Hybrid Weighted-based Clustering Routing Protocol for Railway Communications

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Abstract—In the paper, a hybrid clustering routing strategy is proposed for railway emergency ad hoc network, when GSM-R base stations are destroyed or some terminals (or nodes) are far from the signal coverage. In this case, the cluster-head (CH) election procedure is invoked on-demand, which takes into consideration the degree difference from the ideal degree, relative clustering stability, the sum of distance between the node and its one-hop neighbors, consumed power, node type and node mobility. For the clustering forming, the weights for the CH election parameters are allocated rationally by rough set theory. The hybrid weighted-based clustering routing (HWBCR) strategy is designed for railway emergency communication scene, which aims to get a good trade-off between the computation costs and performances. The simulation platform is constructed to evaluate the performance of our strategy in terms of the average end-to-end delay, packet loss ratio, routing overhead and average throughput. The results, by comparing with the railway communication QoS index, reveal that our strategy is suitable for transmitting dispatching voice and data between train and ground, when the train speed is less than 220km/h.

Index Terms—GSM-R; Emergency Communications; Clustering Routing; Rough Set Theory; QoS

I. INTRODUCTION

Global system mobile for railway (GSM-R) is a mobile communication system, which developed specially for railway applications [1]. In 1993, GSM-R was adopted by international union of railways (UIC) and European telecommunications standards institute (ETSI), for the highly reliable voice/data transmission on high-speed train, and interoperability of automatic train protection (ATP) system.

As an infrastructure network, when natural disasters, such as terrorist, earthquake, hurricane, and other accidents occur, GSM-R’s base station (BS) is subject to destroying, the wireless coverage will disappear, and the communications between the terminals will be lost. At this time, railway emergency communication network is needed to restore the communications in blind areas, and guarantee the railway traffic dispatching smoothly.

Direct mode operation (DMO) has been suggested in the specifications EIRENE-FRSv7 [2] and EIRENE-SRSv15 [3] to support a direct communications mode, and whereby some mobile terminals could communicate with the other terminals in a local area without the use of GSM-R infrastructure. The mode is required for: 1) no GSM-R infrastructure is provided; 2) GSM-R infrastructure has failed to work. But, DMO is an optional item in GSM-R specifications, and the way to carry out the mode is not yet specified.

According to our view, a railway emergency communication example, with a failed cell, is illustrated in Fig. 1. The terminals which lost contact with BS are forming a temporary railway emergency communication network without a backbone infrastructure (destroyed BS), i.e., ad hoc network.

Consider that a large population of GSM-R mobile terminals in a failed cell which are either on the high-speed train or on the ground, hierarchical ad hoc wireless network is a good choice for railway emergency application.

In this paper, we focus mainly on designing a routing protocol suitable for the railway emergency ad hoc network. Key characteristics of this network are the large number of terminals, their mobility, and the ability to operate in the case of GSM-R BS destroyed. The features make it extremely difficult to develop efficient routing protocols for such a railway applications based emergency network. The main challenge is need to support emergency communications, with low latency, low packet loss probability, and high throughput requirements for interactive traffic and QoS satisfying for railway services.

In the clustering railway emergency communication network, the selection of cluster-head (CH) greatly influences the performance of whole network, then the combined weighted clustering algorithm [4-7] can be adopted to get better stability and adaptability. These algorithms allocate certain weight factors for some important system parameters in deciding the suitability of the nodes acting as CHs. The node which has the smallest weight factor will be elected as CH.

But, in these previous works, the weight factors that influence the CH selection are set relatively fixed. In this paper, we will study how to adjust weight factors to adapt
to different application environment by varying the importance of various system parameters. In addition, a clustering routing algorithm will be researched, some parameters such as average end to end delay, packet loss ratio and average throughput will be simulated, and the results will be compared to the GSM-R QoS KPI (key performance indicator) to verifying the feasibility of the proposed algorithm in railway emergency communication.

