Silent Alarm: Link Lifetime Prediction for Reliable Routing in VANET

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ABSTRACT

Transmission of silent alarm messages from a target stolen vehicle node to its final destination node, such as a Police Station, is an attempt to deter problems related to vehicle theft by exploiting the VANET technology. This paper proposed a forwarding scheme for sending silent alarm messages between any two vehicle nodes in a VANET topology based on prediction of link reliability between them. Based on this single hop link prediction, the transmission of silent alarm messages through a complete route can be expected to be efficient and safe using the platform of vehicle-to-vehicle communication and vehicle-to-roadside infrastructure on a highway. Two communication scenarios are considered: when the two vehicles are moving in the same direction and when they are moving in the opposite direction to each others. The strategy for computing a reliable link is based on lifetime prediction technique. The performance of this technique for link reliability will be evaluated using MATLAB simulation.

Keyword:
silent alarm, VANET, link prediction, lifetime optimization, reliable routing.

1.0 INTRODUCTION

Vehicular Ad hoc Network (VANET) is a subclass of Mobile Ad Hoc Network (MANET) that enables communications between nearby vehicle nodes on roads. This is known as vehicle-to-vehicle (V2V) communications, which it formed the thrust and design principle of VANET. To extend the communications to reach the final destination node, which is not necessarily another vehicle, vehicle-to-roadside (V2R) communications may be required. To achieve even larger coverage area and to tackle the problem of sparse vehicles density in rural area, vehicle-to-infrastructure (V2I) communications can be used with support from telecommunications companies. In VANET, a vehicle on a road represents a network node.

Various applications can be developed to exploit the potential of VANET technology, which the development is geared toward the implementation of Intelligent Transportation System (ITS). ITS is a platform for application development to provide autonomous and seemless interactions between its transportation components. Tracking a stolen vehicle is one of such applications, by which alarm messages are transmitted automatically, intelligently, and silently from a target stolen vehicle node to its final destination node, such as a Police Station. Figure 1 shows the flow chart of the proposed Vehicle Theft Deterrence System (VTDS). VTDS provides a comprehensive recording capability to record an attempt of break-in, to track down the path taken, and to get back the stolen vehicle in a single piece. The ultimate objective of VTDS is not to allow a stolen vehicle to go away undetected, and if possible not to allow the event of vehicle theft from happening.

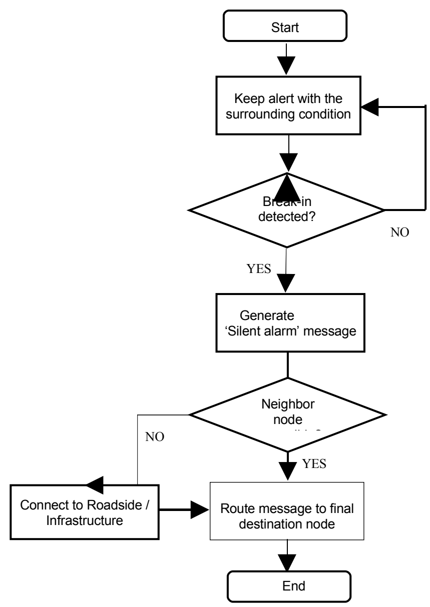

Figure 1. Vehicle Theft Deterrence System flow chart

VANET is a special case of MANET, where the vehicle nodes in the network are moving at averagely high speed as compared to relatively slower nodes movement in MANET. This makes the network topology in VANET change dynamically. This leads situation where links between any two vehicles nodes are appeared only for a short period of time. In overall, a complete route connecting a sender node at one end to a receiver node at the other end via a number of intermediate nodes is very expose to link-disconnection.

Therefore, there is a technical challenge on how a routing scheme in VANET topology can perform its function to optimum, while at the same time providing a measure of reliability. The good thing about VANET is that the vehicle nodes are moving non-randomly along definite paths on a highway, with which it can provide more predictable and deterministic traffic patterns.

