# Efficient Safety Message Forwarding using Multi-Channels in Low Density VANETs

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***Abstract*—Vehicular Ad-hoc networks (VANETs) provide a way for a vehicle to deliver various types of information to users or drivers in other vehicles. Distributing a large amount of information such as multimedia messages in a single control channel makes the control channel easily congested. Transmitting multimedia messages through multi-channel to avoid this congestion becomes a feasible solution. However, low-connectivity in a low vehicle density in multi-channel poses unique challenges and can produce connection failure if this issue is not carefully addressed. In this paper, a network coding technique with *divide-and-deliver* is introduced to solve this unique challenge for delivering multimedia contents through multiple service channels in a low vehicle density. Through the rigorous analytical derivation and extensive simulation, we show the proposed scheme significantly improves reliability with minimum usage of the control channels in a typical VANETs environment.**

## I. Introduction

Vehicular ad-hoc networks (VANETs) provide a communication technology between vehicles or between vehicles and roadside infrastructure units. Recently, VANETs have been a popular research area for both academia and industry. Especially, the capability of disseminating safety messages with traffic information among vehicles on the road in real-time has attracted many researchers [1], [2].

The VANETs standard [3] supports six service channels (SCHs) and one control channel (CCH). All of these seven channels have a 10 MHz bandwidth and a 50 ms interval sharing a 100 ms equally. Vehicles are free to join any one of six service channels during the SCH interval. However, all vehicles must join the CCH to disseminate or listen safety information during the CCH interval. In addition, beacon signals from the all vehicles will be broadcasted in this channel.

Usually safety information is transmitted in a short-text message format. This short message ensures fast and reliable delivery in restricted (e.g., $\leq$ 10 MHz) and unreliable channels in VANETs. Alternatively, users can also enjoy benefits from using rich multimedia content (e.g., video, audio) to easily recognize and understand the information. Some studies already addressed the significance of multimedia information in safety applications [4], [5].

Transferring a short safety message in the control channel would not have a problem. However, transferring a large amount of information such as multimedia contents in the control channel would lead the channel to be severely congested. Theoretically VANETs can provide up to 60 MHz of bandwidths if all SCH channels are used. However, this support is limited to the SCH interval. If the multimedia content can be delivered through the SCHs, the congestion of CCH can be lessened.

For delivering multimedia messages, if only one of the SCHs is used, it uses only one-sixth of the total bandwidth in the SCH interval. To maximize the utilization of available bandwidth, distributing packets through all the channels in the SCH interval is more effective than using only one channel. Our proposed way for utilizing multiple channels is to *divide* the entire multimedia safety application information into packets considering the number of available SCHs and *deliver* the packets in each SCH. We call this simple scheme *divide-and-deliver*. In this way, the amount of bandwidth used in each channel for delivering multimedia messages can be minimized. Moreover, vehicles in each channel can forward the divided small packets to the other vehicles via multi-hop. If a single channel is used in the SCH interval, a vehicle can only forward a large number of packets by one-hop since there is not much bandwidth left for the multi-hop forwarding. With the multi-hop forwarding, the *divide-and-deliver* scheme can deliver multimedia messages quickly to the target vehicle or infrastructure with fewer CCH intervals.

However, there is a unique challenge in realizing the divide-and-deliver scheme in a multi-channel VANET environment. The specific challenge is low reliability due to low connectivity between vehicles. The distributed vehicles over multi-channel decrease the density of vehicles in every channel. In some cases, there may be channels where no vehicles exist within a radio range of a vehicle. While there are many other factors to lower reliability such as wireless channel, mobility or obstacles, the effect of these physical layer factors does not change from single channel to multi-channel. Indeed, this low density or low connectivity is critical to the packet relay.

Therefore, in this paper, we enhance the *divide-and-deliver* scheme that addresses this low density problems utilizing *network coding*. With network coding, we show that our scheme achieves an efficient and reliable communication between vehicles utilizing multiple channels while reducing the amount

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of bandwidth borrowed. We also analyze the impact of the bandwidth borrowed on reliability and delay. Our results show that the proposed scheme reduces the delay and increases the reliability of the system compared to a scheme utilizing only the entire SCH interval.

