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VANET과 IP 게이트웨이에 기반한 긴급메시지의 효율적 방송 방법

Efficient Broadcasting Scheme of Emergency Message based on VANET and IP Gateway

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요 약 VANET에서 차량은 사고나 예기치 못한 긴급 상황에 관한 정보를 감지하고 이 정보를 뒤따르는 차량들에게 전파함과 동시에 서버에 전달한다. 하지만 긴급메시지의 전파는 방송 전송 방식을 취하게 되고 방송메시지의 다량 발생 즉, 폭풍 현상을 유발하게 된다. 본 논문에서는 이러한 문제점을 해결코자 전파전달범위내에서 가장 먼 곳에 위한 차량을 선출하는 방법을 사용하고 특히, 수신 패킷의 SNR에 따른 송신자와의 상대적 위치를 이용한 SNR 기반 백오프 방법을 검토한다. 상대적 위치를 통해 송신자에서 가장 멀리 떨어진 노드가 상재적으로 짧은 백오프 시간을 갖고 전달 과정에 참여케 됨으로써 다른 노드들은 이를 엿듣게 되어 전달자 임무를 포기하게 된다. NS-3 VANET 시뮬레이션 환경을 구축하여 WiFi-IP 게이트웨이 기반 서비스 네트워크에 대해서 SNR 기반 백오프 방식을 포함한 긴급 메시지 전송방식들을 시뮬레이션을 수행하였다. 다른 일반 방송 방식에 비해 SNR 기반 백오프 방식이 1/20 정도 전송횟수의 감소를 보이면서도 최적의 전파지연시간과 홉 수를 통해 긴급메시지 전파능력을 보여준다.

Abstract In vehicular ad-hoc networks (VANETs), vehicles sense information on emergency incidents (e.g., accidents, unexpected road conditions, etc.) and propagate this information to following vehicles and a server to share the information. However, this process of emergency message propagation is based on multiple broadcast messages and can lead to broadcast storms.
To address this issue, in this work, we use a novel approach to detect the vehicles that are farthest away but within communication range of the transmitting vehicle. Specifically, we discuss a signal-to-noise ratio (SNR)-based linear back-off (SLB) scheme where vehicles implicitly detect their relative locations to the transmitter with respect to the SNR of the received packets. Once the relative locations are detected, nodes that are farther away will set a relatively shorter back-off to prioritize its forwarding process so that other vehicles can suppress their transmissions based on packet overhearing. We evaluate SLB using a realistic simulation environment which consists of a NS-3 VANET simulation environment, a software-based WiFi-IP gateway, and an ITS server operating on a separate machine. Comparisons with other broadcasting-based schemes indicate that SLB successfully propagates emergency messages with latencies and hop counts that is close to the experimental optimal while reducing the number of transmissions by as much as 1/20

Key Words : VANET, Broadcasting algorithm, Friis Equation, ns-3, Network simulator

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Ⅰ. Introduction

With the increasing vehicles over the years, the number of car accidents is also increasing at a high rate. In lower visibility conditions such as foggy, rainy, snowy, and sandy weather, the probability of accidents increases even further. In February 2015, for example, a major accident occurred on the Youngjong Big Bridge of the Incheon Airport Highway in Korea, causing 2 deaths in a tragic accident of more than 100 vehicles under foggy weather conditions. The major reason for such accidents is due to the fact that the driver′s sight can be limited to only a few meters under some harsh weather conditions; thus, delaying the driver's recognition and response time. In addition, with rain or snow, a vehicle′s braking distance can be affected to escalate the chances of multi-vehicle crash.

To avoid such traffic incidents, "cooperative driving", a conceptual technology of vehicular networking, possess promises for safe and efficient driving conditions. Specifically, by forming a wireless network of vehicles and sensors, cooperative driving technologies can offer road condition data, acceleration and braking data, vehicle location information, sensor's detected obstacle, and even provide entertainment services for passengers in the vehicles [1]. Technically, these vehicular ad-hoc networks (VANETs) introduce a new set of requirements that brings interest to wireless research community. First of all, the most prominent characteristic of a VANET that sets it apart from any other wireless network is the dynamics in the channel and link environment caused from high-speed mobility and relatively quick changes in the surrounding environment. As a result, the topology in a VANET becomes very dynamic and frequent network fragmentation occurs; thus, requiring an ad-hoc configurable multi-hop network topology, or even a routing topology-free data transfer method.

