An Efficient Broadcast Protocol Based on Roadside Infrastructure for Vehicle Network

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ABSTRACT

Aiming at the problem of network disconnection in vehicle networks, this paper proposes a broadcast protocol based on existing carry-forward mechanism, which aims to shorten the re-healing time between nodes by using roadside fixed infrastructures. The information transporting process and re-healing time algorithm were analyzed in detail in two scenarios, and were compared with SCB and SCF mechanisms by the simulation experiments. The results show that the proposed broadcast protocol based on roadside infrastructures can significantly reduce the re-healing time in the case of network disconnection.

Keyword: vehicle network, roadside infrastructure, network disconnection, re-healing time

INTRODUCTION

In inter-vehicle communication (IVC) systems, vehicles rely on broadcast to share emergencies, traffic conditions, weather and road data, and to disseminate the advertisements and notifications. However, the high speed of vehicle movement reduces time using for exchanging information and causes the rapid and frequent change of network topology, resulting in more unstable wireless channels. Therefore, the traffic information broadcasting protocol that can fit for the basic characteristics of vehicular Ad Hoc network (VANET) and meet the requirements of drivers needs to meet the following conditions[1]: it can support high-speed movement of nodes, ensure the real-time, reliable and reachable of information announcing, possess high resource utilization rate, fit for harsh channel environment of wireless network, provide strong scalability and robustness, as well as provide fair chances of sharing resources for various application information.

BACKGROUND AND RELATE WORK

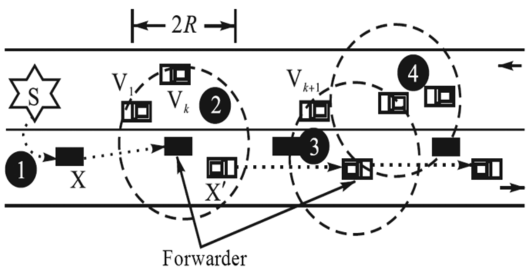
Mobile Ad Hoc network (MANET) has developed a large number of unicast routing protocols. However, these protocols have their own features which cannot be directly used for VANET. The researchers have developed unicast routing protocols for VANET[2-6]. Most of these protocols use a location-based greedy algorithm to achieve communication among cars. The location-based algorithm is to use the coordinates of nodes or the information related to the relative position to generate an effective route by network[2-3]. In sparse VANET, the protocol using for routing packets is called a delay-tolerant routing protocol. In some specific network environments, such as interstellar networks, military Ad Hoc networks, sensor networks and VANET, they often appear the case of disconnecting network so as to not ensure the end-to-end path of the messages in the transmission process, this type of network is called a delay-tolerant network (DTN). In this case, the establishment of the end-to-end route may not be possible, so the references [6] and [7] use the carry-forward method to recover the connection between nodes.

Most of the researches on VANET focus on broadcast storm problem in high-density network topology, all of which are based on the well-connected VANET. According to vehicle traffic data from California's I-80 highway, the reference [8] found that in the case of 100% equipment availability (i.e., all vehicles are equipped with wireless communications), the probability of network disconnection on the highways late at night reaches 35%. And the network disconnection can be observed even with a large equipment allocation rate during the commuter rush hour while the network connection is good. Obviously, the problem of network disconnection is an important research field, it is necessary to develop a reliable and efficient routing protocol to support highly diversified network topologies.

Aiming at the problem of network disconnection existing in VANET, with the existing carrying and forwarding mechanism, this paper proposes a novel broadcast protocol based on roadside units (RSU) so as to shorten the re-healing time for recovering the connection between nodes.

Store-Carry-Forward Mechanism (SCF)[9-10] uses a reverse moving vehicle as a forwarder to send a message to the next cluster (the vehicles which move in the same direction and can only communicate each another with the mode of one-hop or multi-hop belong to the same cluster). But the message can only be send to the first vehicle in the next cluster. When the popularity rate of dedicated short-range communication devices (DSRC) is not sufficient, the number of disconnected nodes increases, and the number of SCF operations performed by the reverse forwarder increases so as to increase the SCF overhead.