This paper proceeds as follows: In Section II, we describe the previous research regarding multi-channel and multimedia distribution in VANETs. In Section III, we explain the design of the proposed protocol. In Section IV, we show the simulation results and analysis. In Section V, we conclude the paper.

## II. Related Work

Use of multiple channels has been an interesting topic for mobile ad-hoc networks (MANETs) and VANETs, and many studies have been conducted.

In [6], one channel is assigned for the control purpose while other channels are used for general data transfer for multi-hop mobile ad-hoc networks. To use the data channels, nodes need to exchange control packets with others in the control channel. However, this approach requires dual radio transceivers to listen to packets in a control channel while transferring data on data channels. Hence, this approach is not adequate as we assume one radio transceiver for each vehicle in our scheme.

In [7], a cluster is formed within a communication range. In the cluster, one cluster-head vehicle is selected and other cluster-member vehicles are followed by the control of the header vehicle. The header vehicle also assigns specific channels for other member vehicles, which enables an efficient sharing of multiple channels. However, this cluster-based approach requires extra protocol to set up and maintain clusters. Our approach does not set up a cluster but relay packets through selected vehicles.

Another approach for using multiple channels is using directional antennas [8]. With the directional antennas, we can maximize the spatial reuse, which results into decreasing packet delay. However, to use a directional antenna in multiple channels, the information regarding which channel and which direction to be used requires coordination between the vehicles.

These approaches are different from our proposed scheme. Their algorithms focused on assigning a channel for each vehicle to share or transfer messages. So their decision is to select one channel out of multiple channels. Instead of selecting a channel, we want to use multiple channels at once to utilize more bandwidths for delivering large-sized multimedia messages and minimize the delay for the delivery of the messages between the end-point vehicles.

In addition to using multiple channels, the multimedia delivery in VANETs was also an interesting topic in the literature. Considering the VANETs' physical characteristic including the lossy wireless channel and highly dynamic topology of vehicles, it is difficult to transfer large-sized multimedia files or support reliable streaming services. The benefit of using multimedia information for safety application in VANETs was well explained in [4], [9].

In [4], the authors proposed a streaming video service using network coding. Each vehicle broadcasts packets with a range of sequence numbers and how many packets it has. Based on this information, vehicle can know which vehicle has more information that itself. Then, vehicles ask packets from the vehicle that has more packets. Since this scheme has all the vehicles broadcast, there are redundant packets in a channel. In [9], multimedia streaming service by symbol-level network coding was proposed. However, to select relay and support smooth playback, this algorithm requires vehicles to periodically advertise internal status such as the size of playback buffer and the rank of coded packets. In [10] [5], network coding based content distribution was proposed for VANETs. Different from streaming service, this operation is initiated by interested vehicles and requires the exchange of content information that vehicles have.

Most of these multimedia delivery approaches use single channel and do not consider multiple channels in delivering multimedia messages to the road side units or vehicles. They also do not address the challenges in multiple channels introduced in this paper. While others use network coding only for compensating the packet losses in the same channel, we use network coding for compensating the packet losses in other channels. Our results show network coding is a good technology for delivering multimedia messages over multiple channels in VANETS.

## III. Protocol Design

In this section, we introduce the design of our proposed scheme while addressing the challenges associated with the multi-channels.

### A. Low Success Rate

For the *divide-and-deliver* algorithm to be successful, the divided packets should be delivered successfully in all SCH channels. We tested the initial design of the algorithm via simulations. In our simulations, we set the transmission range to 300 m and distribute vehicles over a 10 km road with different densities. In each run, a source vehicle is randomly selected to broadcast six packets of a multimedia message. After the broadcasts, all vehicles switch to one of the six service channels. The vehicles that receive the packets successfully, called relay vehicles, forward one packet in their channel. If each packet is forwarded successfully to another vehicle in each channel, this run is regarded as a success case. The success rate is defined as the number of success cases over the total number of simulation runs. The simulation results in Figure 1 show the success rate of the *divide-and-deliver* algorithm is high when the vehicle density is high. However, it shows the low success rate when the vehicle density is low.

