Road Side Unit Assisted
Stochastic Multi-hop Broadcast Scheme
for Instant Emergency Message Propagation

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Abstract— VANET (Vehicular ad hoc Network) is a special kind of ad hoc wireless network where every single node is a vehicle moving in a relatively high velocity, which leads to exclusive challenges like rapid changing topologies, safety and privacy concerns. In this specific network, broadcasts tend to be carrying important messages such as car accident notification, disaster alert or extreme traffic condition. Thus the propagation of broadcasted emergency messages could be critical to save human lives and property. Many researchers have proposed routing or broadcast protocols to solve this problem in VANET. With consideration of the other common issues. The objective of this paper is to propose a broadcast scheme in VANET that is not likely to cause broadcast storm problem with a reasonable delay and high delivery rate. Since VANET is an attack-prone network and any kind of malicious behavior in VANET might cause serious loss or even death in reality, we should also refrain from using beacons to exchange privacy-sensitive information in V2V (Vehicle to Vehicle). In this paper, a multi-hop broadcast scheme that makes use of RSU and V2I (Vehicle to Infrastructure) communication is proposed. The simulation result shows that the proposed scheme outperforms static stochastic broadcast scheme in terms of delivery rate. Comparing to flooding, we offer a better delay and less network usage.

Keyword— VANET, Broadcast, Percolation, Stochastic, Wireless

I. INTRODUCTION

WIRELESS ad hoc network is a network that does not rely on existing infrastructure to relay packets and uses all nodes both as clients and as routers. In this way, it does not require any type of access points or routers to be pre-installed in the network. It's decentralized, dynamic and easy-to-deploy characteristics make this kind of network a very active and challenging research area.

One of the most promising and practical topics is vehicular ad hoc network (VANET) [1]. Research in this area is significant because the increasing car accident and safety related problems [2] are threatening human lives and property, and intelligent transportation system (ITS) is designed to help solving these problems. In developing countries, motorization is happening in urban area with high population and cars are moving at high rather speed in these regions, which is considerably dangerous. Vehicle manufactures are developing various ITS systems to assist and protect driver's life and their property. VANET is one of the most basic systems to be implemented. Due to its wireless ad hoc nature, it could sustain extremely low connectivity and being established quickly, easily even in extreme condition.

VANET is simply wireless ad hoc network formed by vehicles, which allows nodes to perform vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication to obtain traffic condition, alert messages and benefit from navigation system. Despite of the simple concept of VANET, it introduces a lot of exclusive problems, mainly because cars are nothing like mobile devices in MANET (Mobile ad hoc network) or stationary monitors in WSN (Wireless sensor network). Its specialty also gives the following unique characteristic to VANET:

- Nodes move at rather high velocity
- Nodes move in an organized, predictable way
- Power consumption is usually negligible for vehicles

- Nodes are assumed to have modern on-board-unit (OBU) installed, including GPS, WIFI connectivity, etc.
- A special kind of stationary nodes could exist, which is called road-side-unit (RSU), as is shown in Figure 1
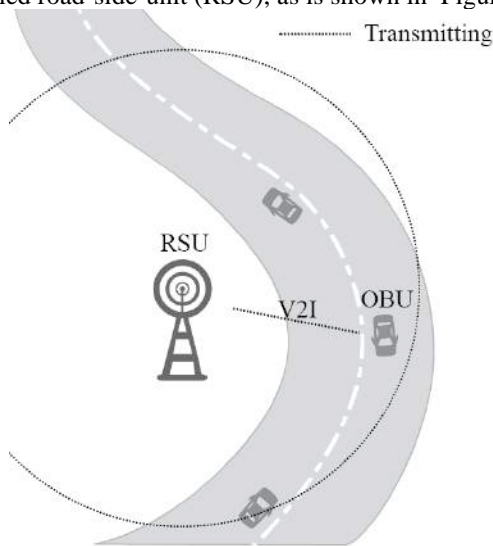

Fig. 1. RSU and V2I in VANET

The previous listed characteristics makes every applicable protocol and scheme for VANET requires much more detailed design rather than directly import from currently existing ad hoc network technique such as mobile ad hoc network(MANET) [3]. In addition to other ad hoc network, researchers need to take the following risks into consideration in VANET:

- The usage of privacy-sensitive information
- Easily fragmented network topology
- Security
- Scalability

Also, the usage of beacons and geography information services should be limited. Beacons should not carry privacy sensitive information such as geo-location, vehicle's direction or speed, because beacons are prone to interception. We also shouldn't make assumption of location services because emergency broadcast should be working independently from any infrastructure-dependently network, to make sure its availability even in extreme condition.