The organization of the paper is as follows: In Section II, we provide a new method of clustering and weight factor allocation for CH selection parameters based on rough set theory. In Section III, we develop a hybrid weighted-based clustering routing strategy, which contains intra-cluster routing and inter-cluster routing. In Section IV, some experimental results via computer simulation are presented and the performances of the clustering routing strategy proposed in this paper are reviewed. The paper is concluded in Section V.

II. CLUSTERING AND WEIGHT FACTOR ALLOCATION FOR CH SELECTION PARAMETERS

The CH selection parameters have direct affect on rationality of cluster structure. The problem of parameters selection to decide CHs and allocation of importance degree for each parameter can be solved by rough set theory [8]. The detail steps are as follows.

TABLE I. DECISION TABLE

<table>
<thead>
<tr>
<th>Object</th>
<th>( D )</th>
<th>( S )</th>
<th>( P )</th>
<th>( C_j )</th>
<th>( T_c )</th>
<th>( M )</th>
<th>Evaluation level</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>II</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>III</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>IV</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>V</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2</td>
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<tr>
<td>VI</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>VII</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td>VIII</td>
<td>1</td>
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<td>2</td>
<td>3</td>
<td>2</td>
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<td>1</td>
</tr>
<tr>
<td>IX</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

1) Set up decision table. The decision table is composed of condition attribute values (the decision values for CH selection parameters) and decision attributes values (network performance evaluation levels) of each object. The object’s decision attribute value \( v_j \) is determined jointly by test value of each condition attribute parameter and the threshold value \( v_{th} \), as showed in equation (1), where the decision attribute value is obtained from the pre-evaluation result of network QoS levels by using grey system clustering theory.

\[
v_j = \begin{cases}
1, & d_j \geq \frac{c_{ij} + c_{j}}{2} \\
2, & \frac{c_{ij} + c_{j}}{2} \leq d_j < \frac{c_{ij} + c_{j}}{2} \\
3, & d_j < \frac{c_{ij} + c_{j}}{2}
\end{cases}
\] (1)

To define the CH selection parameters set, the characteristic of railway communication, such as service type of GSM-R nodes, should be considered, in addition to the parameters set proposed in [4-6]. In this paper, similar to [7], the CH selection parameters set is composed of 6 parameters, including the degree difference from the ideal degree \( (D) \), relative clustering stability \( (S) \), the sum of distance between the node and it’s one-hop neighbors \( (P) \), consumed power \( (C) \), node type \( (T) \) and node mobility \( (M) \). An example decision table composed of these parameter values is showed in Table. 1.

In above table, the condition attribute value of the object is obtained from grading quantized results of that parameter’s real measurement. The evaluation level 1, 2, 3 respectively represents the meanings of strong rationality of clustering architecture, general rationality of clustering architecture and irrationality of clustering architecture, that caused by CH selection parameters.

2) Calculate the positive region \( pos_c(D) \) of condition attribute set \( C \) and the positive region \( pos_{C-c_j}(D) \) of \( \{C-c_j\} \), with respect to decision attribute \( D \), where \( \{C-c_j\} \) is the subset of attribute set \( C \) surplus the attribute \( c_j \). According to the data in table 1, it can be calculated:

\[
U/C = \{[1,3]\} [2] [4] [5] [6] [7] [8,9]
\] (2)

\[
U/D = \{[6,7,8,9] [2,3,4,5] [1]\}
\] (3)

\[
pos_c(D) = \bigcup_{x \in D/C} CX = \{2,4,5,6,7,8,9\}
\] (4)

\[
pos_{C-c_j}(D) = pos_{\{C-c_{-j}\}}(D) = pos_{\{C-c_{-1}\}}(D)
\] (5)

3) Calculate the degree of the dependency \( \gamma_c(D) \) between decision attribute \( D \) and condition attribute set \( C \), and the degree of the dependency \( \gamma_{(C-c_j)}(D) \) between \( D \) and \( \{C-c_j\} \).