Nevertheless, the action of performing message broadcasting at each node for message propagation causes a noticeable amount of packet overhead and can essentially cause the network to break down due to "broadcast storms". To address this problem, in this work, we introduce a signal-to-noise ratio (SNR)-based linear back-off (SLB) scheme where vehicles implicitly detect their relative locations to the transmitter with respect to the SNR of the received packets. The proposed protocol, SLB, exploits the signal to noise ratio (SNR) to determine the back-off transmission time so that nodes can infer the farthest node possible for forwarding data packets. With the proposed SLB scheme, we evaluate the performance of a whole system using the VANET implementations in the NS-3 simulator and design the WiFi-IP gateway that connects an intelligent transportation service (ITS) server.

The rest of this paper is organized as follows. In section 2, we describe the position of our work within the existing literatures related to VANET. Section 3 presents the proposed and implemented prototypes of Wi-Fi SLB and WiFi-IP gateway. Section 4 reports the simulation results for three Wi-Fi broadcasting schemes with general broadcast, suppression-broadcast, and SLB broadcast. Finally, the conclusions and future directions are discussed in Section 5.

Ⅱ. RELATED WORK

In the existing literature, many VANET related standards [1-3] and VANET Routing and Forwarding (VRF) protocols have been proposed. These existing emergency message forwarding protocols have similarities with our work in the fact that they target to identify the point of farthest possible transmission and minimize the elect of broadcast storms. In this section we list out a few of these protocols and position our work among the literature [4-20]. C. Ho, et al. and L. Bresemeister et al. propose a multicast-based forwarding algorithm by selecting a receiver that is farthest away from the transmitter [4, 6].

These schemes perform in a multicast way with information based on a separate routing layer while compared to them, our proposed method focuses on MAC-layer broadcasting which is light-weight and known to be a more efficient method. On the MAC-layer broadcasting domain, Qing Xu et al. designed a MAC layer re-broadcasting scheme to increase the propagation reliability of a receiver node with a QoS model using the IEEE 802.11 Distributed Coordination Function (DCF) [9, 10]. Peng and Cheng [19] also introduce a scheme that performs strict scheduling for achieving distributed QoS. Barradi et al. [21] proposed an effective scheme to establish strict priorities among four access categories of the control channel in the current IEEE 802.11p using distinct ranges of back-off window sizes and arbitration inter-frame spacing (AIFS). Comparison to such methods, the recent work focuses on a different objective. Specifically, while prior work focuses on satisfying QoS requirements, our work targets to achieve low packet delivery latency to a target distance. There have also been efforts to modify the IEEE 802.11 protocol to perform effective packet propagation in a vehicular network. One example by Korkmaz, et al. propose an additional feature of exchanging Request-to-Broadcast (RTB) and Clear-to-Broadcast (CTB) messages to the IEEE 802.11 MAC protocol as a way to select the nodes that are farthest away and minimize the number of transmissions [12]. Apart from these schemes, our proposed scheme is independent of MAC layer protocols and uses physical layer characteristics as a reference of determining the farthest away node.

More explicit approaches also exist in defining the farthest away vehicle, such as the work by Bi et al. where the nodes are equipped with GPS sensors and use the proposed Position based Multi-hop Broadcast Protocol (PMBP) [21]. This scheme would require nodes to have an additional sensor and at the same time require them to have global topology of vehicle placement to determine its forwarding privileges. To the best of our knowledge, this work is one of the first efforts to use physical layer characteristics, such as SNR, to prioritize nodes for efficient packet forwarding in the context of data transmissions in vehicular networks. We also emphasize that compared to various schemes that were designed based on cross-layer design paradigms (e.g., modifications for both routing and MAC layers), the scheme proposed in this work is easily adoptable to previously proposed systems as well since only exploits the characteristics of the physical layer to achieve additional communication efficiency.

III. Broadcast propagation using SNR-based linear backoff

1. Environment of the VANET and IP Gateway

In this paper, broadcasting mechanism proposes simple relay, distance calculation, and retransmission mechanism without any response from neighboring vehicles. The aforementioned ones are determined depending on the receiving power strength. Figure 1 shows reference architecture for VANET communications. RSU (Road Side Unit) configures the network and service infrastructure on the roads to support vehicle communication and inter-RSU communication. OBU (On Board Unit) is a device that is installed on the inside of the vehicle to support vehicle communication. AU (Application Unit) runs an application by using communications capabilities of OBU.

