Acta Technica 62 (2017), No. 7A, 475–484

Routing of wireless mesh networks based on acyclic forwarding

Na Luo[1]

Abstract. Security application of most mesh networks (Vehicular Ad Hoc Network) should be subject to multi-hop broadcast mode for distribution of security message. At present, lots of multi-hop broadcast forwarder selection schemes have been proposed so as to reduce No. of forwarders. Therefore, D-DMHFS (Density-Distance based multi-hop Broadcast Forwarder Selection scheme) based on density and distance has been proposed, which is called D-DMHFS. D-DMHFS is mainly used to solve two problems: redundant rebroadcast in dense region and high transmission delay in sparse region. Timer should be set at the node according to distance and network density before received message is determined to be rebroadcasted in the proposed D-DMHFS. The node should be the next-hop forwarder if there is no other node forwarding the message in the timing period. Simulation result shows that rebroadcast times and transmission delay performance of proposed D-DMHFS protocol can be significantly improved in comparison with current scheme. Message rebroadcast times are dropped by about 57% in dense region, and transmission delay is shortened by about 82% in sparse region.

Key words. Emergency message, Mesh network, Multi-hop broadcast, Broadcast protocol, Node density.

1. Introduction

Different from unicast mode used in traditional Internet access network, security application of MESH network should be subject to broadcast mode for transmission of message. In addition, some vehicles may be far away from message sending place and are not in one-hop communication range, thus multi-hop broadcast should be used for transmission of message. An ideal broadcast mechanism is required to immediately transmit information to relevant vehicles with performance requirements of low delay and high transmission rate. However, wireless communication usually is not reliable and has hidden node problems, collision of data package, channel fading, barrier, and other problems which may challenge broadcast mechanism. Therefore,

[1]Jiangxi economic management cadre institute of information engineering, Nanchang, Jiangxi province, 330088

aiming at multi-hop broadcast problems of security application for MESH network, in face of transmission problems of emergency message for high-speed scene, D-DMHFS based on density and distance is proposed. Waiting time for message receiving node should be set according to distance before rebroadcast of message. The timing time should be limited to an interval. Interval border should be inverse ratio of the distance from sending node. Different from other schemes, vehicle density is considered in D-DMHFS at the time of deducing time border. Specifically, when network density is fairly high, wider interval will be used in D-DMHFS so as to reduce probability for simultaneous forwarding of message by several vehicles; when network density is relatively low, waiting time will be reduced so as to reduce transmission delay. Two functions are cited in D-DMHFS so as to calculate border of waiting time for realization of two purposes eventually: 1) reduce No. of rebroadcast message when network density is fairly high; 2) reduce message transmission delay when network density is relatively low.

2. Related work

In order to reduce transmission num-hop and to reduce transmission delay, distance between sending node and receiving node is applied to most multihop broadcast protocols for selection of forwarder which is the farthest node from sending node with the shortest waiting time; transmission power or data transmission rate should be adaptively adjusted according to network density, channel condition, and etc.

SB (Smart Broadcasting) protocol based on RTB / CTB handshaking mechanism is proposed in Literature [3]. However, SB protocol is relied on some parameters, such as CW (contention window). FR-EDM protocol is proposed in Literature [4] so as to improve transmission reliability of message for repeated broadcast of message within scheduled scope. Bi-Zone protocol is proposed in Literature [5], which uses distance threshold to divide transmission range of forwarder into two neighboring regions. If the distance from the node to forwarder is longer than distance threshold, the node will have shorter waiting time.

In addition, some researchers use broadcast probability to reduce No. of rebroadcast message. Each node in these protocols rebroadcasts message according to probability. The lower the rebroadcast probability is, the less the message distribution cost is, thus transmission probability of message to other vehicles will be lower. On the contrary, the higher the rebroadcast probability is, the more the message distribution cost is. Accordingly, transmission possibility of message to other vehicles will be higher. Therefore, there is equilibrium problem between cost for message distribution cost and distribution probability. Different ways are used in current protocols so as to deduce rebroadcast probability: fixed probability value. For example, it is set in Literature [6] and Literature [7] according to channel conditions and is calculated in Literature [8] according to No. of received messages at given time interval. In addition, the value is set in Literature [9] and Literature [10] by using one-hop neighbor No. These probability calculation models are not set aiming at security application of MESH network.