\[
\gamma_c(D) = \left| pos_c(D) \right| / \left| U \right| = 7/9
\]

\[
\gamma_{(C-c_{j})}(D) = \left| pos_{(C-c_{j})}(D) \right| / \left| U \right| = 4/9
\]

\[
\gamma_{(C-c_{j})}(D) = \left| pos_{(C-c_{j})}(D) \right| / \left| U \right| = 5/9
\]

\[
\gamma_{(C-c_{j})}(D) = \left| pos_{(C-c_{j})}(D) \right| / \left| U \right| = 7/9
\]

\[
\gamma_{(C-c_{j})}(D) = \left| pos_{(C-c_{j})}(D) \right| / \left| U \right| = 6/9
\]

\[
\gamma_{(C-c_{j})}(D) = \gamma_{(C-c_{j})}(D) = 7/9
\]

4) Calculate the significance \( \sigma_{C-c_j}(c_j) \) of condition attribute \( c_j \) with respect to decision attribute \( D \). The significance of subset \( C \subseteq C \) of condition attribute with respect to \( D \) is defined as:

\[
\sigma_{C-c_j}(C) = \gamma_c(D) \cdot \gamma_{(C-c_{j})}(D)
\] (7)

Then, the significances of each attribute can be obtained as:
$$w = \frac{\sigma_{CD}(c_i)}{\sum \sigma_{CD}(c_j)}$$  \hspace{1cm} (9)$$

Substituting Eq. (8) into Eq. (9), the value of $w_1$, $w_2$, $w_3$, $w_4$, $w_5$ and $w_6$ can be obtained as $3/8, 1/4, 0, 1/4, 1/8$ and $0$ respectively.

Thus it can be seen that each attribute (CH selection parameters) has different significance (weight factor). If the weight factor of one parameter is equal to 0, then whether this parameter exist or not will not influence the result of this evaluation, and this parameter can be regarded as redundant parameter. According to data of table 1, the CH selection parameters and their weight factors of this evaluation can be obtained as: weight factor of degree difference from the ideal degree ($D_v$) is $3/8$, weight factor of relative clustering stability ($S_v$) is $1/4$, weight factor of consumed power ($C_v$) is $1/4$, weight factor of node type ($T_v$) is $1/8$.

6) Calculate the combined weight $W_v$ of node $v$.

$$W_v = w_1D_v + w_2S_v + w_3C_v + w_4T_v$$  \hspace{1cm} (10)$$

The node which has the smallest $W_v$ in all neighbor nodes will be elected as CH. If the number of nodes that has the smallest $W_v$ is more than 1, then the node which has most remaining energy should be elected as CH. The CH broadcasts the Hello message to claim its status, and the node with most remaining energy should be elected as CH. Each node in the cluster updates the routing table with advertisement periodically or when significant new information is available to maintain the consistency of the routing table with the dynamically changing topology of the railway emergency network.

Periodically or immediately when network topology changes are detected, each mobile node advertises routing information by broadcasting or multicasting a routing table update packet. After receiving the update packet, the neighbors update their routing table and retransmit the update packet to the corresponding neighbors of each of them. The process will be repeated until all the nodes in a cluster have received a copy of the update packet. The update data is also kept for a while to wait for the arrival of the best route for each particular destination node in each node before updating its routing table and retransmitting the update packet. If a node receives multiple update packets for a same destination during the waiting time period, the routes with more recent sequence numbers are always preferred as the basis for packet forwarding decisions.

The elements in the routing table of each mobile node change dynamically to keep consistency with dynamically changing topology of the network. To reach this consistency, the routing information advertisement must be frequent or quick enough to ensure that each mobile node in a cluster can almost always locate all the other mobile nodes in the cluster. Upon the updated routing information, each node has to relay data packet to other nodes upon request in the dynamically created railway emergency network.

