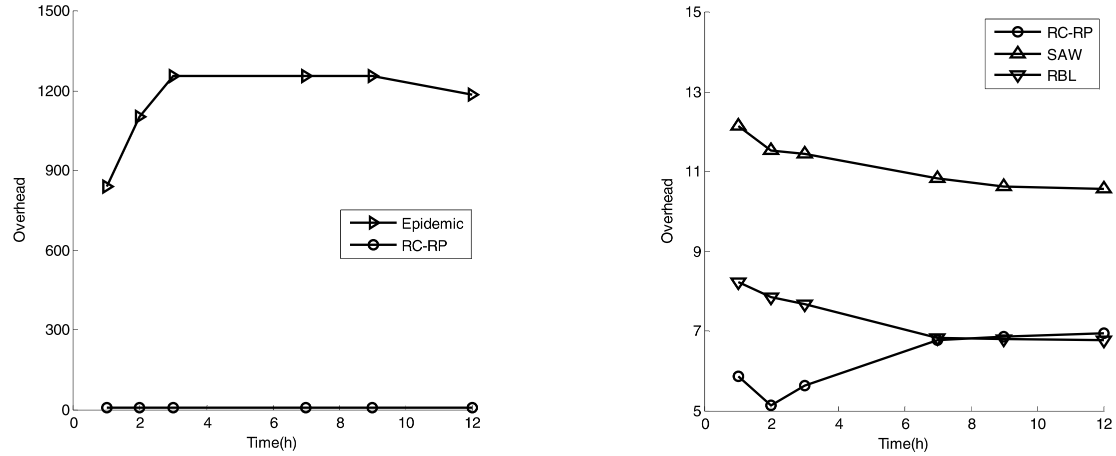

FIGURE 7. comparison of network overhead.

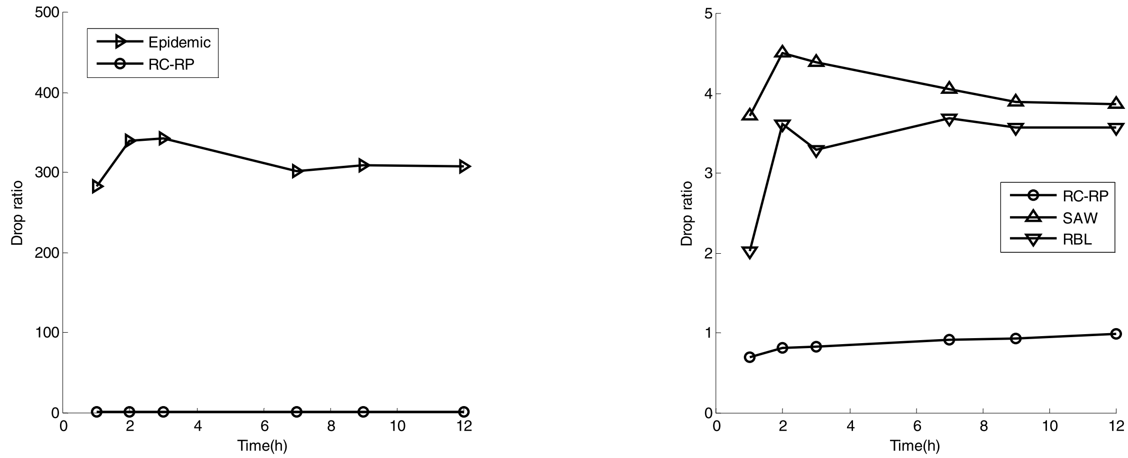

FIGURE 8. comparison of message drop ratio.

