# Network Coding Assisted Cooperative Relay Scheme for Sender-oriented Broadcast in VANETs

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***Abstract*—In vehicular ad hoc networks (VANETs), a multi-hop broadcast protocol is required to disseminate traffic warning information. Reducing broadcast message overhead while maintaining a high dissemination ratio is a very challenging task. In this paper, we study how to improve the performance of sender-oriented broadcast protocols using network coding. We propose a scheme which uses network coding to improve the packet dissemination ratio without increasing the message overhead. In the proposed scheme, the source node specifies two relay nodes. With cooperation between two relay nodes, the proposed scheme significantly increases the packet reception ratio by utilizing the broadcast nature of wireless channel. We show the effectiveness of the proposed scheme by using both theoretical analysis and computer simulations.**

## I. Introduction

Vehicular ad hoc networks (VANETs) have been attracting interest for their potential role in intelligent transport systems. In a VANET, a multi-hop broadcast protocol is required for many applications such as a collision warning system. Due to the various vehicle densities for different road segments, providing an efficient broadcast protocol is a well-known challenging problem. When the vehicles are densely distributed, eliminating redundant broadcast is particularly important. When the network is sparsely connected, it is important to improve the packet reception ratio by cooperation of receivers in the neighborhood.

Since redundant broadcasts can cause a high packet collision probability and end-to-end delay, many protocols have been proposed to eliminate the redundant broadcasts. These protocols can be classified into two categories: (i) receiver-oriented protocols, and (ii) sender-oriented protocols.

In the receiver-oriented protocols, upon a packet reception, each node determines whether to forward or not by using an autonomous approach. In contrast to receiver-oriented protocols, in the sender-oriented protocols, each sender node specifies the next forwarder nodes. Wisitpongphan and Tonguz [1] have proposed three receiver-based broadcast schemes: weighted p-persistence, slotted 1-persistence, and slotted p-persistence schemes. There also have been some other approaches [2]–[5]. However, it is difficult for the receiver-based protocols to eliminate the redundant broadcasts. Therefore, in this paper, we consider sender-oriented protocols.

In sender-oriented protocols, the sender node specifies the relay nodes before the packet delivery. Generally, the selection of relay nodes is based on the information collected from exchanging hello messages among neighbor nodes. Sahoo et al. [6] have proposed BPAB, which aims to use the most distant node in the intended direction to relay messages. However, in a fading channel, the use of the most distant node results in lost messages. The research in [7] considers vehicle movements in the relay node selection. Since the link quality is also an important point, in our previous work, we proposed FUZZBR [8], a fuzzy logic [9] based broadcast protocol which chooses a relay node by considering inter-vehicle distance, vehicle movement and signal strength. Due to the dynamic network topology and channel fading, a packet loss also can be occurred at a forwarder node. In FUZZBR, retransmissions are used when a packet loss occurs at a relay node. However, the retransmissions are inefficient in terms of end-to-end delay and message overhead. To improve the packet reception ratio at the receivers without increasing the message overhead, we use a network coding based approach in this paper.

Network coding has been attracting interest in wireless networks due to its possibility of utilizing the broadcast nature of wireless channels. There have been many protocols applying the ideas from network coding [10]–[13]. The works in [10]–[13] are not proposed for vehicular ad hoc networks. Nguyen et al. [14] have analyzed the benefit of network coding in single-hop wireless networks. Li et al. [15] have applied network coding to a deterministic broadcast (sender-oriented) protocol. In a multi-hop network, the benefit can be improved by using cooperation among neighbors, which are not considered in [14], [15]. Some protocols have employed network coding to improve content distribution performance in lossy wireless networks [16]–[21]. These works are focused on downloading performance of large files, which are different from the aim of this research. Joint operation between data forwarding (relay node selection) and network coding are not clarified in these previous works [10]–[21].

This paper proposes a network coding assisted cooperative protocol in VANETs. In the proposed protocol, each sender node specifies the next relay nodes based on our previously proposed relay node selection algorithm [8]. The source node (the source of the network flow) encodes the data packets

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before the transmission using a linear network coding algorithm. The network coding is conducted for packet pairs (2 packets as a block). The source node selects two relay nodes. Each relay node specifies a next relay node. By utilizing the network coding and cooperation between two relay nodes, the proposed protocol can improve the packet dissemination ratio significantly.