Due to high speeds of the vehicle nodes, fast and reliable routing protocol is indeed required so that the transmitted silent alarm messages could be received reliably by its final destination node. This can only be achieved when there is a mechanism that optimizes the available link between any two communicating vehicle nodes so that transmission delay and packet loss could be avoided. Since the link optimization is done hop by hop, the routing function should follow the same procedure as suggested in [9]. It is therefore proposed to adopt *on-demand* approach of routing, where forwarding of the silent alarm message to the next node is done whenever a nearby passing vehicle node is detected. The same process is repeated until the final destination is reached. In this way, the silent alarm messages can be transferred from one vehicle node to another even if any of the vehicles has already moved away and out of contact, thus eliminating the problem of link-disconnection.

The objective of this paper is to develop a technique to optimize the lifetime of a link that exists between any two communicating nodes in a VANET topology subject to speed of the two vehicle nodes. However, the scope of this work is limited only to discuss on how to optimize the usage of the established link and not to discuss on how to select a link from the available links to forward the silent alarm message. For this reason, it is assumed that a link has already been established between any two nodes in the VANET topology before the link can be optimized for packet transmissions.

The rest of this paper is organized as follows. Section II discusses the related works done by others. Section III explains in detail the system model in term of route lifetime prediction for two communication scenarios. In Section IV, evaluation environment is proposed, and finally Section V concludes the research work.

2.0 Related Works

Communication between nodes in VANET should be made fast, efficient, and reliable. For this reason, the transmitted silent alarm messages should be received at destination node in the same manner. To achieve these objectives, VANET cannot tolerate with transmission delay and packet loss, which they are the parameters for reliability. Work by [3] stated that VANET network topology is dynamic and the nodes are often split up. They choose to model the VANET topology based on node clustering, from which the connection lifetime is then investigated. However the focused of investigation is on non-safety applications that do not require transmission speed.

Another work by [4] has proposed Movement Prediction-Based Routing (MOPR) concept for VANET. The routing concept is expected to improve routing process by selecting the most stable route in term of link lifetime with respect to the movement of vehicles. An algorithm is then proposed to find stable route by predicting the link lifetime. This is done by predicting future positions of vehicles that occupy each routing path based on their current positions, speed and directions. However, the stable node in their work is computed based on the assumption that the nodes are having the same directions and speeds to a destination node.

A work by [5] has improved the MOPR. This was achieved by decreasing the size of RREQ (Route Request) packet transmitted between nodes. A level of intelligence was developed into the algorithm, which allows nodes to know in advance about the positions and movement (current distance) of neighbor nodes when receiving a new RREQ packet. Although the algorithm has the ability to predict link lifetime, it does not consider the delays that may appear during the setup process.

A solution has been proposed by [6] for the problem of optimal next-hop selection in a route between two vehicle nodes on highway. The authors also try to find the optimal number of hops in one route. For their research, the optimal selection of next-hop is the maximum route lifetime based on vehicle speed and inter-node distance. An extension of the research, the authors proposed a scenario where two vehicles are moving on the highway. To get the optimal path, the author suggested finding the optimal inter-node distance first. Having this value, the expected link lifetime is then computed. However, this research has only focused for one direction only. They ignore the scenario of opposite direction of vehicle movement. However, the work still failed to get the optimal number of hops for each route.

3.0 Methodology

In this section, the focus of discussion is on the development of a scheme that describes the establishment of a reliable link between any two vehicle nodes in a VANET topology. Ultimately, reliable routing of the silent alarm messages could then be achieved via a complete route between the target stolen vehicle and the Police Station.

A. The System Model

The system model for reliable link between two nodes will be based on headway model [7]. Headway is the time interval between two vehicles passing a point as measured from front bumper of the first vehicle to front bumper of the second vehicle. The headway is equivalent to difference meter length corresponds to different speeds of the two vehicles, with the assumption that minimum car length is 4 meters. According to Roess et al. (2004), there are three parameters to consider with respect to headway model: speed (km/h), density vehicle/km/lane), and flow (vehicle/h/lane) of which their relationship can be expressed as:

$$F = S \text{ x } D \qquad (1)$$

where F is traffic flow, S is mean traffic speed, and D is traffic density. This headway model will be used as the basis for the development of mathematical models discuss next.

B. Vehicles Moving in the Same Direction

In its simplest form, lifetime of a link between two nodes moving in the same directions could provide a basis for lifetime of a complete route. Figure 2 illustrates a scenario where node i and node j are moving in the same direction on a highway.