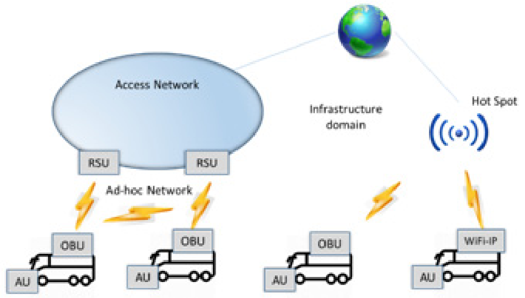

Fig. 1. A reference architecture of VANET with WiFi-IP gateway
그림 1. WiFi-IP 게이트웨이를 포함한 VANET 참조 구조

For the proposed mechanism, followings may be considered. Vehicles should be able to disseminate an emergency message when they get into an accident. The message includes geographic information and vehicle's direction by using a GPS. Another vehicle receiving the emergency message can estimate whether the accident position is front side or back side with the vehicle's direction message. Vehicles which receive broadcasted packets have time offset. We set that the farther receiving vehicle is, the shorter time offset it owns. Vehicles which receive broadcast packets can be synchronized by a message because wireless propagation time is negligible. Finally, a vehicle has no sooner gotten into an accident than it disseminate emergency message, and other following vehicles may receive the same message consequently.

2. WiFi-IP Gateway

In this section, we discuss about other technical components of the system that are required to design an effective VANET system when applying the SLB scheme. Specifically, the following paragraphs discuss about a simple WiFi-IP gateway design that interconnects the SLB-based WiFi nodes with the IP-based larger Internet infrastructure shown in Figure 2. We point out that since IEEE 802.11p has been proposed as the standards for VANETs and has been integrated into the IEEE 802.11 standards [28]. Therefore, assuming that this technology will spread as the base-radio technology for enabling VANETs applications, we assume radio characteristics that match this physical layer at the 5.8-5.9 GHz band.

WiFi-IP Gateway: While SLB allows emergency information to be propagated throughout a routing topology-less vehicular network, by having this information transmitted to the Internet (or ITS server), the information can benefit a larger number of drivers distributed in a wide geographic region (e.g., provide remote traffic condition alerts). For this reason, we design a simple prototype of a WiFi-IP gateway device which can essentially be used as RSUs or AUs that collect and relay the information of the vehicular network. Our design of the WiFi-IP gateway takes input from its WiFi radio and forwards this information to an Internet-connected radio module. Specifically, for global wireless connectivity, we put in support for cellular networks. As we will discuss in the following section, we currently have the WiFi ports of the WiFi-IP gateway connected with the output of our NS-3 simulation environment, which simulates a vehicular networking environment.

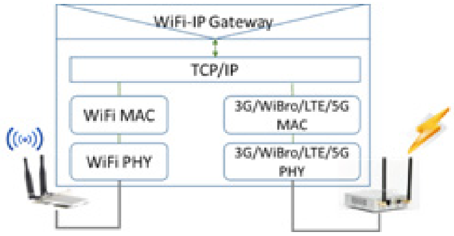

Fig. 2. A WiFi-IP gateway layered structure
그림 2. WiFi-IP 게이트웨이 계층 구조

3. Distance Calculation using Received Power Strength

When source vehicle broadcast emergency message, following vehicle can calculate their distance with receiving power strength by using Eq. (1). The lower receiving power strength is, the farther distance is. With the receiving power strength, a receiver vehicle can calculate distance from the sender vehicle with Eq. (1). P_r and P_t are the value of power at the input of the receiving vehicle and output power of transmitting vehicle, respectively. λ is the wavelength and D is the distance between the vehicles. Namely in Figure 3, if a vehicle receives about -72 dBm, it means that the received vehicle is about 250m away from the source vehicle.

$$P_r = G_t G_r \left(\frac{\lambda}{4\pi D}\right)^2 P_t \tag{1}$$

One important factor of such emergency messages is the need for fast propagation throughout the network. The latency of a packet to propagate

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throughout the network (for a target distance D_{target}) can be simply designed as follows.