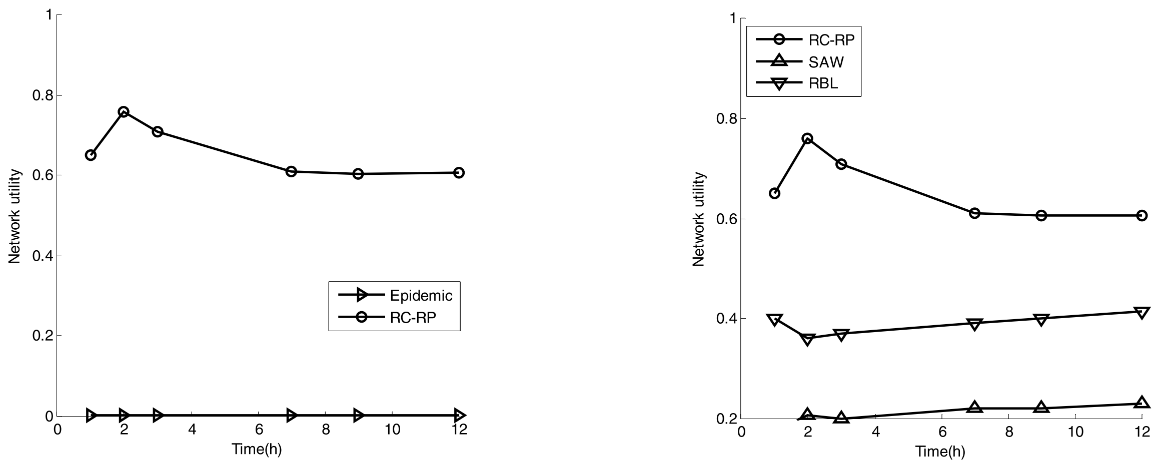

FIGURE 9. comparison of network utility.

changing the message generation interval. The message generation interval was gradually increased from 5 s to 55 s; that is, the number of messages in the network was gradually reduced from 8640 to 785. Figure 10 shows a comparison of the delivery ratio, Figure 11 shows a comparison of the network overhead, Figure 12 shows a comparison of the

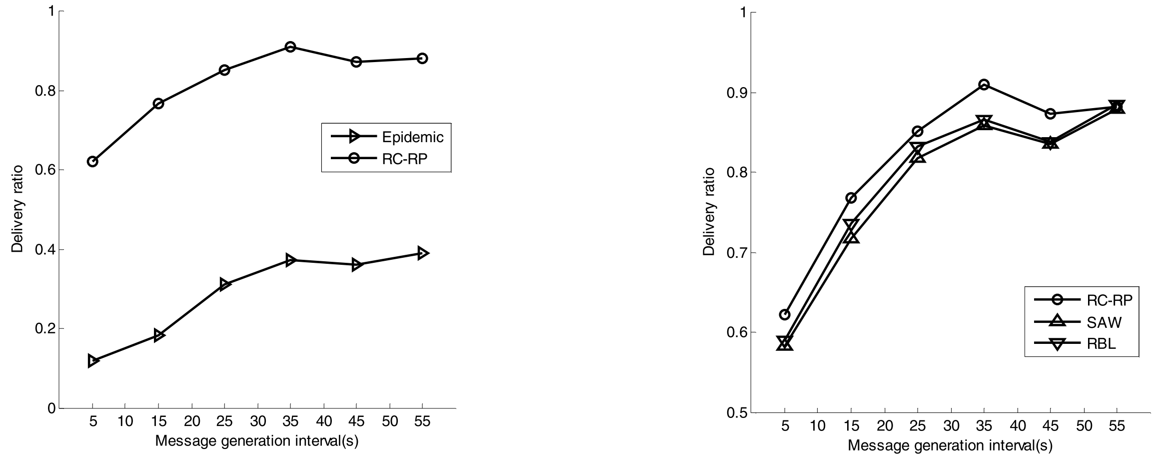

FIGURE 10. comparison of delivery ratio.