The low success rate for the low density case is caused by two factors: 1) unoccupied channel (UC) and 2) unreached vehicle (UV). The unoccupied channel means there are channels where no relay vehicles exist. Since vehicles select the service channels randomly, there are cases where relay vehicles exist only in some of the channels, but not all of them. This is

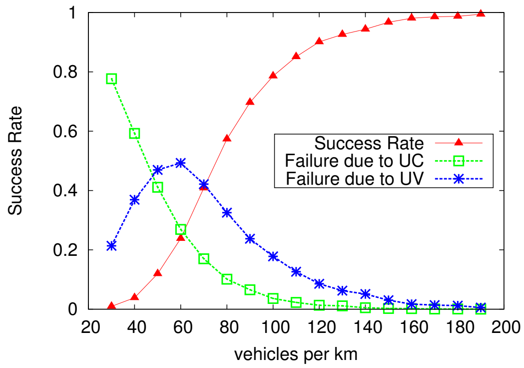



Fig. 1: One-hop success rate

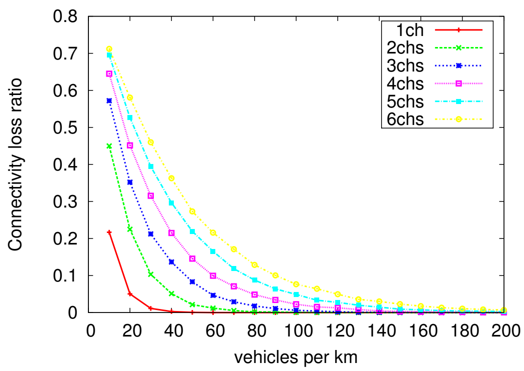



Fig. 2: Loss of connectivity

the main reason for the low success rate in the low density case. Another reason for the low success rate is the unreached vehicle. The unreached vehicle situation occurs when there are no vehicles in the transmission range of a relay vehicle after relay vehicles occupy all the six channels. So, the relay vehicle cannot deliver a packet in a channel. Figure 1 shows these two failure factors as well as the success rate.

These two factors are related to the low connectivity between vehicles in the low vehicle density case. Figure 2 shows the ratio of the connectivity losses over the total number of vehicles according to the different number of channels and densities. When there are no vehicles in the transmission range of a vehicle, it is counted as a connectivity loss. When the vehicles are placed in a single channel (1ch), the connectivity loss rate is low. However, when the vehicles are placed in six channels (6ch), the connectivity loss rate increases. From Figure 2, an interesting observation is that, even though vehicles are well connected with other vehicles in a single channel (CCH interval), vehicles start losing connectivity to neighboring vehicles in a multi-channel interval (SCH interval). So, the *divide-and-deliver* method should address this low connectivity issue.

### B. Lost Packet Compensation

After the divided packets are delivered through the SCH channels, the packets need to be collected in the next CCH interval. When some packets fail to be delivered in some channels due to the previous reasons, these packets are regarded as lost packets. The lost packets can be compensated when the same packets are delivered successfully through other channels. Then, vehicles need to know which packets will be delivered successfully and which packets will not be delivered. However, a vehicle in a channel hardly knows which packets are lost in other channels. So, it is a difficult problem to predict the lost packet correctly. In the worst case, most of bandwidth would be wasted with the unhelpful packets that cannot compensate the lost packets in other channels. To solve this packet compensation problem, network coding is a viable method.

Since the network coding enables packets to share the contents of other packets, in the case when some packets are missing, the lost information can be recovered from other packets that are received successfully. Due to this characteristic, it is possible simply to increase the number of packets in each channel without considering which packets would be dropped in other channels.