The routing of updates and packets between nodes is based on the routing table, which is formed by forwarding the routing request/update packet (RREQ). A RREQ packet contains the sequence number of RREQ, cluster identifier (ID) of initial source, address of the destination, address of the last hop, and the number of hops. The route is established by letting some node $v$ originates a RREQ message, which is received by (approximately) all nodes currently within wireless transmission range of node $v$. When another node $u$ receives a RREQ packet, it examines the cluster ID of its last hop, i.e., node $v$. If node $v$ and $u$ have the same cluster ID, the RREQ packet with the largest sequence number will be used and node $u$ will be stored as new destination of the RREQ packet, and other existing RREQ packets will be discarded. Otherwise, the RREQ packet is propagated to the distributed gateways of adjacent clusters. In this case, the distributed gateways update the routing information to acquire the route to adjacent clusters. After a period of RREQ packets broadcasting, each node in a cluster will have an intra-cluster routing table. In addition to the routing...
information of CH and cluster members, the routing table contains also the routing information of gateway/distributed gateway.

B. Inter-Cluster Routing

Typically, the mobile terminals in a train have higher speed relatively to the terminals on the ground. For the reason, the terminals in a train and terminals on the ground tend to be in the different clusters by the clustering. On-demand routing scheme is appropriate for the inter-cluster routing, which aims to respond to the frequently changing topology of railway emergency communication network.

In the inter-cluster routing, some node S attempts to discover a route to some other node D by originating a RREQ packet. Each RREQ message identifies the source and destination of the route discovery, and a unique request ID, determined by the initiator of the RREQ. Also, it contains a record listing the address of each intermediate node through which this particular copy of the RREQ message has been forwarded. This route record is initialized to an empty list by the initiator of the RREQ message. The RREQ message is propagated to the gateways/distributed gateways of adjacent clusters, and the RREQ transmission will go on until the target of the route discovery is found.

The inter-cluster routing is composed of route discovery and maintenance of the preferred route that work together in the railway emergency ad hoc network. The route discovery is the mechanism by which a node S wishing to send a packet to a destination node D obtains a preferred route to D. The route discovery is used only when S attempts to send a packet to D and does not already know a route to D, which consists of seven steps below for discovering the preferred route:

Step 1. A node S (source) transmits a RREQ packet as a single local broadcast packet, which will be received by the gateways/distributed gateways of adjacent clusters.

Step 2. When another node receives a RREQ packet, if the sequence number of the packet is not the largest request ID, then it discards the RREQ.

Step 3. Otherwise, the received request ID has the largest sequence number. Then, if this node examines the destination address is not listed in the route record in its route cache, it appends its own address to the route record in the RREQ message and propagates it (with the same request id).

Step 4. Repeat Step 2 and Step 3, until the route record of the destination is found in the route cache.

Step 5. The destination returns a route reply (RREP) message to the initiator of the RREQ, giving a copy of the accumulated route record from the RREQ.

Step 6. When the source receives this RREP, it computes the routing weight. For some route $\pi$, the consumed energy is expressed by [9]

$$C_\pi = \sum_{v=1}^{n} 1/E_v(v).$$  \hspace{1cm} \text{(11)}$$

where $E_v(v)$ is the remaining power of a node $v$, and $n$ is the number of nodes in the route $\pi$. The routing weight of route $\pi$ can be written as

$$W_\pi = a_1 C_\pi + a_2 N_{CH} + a_3 N_{hop},$$ \hspace{1cm} \text{(12)}$$

where $N_{CH}$ is the number of CHs in the route $\pi$, $N_{hop}$ is the total number of routing hops, and $a_1$, $a_2$, and $a_3$ are the weighing factors for the routing parameters, which satisfy

$$a_1 + a_2 + a_3 = 1.$$ \hspace{1cm} \text{(13)}$$

Step 7. The source chooses the route with the smallest $W_\pi$ as the preferred, or the best route $O_R$, i.e.,

$$O_R = \min \{W_\pi | \pi \in A\}.$$ \hspace{1cm} \text{(14)}$$

where $A$ is the set of routes form the source to the destination. The preferred route is used for sending subsequent packets to the destination, and the other routes are cached in the route cache as candidate routes.

Route maintenance is the mechanism by which node S is able to detect, while using a source route to D, if the network topology has changed such that it can no longer use its route to D because a link along the route no longer works. Links can be broken when the mobile nodes move from place to place or have been shut down etc. The broken link may be detected by the communication hardware or be inferred if no broadcasts have been received for a while from a former neighbor. In the route maintenance, S could attempt to use any candidate route it happens to know to D, or could invoke the route discovery again to find a new route if the candidate route is not available.