$$HC = \frac{D_{target}}{D_{tx}} \quad (2)$$

$$Prop_d = HC * Proc_d \quad (3)$$

Here, HC is the total hop count, D_{tx} is the maximum transmission distance of a broadcast, $Proc_d$ is the processing latency, and $Prop_d$ is the expected propagation delay. This of course is the most ideal case where vehicles are densely located and there always is a vehicle that D_{tx} is away. Practically, due to the locations of the vehicles, HC can be increased to a larger number. Therefore, we change Eq. 3 as below.

$$HC = \frac{D_{total}}{E(D_{FV})} \quad (4)$$

Where $E(D_{FV})$ is the expected distance between the transmitter and the vehicle farthest away within communication range D_{tx}. As mentioned above, assuming a uniformly random distribution of the vehicles and a maximum communication distance of 250 meters, in this work and in the evaluations that follow in Section 4 we set $E(D_{FV})$ as 125 meters.

Despite using SLB, identifying a single forwarding node is difficult since nodes can be densely located. Specifically, while we differentiate the back-off times of each node BO_n with the SNR of the received packet, $MAX_{backoff}$ can be configured identically on multiple nodes. Despite the randomness within the range of [1: $MAX_{backoff}$] in selecting BO_n, if nodes select the same BO_n and $BO_n = min_{1 \le i \le k}\{BO_i\}$ (where k is the total number of nodes in the network), packets may collide and cause delivery failures with a CRC error at the receiving end. In turn, this will allow other nodes $(1 \le i \le k)$ to act as the forwarder. If the packets do not collide, the other potential forwarders will suppress their broadcasts.

4. Broadcast Packet Replay Algorithm

If all WiFi vehicle nodes simultaneously send broadcast packet, the packets will be dropped and it increases drop rate. In order to solve the previous problem, we propose broadcast packet relay algorithm by selecting particular forwarder.

As mentioned above, the maximum length of highway by power value is assumed to set to 250m in Figure 3. We divide several forwarder groups every specific division (50m) with having the similar power strength, which is also assumed for simple analysis, such as P0, P1, P2, P3, P4 and P5. In addition, we set time offset T0, T1, T2, T3, T4 and T5 to each P0, P1, P2, P3, P4 and P5 respectively. Time offset value becomes small toward T5. So, T5 is the minimum value in this case. However the offset value can be changed according to the implementer's decision.

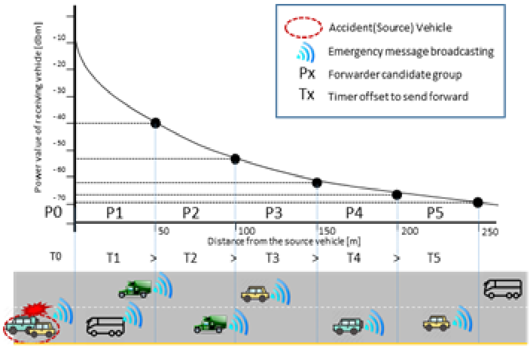

Fig. 3. Proposed relay mechanism of broadcast packets.
그림 3. 제안된 방송 패킷의 전달 방식

In the proposed example, P5 is selected as the first forwarder candidate because P5 has the smallest time offset. Hence, the vehicle in the region of P5 relays the broadcasted emergency message after T5, which is the smallest time offset. At this time, other vehicles in the region of P1 to P4 receive the relayed packet, so they don't need to participate in the emergency packets relay any more. However, if there is no relayed packet for T5 time, it means that no vehicle exists in P5 region. Therefore, a vehicle in P4 region can be selected as the next forwarder candidate because T4 has the next smallest time offset, and the vehicle in the region of P4 tries to relay the broadcasted emergency packet after T4. This process is repeated to reach P1 region in sequence. If there is no vehicle in all regions, P1 to P5, the source node repeatedly broadcasts the emergency packet with resend bit marking.

