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# Improving Reliability of Message Broadcast over Internet of Vehicles (IoVs)*

Elias Eze C, Sijing Zhang, Enjie Liu
Centre for Wireless Research, Institute for Research in Applicable Computing (IRAC)
Department of Computer Science and Technology, University of Bedfordshire, Luton, England
elias.eze@study.beds.ac.uk, {sijing.zhang, enjie.liu}@beds.ac.uk

***Abstract*— With the envisioned era of Internet of Things (IoTs), all aspects of Intelligent Transportation Systems (ITS) will be connected to improve transport safety, relieve traffic congestion, reduce air pollution, enhance the comfort of transportation and significantly reduce road accidents. In IoVs, regular exchange of current position, direction, velocity, etc., enables mobile vehicles to predict an upcoming accident and alert the human drivers in time or proactively take precautionary actions to avoid the accident. The actualization of this concept requires the use of channel access protocols that can guarantee reliable and timely broadcast of safety messages. This paper investigates the application of network coding concept to increase content of every transmission and achieve improved broadcast reliability with less number of retransmission. In particular, we proposed Code Aided Retransmission-based Error Recovery (CARER) scheme, introduced an RTB/CTB handshake to overcome hidden node problem and reduce packets collision rate. The performance of CARER is clearly shown with detailed theoretical analysis and further validated with simulation experiments.**

**Keywords— VANET, Broadcast, DSRC, MAC, XOR**

## I. INTRODUCTION

Recent estimations by experts maintain that there will be 25 billion connected devices by the end of this year, and by 2020, 50 billion devices [1] among which vehicles will constitute a significant portion. This envisaged new era of IoTs is driving the evolution of envisioned Vehicular Ad-hoc Networks (VANETs) into the Internet of Vehicles (IoVs) paradigm. With IoVs paradigm, each mobile node is considered as a smart object equipped with multi-sensor platform, computation units and communications technologies to provide either direct or indirect IP-based connectivity to the Internet and to other vehicles. Additionally, a vehicle in IoVs is considered a multi-communication model which enables the interactions between intra-vehicle components, vehicles-to-vehicles (V2V), vehicles-to-road side units (V2I), or vehicles-to-pedestrians (V2X). IoVs is an area of significant importance considering nowadays' increasingly overcrowded motorways. Effective vehicular connectivity techniques can significantly enhance efficiency of travel, reduce high rate of road traffic accidents and improve safety of both drivers, passengers and pedestrians as well as mitigate the impact of road congestion, and overall provide a more comfortable travelling experience.

According to UK Department for Transport's June 2015 reports, vehicle traffic levels increased by 2.4 percent between 2013 and 2014 with a total of 194,477 casualties of all severities in reported road traffic accidents during 2014 alone [2]. In a similar case, a recent report by WHO on road traffic deaths in selected African countries says Nigeria accounts for the highest fatalities with 33.7 percent per 100,000 population every year. It is estimated that the volume of traffic in the Nigeria will increase from eight million at present, to 40 million by 2020 [3]. This calls for all hands on deck to safeguard lives as IoTs finds its way into reality in near future. Most of these traffic accidents are avoidable using ITSs and safety vehicular communication systems. Statistics have shown that over 60 percent of chain traffic accidents could be prevented if drivers are informed about an automobile accident at least 500ms ahead of time [4].

Though many research results have been published in different areas of IoVs like routing, security and broadcasting, one intrinsic area that still poses a significant challenge is safety message broadcast reliability. The harsh environment of VANETs often lead to possibility of losing data packets meant to deliver life-saving information, thereby making communication reliability a challenge. This challenge has been tackled with approaches like RTS/CTS, BRTS/BCTS, Automatic Repeat reQuest (ARQ) and ACK/N-ACK [5-6]. However, these approaches can only work efficiently with one-to-one, unicast communication as opposed to IoVs where traffic safety depends on many one-to-many, broadcast communication scenarios. Hence, relying on traditional error recovery mechanisms to ensure reliability in vehicular networks would worsen the problem rather than improving reliability as they will lead to severe network congestion thereby deteriorating the highly desired message broadcast reliability.

Many results have also been published on retransmission-based error recovery mechanisms [7-8] for VANETs. The key aim of repetition-based error recovery technique is to allow each node[1] to repeat the transmission of its raw packet(s) within the timeout period thereby giving the nodes within their transmission range multiple chances of receiving the packets not correctly received. Since retransmission increases network overhead and after a given number of consecutive repeats may lead to excess channel congestion, this paper investigates the possibility of reducing the number of retransmissions while increasing the content and efficiency of each retransmission. Hence, it enables all the stations within the radio range to receive the combined original packets using network coding concept [9] and reduce contention with the aid of a node selection metric, η to rebroadcast the encoded messages.