Scalability is another major concern due to the unpredictable size of ad hoc network. In modern VANET, the size of the network could expand across cities, or even counties connected by highways or railways. Among the connections, the network condition is also not unified. For example cars might be using different OBUs and the distribution or even existence of RSUs might vary according to culture and corresponding policies. If a scheme can only work with strict dependencies it is said not scalable.

Since most of concerns in VANET are safety of the vehicles and their drivers, it is not difficult to infer that emergency broadcast is one of the most critical areas in VANET communication. Every car accident, natural disaster and other alerts need to be propagated in the network very fast with reliability. Optimization of emergency message propagating includes many areas such as reliability research, broadcast schemes in VANET and privacy protection. In these areas, broadcast schemes are the most direct contributors. For this

reason, this paper mainly focused on emergency broadcast schemes in VANET. As a common methodology in propagating emergency messages, broadcast is widely used in many areas. Pure flooding is one of the most simple and effective methods, namely every node must retransmit the packet when it receives the one. Although this scheme is good enough for simple situation, it is not robust to be applied for practical usage. This is because flooding packets without constraints could potentially cost too many resources in the high density area and increase the duplicate messages while risking congest the network, which could finally lead to collisions or even unresponsiveness (broadcast storm problem). As we stated actual VANET can have a quite large scale, it might span across cities or even countries, in this case emergency messages are no longer interested by distant audience but the cost of propagating those messages can grow exponentially. Thus, further design and constraints must apply.

In order to solve this problem, many approaches were proposed [4]. In counter-based approaches, number of rebroadcasting is limited and nodes would not retransmit a packet after the packet reaches a certain counter. In location-based approaches, only nodes in a specified location retransmit a packet. In distance-based approaches, only nodes with furthest distance to a source node can retransmit a packet. In cluster-based approaches, packet retransmitting relies on certain nodes within a specified structure. In probability-based approaches, every node has a possibility to retransmit packet when they receive one.

Each solution proposed above has its pros and cons. Counter-based approaches can somehow control the transmission range in terms of hop count but are prone to malicious modification since the counters are usually stored in the message. Also the hop count and actual distance are not directly associated, it needs to refer the node density and sometimes network topology. Location-based approaches specified location area in packets so that it could limit the transmission area. Thus, it is also prone to attacks since attackers can easily obtain information of broadcasting area. And a stable access to location service is required for each node, which is rather hard to guarantee in VANET and might have negative impact on performance. Distance-based approaches are the state of the art broadcast scheme because it tends to select the furthest nodes as relays. Thus, it maximizes the dissemination ranges. On the other hand, it does not have any control scheme once a packet is broadcasted to networks. Thus, priority or counter based mechanism must be applied to limit the transmission. Probability-based approaches are flexible schemes since all their behaviours rely on how to decide the probability, depending on different scenarios researchers use different approaches to adjust the rebroadcast probability accordingly. Most of the pragmatic schemes are hybrids of the four basic schemes or with modifications.

The effectiveness of broadcast also heavily depends on a technique of packet transmission. Dedicated short-range communication (DSRC) [5] allows high-speed connection in both V2V and V2I. It uses 5.9 GHz band and transmission range could reach 1 km. This allows us to transmit packet over 3 times further than conventional IEEE 802.11 [6] and also mitigates a fragmentation of network in low node density

area. The power consumption of this module is also negligible since cars are generating power on the run.