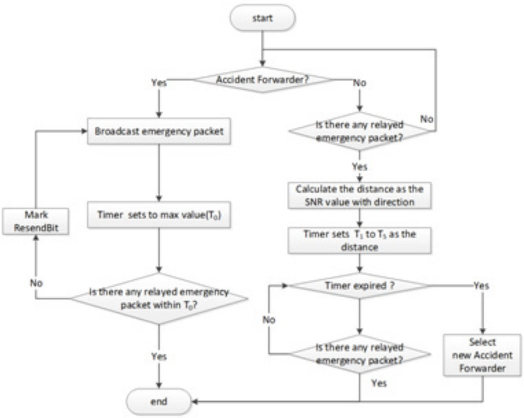

Fig. 4. Flow chart of proposed relay scheme from perspective of arbitrary node
그림 4. 임의의 노드로부터 제안된 전달 방식의 흐름도

Figure 4 shows the flow chart of proposed scheme for an arbitrary node. If an accident occurs at the arbitrary node, the node immediately broadcasts emergency packets and the timer is set to the maximum value. After that, the node checks whether the emergency packet is relayed or not during the timer value. If the node does not receive any packet till the timer is expired, the node goes back to the step with *resendBit* mark. If the node receives the emergency packet which is relayed, the node terminates the operation, because it means that another node is relaying the emergency packet. In the case that a node does not occur to accident, a node checks whether the relayed emergency packet exists or not. If there is no packet, a node goes back to the start point. If an emergency packet is detected, the node calculates distance from the power strength, sets the timer according to the distance, and then the node checks the timer. If the timer is expired, the node relays the received emergency packet immediately. Otherwise, the node waits for an emergency packet, which is the one from another vehicle having lower time offset, till the timer is expired.

Ⅳ. Simulation Configurations and implementations

To verify proposed SLB scheme, we set up a simulation environment using the VANET extensions implemented for the NS-3 simulator [16]. This extension exploits the benefits of NS-3 and provides propagation models that match vehicular scenarios. Using this simulation environment we implemented additional extensions for our evaluation.

Table 1. Command line parameters of the simulation
표 1. 시뮬레이션 명령시 파라미터

Parameter Value	*Meaning and Default Value*
Project XML file	*SimpleStraightHighway.xml*
pRate	*WiFi Penetration rates(20%~100%)*
cFlow	*Vehicle flow rates(~100%)*
accidentTime	*Accident time*
delay	*Node's processing delay(1ms)*
randomDelay	*Node's additional random processing delay*
deltaX	*Propagation distance(~3Km)*
suppressionFactor	*Message suppression or not*
gatewayRate	*WiFi-IP gateway rates(0.1% ~ 1%)*
serverIP	*ITS server's IP address*
serverPort	*ITS server's receiving port(3000/UDP)*

Table 1 presents the set of software parameters that are configurable in the NS-3 simulation environment. The Project XML parameter selects the physical simulation environment with an active vehicle flow rate (*cFlow*) which is a rate from uniformly generated vehicle. In our tests we select the SimpleStraightHighway.xml which simulates a rural highway environment with different Project Model parameters to test for both WiFi broadcast-based schemes and the proposed SLB scheme. The penetration rate (*pRate*), accidenttime(*aTime*), and node processing delays(*delay*) can be configured as well. The penetrationrate(*pRate*) represents rates of WiFi node installed vehicle, accidenttime(*aTime*) represents the accident occurs time on the simulation, and delay represents the broadcast forwarder processing time. Furthermore, the *deltaX* parameter represents the maximum propagation distance in Eq.(4) and the suppression parameter is used for configuring the simulation environment for testing the performance of the WiFi's simple broadcast scheme with and without suppression. Finally, there are parameters to configure the WiFi-IP gateway such as *serverIP* and *serverPort*, relating to the ITS server details and gateway rate, which details how often a WiFi-IP gateway can be observed on the road.

We present the parameter configurations for our evaluations in Table 2. Specifically, we assume a straight highway environment with a uniformly random generation of vehicles injected to the environment. Given a highway length of 10 KMs, we assume that a vehicle accident is detected in 50 seconds of the simulation at a random location and target to propagate the information for 3 KMs. We point the readers to Table 2 for other parameter details.

Table 2. Parameters used in the simulations
표 2. 시뮬레이션 파라미터

Parameter	*Value*
Total Highway Length	*10 Km*
Vehicle Generation rates	*Uniform RV*
Number of Lane	*3 lanes per direction*
Vehicle accident time	*50 Sec. after simulation*
Target Propagation distance	*3Km from accident position*
WiFi MAC/PHY	*IEEE 802.11g*
Lowest vehicle speed limit	*50Km/h*
Highest vehicle speed limit	*110Km/h*
Minimum gap btw. vehicles	*10m*
Per vehicle processing delay	*5ms*
Delay among SNR Groups	*1ms*
Retransmission period	*1 second*
WiFi-IP gateway rate	*1%*
Simulation duration	*300 s*