Different from other applications in MESH network, effective transmission of data is very important in security application of MESH network, which is related to life safety. Therefore, transmission delay and reliability of message have to be considered at the time of broadcasting message. However, it is of great challenge to satisfy the two performances. In addition, the relation between transmission delay and transmission reliability has to be weighed.

At present, optimized next-hop forwarder selection mechanism is applied to most protocols so as to reduce transmission delay. What's different between these protocols is: the method to calculate waiting time interval is different. However, there protocols suffer message collision in dense region and high transmission delay of message in sparse region. The problem of network density is not considered at the time of calculating time interval. For example, scheme in Literature [5] is taken as an example. A timer is set for each node before rebroadcasting message. Border of timing time should be $[T_{lower}, T_{upper}]$. If the distance from the node to sending node is longer than distance threshold scheduled distance threshold d_{th}, $T_{lower} = 0$ and upper limit T_{upper} of timing time should be:

$$T_{upper} = T_{\max} \times \left(1 - \frac{d}{R}\right) . \tag{1}$$

Where R indicates transmission distance of vehicle; $T_{\max}$ indicates the longest waiting time; d indicates the distance from sending node.

In terms of the node with shorter distance to sending node than to distance threshold d_{th}, upper limit T_{upper} of timing time should be set to be maximum, which is $T_{upper} = T_{\max}$, while the lower limit should be T_{lower}:

$$T_{lower} = T_{\max} \times \left(1 - \frac{d_{th}}{R}\right) . \tag{2}$$

The following scene should be considered: if several nodes are on the border of transmission distance, it is known according to Equation (1) that $\frac{d}{R} = 0$, which means that $T_{upper} = 0$. Upper limit and lower limit of timing time for these nodes should be 0. They can rebroadcast message after receiving message without wait, which leads to a large number of message redundancy, increases channel expenses, and definitely causes channel competition. These problems are more serious, especially in dense region. Although distance between these nodes and sending node is different, timing time of them is very close. In the case, lots of their timing time is overlapped with high message collision probability.

Timing time set which is based on CW is used in Literature [11]. Value of CW varies in the interval of $[CW_{\min}, CW_{\max}]$, which is depended on distance and transmission range and is shown in Equation [3].

$$CW = \left\lfloor \left(\frac{R}{d} \times (CW_{\max} - CW_{\min})\right) + CW_{\min} \right\rfloor . \tag{3}$$

3. Routing of Wireless Mesh Networks

Network density and type of emergency message are not fully considered in these above-mentioned protocols at the time of selecting next-hop forwarder. As vehicle distribution of MESH network has space-time characteristics, distribution varies with time, thus vehicle distribution is required to be considered at the time of determining next-hop forwarder so as to effectively narrow transmission delay. In addition, different message types have different requirements for transmission delay. Therefore, D-DMHFS is proposed in the thesis. Distance and vehicle density information are required to be considered in combination with different emergency message types at the time of selecting next-hop forwarder so as to realize the purpose of reducing transmission delay eventually.

In order to reduce No. of forwarders and to reduce delay, distance and network density message are considered in D-DMHFS at the time of calculating timing time. In addition, two functions are used to calculate T_{lower} and T_{upper}.

3.1. Constraint condition

Expressway is proposed to be research object in D-DMHFS based on the following constraint conditions:

(1) All vehicles are equipped with GPS equipment, which can obtain their geographical positions;

(2) All vehicles have dedicated short range communications (DSRC), which can be used be directly communicate with other vehicles or in the way of multihop.

(3) Each vehicle should periodically broadcast cooperative awareness message (CAM), including position, direction, and velocity information of vehicles [12]. In addition, broadcast period is .