As is mentioned previously, there are special class of nodes called RSU (road side unit) exist exclusively in VANET. These nodes are usually installed in an intersect area on a highway, gas station and the other area according to the node density. Usually to form an infrastructure network or directly connected to one. They can also boost the connectivity in their own area. However, these RSUs rarely contribute to conventional VANET broadcast. One of the potential optimization for broadcast scheme is to use RSUs as a resources.

This paper is organized as follows: introduction of some existing broadcast schemes are in Section II, the proposed network architecture and usage of RSU are explained in Section III, detailed design of broadcast scheme is written in Section IV, simulation and result are recorded in Section V, Section VI conclude this paper.

II. RELATED WORKS

Most of the practical broadcast schemes are either variation or hybrid of the 4 basic broadcasts: Counter, Location, Distance and Probability [4].

Smart broadcast [7] is a variation of distance-based broadcast, the area around a source node is divided into different sections as shown in Figure 2, which allows every node to have their own contention window. In this way, the outer most nodes in S2 have the highest priority to access the channel. When broadcast starts, other nodes around the source node will start trying to gain the access to the broadcast channel but only the node with

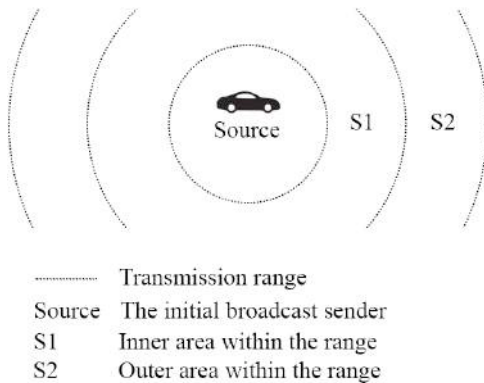|	
··········	Transmission range
Source	The initial broadcast sender
S1	Inner area within the range
S2	Outer area within the range

Fig. 2. Sections in smart broadcast

higher priority (further distance to the source node) will have it. This scheme provides a way to select relay for rebroadcasting using distance-based broadcasting scheme and it is practical and it guarantees maximum dissemination range.

Another interesting broadcasting is called stochastic broadcast for VANET [8], which is a combination of distance-based broadcast and stochastic broadcast. In the paper, every node must decide their own rebroadcast probability (the probability of being a relay). The paper proposed two ways to determine a retransmit probability: one is fixed; another dynamically determined according to a one-hop distance. That research has following 2 advantages.

First, every node determines a probability by itself, which means transmission is not used except broadcasting and the relay selection process is considerably safer without bringing in impact to the performance. This eliminates privacy issues and provides scalability. Second, it uses a percolation study to estimate a theoretically maximum connectivity and calculate the optimal node density to form a connected graph. However, this paper does not mention about dynamical adjustment of the probability according to a network condition changes. In this paper, the proposed scheme utilizes RSUs to deal with the rapid fragmented network.

The objective of this paper is to propose a broadcast that could propagate emergency messages with high deliver rate, reasonable delay and does not overwhelm a network with broadcast storm. Privacy is also taken into consideration by limit a usage of beacons.

III. NETWORK ARCHITECTURE

VANET could be simplified into two scenarios: city with high node density, highway with sparse density and easily fragmented. Oversimplify the VANET could lead to assume the network is connected, which ignores the fact that VANET is easily fragmented due to its nature [9]. In this paper, instead of making such assumptions, we use RSUs to mitigate network fragmentation and use percolation to help us study fragmentation.

Network fragmentation is a common problem when network connection between several intermediate nodes are lost, these nodes often hold connection to a cluster, and as a result, the connection to another whole cluster of nodes are lost. In wireless network, fragmentation could appear when node density is extremely low or a sparse distribution. The consequences are equally severe: it causes delivery rate to drop significantly.

To deal with fragmentation problems in VANET, this paper proposes a usage of RSUs to assist a broadcast. This paper assumes that every node equips an OBU with DSRC and GPS enabled. Moreover, limited number of RSUs was installed along the road. Although how and where to install RSUs is out the scope this paper, we assume a generic situation. That is, RSUs are deployed in a scattered manner that cannot form a connected network and every RSU works independently.