In our simulations, only a subset of the vehicles on the highway has WiFi connectivity. Other vehicles will operate on the roads without any connectivity. This is a more realistic scenario to given the slow adoption rates of VANET platforms, it is not an ideal VANET scenario though. Furthermore, our scenario takes another subset of the WiFi connected vehicles to have gateway capabilities. These vehicles are selected randomly in our simulations and the gateway rate parameter determines how often these gateway-included vehicles are injected on the road. Comprehensively, given the 10 KM road, as vehicles exit this region, we inject additional vehicles to this road and configure them to be either non-WiFi, WiFi, or WiFi-IP gateway nodes.

In Figure 5, we present the average propagation delay for an emergency message to reach its target propagation distance of *deltaX* (e.g., 3Km) with respect to different WiFi deployment densities(e.g., 20%~100%). We can notice from the results that for all three schemes the end-to-end delivery latency implies a trend of decreasing inverse log-proportionally to the WiFi deployment density.

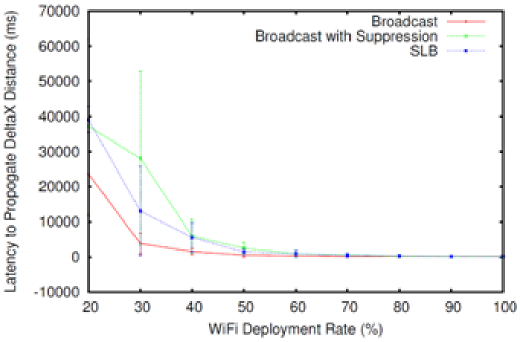

Fig. 5. Propagation delay to reach deltaX (3Km) distance after traffic accident with varying WiFi penetration rates
그림 5. WiFi 장착 차량 투입율에 따른 사고지점으로부터 3Km 위치까지 전파지연시간

As shown in Figure 6, we plot the latency from the initiating node with varying WiFi vehicle densities until the emergency packet reaches the ITS server. Since it is difficult to synchronize the clocks on two different PCs accurately (e.g., millisecond scale), we measure the time from the initial transmission of the emergency packet to the time that the packet is forwarded from the WiFi-IP gateway to the ITS server. As expected given the same percentage of gateways, we can notice that Figure 6 follows the trends of Figure 5 for all three schemes. When observing the same end-to-end latencies with varying gateway rates (see Figure 7), we can still notice that the three schemes show similar trends of decreasing latencies to the ITS server while gateway rate increases.

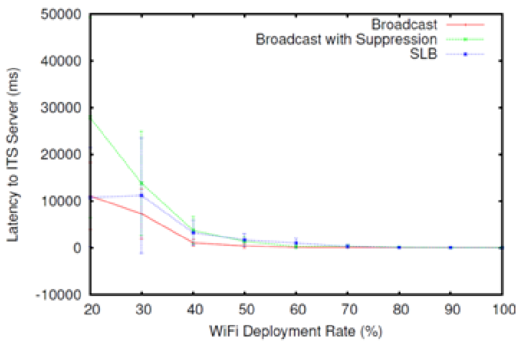

Fig. 6. Latency to ITS server with varying WiFi penetration rates
그림 6. WiFi 장착 차량 투입율에 따른 ITS 서버까지 전달지연시간

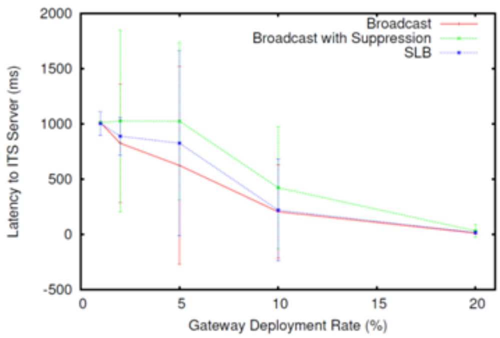

Fig. 7. Latency to the ITS server with varying gateway deployment rates.
그림 7. 게이트웨이 차량 투입율에 따른 ITS 서버까지 전달지연시간

Next, we present the total (minimum) number of hops required to accomplish the task of forwarding the emergency packet for a distance of *deltaX* in Figure 8. We can quickly notice a very similar trend among the three schemes. However, since the suppression scheme allows any node that receives the emergency message to forward it, nodes that are closer to the original sender have chances of acting as the forwarder node; thus, this increases the average number of hops required to send to packet to the target. On the other hand, since all nodes have the opportunity to forward these messages in a simple broadcasting scheme, the broadcasting scheme shows the shortest number of hops. As discussed earlier, this simple broadcast scheme is, in terms of minimizing the hop count, the experimental optimal values that any scheme can achieve.