In our work, a random linear network coding is used. The random linear network coding is commonly used in other wireless networks [11], [12]. In a random linear network coding, a sender selects coefficients randomly from Galois Field and performs a linear combination of packets and coefficients. A receiver can decode when it receives enough number of packets and pre-known coefficients. Equation (1) shows the basic operation of a random linear network coding. In network coding, a number of packets which have the same size are grouped into a segment that is called a generation. The coding is done for each generation. Assume there are $n$ packets in a generation such as $P = [p_1, p_2, p_3, \dots p_n]$, which are plain packets before coding. To apply network coding, a sender chooses $n$ random coding coefficients that are represented by a vector, $C_k = [c_{k1}, c_{k2}, c_{k3}, \dots c_{kn}]$ in the Galois field $GF(2^8)$. The sender generates a network coded packet according to Equation (1) in the Galois field. Then this operation is repeated with newly selected coefficients until the sender generates $n$ coded packets such as $X = [x_1, x_2, x_3, \dots x_n]$.

$$x_k = \sum_{i=1}^{n} c_{ki} * p_i \tag{1}$$

### C. Extra Network Coded Packet

Although it is possible to compensate the lost packets with generating extra packets using network coding, the natural question is how many extra packets should be added to the original number of packets.

When no extra packets are needed, the number of packets to be sent in each channel is $M_{base}$ as in Equation (2), where $R$ is the total number of original packets for the multimedia message and $N$ is the number of channels.

$$M_{base} = \frac{R}{N} \tag{2}$$

When the loss of connectivity is considered, we need put more packets than $M_{base}$. To decide how many packets, $M$, are needed to be added, two factors are considered in this scenario: 1) *channel availability probability* and 2) *vehicle availability probability*. These two factors are related to the two reasons which are identified in the previous subsection (III.A). The channel availability probability is for the unoccupied channel cases while the vehicle availability probability is for the unreached vehicle cases. The channel availability probability indicates the probability of how many channels can be occupied by vehicles. The vehicle availability probability indicates the probability that vehicles exist within the transmission range of a vehicle.

To find out the channel availability probability, we define $\Phi^{N,Vt}(\gamma)$, which is the probability showing that vehicles occupy at least $\gamma$ or more channels. $\Phi^{N,Vt}(\gamma)$ is calculated based on the number of available channels, $N$, and the number of vehicles, $Vt$. $\Phi^{N,Vt}(\gamma)$ can be described with Equation (3), where $\phi^{N,Vt}(\gamma)$ is the probability that vehicles occupy channels less than $\gamma$. $\phi^{N,Vt}(\gamma)$ can be expressed with $S^{N,Vt}(\gamma)$ and $Z^{N,Vt}$. $S^{N,Vt}(\gamma)$ is the number of cases when vehicles occupy less than $\gamma$ channels. $Z^{N,Vt}$ represents all the cases when vehicles can occupy N channels.

$$\Phi_{\gamma}^{N,Vt} = 1 - \phi_{\gamma}^{N,Vt} = 1 - \frac{S^{N,Vt}(\gamma)}{Z^{N,Vt}} \tag{3}$$

For simplicity, $Z^{N,Vt}$ and $Z^N$ are used interchangeably in the following expressions. $Z^N$ also can be expressed as a set of $Q_i^N$, where $i$ = 1,...$N$. The $Q_i^N$ represents the cases when vehicles can occupy exactly $i$ channels out of $N$ channels, excluding cases when occupying less than $i$ channels.

$$Z^N = \{Q_1^N, Q_2^N, \ldots, Q_{N-1}^N, Q_N^N\} \tag{4}$$

Then, $S(\gamma)^{N,Vt}$ can be expressed by adding $Q_i^N$ where $i = 1, \ldots\gamma$

Since $Q_1^N$ is the case all vehicle occupy one channel, it can be represented with Equation (5). Then, $Q_2^N$ can be calculated using $Q_1^N$ as given in Equation (6). $Q_2^N$ is the case when vehicles occupying two channels out of $N$, excluding the cases when vehicles occupy one channel. Then, this formula can be extended to $Q_N^N$ in (7).