In a multi-hop broadcast, when a source node initializes a broadcast, it simply broadcasts a message and utilizes some mechanism to let other nodes relay it. In conventional broadcast schemes, there are no roles for RSUs to participate in this process. Theoretically, putting RSUs into broadcast process by letting them rebroadcast with magnified signal and further transmitting range is beneficial. Here, we proposed a mechanism to be installed on RSUs that could still work independently to participate and contribute to the broadcast process even if they are not connected.

The proposed scheme for RSU in VANET broadcast could be divided into following two parts. For the first part, RSU should use a maximum transmission range to rebroadcast a message when it receives the one. For the second part, to mitigate the broadcast storm, it should suppress a further rebroadcast in the inner region of its broadcast range by using

certain approach as shown in Figure 3. The detailed broadcast scheme for RSU side is described as follows:

(1) When RSU receives a broadcast message, check if it is duplicate message.

(2) If it is not duplicated, RSU immediately preform a rebroadcast burst with a message that contains the original message and also two addition scalar values: broadcast suppression range R_s and minimum broadcast suppression P_m.

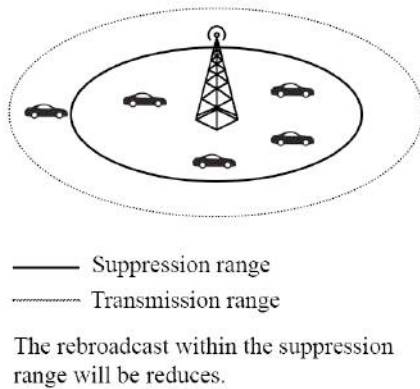Note that R_s and P_m are used to suppress the rebroadcast of nodes in the transmitting range of RSU.

——— Suppression range
·············· Transmission range

The rebroadcast within the suppression range will be reduces.

Fig. 3. RSU broadcast suppression

IV. PROPOSED BROADCAST SCHEME

The proposed broadcast scheme was developed on top of the basic probability-based broadcast, which is explained as follows:

(1) Every node maintains a value P_c, which indicates the current rebroadcast probability.

(2) While receiving a non-duplicate broadcast message, a node enters a probability check process that would cause the node has the probability P_c to rebroadcast the message after a default contention window.

(3) After a probability check, no matter the node retransmits the message or not, P_c is reset to a default value P_d.

Note that P_c was provided depending on different broadcast schemes, which will be discarded every probability check. P_d is the default broadcast probability, which enables every node to have P_d even if P_c was not set.

To align the behaviour of OBUs to the proposed scheme, this paper proposes the following scheme for OBU to deal with broadcasts from RSU:

(1) When an OBU receives a broadcast message from RSU, it checks the message whether it is a duplicate message or not.

(2) If it is not duplicated, OBU uses either signal strength or location services to get its distance to the corresponding RSU, which is denoted as R_{ro}.

(3) If $R_{ro} <$ broadcast suppression range R_s, set the current rebroadcast probability to suppression minimum P_m.

(4) Proceed to probability check.

Considering the broadcast burst from RSU is likely to cover more area with stronger signal strength, the proposed scheme utilizes the scheme mentioned above to ensure that broadcasts from RSU suppress other broadcast within the radius of R_s to suppression minimum value P_m.

Although this paper focused on using V2I to maximum the effectiveness of the broadcast, it is imperative to keep in mind that V2V is still doing a heavy lifting in the broadcast propagating process. Therefore, this paper proposes a dynamic scheme for V2V communication, which is backed by percolation study.

The scheme we proposed for V2V communication could work independently, even without the support of RSUs, this is because in large scale network it is not appropriate to assume there is a reasonable amount of RSUs installed in each area, thus we developed this self-organized scheme for V2V for better scalability.

Wireless ad hoc network could be simplified into a model that consists of infinite nodes generated by a Poisson process using certain density. For example, in flooding every node is connected to the other node only if it's within the transmission range, this is because in broadcasting the only connection is to transmit the broadcast message, if the receivers successfully received a message and rebroadcast is then it's called a connection. So for a constant transmission range and constant area, only node density could affect the chance of forming a connected graph. With the density increased, the chance of all the nodes forming a connected graph is also increased. Continuum percolation is a study that dedicates to analyse this model [10].