The main contributions of this paper is as follows:

1) We propose a network coding assisted cooperative relay scheme for sender-oriented multi-hop broadcast in VANETs. We show the advantage of the scheme using theoretical analysis.
2) We incorporate the scheme with our previous proposed relay node selection scheme and evaluate the performance of the proposed approach using network simulations.

The remainder of the paper is organized as follows. In section II, we describe the notations and system model. In section III, we give a detailed description of the proposed protocol. In section IV, we give a theoretical analysis of the proposed protocol. Next, we present simulation results in section V. Finally, we present our conclusions and future works in Section VI.

## II. Notations and System Model

### A. Linear network coding

Linear network coding [22] is a technique which applies a linear transformation to a block of data before sending them. Due to the broadcast nature of wireless communications, network coding can be used to reduce the number of transmissions.

Suppose a sender node has $k$ native packets to send to multiple receivers. We use $X = (x_i, x_2, \ldots, x_k)^T$ to denote these packets. The sender can construct a batch of linearly coded packets $Y = CX$ as

$$Y = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \end{pmatrix} = \begin{pmatrix} c_{1,1} & c_{1,2} & \cdots & c_{1,k} \\ c_{2,1} & c_{2,2} & \cdots & c_{2,k} \\ \vdots & \vdots & \ddots & \vdots \\ c_{m,1} & c_{m,2} & \cdots & c_{m,k} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_k \end{pmatrix}. \quad (1)$$

where $C$ is the coding vectors. A receiver can retrieve the corresponding native packets (original packets) when the receiver receives more than $k$ linearly independent packets. The coding vectors are chosen from a Galois field. If the field size is sufficiently large, we can obtain linearly independent $k$ combinations using random selections.

### B. System model

The proposed protocol uses only a subset of nodes in the network to relay broadcast packets. Before broadcasting a packet, a sender node attaches the addresses of the relay nodes to the packet. Upon reception of a packet, a node rebroadcasts the packet only if it is itself included in the relay node list. Vehicles exchange information through hello messages. Every vehicle inserts its own position information in hello messages. We assume every node knows its own position and road map information because it is possible to get this position information from GPS-like positioning services.

In this paper, we consider network coding in broadcast communications in multi-hop vehicular ad hoc networks. We only consider intra-flow network coding (inter-flow network coding is beyond the scope of this paper). The network wide broadcast can be classified into several subproblems where each subproblem is a broadcast problem for a broadcast zone.

The broadcast zone (for details see [8]) is defined by a triad [road_no, sender_pos, direction]. "road_no" denotes the road number, "sender_pos" denotes the sender position and "direction" can be "outbound" or "inbound.". For example, the triad [1, ($x$, $y$, $z$), outbound] shows the area which is on the road No.1 and in the "outbound" direction of position ($x$, $y$, $z$).

We note that "outbound" and "inbound" are predefined in each road. For a loop-free road, since the start point and end point can be defined, we define the direction from the start point to the end point as "outbound," and define the direction from the end point to the start point as "inbound." For a loop road, we define the clockwise direction as "outbound" and the counter-clockwise direction as "inbound." As shown in Fig. 2, for road No.1, the direction from A to B is the outbound direction, and from B to A is the inbound direction. In here, "outbound" and "inbound" depend on the position of the vehicles but be independent of the driving directions of the vehicles. We say V1 is at the outbound direction of node V2. In contrast, V2 is at the inbound direction of node V1.

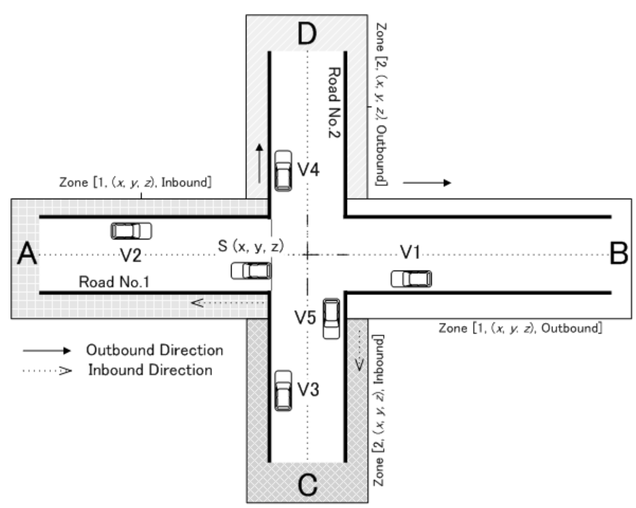


Fig. 2. An urban street topology and definition of road zone.