In order to reduce the SCF overhead, when a forwarder can perform multiple SCF operations between the continuous disconnected nodes, it is necessary to avoid allocating multiple forwarders. Therefore Store-Carry-Broadcast Mechanism (SCB) [9] is proposed. In SCB, the node S is disconnected from the subsequent node V1. As shown in the figure below: S sends a message to X (reverse forwarder)?V1, ..., Vk (the nodes within the broadcast range 2R)?X checks if there is an neighbor node X' close enough to the node Vk+1, if so, X ' becomes new forwarder. Otherwise, X continues. Vk + 1 is disconnected from Vk, then the forwarder will broadcast messages to the next cluster beginning with Vk + 1?When the forwarder discovers that the first vehicle outside the broadcast range connects to the vehicle in front of it, it will discard this message.



The above two mechanisms cannot guarantee the waiting time the tail vehicles in a cluster encountering the reverse forwarders. In particular, there is a longer delay when the DSRC devices have a lower popularity rate.

RSU-BASED BROADCAST PRO- TOCOL MODEL

When studying the data packet transmission problem in VANET, the researchers need to distinguish two situations: (1) a secure message is broadcasted to the rear vehicle, that is, the source vehicle generates a warning message after detecting the accident and sends the warning message to the rear vehicles. The rear vehicles can get this warning message before it reaching the potentially dangerous region. (2) When the target node is far from the source vehicle, the message is sent to a specific node in a distant place. The number of hops required for the packets to reach the destination depends on a variety of factors such as the distance between the sender and the destination and the path by which the packet is transmitted.

3.1 Broadcasting secure messages to the rear vehicles and the algorithm for the re-healing time

For the situation sending secure messages to the rear vehicles, based on the following six rules, RSU can be applied to broadcast protocol model.

(1) When the source vehicle V_0 detects a danger or accident, it broadcasts a secure message to the next neighboring node inside the same cluster, which may be RSU or a rear vehicle driving in the same direction as V_0 (the direction of V_0 is destination direction).

(2) If receives a secure message, RSU will regularly broadcasts the secure message to the oncoming vehicles. Because of the broadcast for the secure message, VANET can reduce the amount of broadcast overhead.

(3) When the secure message is no longer necessary, RSU discards the secure message, stops the broadcast, and waives the security warning.

(4) If RSU is not deployed in the cluster of V_0, the vehicle V_k which is the tail vehicle of the V_0

cluster) will undertake the responsibility designating the forwarder for messages relay.

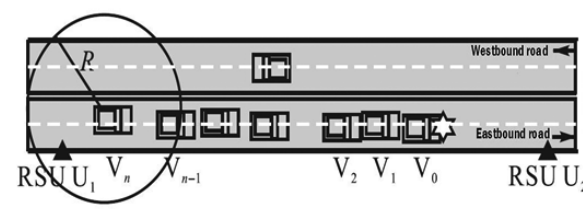
(5) The neighboring vehicle moving in the reverse direction to V_k is selected as the forwarder.

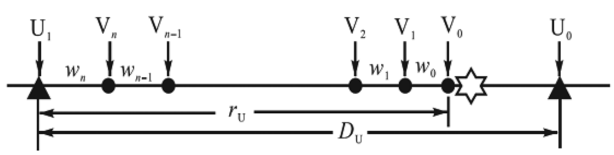
(6) Once received the security message, the forwarder carries the message and passes it to a re-healing node (RSU or V_{k+1}). This rule can help to reduce the number of hops for the re-healing, which is important to reduce the number of broadcast branches in the high density region of vehicle in VANET.

After an accident, the source vehicle generates and sends a secure message to the rear vehicles. According to the relative location of the source vehicle and RSU, there are the two scenarios to discuss.

3.1.1 RSU being within the transmission range of the source vehicle cluster

Because RSU (U_1) locates in the transmission range of the source vehicle cluster, the nodes within the V_0 cluster can send it to the U_1 when the secure message is sent by V_0, as shown in the two figures below. It should be noted that the vehicle V_n does not need to be the last vehicle in the cluster.





According to the experimental data in the reference [11], the vehicle density obeys the exponential distribution. The distance between two driving vehicles along the eastbound road can be represented by the vehicle density λe. The number $N_e(r_U)$ of vehicles in the interval r_U (the distance between the source vehicle and the rear first RSU) obeys a Poisson distribution.

$$P_r[N_e(r_U)=n]=e^{-\lambda_e r_U}[\frac{(\lambda_e r_U)^n}{n!}] \tag{1}$$

Assuming there are n vehicles within r_U, and the distance between the i-1 vehicle and the i vehicle is w_i, $w(n)=\max_{0\le i\le n}\{w_i\}$. According to the increasing mode of Poisson distribution, n vehicles are uniformly distributed in the r_U range, based on the results of stochastic partitioning of intervals in the references [12-13], we can get the following formula.

$$\begin{aligned}P_r&=[w(n)<R\mid N_e(r_U)=n]\\&=\sum_{j=0}^{\min\{[r_U/R],n+1\}}\binom{n+1}{j}(-1)^j\left(\frac{r_U-jR}{r_U}\right)^n\end{aligned} \tag{2}$$

Where $\binom{n=1}{j}=\frac{(n+1)!}{j!(n+1-j)!}$ represents the number of arbitrarily taking j numbers from n+1 numbers.