$$Q_1^N = {}_1C_N * 1 \tag{5}$$

$$Q_2^N = {}_2C_N * (Z^2 - {}_1C_2 * Q_1^N) \tag{6}$$

$$Q_i^N = {}_iC_N * (Z^i - \sum_{x=1}^{i-1} {}_xC_i * Q_x^N) \tag{7}$$

With $Q_i^N$, Equation (3) can be expressed with Equation (8)

$$\Phi_{\gamma}^{N,Vt} = 1 - \frac{\sum_{i=1}^{\gamma-1} Q_i^N}{Z^{N,Vt}} \tag{8}$$

For the vehicle availability probability, $\Psi$, a Poisson distribution model, $f(n;\lambda) = \frac{\lambda^n e^{-\lambda}}{n!}$ is used since vehicles are assumed to be distributed randomly. Equation (9) shows the vehicle availability probability using $f(n;\lambda)$, where $n$ is zero and $\lambda$ is the density of vehicles in a channel, $d$.

$$\Psi_d = 1 - f(n = 0; \lambda = d) = 1 - e^{-d} \tag{9}$$

Through $\Phi_{\gamma}^{N,Vt}$ and $\Psi_{Vt}$, the appropriate value of $M$ can be computed. In next sub-section, our proposed scheme to use $\Phi_{\gamma}^{N,Vt}$ and $\Psi_{Vt}$ is explained.

### D. *Proposed Protocol*

A vehicle that has multimedia safety information becomes a source vehicle to other neighboring vehicles. A source vehicle in the CCH interval transmits a number of encoded packets with a desirable success rate, $\rho$. The vehicles that receive the broadcast packets successfully become relay vehicles. With $\rho$, the relay vehicles in the SCH interval decide how many extra packets need to be added. To decide the number of packets to broadcast, the relay vehicles use the channel availability probability, $\Phi$ and the vehicle availability probability, $\Psi$ with the required successful rate, $\rho$ as given in Algorithm 1.

**Algorithm 1** Finding M for the given success rate, $\rho$

```
procedure FINDINGM(ρ)
    R ←total number of original packets
    N ←total number of channels
    Vt ←total number of neighbor vehicles
    M ← R/N
    γ ← N
    while Φ_γ^{N,Vt} * Ψ^γ_{Vt/γ} < ρ or γ > 1 do
        γ ← γ − 1
        M ← ⌈R/γ⌉
    end while
    return M
end procedure
```

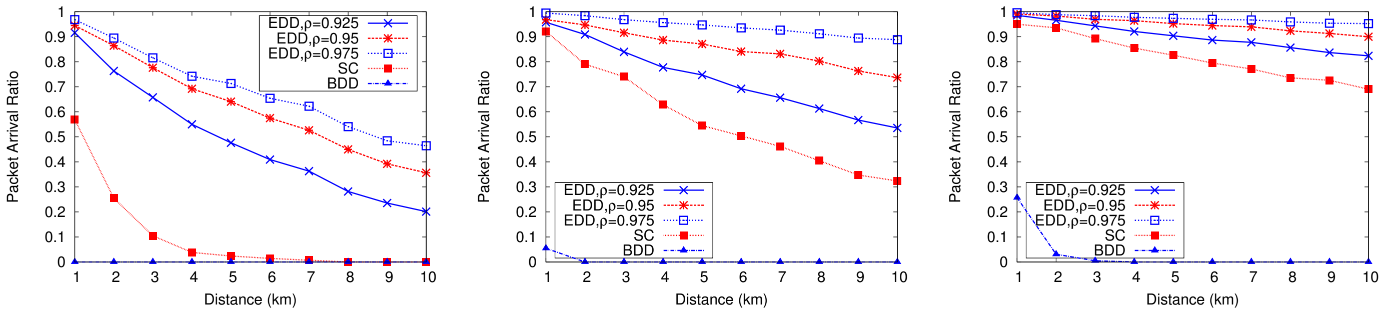
According to Algorithm 1, a relay vehicle increases the number of packets to be sent in each channel until it meets the required success rate, $\rho$. After the SCH interval ends, vehicles move to the CCH. Then, vehicles start recovering original information by gathering the coded packets that other vehicles have. To reduce the collision between vehicles in a sharing process, a smart broadcasting algorithm [13] is used. With the smart broadcasting algorithm, the vehicle that is the farthest from a source vehicle can have higher priority to send packets by getting a smallest contention window size.