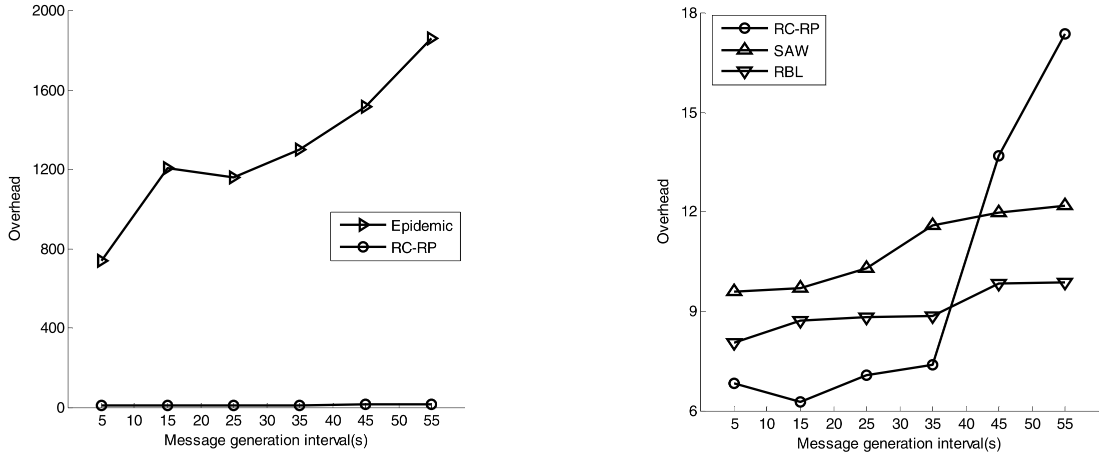

FIGURE 11. comparison of network overhead.

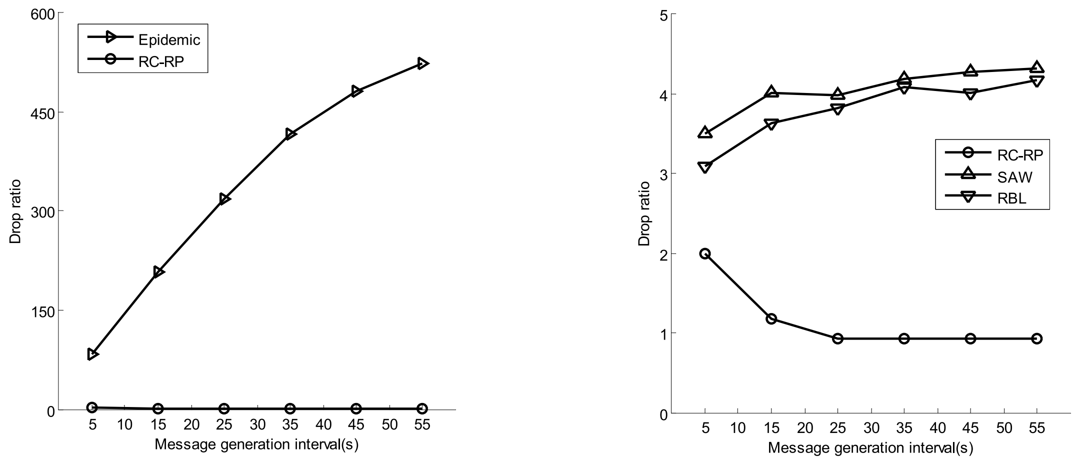

FIGURE 12. comparison of message drop ratio.

message drop ratio, and Figure 13 shows a comparison of the network utility.

Figures 10a, 11a, 12a, and 13a, show that the RC-RP routing policy significantly improved the message delivery ratio and the network utility and reduced the network overhead and the message drop ratio compared with the Epidemic routing policy. The most notable changes were observed in the network overhead, message drop ratio and network utility. Compared with the Epidemic routing policy, the RC-RP routing policy increased the average delivery ratio 1.82 times,