The function $W(s)=P_r[w(n)<R,N_e(s)=n,\forall n]$ is defined as the function which can calculate the probability that the remaining cluster length (from any vehicle on the freeway) is greater than s-R(s>R). Considering the possible values of n on r_U and putting it into the formulas (1) and (2), we can get the following formula.

$$W(s)=e^{-\lambda_e s}\sum_{j=0}^{[s/R]}\frac{(-1)^j}{j!}\times\sum_{n=j-1}^{\infty}\frac{n+1}{(n+1-j)!}[\lambda_e(s-jR)]^n \tag{3}$$

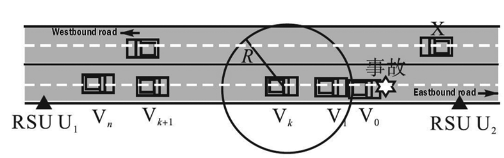
The probability that the next RSU is within the transmission range of the source vehicle is:

$$\begin{aligned}P_I&=\int_0^{\infty}W(r_U)R_U(r_U)dr_U=\frac{1}{D_U}\int_0^{D_U}e^{-\lambda_e r_U}\sum_{j=0}^{[r_U/R]}\frac{(-1)^j}{j!}[\lambda_e(r_U-jR)]^{j-1}\times\\&[j+\lambda_e(r_U-jR)]e^{\lambda_e(r_U-jR)}dr_U\end{aligned} \tag{4}$$

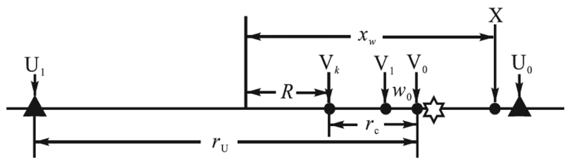
Where D_U is the distance between two neighboring RSU, and $R_U(r_U)=\frac{1}{D_U}$ is the density function of r_U.

3.1.2 RSU being not within the transmission range of the source vehicle cluster

When U_1 is not within the transmission range of the source vehicle cluster, i.e., the distance between U_1 and the last vehicle V_k in the source vehicle cluster is greater than R (the figure below), the traffic secure message is stored and forwarded to the reverse driving vehicle X, the X relays the message to U_1 or the first vehicle V_{k+1} in the next cluster.



When the next node is RSU (the figure below), the following U_1 is the re-healing node and the distance between U_1 and the vehicle X is r_U-r_c-R+x_w. At this time, the re-healing time $E[t_U]$ the secure message being sent to the next node is approximate the formula 5.

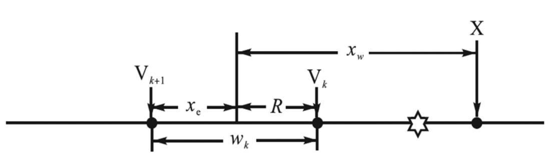


$$E[t_U]\approx\frac{\int_R^{D_U}\max[0,(r_U-E[r_c\mid r_U]+E[x_w]-2R)](1-W(r_U))dr_U}{v_w\int_R^{D_U}(1-W(s))ds} \quad (5)$$

Here the x_w is the distance from the covering range of the last vehicle in the source vehicle cluster to the X. The distance between the vehicles in the westbound road is $E[x_w]=1/\lambda_w$, where the λ_w is the vehicle density in the westbound road. The probability that the vehicles V_0—V_k are closely connected in the interval r_c (i.e., the distance between two continuous vehicles is less than R) is $W(r_c)$. In this case, if there is no connected vehicle behind V_0 (i.e., $k=0$) then $r_c=0$ and the corresponding probability is $P_r[w_0>R]/1-W(r_U)$. If there is at least one connected vehicle (i.e., $w_0<R$) behind V_0 then $r_c>0$ and the corresponding probability is 1- $W(r_U)$- $P_r[w_0>R]/1-W(r_U)$. Therefore, there is the formula (6).