[1] Nodes, stations, and vehicles are used interchangeably in this paper.

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This paper exploits the manifold benefits of network coding to achieve reliable and efficient communication in IoVs by proposing a scheme called Coding Aided Retransmission-based Error Recovery (CARER) communication scheme. This scheme enables each node to perform an exclusive OR (XOR) operation on its packet pool, ρ[2] and to retransmit the XORed packets in one-hop broadcast to other vehicles within their vicinity. Broadcasting the XORed version instead of the raw packets creates ample opportunity for high rate of lost packets recovery from each repetition.

The remaining part of the paper is arranged as follows: the background and review of related work are presented in Section II. Section III introduces the proposed CRER scheme, followed by an analysis of packet recovery probability (PRP) as a function of the total packet loss probability (PLP) in Section IV. Analysis of Packet Collision Probability (PCP) is presented in Section V while Section VI presents the Location-aware algorithm (LAA). Section VII presents the scheme validation and analysis. Section VIII discusses the analytical and simulation results, while Section IX concludes the paper.

## II. PROPOSED CARER PROTOCOL

We consider a vehicular highway of $n$ lanes with half of the lanes used for nodes moving to one direction and the other half used for nodes moving to the opposite direction. The vehicles maintain directional velocity (because nodes only move in two different directions in highways) which is randomly distributed among a discrete set $V = \{(30 + 10 * k)m/s,\ \forall k \in [0,5]\}$. The nodes are equipped with a Global Positioning System (GPS) which is used to acquire position information, moving direction and velocity, and a half-duplex transceiver for wireless communication. Fig. 1 shows a Location-aware Algorithm (LAA) which each node uses to calculate both the distance and direction of the neighbour vehicles. The CSMA/CA-based IEEE 802.11e MAC [10-11] is used for channel access and service differentiation among multiple vehicles. In order to ensure reliable transmissions of the broadcasted encoded messages, the traditional three-way handshake of CSMA/CA-based MAC is adopted by using request-to-broadcast and clear-to-broadcast (RTB/CTB) frames exchanged before encoded messages are transmitted. Additionally, the proposed CARER protocol enables the selection of one vehicle for rebroadcasting the encoded message towards the intended propagation direction based on a metric η specifically designed for vehicular communications.

### A. Safety Message Coding

With the proposed CARER scheme, each mobile node will perform an exclusive OR (XOR) operation over its own generated raw packets and any other packets contained in ρ. Then, using location-aware algorithm (LAA) and a rebroadcasting metric η, another node is selected to retransmit the encoded packets instead of the source vehicles repeating their raw packets indiscriminately. Here, nodes $i+1$ and $i-1$ retransmit the encoded versions of the packets $[i \oplus (i+1)]$ and $[(i-1) \oplus i]$ for $m+1$ times respectively to enable every vehicle within their vicinity to recover any packet(s) they may have lost.

Packet recovery probability (PRP) is defined as the probability that a raw packet is lost but recovered with CARER scheme after $m$ number of retransmissions. We used analytical study to derive PRP as a function of the total error probability. Let $P_l(CARER)$ be the loss probability of CARER protocol. Then, we have

$$P_l(CARER) = \in_i [(1-\alpha_i)(1-\beta_i)] \tag{1}$$

Where $\in_i$ represents the packet error probability, $\alpha_i$ and $\beta_i$ represent the probability that node $i$ can successfully recover raw packet $i$ after successfully decoding the encoded retransmitted packets $[(i-1) \oplus i]$ and $[i \oplus (i+1)]$ respectively. $P_l(C)$ implies that: 1) node $i$ lost the raw packet $i$; 2) node $i-1$ cannot recover raw packet $i$ from the encoded packet retransmission $[(i-1) \oplus i]$; and (3) node $i+1$ cannot recover raw packet $i$ from the encoded packet retransmission $[i \oplus (i+1)]$ as well. Considering that node $i-1$ repeats the encoded packets $[(i-n) \oplus ni]$ for a total of $m+1$ times before all the vehicles within the radio range of vehicle $i-1$ are able to successfully recover their lost packet(s), it follows that $\alpha_i$ is the probability that at least a single packet was received out of the $m+1$ retransmitted encoded packet $[(i-n) \oplus ni]$ by vehicle $(i-1)$. Hence, the encoded retransmission $[(i-n) \oplus ni]$ by vehicle $(i-1)$ can be recovered as shown in the formula:

$$\alpha_i = \mu_i \left( \frac{(1 - \in_{i-n}^{m+1})}{1 - (1 - \in_{i-n})} \right) \tag{2}$$