By introducing the concept of broadcast zone, the broadcast in VANETs can be divided into several subproblems of directed broadcasts. In each problem, each sender node (the source node or relay node) specifies the next relay nodes until all receivers are reached.

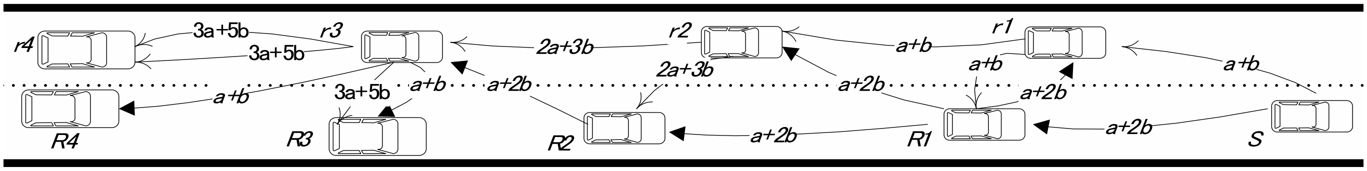


Fig. 1. Network coding assisted relay scheme in the proposed protocol.

## III. Proposed Protocol

### A. Protocol overview

The proposed protocol, FUZZBR-NC (Fuzzy logic based broadcast with network coding), specifies relay nodes to forward a packet. FUZZBR-NC selects relay nodes by jointly considering multiple metrics of inter-vehicle distance, node mobility and signal strength based on the fuzzy logic algorithm proposed in [8].

In the proposed protocol, the source node specifies 2 relay nodes for each broadcast zone. The source node processes network coding based on a batch of two packets (we say these two packets belong to the same generation). The source node uses network coding to encode 2 consecutive native packets to get 2 encoded packets, and transmits the encoded packets. Upon reception of a packet, a relay node could re-encode the packet or directly rebroadcast the packet depending on the reception status. If the node successfully receives both 2 packets, the node rebroadcasts the linear combinations of the received encoded packet (re-encoding). If the node only receives one of the 2 packets, it is impossible to decode or re-encode. In this case, the node rebroadcasts the packet. Each node, including relay nodes, can retrieve the native packets if the node receives any two encoded packets. By using network coding assisted relay scheme, the packet dissemination ratio can be significantly improved.

### B. Packet encoding at the source node and relay nodes

In the proposed protocol, the coding vectors are selected from

$$C = \begin{pmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 2 \\ 2 & 3 \\ 3 & 5 \end{pmatrix}. \tag{2}$$

Therefore, when the native packets are $a$ and $b$, the possible encoded packets are

$$Y = \begin{pmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 2 \\ 2 & 3 \\ 3 & 5 \end{pmatrix} \begin{pmatrix} a \\ b \end{pmatrix} = \begin{pmatrix} a+b \\ a+2b \\ 2a+3b \\ 3a+5b \end{pmatrix}. \tag{3}$$

Since the number of packets for each generation is 2, any two of coding vectors $C = (c_1, c_2, c_3, c_4)^T$ could be used for encoding the packets. The source code encodes the packets using any two coding vectors. The benefit of using these coding vectors is that we can transform from any two encoded packets to other two encoded packets. For example, we can get $(y_3, y_4)$ from $(y_1, y_2)$. This is very useful for improving the packet dissemination ratio by cooperation among neighbors because that each node can decode the packets as long as the node receives any 2 packets.

### C. Network coding assisted cooperative relay scheme

In the proposed protocol, the source node specifies 2 relay nodes for each broadcast zone. The source node processes network coding based on a batch of two packets. The source node uses the network coding algorithm to encode two consecutive packets and transmit. Upon reception of a packet, each node does the actions as shown in Algorithm 1.