On the other hand, if a node does not send any message during a broadcast (does not connect to any other node), it can be treated as if it was not there. In Figure 4 we demonstrate two scenarios when node S broadcast the message to node D through relay node I, the scenario 1) is equivalent to scenario 2) because nodes that did not rebroadcast the message will not add new connection. In percolation study we only consider nodes with connections so those nodes are negligible. Thus setting a rebroadcast probability to all nodes basically reduce the active node density, which makes the network an analogue of continuum percolation.
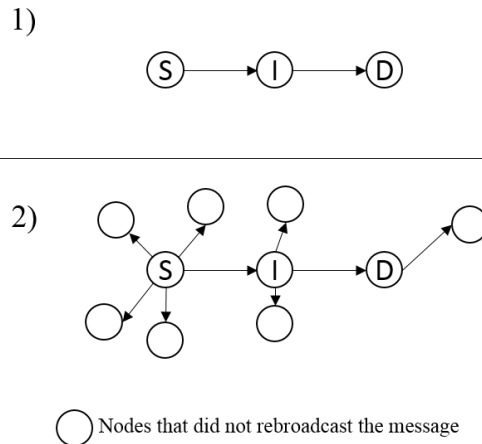

⊙ Nodes that did not rebroadcast the message

Fig. 4. Nodes did not rebroadcast messages is negligible in wireless broadcast

If nodes are distributed in a space by density ρ, we could denote an expected neighbourhood of a certain node as λ is calculated using following Eq.(1) [11]:

$$\lambda = \rho \pi r^2 \tag{1}$$

where r denotes a node transmission range. With higher λ, it is more likely that infinite nodes are in one connected cluster as is shown in Figure 5. The author of [8] used λ_c=4.508 to 4.515 and verified this value to have 99.99% probability to form one connected cluster, which means no minors such as shown in Figure 5. In this paper, we try to align the proposed scheme to match this value in order to maximize the broadcast effectiveness.
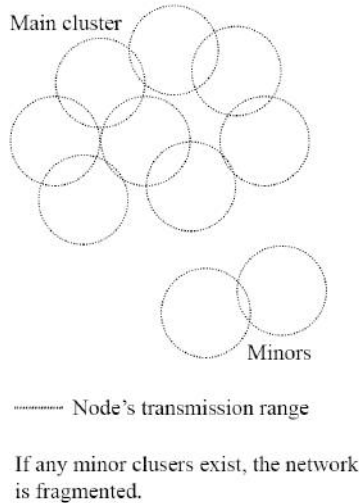

Fig. 5. Percolation

As is explained previously, if a node does not participate rebroadcasting in the broadcast process, the node is considered to be not in this network [8]. In stochastic broadcast, we have Eq.(2):

$$\lambda_s = P \rho \pi r^2 \tag{2}$$

where P denotes the rebroadcast probability. For example, if λ=10 and the rebroadcast probability for every node is 50%, λ_s=5 is good enough to ensure the network to be connected, that is, the broadcast can be propagated. As explain in continuum percolation, please note that the ideal situation is λ_s=4.5, which means rebroadcast probability should be roughly 45%.

In order to maintain λ_s, it is necessary to adjust P dynamically while the network topology changes. Thus, every node needs to maintain a neighbour node list using either beacons or location services. In this paper, we assume every node maintains a neighbour list using a simple one-hop beacon and total neighbourhood count to be N.

The V2V communication scheme is explained as follows:
- Once the node receives a non-duplicate broadcast message from another vehicle, set P_c using the following Eq.(3):

$$P_c = \begin{cases} 0 & (N = 0) \\ 1 & (0 < N < 5) \\ \dfrac{4.5}{N} & (N \geq 5) \end{cases} \tag{3}$$

(1) Reset the neighbour list.
(2) Proceed to probability check.
(3) Reset P_c to P_d

In this way, P_c could be aligned to a reasonable value using N. Since N is a dynamic value and constantly changing, P_c is theoretically always an optimal value.