Where $\mu_i$ represents the probability that vehicle $(i-1)$'s retransmitted encoded packets, $[(i-n) \oplus ni]$ can be decoded by node $i$ when successfully received. Since vehicle $i-1, i-2, \ldots, i-n$ must have at least one of $i-1, i-2, \ldots, i-n$ raw packets to be able to decode any of the encoded packets such as $[(i-1) \oplus i]$, $[(i-2) \oplus 2i]$, $\ldots, [(i-n) \oplus ni]$ retransmissions, $\mu_i$ as well means that vehicle $i-n$ already has at least one of the $[(i-1) \oplus i], [(i-2) \oplus 2i], \ldots, [(i-n) \oplus ni]$ packets and therefore can decode the retransmissions of the encoded packets. So that we can now have:

$$\mu_i = 1 - \in_{i-n} \tag{3}$$

Where $\in_{i-n}$ represent the loss probability of the encoded packets $[(i-n) \oplus ni]$. Hence, eq. (3) can now be rewritten as:

$$\alpha_i = \left( \frac{(1 - \in_{i-n})(1 - \in_{i-n}^{m+1})}{1 - (1 - \in_{i-n})} \right) \tag{4}$$

With the encoded safety messages, the area of interest for retransmission is the immediate transmission range of vehicle $i$ and $i-n$ which is successfully selected to rebroadcast it for the reach of the immediate cluster of vehicles within its range but out of range to the source node (see as exemplified in Fig. 1). From eq. (4), it is observed that $\alpha_i$ strongly depends on

[2] The set of packets, $[P_1, P_2, P_3, \ldots, P_n]$ contained in the virtual buffer which are heard within the last $t$ seconds.

$\alpha_{i-1}, \alpha_{i-2}, \alpha_{i-3}$, and so on till $\alpha_{i-n}$. However, it is assumed that the difference between $i-1, i-2, \ldots, i-n$ is trivial and insignificant. Hence, substituting $i-n$ with $i-1$ in (4), gives a linear equation of $\alpha_i$ which can be solved as

$$\alpha_i = \left(\frac{(1-\in_{i-1})(1-\in_{i-1}^{m+1})}{1-(1-\in_{i-1})}\right) \quad (5)$$

Following the above analysis for $[(i-n) \oplus ni]$, encoded message $[ni \oplus (i+n)]$ retransmission by vehicle $(i-n)$ can be decoded by using the formula

$$\beta_i = X_i\left(\frac{(1-\in_{i+n}^{m+1})}{1-(1-\in_{i+n})}\right) \quad (6)$$

Where $X_i$ represents the probability that vehicle $(i+1)$'s retransmitted XORed packets, $[ni \oplus (i+n)]$ can be decoded by node $i$ when successfully received. Again, following the steps that lead to the derivation of eq. (3), we have

$$X_i = 1-\in_{i+n} \quad (7)$$

Then, putting eq. (7) into (6) gives us

$$\beta_i = \left(\frac{(1-\in_{i+n})(1-\in_{i+n}^{m+1})}{1-(1-\in_{i+n})}\right) \quad (8)$$

Hence, substituting $i-n$ with $i-1$ in eq. (9) gives a linear equation of $\beta_i$ which can be solved as

$$\beta_i = \left(\frac{(1-\in_{i+1})(1-\in_{i+1}^{m+1})}{1-(1-\in_{i+1})}\right) \quad (9)$$

Finally, putting eq. (6) and (9) into (1), $P_l(CARER)$ can be rewritten as

$$P_l(CRER) = \in_i\left(\left(1-\frac{[(1-\in_{i-1})(1-\in_{i-1}^{m+1})]}{1-(1-\in_{i-1})}\right) \times \left(1-\frac{[(1-\in_{i+1})(1-\in_{i+1}^{m+1})]}{1-(1-\in_{i+1})}\right)\right) \quad (10)$$

Once more, with reference to the assumed triviality of the difference between vehicles $i-1, i-2, \ldots, i-n$ and $i+1, i+2, \ldots, i+n$ with respect to vehicle $i$, both the loss probability of the encoded safety messages $i-1$ (i.e. $\in_{i-1}$) and $i+1$ (i.e. $\in_{i+1}$) can be represented as $\in_i$. Hence, eq. (10) can be simplified and expressed as a functions of $m$ and $\in_i$, resulting in

$$P_l(CRER) = \in_i\left(\left(1-\frac{[(1-\in_i)(1-\in_i^{m+1})]}{1-(1-\in_i)}\right) \times \left(1-\frac{[(1-\in_i)(1-\in_i^{m+1})]}{1-(1-\in_i)}\right)\right) \quad (11)$$