As shown in Fig. 1, the source node $S$ encodes the packets $(a, b)$ to get the linear combinations $(a+b, a+2b)$. The source node selects two relay nodes $r1$ and $R1$. Node $r1$ and node $R1$ receive the packet $a+b$ and $a+2b$ respectively. After that, node $r1$ and node $R1$ rebroadcast the packets they received. In this way, node $r1$ and node $R1$ can receive from each other one packet and successfully decode to get the original native packets. The packet forwarding is also transferred to the next hop relay nodes $r2$ and $R2$. In here, since $r2$ receives two encoded packets, the node transforms the two received packets to get a new linear combination of native packets $(2a+3b)$. The node $R2$ can get the original packets by decoding $(2a + 3b, a + 2b)$. Typically, since each node is aware of the communications happening in the neighborhood, it is possible to select a different relay node from other nodes. In the case when both $r2$ and $R2$ select node $r3$ as the next relay node, the node $r3$ selects 2 next relay nodes. This happens very rarely especially in a high-density networks.

### D. End-to-end delay consideration

The proposed protocol sends data with encoding based on a batch of 2 packets. This incurs a concern of the possible delay to the first packet. However, in real-world scenarios, one packet is always impossible to contain all necessary information that should be broadcasted. There are always more than two packets consecutively arriving in the send queue. This means that the batch processing does not incur too much delay. Moreover, with the network coding, many retransmissions can be avoided, which reduces retransmission delays.

## IV. Theoretical analysis

### A. Successful forwarding probability

We first analyze the case of typical sender-oriented protocols. The relay nodes are specified by the upstream sender node. For a fair comparison, we assume that only one relay

**Algorithm 1** Actions at each relay node upon reception of an encoded packet

```
if (The packet is the first packet of this generation) then
    Wait for a short time period to check whether could receive the second encoded packet or not.
    if (The second encoded packet is successfully received) then
        if (A rebroadcast at the other relay node is confirmed) then
            Transform the encoded packets to a new encoded packet (any one of other two different linear combinations), and transmit the new packet.
        else
            Transform the 2 encoded packets to get 2 new encoded packets (with two different linear combinations), and transmit these new packets (however, if a rebroadcast at the other relay node is confirmed after the first transmission, the second packet would be canceled).
        end if
    else
        Rebroadcast the received encoded packet.
    end if
else
    if (Any rebroadcast of the packet is detected) then
        Transform the encoded packets to a new encoded packet (any one of other two different linear combinations), and transmit the new packet.
    else
        Transform the encoded packets to get 2 new encoded packets (other two different linear combinations), and transmit these new packets consecutively (by specifying different relay nodes for different packets).
    end if
end if
```

node is selected (in the proposed protocol, the average number of relay nodes for each packet is the same because that two relay nodes are selected for two packets). If the packet loss probability of the link is $p_l$ (for simplicity, we assume this probability is constant), the probability for successful forwarding of two consecutive packets is

$$PF = (1 - p_l)^2. \tag{4}$$

In the proposed protocol, the probability is

$$\begin{aligned} PF_{nc} =& 1 - p_l^4 - \binom{4}{1}(1 - p_l)p_l p_l p_l \\ & - \binom{2}{1}(1 - p_l)(1 - p_l)p_l p_l. \end{aligned} \tag{5}$$

The rationale behind this is that the forwarding (in the proposed protocol) only fails when **(i)** the total number of received packets at two relay nodes is smaller than 2, or **(ii)** two relay nodes receive only one packet and the packet received at two relay nodes are the same.

When the $p_l$ is 0.1, this probability is 0.9801. However, without network coding we get only 0.81 according to (4). This shows the network coding used in the proposed protocol can significantly improve the successful forwarding probability.

### B. Packet reception probability lower bound

We analyze the lower bound for packet reception probability of two consecutive packets at receiver nodes (except for the relay nodes). We assume the data packets are successfully forwarded at the relay nodes. Each node at least has two chances to receive a data packet: one is from the sender node and the other is from the relay node. Without network coding, the probability lower bound is

$$PR = (1 - p_l^2)^2. \tag{6}$$

In the proposed protocol, a node can decode the packets when 2 or more encoded packets are received. Therefore, we can calculate the probability as

$$PR_{nc} = 1 - \left(\binom{4}{0}p_l^4 + \binom{4}{1}(1 - p_l)p_l^3\right). \tag{7}$$

When $p_l$ is 0.1, the probability in the proposed protocol is 0.9963. Without network coding, this probability is 0.9801.