V. PERFORMANCE EVALUATION

To evaluate the performance of the proposed scheme, a simulation was conducted in two different scenarios using different sets of parameters. In this simulation, static stochastic broadcast scheme, pure flooding scheme and the proposed is evaluated in both city and highway environment. General parameter used in this simulation is listed in Table I.

Please note that is this simulation we intended to the followings:
- Suppress the further broadcast near the RSUs within 80% of its transmission range.
- Suppressed rebroadcast probability is not set to 0 because if the node density is high, there might still be rebroadcast to cover the delivery failure caused by collisions.
- We set the RSUs with stronger presence by extending the communication range to simulate further transmission range.
- Replace actual nodes as RSUs for propose scheme. This is to avoid the performance boost brought by addition nodes (RSUs).

In the simulation, the performance of a broadcast scheme was evaluated using three metrics: message delivery rate, network delay and number of broadcasted packets.

Message delivery rate is the basic performance evaluation, which indicates if the message was successfully delivered to all nodes. Network delay basically shows how long it takes for the message to propagate to all possible nodes and it evaluates the effectiveness of each rebroadcast. As message travels along many hops, the delay increases. Number of broadcasted packets indicates how many broadcast packets are used in the broadcast process, it evaluates the network usage and potential broadcast storm problems.

Since pure flooding rebroadcast every message it receives, it can achieve the theoretically highest deliver rate and generate the most packets and create the infamous broadcast storm problem, we only simulation this scheme to compare it with the other broadcast schemes so please note that it is not for practical usage.

As shown in Table II, the parameters used in the first simulation aim to recreate a broadcast on highway scenario with the aid of RSUs installed along the road. The result was shown in Figures 5-7.

TABLE I
GENERAL STOCHASTIC BROADCAST SIMULATION PARAMETERS

Parameter	Value
R_s	0.8×RSU transmission range
P_m	0.05
P_d	0.2
Communication range V2V	1 km
RSU burst	3 times without contention window
RSU burst range	1.5 km
Beacon contention	≤1ms
Rebroadcast contention	≤2ms

TABLE II
SIMULATION 1 PARAMETERS

Parameter	Value
Area	20km × 0.1km
Number of RSU	5
RSU distribution	Uniform, installed along the road
Mobility	Random waypoint
Speed	50km/h to 80 km/h
Number of nodes	15 to 45 (10 to 40 for RSU-Assisted broadcast)

From Figures 6 and 7, the proposed broadcast scheme achieved better deliver rate and lower delay at the same time in high node density due to higher RSU's coverage. Since deliver rate has been increased, number of broadcasted packets will increase accordingly in order to cover more nodes. In Figure 8, we can see that number of broadcasted packets is increasing but please note there is an overhead cause by proposed method.

As shown in Table III, the parameters we used in the next simulation are about recreating a broadcast in city scenario where RSUs are randomly installed in the city and cars moving to random way point.

In city scenario the proposed broadcast scheme got a performance boost in the sense of delay and packet usage due to the sparse distributed RSUs comparing to highway scenario. From Figures 9 and 10 the proposed broadcast scheme achieved higher deliver rate with almost the same delay comparing with static stochastic broadcast. If comparing Figure 11 with Figure 8, it is obvious that in city scenario packet usage also decreased. Achieving high deliver rate with lower delay and lower packet usage means every broadcast covers more nodes, which is our intention to mitigate broadcast storm problem and boost the effectiveness of the broadcast scheme.

TABLE III

SIMULATION 2 PARAMETERS

Parameter	Value
Area	9km × 9km
Number of RSU	5
RSU distribution	Random
Mobility	Random waypoint
Speed	10km/h to 30 km/h
Node count	15 to 45 (10 to 40 for RSU-Assisted broadcast)