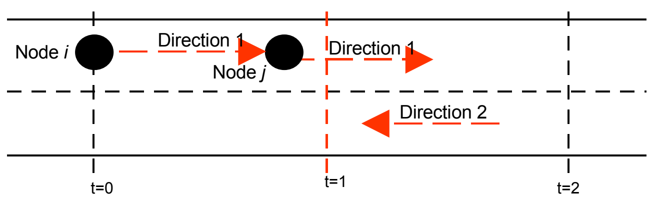

Figure 2. Two nodes moving in same direction

In VANET topology, any two nodes could establish a link when they are within a communication range R. According to [8], if the absolute distance between two nodes i and j is $|d_{ij}|$, and their corresponding speeds are v_i and v_j respectively, then the lifetime of the link between i and j can be predicted by:

$$Lifetime_{link} = \frac{R - |d_{ij}|}{|v_i - v_j|}. \qquad (2)$$

Since a route consists of one or more links, the lifetime of a complete route is the maximum of all its link's lifetimes. i.e.

$$Lifetime_{route} = \sum \max_{\forall links \in route} \{Lifetime_{link}\} \qquad (3)$$

Based on this route lifetime, silent alarm messages from a target stolen vehicle to its final destination of a Police Station could then be reliably transmitted.

C. Vehicles Moving in Opposite Directions

The link lifetime equation (3) can be altered slightly to predict link lifetime when the two vehicles are moving in opposite directions. It may be based on radio characteristics, signal strength, and direction of motion. Since the road carrying oncoming traffic can be quite far apart from the road carrying forward traffic, the equation now must take into account the separation distance, w. For simplicity, we may ignore the width of the road.

When two vehicles are moving in opposite direction, there are two sub-models exist: vehicles are moving towards each other and vehicles moving away from each other. In this case, headway model as described in Section A will be used. Hence, the mathematical model suitable to compute the link lifetime is expressed as [8]:

$$Lifetime_{link} = \frac{R + s.d_{ij}}{v_i + v_j} \qquad (4)$$

In equation (4), $s = 1$ when the two vehicles are moving towards each other, and $s = -1$ when they are moving away from each other. This lifetime gives the expected time to live (TTL) of the link based on current speeds of the two vehicles at a distance $|d_{ij}|$ from each other before they move apart by more than the communication range R.

Figure 3 illustrates the scenario of vehicles moving toward each other, while in Figure 4 vehicles are moving from each other.

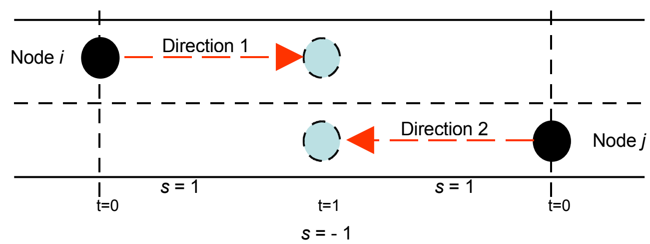

Figure 3. Two nodes moving toward each other

When $t = 0$: Node i and node j moving towards each other in opposite different directions. At this point of time, $s = 1$. When $t = 1$: Node i and node j will change the movement where they start to move away from each other. At this time, $s = -1$.

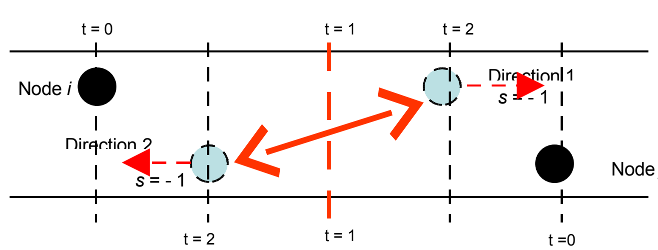

Figure 4. Two nodes moving away from each other

Following this, the distance between the two vehicle nodes will be increasing, and as a result the link lifetime will be decreasing, and at further distances the link is weakening. Subsequently, when the two nodes move apart by a distance greater than *R*, the link is disconnected. Graphically, it can be represented as Figure 5. Additionally, as distance going larger, the reception probability will be lower. Therefore, the link lifetime is also dependent on reception probability R_p of the transmitted messages. This could be expressed as:

$$Lifetime_{link} = R_p \tag{5}$$

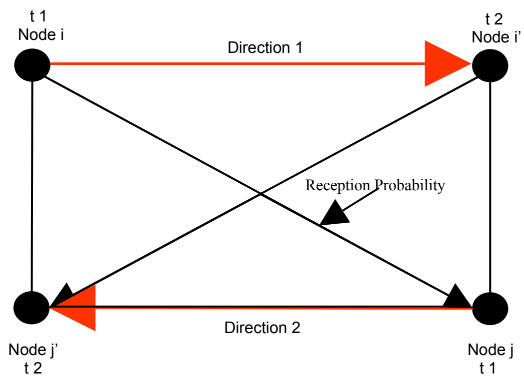

Figure 5. Reception probability when two nodes are moving in opposite directions

Therefore, to predict the lifetime of the link, distance between the two nodes is used as the primary indicator of whether or not the two nodes are able to communicate with each other.

D. Link Lifetime Optimization

Based on the two vehicle movement scenarios discussed above, we develop a technique to optimize the link lifetime between any two vehicle nodes. However, the link lifetime is not only dependent on the distance between the two vehicle nodes, but also dependent on the reception probability at the receiver end of the link for the transmitted silent alarm message. It can be stated as:

Maximize *Lifetime $_{link}$*
Subject to *Distance*
Reception probability (6)

The algorithm for the optimization is as follow:

1. two nodes are in communication and moving in opposite directions
2. if t ≠ 1, then *s* = 1
3. optimize *lifetime $_{link}$*
4. if t = 1, then s = -1
5. optimize *lifetime $_{link}$*

Based on Equations (4) and (5), and the optimization objective (6), the following graphs of Figure 6 could be produced, which is useful in determining the optimized area.

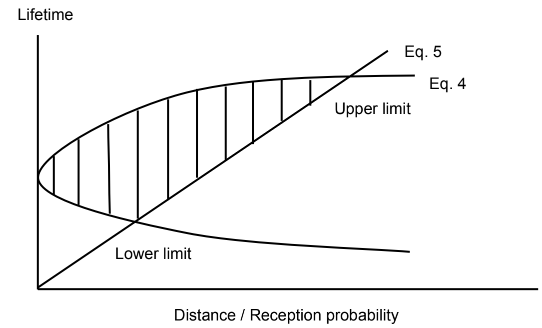

Figure 6. Optimized link lifetime

From the graph, the optimized link lifetime could be obtained from the shaded area. Additionally, the intersection points between these two graphs may provide upper and lower limit values for the link lifetime.

4.0 Evaluation Environment

Simulation approach will be used to evaluate the proposed technique. The followings are the possible parameters to consider for finding the optimal link lifetime.

Table 1: *Simulation Parameters*

Parameters	Values
Transmission range (*R*)	200 m
Distance (*d*)	> 4 m
Number of lanes (*L*)	4 (2 directions)
Speed (*v*)	Max = 70 mph (31.3 m/s) Min = 40 mph (17.8 m/s)
Data rate	1 packet per second
Transmission Rate	1 Mbps

Matlab simulation can now be developed to simulate the proposed link lifetime optimization technique. The results of the simulation will be presented in the next paper presentation.

5.0 Conclusion

A VANET system not only requires fast but also reliable information transfer between the pair of nodes, while it is actually being constrained by multiple limiting factors. Specifically, the link lifetime between two communicating vehicle nodes are too short for best performance due to their high speed movements on roads. In this work, a system model with its mathematical components has been presented, and its supporting optimization technique has been developed to achieve improved link lifetime. With better link lifetime, silent alarm messages can now be forwarded to its final destination node, such as the Police Station, successfully at fast rate through a complete route that has optimal lifetime.

Therefore, the major contribution from this research work is in proposing a model for route lifetime prediction for two vehicle nodes moving in opposite directions on a straight highway. Apart from distance between two vehicle nodes, reception probability at the end of a link is another factor that determined the maximum lifetime of that link. When the individual link is combined together, a complete route optimization is then obtained.

Our future work is to develop a method to anticipate the disconnection moment so that perfect timing can be computed, thus better link lifetime can be obtained. Probably by modifying slightly on the proposed algorithm for link lifetime prediction between two nodes, we can anticipate the duration of a network connection.

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