(4) DENM(Decentralized Environment Notification Message)[13], Vehicle will immediately send decentralized environment notification message [13] when emergency conditions are detected, including position, message transmission direction, and etc.

3.2. D-DMHFS scheme

Distance is cited as performance indicator of selection forwarder in proposed D-DMHFS. The node with the shortest distance to sending node is attempted to be selected as message forwarder. DENM message will be immediately generated after vehicle accident is found. In addition, the message should be broadcasted to back vehicles. In terms of vehicles receiving the message, drivers should firstly detect whether they have received the message before. If it is new message, fresh time of the message should be judged; if it is not overdue, drivers should add their position coordinates to DENM message, should set timer, and should wait for completion of timing for timer. If there is vehicle forwarding DENM message during the period of completion of timing for timer, it indicates that there is vehicle forwarding DENM message so as to give up competition of forwarding message at this time.

3.3. Heterogeneity segment

Reverse transmission distance of vehicle should be divided into different segments with total segments of K:

$$K = R/\rho_{avg} \,. \tag{4}$$

Where ρ_{avg} can be calculated according to Equation (5).

$$\rho_{avg} = \frac{1}{K}\sum_{i=1}^{K} h_i * V_i \,. \tag{5}$$

Where h_i indicates time headway and V_i indicates velocity of vehicle i.

3.4. Classification and freshness degree of DENM message

It should be divided into 6 types according to different characteristics of different DENM messages required for time, such as collision warning, sudden break warning, and etc., which is shown in Table 1. Different DENM messages have different requirements for transmission delay. For example, collision warning and sudden break warning messages have rigorous requirements for time, which is required to be quickly transmitted to follow-up vehicles so as to ensure shorter fresh time. In comparison with collision warning message, longer delay of assistant message for left turn is allowed so that its fresh time can be wider from the perspective of security.

Table 1. Classification of DENM message and corresponding freshness degree

Message classification	Rigorous time	Fresh time
Collision warning	Super-high	5 Second
Sudden break warning	Super-high	5 Second
Warning of emergency vehicle	Super-high	5 Second
Warning of lane change	High	10 Second
Pre-collision induction warning	High	10 Second
Assistant message for left turn	High	10 Second

3.5. Timer set

Timing time of timer at each node is randomly selected from the interval of $[T_{lower}, T_{upper}]$. The reason why timing time is randomly selected from the interval is to reduce probability of the same timing time for node so as to alleviate channel competition. However, upper limit T_{upper} and lower limit T_{lower} in the interval of each node are depended on distance and local density message.

Definition of upper limit T^i_{upper} for node i is shown in Equation (6).

$$T^i_{upper} = \max\left\{T_{\max} \times (1 - \Delta d) \times \rho, T_{\min} + CW_{length}\right\} \,. \tag{6}$$

While lower limit T^i_{lower} of node i is:

$$T^i_{lower} = T^i_{upper} - CW_{length}\,. \tag{7}$$

Where $T_{\min}$ and $T_{\max}$ respectively indicates the shortest and the longest waiting time. ρ indicates local vehicle density, which is shown in Equation (8).

$$\rho = \frac{N}{N_{\max}}\,. \tag{8}$$

Where $N_{\max}$ indicates one-hop neighbor No. at the time of traffic jam; while N indicates one-hop neighbor No., which equals to received CAM messages.

However, CW_{length} and Δd are respectively shown in Equation (9) and Equation (10):

$$CW_{length} = (T_{\max} - T_{\min}) \times \rho/k, k = 1, 2, \cdots, K \tag{9}$$

$$\Delta d = \left\lfloor \frac{d}{R} \right\rfloor \times \frac{1}{k} \tag{10}$$

3.6. Forwarding of DENM message

DENM message in vehicles (assumed node i) will be generated when emergency accidents are detected, including emergency event position, transmission direction of DENM message, fresh time, num-hop, and timestamp. Its format is shown in Table 2.