Since RSUs are distributed randomly in city scenario, message deliver rate dropped a little comparing to the highway scenario from Figure 9 and Figure 6. In general, the proposed broadcast scheme outperforms the static stochastic broadcast and went toward the upper bound, without bring heavy traffic to the network and cause broadcast storm problem (comparing to flooding). Also, there's no need to acquire the network condition in order to calculate the broadcast probability before the broadcast (comparing to static stochastic broadcast).
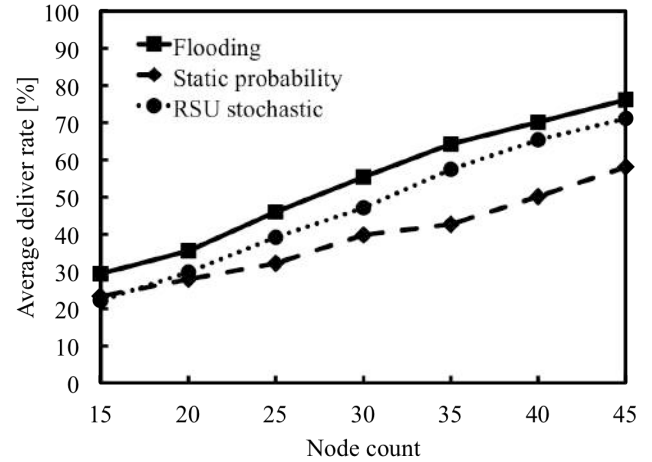

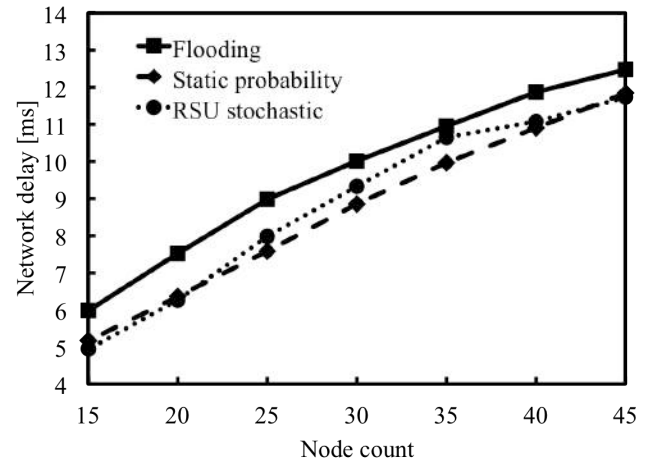Fig. 6. Message deliver rate in highway simulation scenario

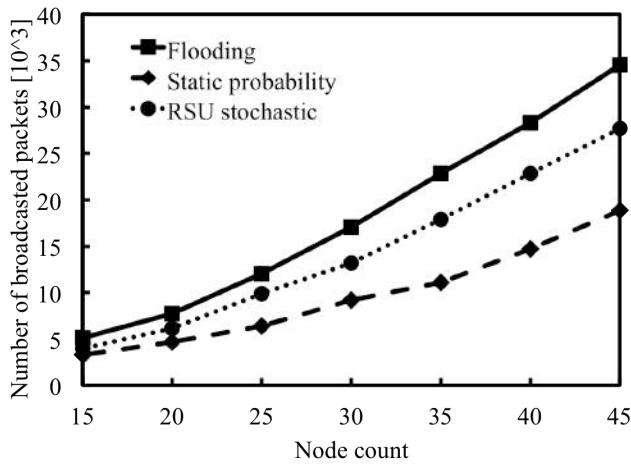Fig. 7. Delay in highway simulation scenario
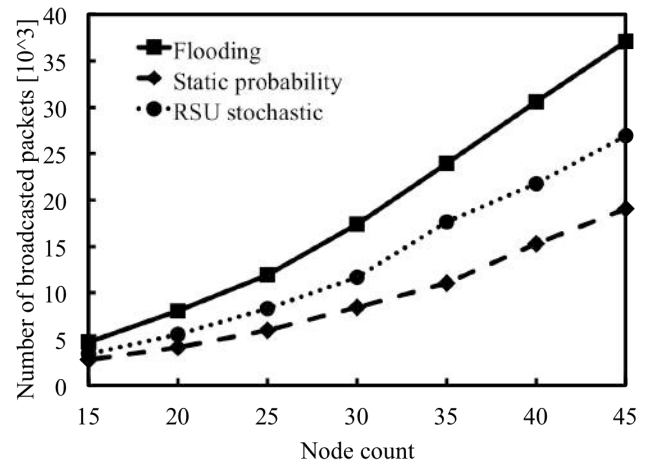
Fig. 8. Packet usage in highway simulation scenario