Fig. 2 gives the example of clustering routing, in which a node S is attempting to discover a preferred route to node D. There exist two different routes from node S to node D by performing the route discovery procedure. One route record is S-C3-DG1- C2-G3-G1-C1-D, denoted by dotted line, and the other is S-C3-DG2-C4-G6-G2-C1-D, denoted by dot-dashed line. The route with the smallest routing weight is selected as the preferred route for transmitting data packets from node S to node D.

The hybrid weight-based clustering routing algorithm provides multiple routes for data packets transmission. Allowing for the energy constrained mobile nodes in railway emergency network, the
remaining power of the nodes, the number of CHs, and the total number of hops in a route are taken into consideration as metrics to find the preferred or the best route. A route with the smallest routing weight is always preferred and the other routes are stored as less preferable. As a result, the time delay for route discovery and the cost for routing maintenance are reduced greatly.

IV. SIMULATION INVESTIGATION

Simulation results are presented in this section to evaluate the performance of the proposed hybrid clustering routing algorithm in a railway emergency network.

A. Simulation Parameters

In order to model a real situation, we take a portion of Qinghai-Tibet railway as emergency communication model and give some assumptions for the simulation parameters.

1) Environment Parameters

In Qinghai-Tibet railway line, the distance from Geeru station to Nanshankou station is 32 km or so. Along the 32 km railway line, the base stations in Geeru station are six-carrier configuration, and the others are two-carrier configuration. The average distance between two base stations is about 8 km.

Assume a railway emergency network in which some BS with two-carrier configuration is suffering from natural disasters and fail to work. In this case, two emergency communication scenarios are considered: scenario 1- a train is stopped in the failed cell; scenario 2- a high-speed train is moving through the failed cell. For scenario 1, the mobile nodes are random distributed in the area of 4000mx1000m, and the distribution area of 12000mx4000m for scenario 2 allowing for the high mobility of nodes in a train.

We consider a grade of service (GOS) of 5% for an Erlang B formula is specified for the railway wireless communication network. If the offered traffic per user is 0.025Erl, the maximum carried traffic and the total number of users (nodes) that could be served for 5% GOS can be computed as shown in Table 2.

In Table 2, the total served number of nodes is 389 for a two-carrier BS. For a railway dispatching communication situation, the nodes involved in the emergency communication at one time is actually no more than one hundred.

2) Channel Model

The channel model used in the simulation consists of two models: the shadow fading model and the multipath fading model given in [10], [11].

3) Algorithm Parameters

We give simulation parameters in Table 3.

<table>
<thead>
<tr>
<th>TABLE II.</th>
<th>CAPACITY OF GSM-R BS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of carriers</td>
<td>Number of channels</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE III.</th>
<th>SIMULATION PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>Values</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>Scenario 1: 30, 40, 60, 80, 100</td>
</tr>
<tr>
<td>Distribution area</td>
<td>Scenario 1: 4000mx1000m</td>
</tr>
<tr>
<td>Transmitting power of nodes</td>
<td>281.8mw</td>
</tr>
<tr>
<td>Coverage radius</td>
<td>250m</td>
</tr>
<tr>
<td>MAC protocol</td>
<td>IEEE 802.11 DCF</td>
</tr>
<tr>
<td>Propagation channel</td>
<td>Shadow fading model, multipath fading model</td>
</tr>
<tr>
<td>Mobility model</td>
<td>Random way point mobility model</td>
</tr>
<tr>
<td>Mobile speed</td>
<td>Scenario 1: up to 3m/s with 0 pause time</td>
</tr>
<tr>
<td>Simulation time</td>
<td>500s</td>
</tr>
<tr>
<td>Traffic type</td>
<td>CBP with packet size 128byte/s</td>
</tr>
<tr>
<td>Transmission Rate of packets</td>
<td>1packet/s</td>
</tr>
<tr>
<td>Initial energy of nodes</td>
<td>50J</td>
</tr>
<tr>
<td>Ideal degree of nodes</td>
<td>5</td>
</tr>
<tr>
<td>T</td>
<td>10s</td>
</tr>
<tr>
<td>Eunit</td>
<td>Scenario 1: 0.2J (k=1)</td>
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<tr>
<td></td>
<td>Scenario 2: 0.4J (k=2)</td>
</tr>
<tr>
<td>w1, w2, w3, w4</td>
<td>Scenario 1: 0.3, 0.1, 0.4, 0.2</td>
</tr>
<tr>
<td></td>
<td>Scenario 2: 0.15, 0.4, 0.3, 0.15</td>
</tr>
<tr>
<td>a1, a2, a3</td>
<td>0.3, 0.3, 0.3</td>
</tr>
</tbody>
</table>