Table 2. DENM message format

Event Position	direction	Fresh time	Num-hop	Timestamp

Where Event position indicates geographical position of events; direction indicates transmission direction of DENM message, which is bit. If it is 1, it indicates back; if it is 0, it indicates front / back. In terms of expressway, emergency messages are transmitted to back vehicles. Fresh time indicates freshness time of the message, which is set according to Table 1. However, num-hop indicates forwarded times of DENM message. 1 will be added for each time of forwarding with initial value of 0. Timestamp indicates generation time of DENM.

One-hop neighbor node N_i of node i will receive DENM message. Node j should be taken as an example. Whether DENM message has been received before should be detected after it is received at node j. If it has, the message should be directly abandoned. Otherwise, whether fresh time of the message is overdue should be judged. If it is overdue, the message should be directly abandoned. Otherwise, T_{lower} and T_{upper} should be calculated according to Equation (6) and Equation (7). Then, a timing time should be randomly selected from the interval of $[T_{lower,}T_{upper}]$. Next, timing will be completely set. If there is other node forwarding the message during the completion period of timing, it indicates that there is node successfully

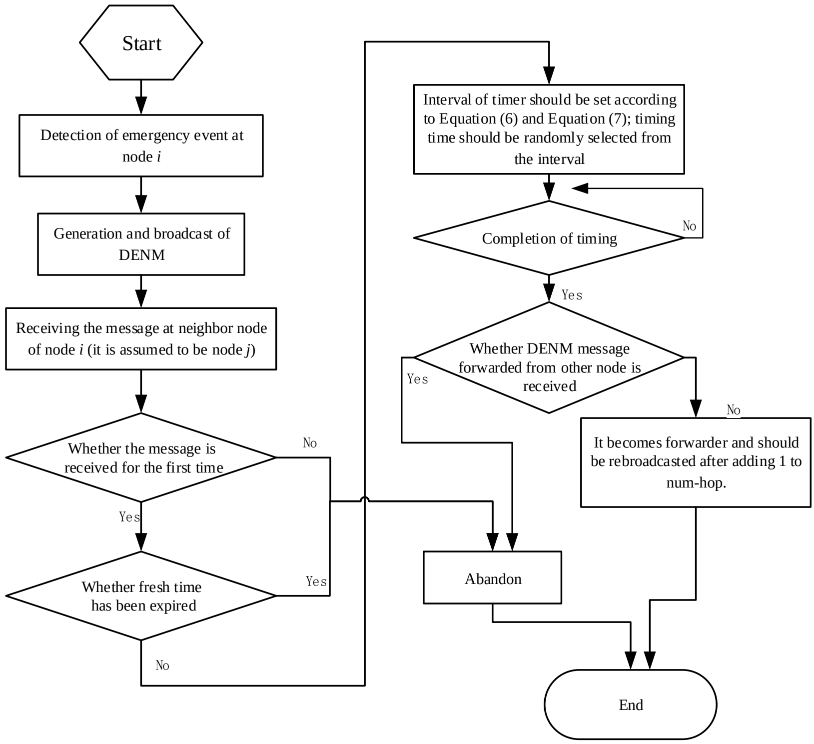

Fig. 1. Overall flow for D-DMHFS protocol

forwarding the message. In the case, the message should be directly abandoned. Otherwise, 1 should be added to num-hop after completion of timing for timer. Then, DENM message should be broadcasted. Flow for D-DMHFS Protocol is shown in Fig. 1.

4. Performance simulation and analysis

4.1. Simulation parameter and performance indicator

NS-2.34 [14] emulator should be used to analyze proposed D-DMHFS protocol performance. Firstly, NS-2.34 MAC layer parameter should be modified and ACK/RTS/CTS mechanism should be abandoned. Then, SUMO emulator [15] should be used to generate moving track file. In addition, expressway with six lanes in each direction should be selected as simulation scene with the distance of 4km. Traffic flow density varies from 20km to 12km. Vehicle speed ranges from 80km/h to 120km/h. Simulation parameter is shown in Table 3 in detail.