## IV. Performance Evaluation

In this section, we evaluate the performance of our scheme using simulations. First, we describe simulation environment. Then, we analyze the results from the simulations.

### A. *Simulation setup*

To analyze the performance of the algorithm, ns-3 simulator was used. Vehicles are placed on a 10 km road with two lanes and the same direction. The number of relayed packets is measured at every 1 km point. Packets are generated at the




(a) Reliability at 30 vehicles/km (b) Reliability at 50 vehicles/km (c) Reliability at 70 vehicles/km

Fig. 3: Packet arrival ratio

origin (0 km position) and relayed by vehicles until packets arrive at the end point (10 km position). The size of multimedia information is 12 Mbyte. The payload of each packet is 1 Kbyte and the transmission speed is 3 Mbps. The number of packets that a source vehicle sends in CCH interval is 12. These 12 packets can occupy more than 70% of the CCH interval when they are sent as 3 Mbps. We set the number of SCHs, $N$ as six. Vehicles move with average speed of 50 miles per hour and standard deviation of 5 miles per hour.

## *B. Results*

In this sub-section, the performance of this proposed algorithm will be analyzed in three ways: 1) reliability, 2) occupied bandwidth in each channel, and 3) usage of intervals.

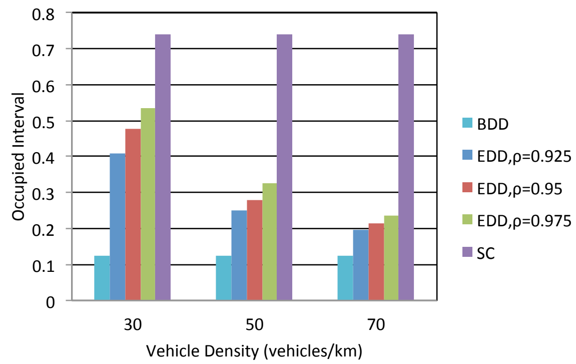
The reliability is the main criteria for our scheme since the safety messages need to be transferred to a road side unit which would be located far away and not be available immediately. To measure the reliability, the number of packets that arrive successfully at each measuring point,called packet arrival rate, is measured. For comparison, a *basic divide-and-deliver* (BDD) and a single channel (SC) method are used. The BDD method is the simple method described in the introduction, which divides packets by the number of channels and sends the divided amount of packets to each channel. This BDD method does not consider network coding or adding extra packets. The SC method uses only one channel in the SCH intervals. The proposed method, *enhanced divide and deliver* (EDD), has vehicles to calculate the number of packets to be sent in each channel, $M$ according to $\rho$, which is specified at the beginning of simulation.

The packet arrival rate depends on both the signal-to-noise ratio (SNR) at the recipient vehicle and the number of the recipient vehicles within the communication range from a sender. Since packets are randomly dropped in wireless channels, the packet arrival rate will be a function of the number of vehicles in the range, if vehicles are under similar SNR profiles. The number of vehicles has a huge impact on the packet drop rate when the safety message is transmitted by broadcasting. If a vehicle fails to receive the message due to low SNR, there will be still a chance that other vehicles receive the message successfully and deliver the message. When the number of vehicles decreases, the chance for successful reception will also be reduced and therefore the packet drop rate will increase. Moreover, in the low density situation, there might be no vehicle existing in a radio range as shown in Figure 1. Therefore, developing algorithms that work well in this low or zero number of vehicles scenario is very important. The proposed algorithm enhances the packet arrival rate drastically by using network coding even when no vehicles receive a message in some channels.