### C. Expected number of messages for a successful delivery to relay nodes

For simplicity, we assume all packets can be received by one retransmission at the sender node. The expected number of transmissions for each data packet is

$$N = 2p_l + 1 - p_l. \tag{8}$$

The proposed protocol can use one data packet to recover any one packet loss in the same generation even if the lost packets are different for different nodes. Therefore, in the proposed protocol, the expected number of data messages per data packet is

$$N_{nc} = \frac{1}{2}\left(4p_l^4 + 3(1 - PF_{nc} - p_l^4) + 2PF_{nc}\right), \tag{9}$$

where $PF_{nc}$ is as shown in (5). When $p_l$ is 0.1, without network coding, the number is 1.1. In the proposed protocol, the number is 1.01.

## V. Simulation Results

We used network simulator ns-2 (version 2.34) [23] to conduct simulations. Simulation environments are shown in Table I. We used SUMO [24] and TraNS [25] to generate street scenarios. In SUMO, a vehicle's speed is adapted to the speed of the leading vehicle. In our scenarios, the maximal vehicle velocity was 18m/s. The distance between any two neighboring intersections was 400 m. Each road had one lane in each direction. There were 619 nodes moving toward their destinations (these destinations were selected randomly).

TABLE I
SIMULATION ENVIRONMENT

| | |
|---|---|
| Street Scenario | 5 horizontal roads and 5 vertical streets |
| Topology | 1700m × 1700m |
| Number of nodes | 619 |
| Mobility generation | SUMO + TraNS |
| Number of sources | 5 to 55 |
| Number of packets | 50 packets at each source per flow |
| Packet size | 512bytes |
| Data rate | 1 packet per sec |
| MAC | IEEE 802.11 MAC (2Mbps) |
| Propagation model | Nakagami Model |
| Simulation time | 150 s |

TABLE II
PARAMETERS OF NAKAGAMI MODEL: FREEWAY (STREET)

| gamma0_ | gamma1_ | gamma2_ | d0_gamma_ | d1_gamma_ |
|---|---|---|---|---|
| 1.9 (2.0) | 3.8 (2.0) | 3.8 (2.0) | 200 (200) | 500 (500) |
| m0_ | m1_ | m2_ | d0_m_ | d1_m_ |
| 1.5 (1) | 0.75 (1) | 0.75 (1) | 80 (80) | 200 (200) |

Therefore, we can simulate a street which has various node densities on different road segments. We generated scenarios with various number of broadcast flows. We generated multiple flows (2 or 3) for each source node to simulate the consecutive packet arriving at the send queue.

We used the Nakagami propagation model. The parameters of the Nakagami model are shown in Table II. We used these parameter values because they model a realistic wireless channel of vehicular ad hoc networks [26]. Other simulation parameters were the default settings of ns-2.34. After the first 20 seconds (to allow the exchange of hello messages), senders sent messages with a packet size of 512 bytes. All nodes in the network were defined as intended receivers. The simulation time was 150s. We launched simulations with 50 different scenarios, and analyzed the average value of the results.

FUZZBR-NC was compared with FUZZBR-w/o-ReTr (FUZZBR without retransmissions) and FUZZBR [8]. The performances of other existing approaches can be found in [8]. In FUZZBR, a sender node retransmits a packet when the forwarding of the packet at a specified relay node is not detected in a predefined time period (40ms in the simulation). Since a packet might be retransmitted multiple times depending on the reception status, to avoid an endless retransmission, for each packet, we set the maximum number of retransmission times to be 4. In contrast to FUZZBR, FUZZBR-w/o-ReTr does not take any action when a packet loss occurs at a relay node. In the following simulation results, the error bars indicate the 95% confidence intervals.

### A. Number of Messages

Fig. 3 shows the number of messages per data packet for various numbers of broadcast flows. In FUZZBR, we observe an increase of the number of messages with the increase of the number of sources. This is due to the retransmissions following the increase of the number of packet collisions. FUZZBR-w/o-ReTr shows lower number of messages due to the increase of the packet losses. The proposed protocol (FUZZBR-NC) shows a low message overhead because that the network coding assisted cooperative relay scheme can significantly increase the reliability at the relay node without retransmissions.