B. Evaluation Indexes

To measure the performance of our hybrid clustering routing algorithm, four indexes are identified: the average delay, packet loss rate, routing overhead, and the average throughput.

1) The Average Delay $D_{avg}$

The average delay is defined to be the end-to-end delay that is obtained by accumulating the delay, which is experienced on each transit node from source to destination to forward a packet. $D_{avg}$ can be computed by

$$D_{avg} = \frac{1}{N} \sum_{i=1}^{N} [T_p(i) - T_s(i)].$$

(15)

where $N$ is the number of data packets sent by the source in the simulation time, $T_p(i)$ denotes the arrival time of the $i$th packet, and $T_s(i)$ denotes the transmission time of the $i$th packet.

2) Packet Loss Rate $PLR$

Packet loss rate is the ratio of the number of packets not received by the destination to the number of packets sent by the source, which is given by

$$PLR = \frac{1}{N_S} (N_S - N_R).$$

(16)

where $N_S$ is the number of packets sent by the source, and $N_R$ is the number of packets received by the destination.

3) Routing Overhead $RO$

Routing overhead is defined to be the ratio of the number of the routing control packets to the total number of packets in the network, which is expressed as

$$RO = N_c / N_p.$$

(17)
where \( N_C \) is the number of control packets, and \( N_P \) is the total number of packets in the network.

4) Average Throughput \(-TH\)

The average throughput is defined as the number of bits received by the destination per unit time. In order to compare it with the railway communication QoS, Byte/h is adopted as unit of throughput in this paper. \( TH \) can be obtained as

\[
TH = 128 \times 3600 \frac{N_P}{T}
\]

(18)

C. Experimental Results

First, we compare the end-to-end delay performance of our proposed routing algorithm, termed as HWBCR, with ECBRP scheme in [12], [13] for different number of nodes. Fig. 3 shows that the delay of HWBCR is much smaller than that of ECBRP, and the delay of both them decrease as the number of nodes increases. This is because the network connectivity tends to be optimal when the number of nodes is large enough. Also, we can see that, the delay of HWBCR meets the requirement of voice delay (\( \leq 0.5s \)) and data delay specifications (\( \leq 5s \)) in railway emergency communication.

![Figure 3. Delay versus number of nodes (maximum speed of 3m/s).](image)

In Fig. 4, we present the delay performances comparison for different node mobility. With the node mobile speed increasing, the delay increases rapidly, which means that higher mobility causes more broken links, and thus increasing delay. The delay of HWBCR is much smaller than that of ECBRP, the reason is that: 1) in the clustering procedure, clustering stability related to node mobility is a key factor for CHs election. 2) in the clustering routing, the number of hops as a metric of the preferred route, smaller number of hops means the time between route discovery and sending data packet is small. Besides, multiple candidate routes would reduce the time delay for route discovery and routing maintenance greatly. Also, Fig. 4 shows that the delay of HWBCR meets the requirement of voice delay and data delay specifications for up to medium node mobility. Under high node mobility, only data delay specification can be satisfied.