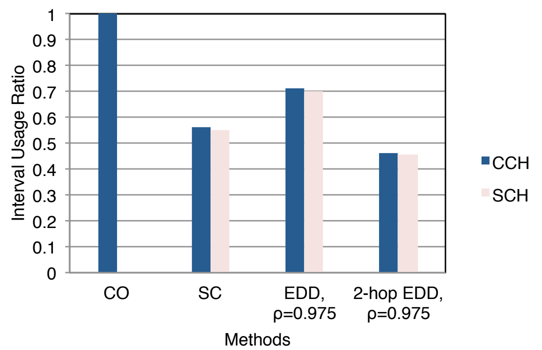
In Figure 3, the packet arrival rate at every measuring point is shown. Transferring packets in SCH intervals without considering the reduced vehicle density has a weakness in the reliability. The packet arrival rate of the BDD method is lowest out of the three methods. The SC method is better than the BDD method, but shows low reliability in low vehicle density simulation as shown in Figure 3a. The lack of vehicles to receive packets successfully in a selected channel is the reason for the low reliability in the SC method. However, in the EDD method, even though some packets fail to be relayed in a channel, there are packets successfully relayed in other channels. Using these surviving packets with the help of network coding, the EDD method can achieve higher reliability compared to other methods. The reliability of the EDD method increases as $\rho$ increases, which put more additional packets in a channel to overcome the loss of connectivity due to the low density.

Figure 4a shows the ratio of the time used by transferring packets in a channel to the duration of the SCH interval. For the EDD method, the amount of additional packets decreases as the vehicle density increases. This decrease shows the EDD method uses the channels efficiently. Another observation is the increase of the amount of packets as $\rho$ increases in the same density. A higher $\rho$ makes vehicles put more packets, which increases the reliability as shown in Figure 3. While the EDD method can change the amount of packets, other methods such as SC and BDD introduce a fixed number of packets in a channel. The BDD method uses the smallest resources in the SCH interval. However, the BDD method shows the lowest reliability as shown in Figures 3. Hence, as noted earlier, when a road side unit is far from the source vehicle, this method is not adequate.

Figure 4b shows how fewer CCH intervals used for deliver-




(a) Occupied bandwidth




(b) Used intervals

Fig. 4: Channel usage

ing traffic. As described in the introduction, the CCH interval can be congested easily by frequent short safety messages. If the large sized multimedia messages also need to be sent in the CCH interval, the congestion of a channel becomes severe and not much bandwidth would be left for other safety messages. To show the reduced usage of the CCH intervals, a CCH-interval only (CO) method is compared with our scheme as well as the single channel (SC) method. In the CO method, the packets are only sent in the CCH intervals. Both SC and EDD methods use less CCH intervals than the CO method since they use SCH intervals. This indicates that these algorithms can provide more bandwidth in the CCH interval for other safety applications such as beacon messages than the CO method.

As seen in Figure 4b, the SC method uses fewer intervals than the EDD method. The reason is that the EDD method needs to share packets in the CCH intervals instead of forwarding packets to the farthest vehicle as the SC method. However, the EDD method can use multi-hop forwarding in the SCH intervals. For the SC method, there is not much bandwidth left for the multi-hop forwarding since sending a large number of packets occupies most of bandwidth in the selected single channel. In the EDD method, the smaller number of packets than the SC method enables vehicles to use the multi-hop forwarding. The 2-hop EDD method forwards the packets twice in a channel. In Figure 4b, the 2-hop EDD method uses fewer CCH intervals compared to other methods.

## V. Conclusion and Future Works

In this paper, we present a noble idea to deliver multimedia emergency messages in a fast and reliable fashion. To avoid overloading the control channel in VANETs, multimedia contents are divided into available service channels such that the traffic load in each service channel can be minimized. However, loss of connectivity is a critical challenge if vehicle density is extremely low. To overcome this challenge, a network coding technique is incorporated with a noble channel survival concept to increase reliability while reducing the borrowed bandwidth from the service channels. Solid analytical derivation and extensive simulation results show the proposed algorithm significantly enhances reliability while minimizing the consumption of borrowed bandwidth compared to the single-channel scenario.

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