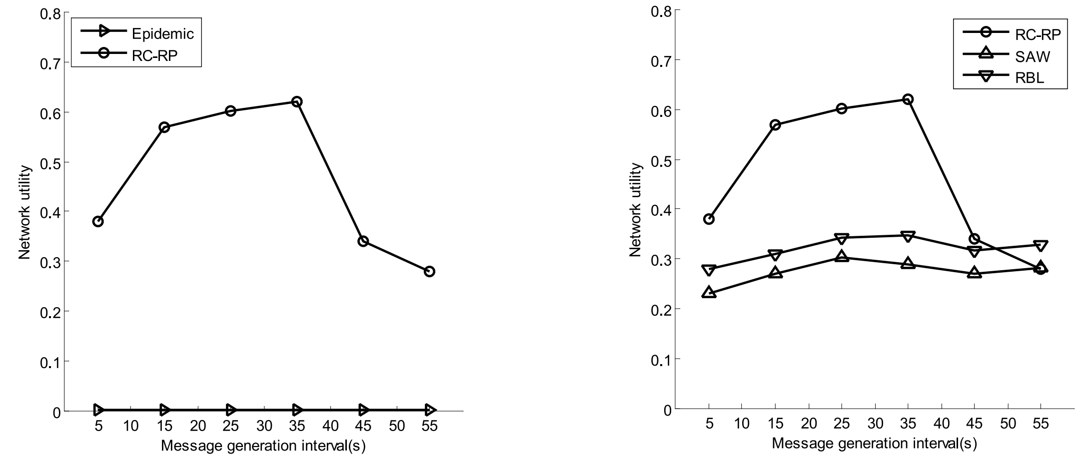

FIGURE 13. comparison of network utility.

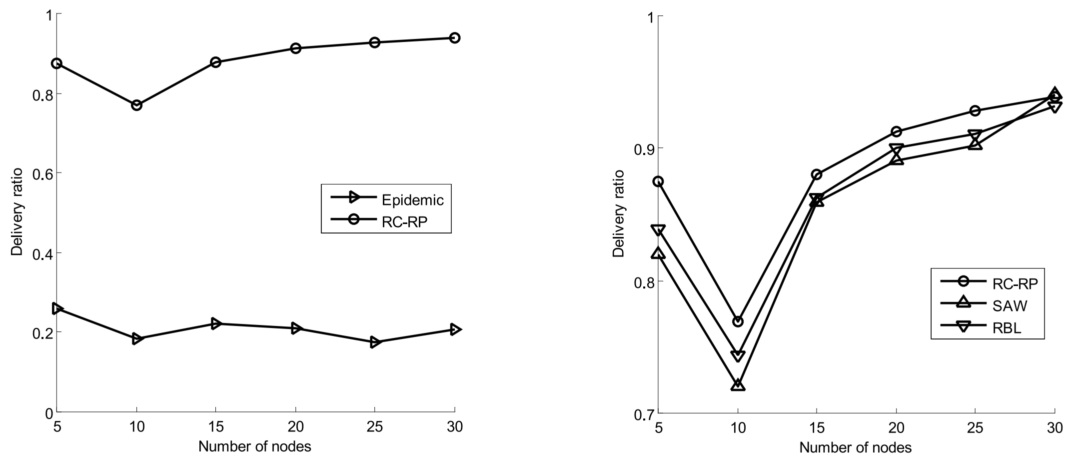

FIGURE 14. comparison of delivery ratio.

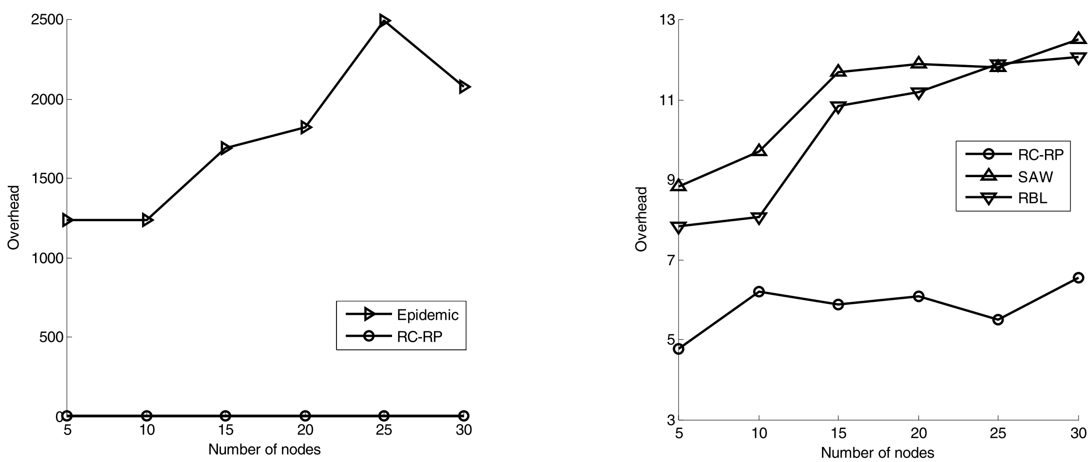

FIGURE 15. comparison of network overhead.