![Figure 4. Delay under different mobility (50 nodes).](image)

The packet loss rate performances under different number of nodes are shown in Fig. 5. We observe that HWBCR has much smaller packet loss rate, about half

![Figure 5. Packet loss rate versus number of nodes (maximum speed of 3m/s).](image)

In Fig. 6, we present the routing overhead performance for different node mobility. With the node mobile speed increasing, the routing overhead increases rapidly, which means that higher mobility causes more broken links, and thus increasing routing overhead. The routing overhead of HWBCR is much smaller than that of ECBRP, the reason is that: 1) in

![Figure 6. Packet loss rate under different mobility (50 nodes).](image)

The packet loss rate performances under different number of nodes are shown in Fig. 5. We observe that HWBCR has much smaller packet loss rate, about half

![Figure 7. Routing Overhead versus number of nodes (maximum speed of 3m/s).](image)
the packet loss rate of HWBCR, due to little congestions and packet drops. Again, we note that the PLR performance of HWBCR is approaching the reliability target (≤10⁻²) with larger number of nodes.

The packet loss rates under different node mobility are plotted in Fig. 6. When node speed increases, the PLR performances deteriorate dramatically. It is caused by the lots of congestion and packet drops in the frequently changing network. Consequently, the PLR performance of HWBCR is maintained at the reliability target (≤10⁻²) for medium node mobility.

Fig. 7 shows the impact of the number of nodes on the routing overhead. As the number of nodes increasing, the overhead of routing increases. The routing overhead of HWBCR is slightly larger than ECBRP. This is due to the fact that the routing table maintenance in a cluster may bring more routing overhead.

In Fig. 8, we observe the routing overhead with different node mobility. The RO performance becomes worse in high mobility network. On the other hand, HWBCR has much smaller overhead compared to ECBRP. Taking the dynamic nature due to the mobility of nodes into consideration, it might be diminished since the stability of network is preserved as much as possible by the clustering procedure. So, the chance of repairing or re-routing is much smaller in HWBCR than in ECBRP.

We examine the throughput performances for different number of nodes depicted in Fig. 9. As is evident from Fig. 9, when the number of nodes is increasing, the throughput has a great increase. However, the throughput changes a little if the number of nodes is large enough (≥80). Also, we can see that the throughput of ECBRP is close to that of HWBCR. However, the throughput of HWBCR is still a little larger than ECBRP. The throughput of HWBCR meets the requirement of data throughput level-12 (≥0.5×10⁶byte/h) in railway emergency communication.

We also measured the throughputs under different mobility reported in Fig. 10. Higher mobility causes more broken links, and thus decreases throughput. However, the throughput of HWBCR is much larger than ECBRP, especially under high mobility. This is because HWBCR incurs small overhead from inter-cluster routing and maintaining routes within clusters. The throughput of HWBCR meets the requirement of data throughput level-12 in railway emergency communication.

Observe these simulation results, we can reach the following conclusions:

1) HWBCR always exhibits better performance for delay, packet loss rate, and throughput than ECBRP, regardless of the mobility of nodes, i.e., train speed.

2) HWBCR provides reliable QoS guarantee for railway emergency communication for all the traffics including voice and data, when the train speed is less than 60m/s (216km/h).

V. CONCLUSION

In this paper, we presented a hybrid weight-based clustering routing (HWBCR) scheme based on the combined weight rule for a railway emergency communication network. First, clustering procedure is executed, and the degree difference from the ideal degree (\(D_\text{i}\)), relative clustering stability (\(S_\text{r}\)), the sum of distance between the node and it’s one-hop neighbors (\(P_\text{r}\)), consumed power (\(C_\text{r}\)), node type (\(T_\text{r}\)), node mobility (\(M_\text{r}\)) in a destroy BS coverage are used for CHs election. For the clustering forming, the weights for the CH election parameters are allocated rationally by rough set theory. Afterwards, we proposed a clustering routing algorithm, in which the routing in a cluster is simply based on the routing table formed by forwarding the routing request/update packet, and in inter-cluster routing, the remaining power of the nodes, the number of CHs, and the total number of hops in a route from source to destination are taken into consideration as metrics to find
the preferred route. Simulation experiments show that HWBCR realizes efficient railway emergency communication with more reliable and stable QoS guarantee, i.e., lower delay, lower packet loss packet, lower routing overhead, and higher throughput.

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REFERENCES


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