$$E[r_c\mid r_U]=\frac{\int_0^{r_U-R}r_cW(r_c)dr_c}{\int_0^{r_U-R}W(r_c)dr_c}\times\frac{1-W(r_U)-e^{-\lambda_e R}}{1-W(r_U)} \quad (6)$$

When the next node is V_{k+1} (the figure below), V_{k+1} is the re-healing node, the distance w_k between V_k and V_{k+1} is less than R, and the distance between X and V_{k+1} is x_e+x_w. The speeds of vehicles X and V_{k+1} are respectively v_e and v_w, assuming $\lambda_e=\lambda_w=\lambda$, the re-healing time which the secure message is transmitted to the next node at this time is the formula (7).



$$E[t_V]=(\frac{e^{-\lambda R}}{v_e+v_w})(R+\frac{2}{\lambda}) \quad (7)$$

Combined with the formulas (5) and (6), the re-healing time for the secure message to be transmitted the healing node is as follows.

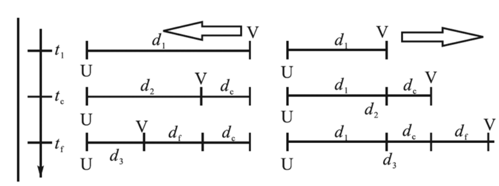
$$\begin{aligned}E[t_r]&=(1-P_I)(E[\min\{t_U,t_V\}])\leq\\&(1-P_I)(\min\{E[t_U],E[t_V]\})\end{aligned} \quad (8)$$

The result of the formula (7) is the upper limit of the re-healing time.

3.2 To send a message to a specific node

When the vehicle V_A needs to send one packet to the vehicle V_D, if the V_D is in the vicinity of V_A, the V_A broadcasts the packet to the V_D. Otherwise, the V_A sends the packet to its nearest RSU (U_1). If the U_1 has the location V_D (indicating that the V_D is at the periphery of U_1), the packet is sent to V_D, otherwise, it sends a packet containing V_D for inquiring location to all RSU's neighbors. If the U_1's neighbor RSU (U2) knows the V_D location, it sends a acknowledge ACK to the U_1, and the U_1 forwards the data packet to U_2 so as to send it to the V_D. If the U_1 does not receive the ACK within a certain period of time T, it sends a location query message to all RSU outside the 2-hop (that is, all RSU neighbors of the RSU neighbor), and then outside the 3-hop, and so on. This operation continues until the U_1 receives an ACK related to the V_D location or has checked all RSU.

The RSU sends the packets to the vehicle, and first needs to predict the location of the vehicle. As shown in the figure below. RSU (U) predicts the location of the V when it receiving the packet P according to the location of the vehicle V, the average speed, and the direction of the last sending beacon.



Assuming that the last beacon received by the U from the V shows that the distance between U and V is d_1, the timestamp is t_1, and the vehicle V was traveling toward left at speed v_1. After the time t_c, the distance traveled by the V is $d_c=v_1(t_c-t_1)+d_s$ (the d_s is the additional distance for the secure consideration), and the distance between the U and V is d_1-d_c. If the direction of the V is reverse to the U, then the distance between the U and V is d_1+d_c. Due to the formula $t_f = \frac{d_1 \pm d_c}{r + d^*}(t_0 + \frac{t_d}{v_1}) + t_s$, where the r is the transmission range of the U, the t_0 is the average transmission time between two neighboring nodes, the t_d and d^* are the average time and average distance respectively carrying the packets by the vehicles, and the t_s is the secure time. The distance of the V moving is d_f=$v_1 t_f$ when the packet P is moving on the way. And the distance of the V from the U is d_3=d_2±d_f when the V receives the P. So the area A_e arrived by the P can be inferred based on the above. If there is no intersection in the road where the V moves, the A_e can be defined as a circle with the center which is the inferred coordinates for receiving the P by the V, and the radius is the error factor r_a of the d (it is generally set to 0.3d). Otherwise, the A_e is defined as a circle with the center which is the intersection coordinates, the radius is the r_a. The U delivers the packet to the vehicle in the A_e so as to forward it to the V.

SIMULATION EXPERIMENTS

SCF, SCB and the proposed protocol are simulated in the Qualnet environment. The Pathloss model is configured to use the Street microcell model in the experimental scenario.