reduced the average network overhead 131.8 times, reduced the average message drop ratio 293.8 times, and increased the average network utility 516 times. As shown in Figures 10b, 11b, 12b, and 13b, compared with the SAW routing policy and RBL policy, the RC-RP routing policy clearly improved the message delivery ratio and

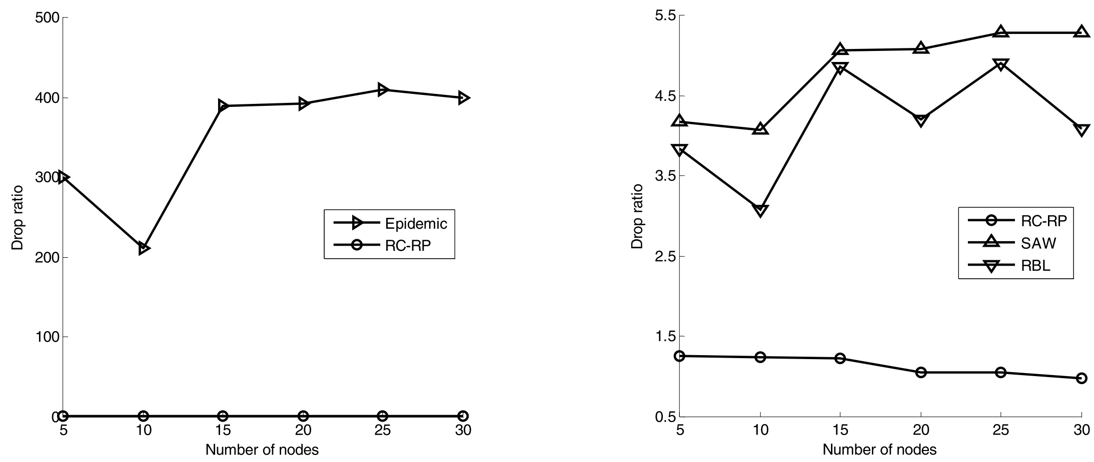

FIGURE 16. comparison of message drop ratio.

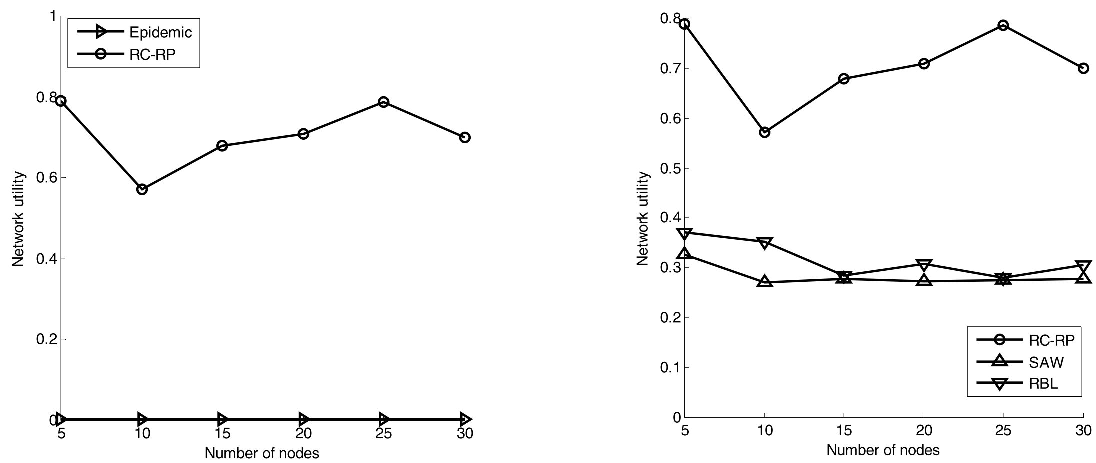

FIGURE 17. comparison of network utility.