Table 3. Simulation parameter

Parameter	Value
Simulation region	4km×3lanes
Propagation model	Nakagami
Transmission range	300m
Data transmission rate	12Mbps
CAM Size	100 bytes
DENM Size	256bytes
Simulation time	200s

Performance of proposed D-DMHFS scheme can be analyzed in aspects of message rebroadcast times, transmission delay, and transmission reliability. In addition, selection distance-based relay scheme (SDR) should be as reference. Vehicle density is not considered in SDR at the time of calculating interval of waiting time.

4.2. Numerical analysis

(1) Average rebroadcast times

Change curve for average message broadcast times of SDR and D-DMHFS with traffic flow density is shown in Fig. 2. It is known in the Figure that rebroadcast times of SDR are increased with rising of traffic flow density. The reason lies in: distance between two nodes is decreased and neighboring nodes are closer due to increase of network density. In the case, timing length of timer for several nodes is closer, which leads to increase of probability for simultaneous broadcast of them, thus probability of message collision is improved so as to make more messages require to be rebroadcasted. In comparison with SDR, performance of proposed D-DMHFS is improved. For example, when traffic flow is between 100vehicles/km and 120vehicles/km, rebroadcast times of messages in D-DMHFS will be respectively decreased by 50% and 70%.

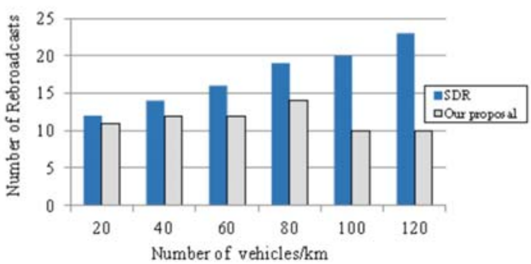

Fig. 2. Average rebroadcast times

(2) Average transmission delay

Average transmission delay conditions of the two schemes are shown in Fig. 3. It is known in Fig. 3 that average transmission delay in SDR is longer than that in proposed D-DMHFS. In addition, average transmission delay of SDR is fairly longer at the time of start. For example, when traffic flow is 20vehicles/km, transmission delay of SDR will be 336ms; while when traffic flow is 60vehicles/km, its transmission delay will be decreased to 133 ms. In fact, it is hard to find a forwarder within the limited communication range under the sparse network environment. Therefore, the node which is close to sending node has higher probability to rebroadcast message, which increases transmission delay. With increase of traffic flow, connection is easier to be formed between vehicles, which improves probability to find next forwarder and narrows transmission delay.

The reason why transmission delay of proposed D-DMHFS is good lies in that when traffic flow is low, T_{upper} in D-DMHFS is small, which reduces transmission delay. When traffic flow is high, T_{upper} will be wider, which reduces probability of identical timing time for two nodes and alleviates channel competition. When traffic flow is 120vehicles/km, average transmission delay in D-DMHFS will be less than 120 ms, which is acceptable.

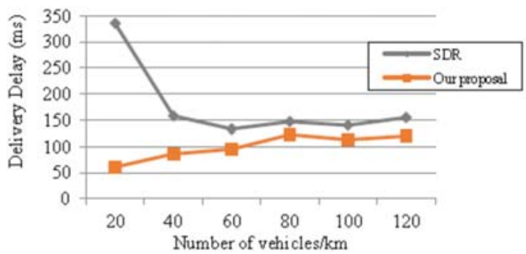

Fig. 3. Change of average delay per hop with vehicle density

(3) Transmission num-hop

In addition, average transmission num-hop of message is shown in Fig. 4. It is known in Fig. 4 that transmission num-hop of proposed D-DMHFS protocol is lower than that of SDR protocol. When traffic flow is between 100vehicles/km and 120vehicles/km, 120vehicles/km of SDR protocol will be 12. It is mainly because that timer of SDR protocol is random and selected next-hop forwarder is not the farthest node to sending node. Moreover, transmission num-hop of D-DMHFS do not change with traffic flow, which maintains about 7 hops.