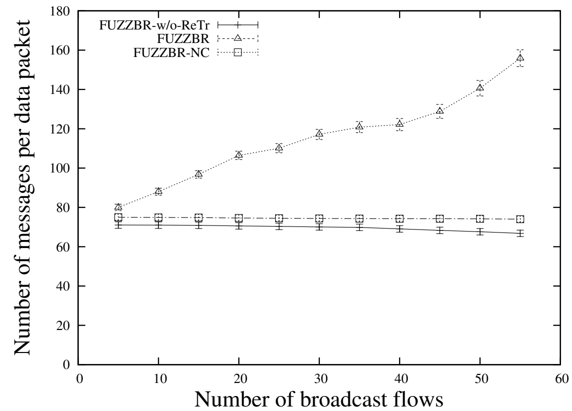


Fig. 3. Number of messages per data packet for various numbers of broadcast flows.

### B. Packet Dissemination Ratio

Fig. 4 shows the packet dissemination ratio for various numbers of broadcast flows. We calculate this performance metric as the number of data messages received by all nodes in the network divided by the multiplication of the number of data messages generated by the broadcast flows and the number of nodes in the network.

Although FUZZBR-w/o-ReTr can choose the best relay node to relay a data message, the message still could be lost at the relay node due to the packet collisions or other reasons. FUZZBR solves this problem using retransmissions at the sender node. However, the retransmissions incur a high overhead, especially when the traffic is heavy (as we can see from Fig. 3). The network coding approach used in the proposed protocol can significantly increase the packet dissemination ratio. As shown in Fig. 4, the proposed protocol can recover many packet losses using the cooperative relay scheme.

### C. End-to-end delay

Fig. 5 shows end-to-end delay for various numbers of broadcast flows. In the simulation, without loss of generality, for each data message, all nodes in the network are defined as intended receivers. However, it makes no sense to average end-to-end delays for all nodes in the network. We consider that 600 m is the distance within which a short propagation delay is required. Therefore, in the delay calculation, for each source node, we only use the receiver nodes of which the distance from the source node is smaller than 600 m.

The proposed protocol shows a low end-to-end delay due to the following two reasons: (i) the proposed protocol reduces the number of messages as compared to FUZZBR, (ii) the

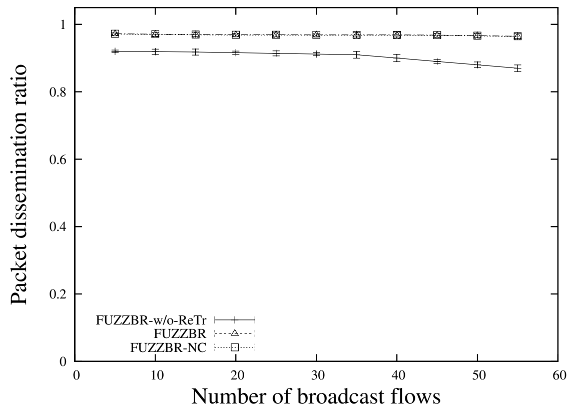


Fig. 4. Packet dissemination ratio for various numbers of broadcast flows.

proposed protocol improves the packet reception probability at the receiver nodes using network coding, which reduces the delay incurred from retransmissions.

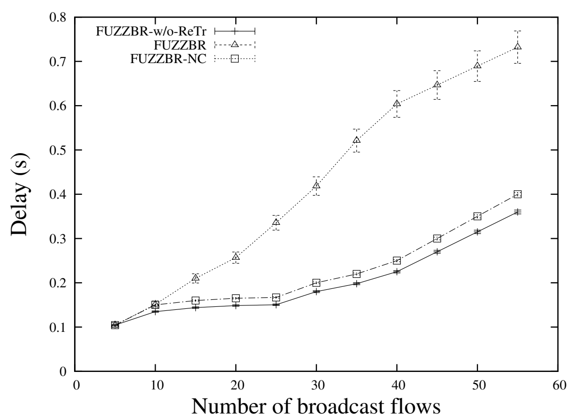


Fig. 5. End-to-end delay for various numbers of broadcast flows.

## VI. Conclusions and Future Works

We proposed a network coding assisted cooperative relay scheme for sender-oriented multi-hop broadcast protocols in VANETs. In the proposed scheme, the relay nodes cooperate with each other to recover from packet losses by employing a network coding algorithm to encode packets. The theoretical analysis and simulation results showed the proposed scheme can significantly improve the packet dissemination ratio without increasing message overhead. In our future work, we will consider using inter-flow network coding to further improve the network overall throughput.

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