network utility and reduces the network overhead and message drop ratio. Compared with the SAW routing policy, the RC-RP routing policy increased the average message delivery ratio by 4.9%, reduced the average network overhead by 11.36%, reduced the average message drop ratio 2.52 times, and increased the average network utility by 70%. Compared with the RBL routing policy, the RC-RP routing policy increased the average message delivery ratio by 3.54%, increased the average network overhead by 8.23%, reduced the average message drop ratio 2.31 times, and increased the average network utility by 45.4%.

3) IMPACT OF THE NUMBER OF NODES CHANGES ON EACH ROUTING POLICY

The remaining parameters in the simulation parameter table remained unchanged, the simulation time was set to 43200 s, the message interval was set to 15 s, and the performance evaluation of each routing policy was performed by changing the number of nodes in group 1. The number of nodes in group 1 was increased from 5 to 20. Figure 14 shows a comparison of the delivery ratio, Figure 15 shows a comparison of the network overhead, Figure 16 shows a comparison of the message drop ratio, and Figure 17 shows a comparison of the network utility.

Based on Figures 14a, 15a, 16a, and 17a, the RC-RP routing policy significantly improved the message delivery ratio and network utility and reduced the network overhead and message drop ratio compared with the Epidemic routing policy. The most notable changes were observed in the network overhead, network message drop ratio, and network utility. Compared with the Epidemic routing policy, the RC-RP routing policy increased the average message delivery ratio 3.23 times, reduced the average network overhead 301.02 times, reduced the average message drop ratio 308.5 times, and increased the average network utility 1282.7 times. Figures 14b, 15b, 16b, and 17b show that compared with the SAW routing policy and RBL policy, the RC-RP routing policy significantly improved the message delivery ratio and network utility and reduced the network overhead and message drop ratio. Compared with the SAW routing policy, the RC-RP routing policy increased the average message delivery ratio by 3.3%, reduced the average network overhead by 89.8%, reduced the average message drop ratio 3.265 times, and increased the average network utility 1.499 times. Compared with the RBL routing policy, the RC-RP routing policy increased the average message delivery ratio by 2.2%, reduced the average network overhead by 77.1%, reduced the average message drop ratio 2.67 times, and increased the average network utility 1.23 times.

VI. CONCLUSION

At present, research on DTN routing policy mostly uses the local resources of the node to select relay nodes, but lacks consideration of the global state of the network. In a resource-constrained DTN, this will result in a local suboptimal activity of the relay node, which cannot achieve optimal or suboptimal global network performance. This paper proposes an OCIGM-based DTN routing policy, RC-RP. To improve the network transmission performance and reduce network overhead, the RC-RP routing policy adopts a mixed single-copy and multiple-copy method for message forwarding and uses an optimized control information method to control the number of copies of multiple copies. Simulation results show that the RC-RP routing policy improves the delivery ratio and reduces the network overhead and message drop ratio compared with existing routing policies.

Although this paper has acquired some progress in the performance of routing, there are still some shortcomings due to the limited of the author's own ability and time. The existing problem and future work are summarized as follows:

(1) When the initial number of messages in the network is fewer, the OCIGM method controls the number of message copies to a small extent. If some dynamic factors such as message popularity are added to the OCIGM method, the problem may be alleviated to some extent.

(2) When the mobile node sends a message delivery situation to the control center, the RC-RP routing policy may increase consideration of the node moving direction when relay nodes are selected.

DISCLOSURE STATEMENT

The authors declare that there is no conflict of interest regarding the publication of this paper.

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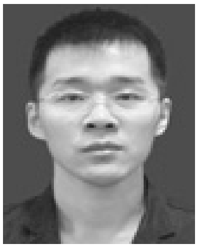

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