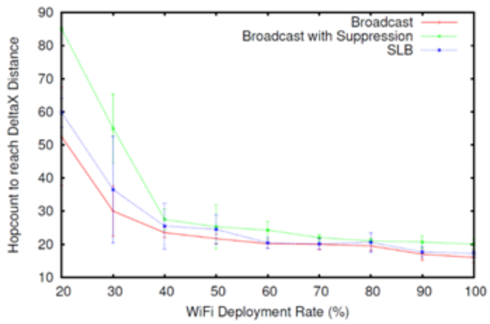

Fig. 8. Total hop counts to reach deltaX(3Km) distance from accident position with varying WiFi penetration rates.
그림 8. WjFi 장착 차량 투입율에 따른 사고지점으로부터 3Km 위치까지 홉 수

While the simple broadcasting scheme shows an ideal hop count, this is only achieved by performing in a greedy manner. As in Figure 9, the broadcasting scheme sends dramatically more packets than the SLB scheme to achieve the experimental optimal hop count. As the density of WiFi-connected vehicle increases, this difference increases even more. We can see from Figure 9 that its packet overhead is still multiple orders of magnitude higher than that of SLB while the suppression mechanism shows improvements to the simple broadcast scheme. We note that this result is dependent on *deltaX* and points out those similar trends have been also seen for other *deltaX* values.

Based on the result, we can conclude that the SLB scheme performs closely to the experimental optimal scheme in terms of latency and number of traveled hops (e.g., network performance metrics). Nevertheless, this optimal value can only be achieved by sacrificing a significant amount of overhead packets by forcing all nodes to forward and propagate packets throughout the network. Our results show that the proposed SLB scheme achieves a reasonable middle-ground between achieving efficient performance in-terms of packet overhead and minimizing the latency and hop count for packet propagation.

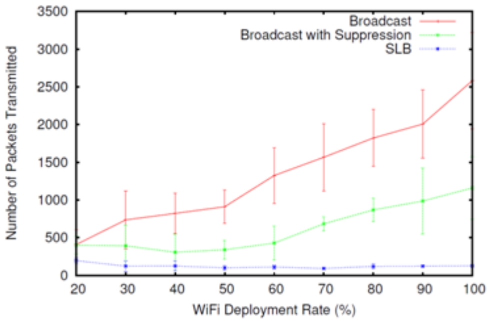

Fig. 9. Total broadcasting packet counts to reach *deltaX*(3Km) distance with varying WiFi penetration rates.
그림 9. WjFi 장착 차량 투입율에 따른 사고지점으로부터 3Km 위치까지 발생된 방송 패킷 수

V. CONCLUSIONS

In this work, we presented SLB, which is a scheme implicitly selecting emergency message-forwarding vehicles based on the SNR values of the received packet so that it can minimize the effect of broadcast storms in vehicular networking scenarios. Vehicles select a forwarding node without a priori information on the network topology by using the SLB, while other nodes suppress their message forwarding capabilities by overhearing to reduce the number of transmissions on the air. Based on our evaluations configured to simulate a real vehicular networking scenario, a real software-based WiFi-IP gateway and an ITS server, we showed that the performance of SLB in terms of packet propagation latency and hop-count was close to that of the optimal values. Furthermore, we presented that the number of packets that are transmitted is reduced significantly under various WiFi deployment rates and this reduction is ~20x to achieve the "close-to-optimal" packet propagation efficiency under dense WiFi deployment rates. Because of the fact that we only utilized a test for a simple highway environment, the effect of different road conditions (e.g., local roads with buildings and congestion) to our proposed protocol can be investigated as a future work. It will also be a good effort to deploy our scheme in the real world such as CACC (Cooperative Adaptive Cruise Control) and Sensor fusion on the VANET application. Furthermore, forward error correction schemes such as Viterbi codes and Reed Solomon codes can be included to increase the reliability and the communication range of a single broadcast so that the number of packet transmissions can even be further reduced.

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