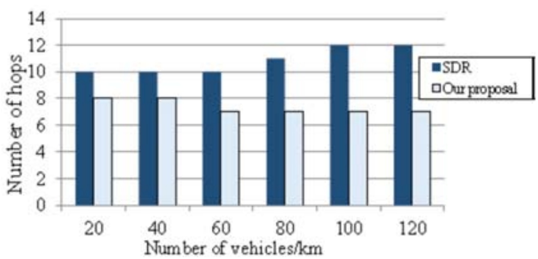

Fig. 4. Change of average transmission num-hop with vehicle density

5. Conclusion

Aiming at broadcast problems of emergency message in MESH network, D-DMHFS based on density and distance is proposed. Timer should be set according to distance from the node to sending node and local density before message is forwarded at the node. If there is no other node forwarding message at the time of completion of timing, message at the node should be immediately forwarded. Simulation result shows that in comparison with SDR, rebroadcast times of D-DMHFS is dense network distribution region is decreased by about 57%, while transmission delay is shortened by about 82% in sparse region, which realizes expected purposes.

References

[1] Z. Tao, D. Wang, J. Zhang: *Ranking nodes in networks with topologies arranged as directed acyclic graphs: US*, US 8270313 B2[P] (2012).

[2] Y. Bejerano, S. J. Han, A. Kumar: *Efficient load-balancing routing for wireless mesh networks*[J]. Computer Networks, *51* (2007), No. 10, 2450–2466.

[3] X. Fang, D. Yang D., G. Xue G.: *A Distributed Algorithm for Multi-Constrained Anypath Routing in Wireless Mesh Networks*[C]// IEEE International Conference on Communications. IEEE, (2011), 1–5.

[4] C. Y. Huang, P. Ramanathan: *Network Layer Support for Gigabit TCP Flows in Wireless Mesh Networks*[J]. IEEE Transactions on Mobile Computing, *14* (2015), No. 10, 2073–2085.

[5] P. Thubert, F. L. L. Faucheur, E. M. Levy-Abegnoli: *Forwarding packets to a directed acyclic graph destination using link selection based on received link metrics: US*, US7924722[P] (2011).

[6] D. Natarajan, A. P. Rajendran: *AOLSR: hybrid ad hoc routing protocol based on a modified Dijkstra's algorithm*[J]. Eurasip Journal on Wireless Communications & Networking, (2014), No. 1, 90.

[7] H. P. Shiang, S. M. Van d.: *Multi-user video streaming over multi-hop wireless networks: a distributed, cross-layer approach based on priority queuing*[J]. IEEE Journal on Selected Areas in Communications, *25* (2007), No. 4, 770–785.

[8] S. Chakraborty, S. Sharma, S. Nandi: *MAC Layer Channel Access and Forwarding in a Directional Multi-Interface Mesh Network*[J]. Mobile Computing IEEE Transactions on, *14* (2015), No. 3, 565–578.

[9] M. Bouaziz, A. Rachedi: *A survey on mobility management protocols in Wireless Sensor Networks based on 6LoWPAN technology*[J]. Computer Communications, *74* (2016), No. 1, 3–15.

[10] D. Das, R. Misra, A. Raj: *Approximating geographic routing using coverage tree heuristics for wireless network*[J]. Wireless Networks, *21* (2015), No. 4, 1109–1118.

[11] R. Zheng: *Information Dissemination in Power-Constrained Wireless Networks*[C]// INFOCOM 2006. IEEE International Conference on Computer Communications. Proceedings. IEEE, (2006), 1–10.

[12] J. J. Lim, G. S. Kang: *Gradient-Ascending Routing via Footprints in Wireless Sensor Networks*[C]// Real-Time Systems Symposium. RTSS 2005. IEEE International. IEEE, (2005), No. 10, 307.

Received May 7, 2017