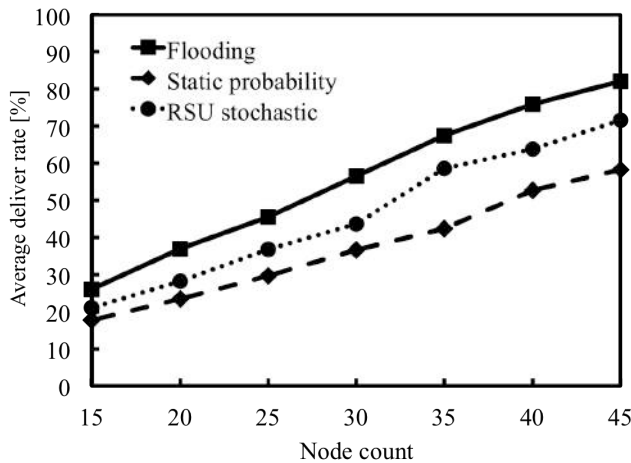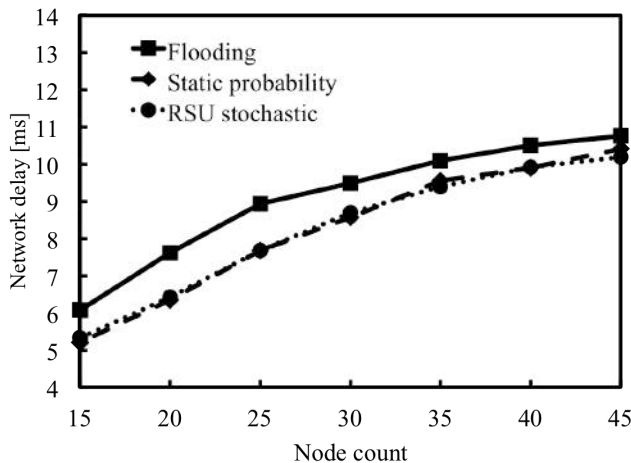Fig. 11. Packet usage comparison in city simulation scenario

VI. CONCLUSION

This paper introduced the challenges in VANET emergency message broadcast and its contribution of protecting human lives and properties. It also summarized our objectives to contribute to emergency message broadcast in VANET research. This paper also categorized different broadcast schemes, analysed their strength and weakness. On top of that, this paper introduced two broadcast schemes that related to the study.

In the discussion of exclusive characteristics of VANET, this paper analysed some major concerns in VANET such as privacy, safety and scalability. In order to boost performance and mitigate network fragmentation, we proposed the usage of RSUs to assist to broadcasting process, explained the scheme for RSUs to work actively and individually in the broadcast.

By simplify VANET model using percolation theory, this paper developed another scheme to be used in V2V broadcasting. In this discussion, this paper explained percolation study and how to apply it to stochastic broadcast instead of flooding broadcast along with how to achieve the theoretically highest performance using stochastic model and apply the result in the proposed schemes.

In order to study the performance of the proposed scheme, this paper conducted two simulations. From the result, the proposed scheme achieves our goals by increasing deliver rate and does not bring huge impact on delay and network usage, especially in city scenario.

The proposed scheme take privacy and scalability into consideration by not using beacons to send personal data, not using location services and every part of the scheme works independently (V2V scheme will work without RSUs, RSUs do not form a connected graph and they are not connected to an infrastructure-depended network), which guarantees scalability even being deployed in large scale network.

The amount and position of installed RSUs may have impact on the performance. In the simulation we replace the nodes with RSUs when RSUs are needed, so that they will not benefit from higher actual node density. Moreover, we avoid assuming connections to location services but we are still using beacons, this is not absolutely the ideal solution. We still have some future works such as evaluating the

Fig. 9. Message deliver rate comparison in city simulation scenario

Fig. 10. Delay comparison in city simulation scenario

performance impact of RSUs and finding alternative, safer way to calculation node density without using beacons.

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