Mobility and Placement configuration is as follows:

Node-position-file Opportunity.nodes

Mobility files NONE

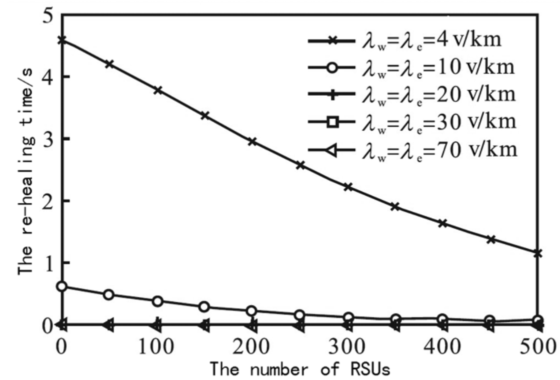
Mobility-position-granularity 1.0

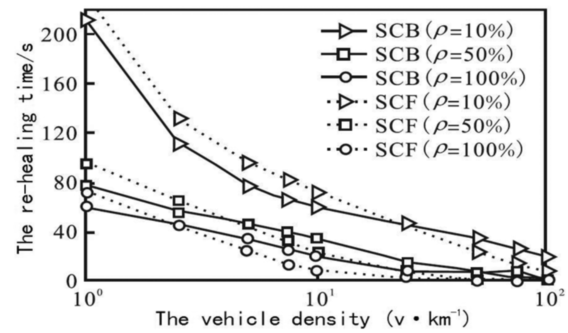
The node wireless subnet and network interface parameter format is as follows:

Subnet N8-169.0.0.0 {0 thru 40} default [N8-169.0.0.0] PHY-RX-model PHY802.11b NETWORK-PROTOCOL IP

Other parameters: the length of the road is 300km; the speed range of the vehicle is 10~40km/h; the number of nodes is 100; the interval of Hello message is 10s; MAC protocol adopts 802.11b.

In the case that all vehicles are equipped with DSRC equipments, the simulation results by using the proposed protocol in this paper for the different number of RSU and vehicle density are shown in the first figure below. In the case that the equipped rate ñ for DSRC equipments is respectively 10%, 50% and 100%, the re-healing time of SCF and SCB tested by the simulation experiments was shown in the second figure below.





It can be seen from the first figure above: the re-healing time decreases as the vehicle density λ_e and λ_w increase. When $\lambda_e = \lambda_w \geq 20v/km$, the re-healing time is less than 0.1s. The reasons are that when the number N_U of RSU is larger than 0, in most cases, the traffic secure message can be transmitted to one RSU. For N_U = 0, if the ë$_e$ and ë$_w$ are large enough, the most vehicles on the freeway can also be connected, so the re-healing time is generally short. Comparing the proposed protocol with SCF and SCB, it can be seen that the re-healing time of the proposed protocol is shortest. Taking the vehicle density ë=10 v/km as an example, the re-healing time of SCF is 4~6s, and he re-healing time of SCB is about 20s. In the case that the RSU are used, the re-healing time is less than 1s. And when the vehicle density is smaller, the advantage of the proposed protocol is even more obvious.

CONCLUSION

For the problem of network disconnection in VANET, this paper applies RSU to the broadcast protocol based on the analysis for the mechanism of carrying and forwarding. The experiments show that the deployment of RSU greatly reduces the transmission delay for VANET, and the more the moving vehicles on the road, the shorter the re-healing time. Taking into account the high density of vehicles in urban areas, it can reduce the problem of broadcast storm for VANET in downtowns by RSU. On the other hand, although the density of deployed RSU can be controlled, the high cost of RSU still causes it to be unable to be deployed widely, and the further researches are needed for the deployment scheme for RSU.

BIOGRAPHICAL NOTES

Peng Xiong is Associate Professor of network and communication in the department of network engineering, in the School of electronic information at Shanghai Dianji University. He received the B.Sc. degree and M.Sc. degree in Electrical Engineering from Nanchang University China in 1998 and 2004, respectively, and Ph.D. degree in Computer science and technology from East China Normal University China in 2009. From 2010 on, he is a faculty member in the school of electronic information, Shanghai Dianji University China. He is a member of China Computer Federation (CCF), and his research is currently focused on network secure, communication protocols, cloud computing and big data. At present, as a visiting scholar, he joined Dr. Xiaoping Liu's laboratory in Carleton University for the study of robot remote communication and control.

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