Then, the recovery probability $(P_r)$ of CARER scheme will be given as:

$$P_r(CARER) = 1 - P_l(CARER)$$

$$= 1 - \left[\in_i\left(\left(1-\frac{[(1-\in_i)(1-\in_i^{m+1})]}{1-(1-\in_i)}\right) \times \left(1-\frac{[(1-\in_i)(1-\in_i^{m+1})]}{1-(1-\in_i)}\right)\right)\right] \quad (12)$$

Consequently, the overall measure of performance improvement in terms of Packet(s) loss recovery potential of the proposed network coding assisted scheme can be determined by the results obtained of eq. (12).

*B. RTB/CTB Handshake*

In order to overcome the hidden node problem and reduce packets collision as well as minimize the overall network overhead, sender nodes engage in RTB/CTB handshake with the recipients within the radio transmission coverage of the sender. If the furthest vehicle away can be selected with RTB/CTB packets, then other nodes in between can overhear the transmission as well. The source node adheres to all the rules of CSMA/CA transmission rules of IEEE 802.11 while attempting to broadcast an RTB packet.

Fig. 1 shows the structure of an RTB frame with an additional five fields (*XOR_info, Vel, Dir, X* and *Y*) as opposed to conventional RTS frame. The *XOR_info* field holds the information about the source node that initially broadcasted the encoded packets. The other fields include V*el* which is the relative moving velocity of the source node, *Dir* which is the encoded message desired propagation direction, while *X* and *Y* represent the coordinates of the transmitter. *XOR_info* field, in turn, contains 1) the address of the source node *Init A*, 2) the coordinates (*Init X* and *Init Y*) of the source node, and 3) the encoded message's sequence number *XOR Seq*.

The source node with the encoded message for transmission will first broadcast a RTB frame and obeys the CSMA/CA-based MAC procedure by starting a retransmission timer with value set as $T_{RTB\_r} = T_{DIFS} + T_{RTB} + T_{CTB}$, where $T_{DIFS}$ represents the time duration of a Distributed coordination function Inter-Frame Space (DIFS), and $T_{RTB}$ and $T_{CTB}$ represent the transmission time durations of an RTB and a CTB frame respectively. In the event of collision with no CTB response from an eligible candidate within $T_{RTB\_r}$ time duration, the sender vehicle immediately contends for channel access to rebroadcast an RTB message until a CTB message is successfully received. With the help of the broadcast node s'

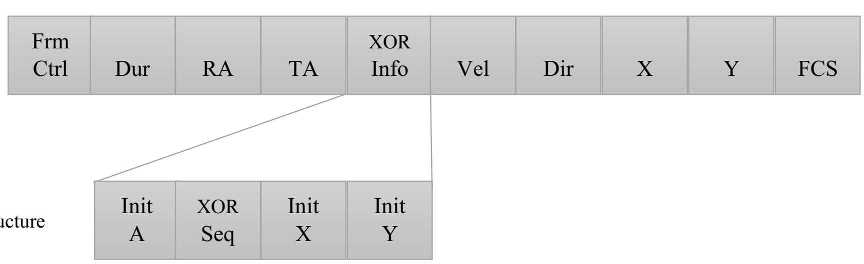


Fig. 1: An RTB frame structure

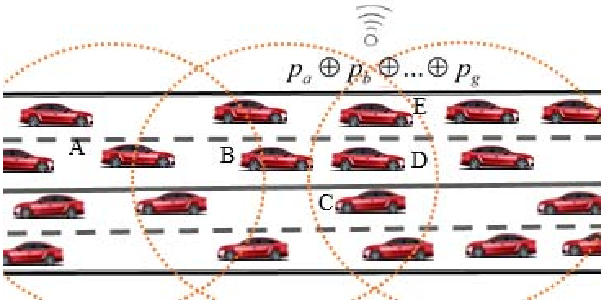


Fig. 2: CARER: Vehicle A selects another node to retransmits the XORed message to enable the vehicles within one-hop broadcast range recover lost packets and those beyond its one-hop broadcast range to receive the encoded message.

information contained in the *Dir* fields of an RTB frame, any vehicle that overhears the RTB frame but not moving in the desired propagation direction of the encoded message will not respond with a CTB message but will set its Network Allocation Vector (NAV) and defer its own transmissions accordingly.

On the contrary, if a vehicle receives an RTB frame, it will use the LAA to check whether it is eligible for replying a CTB frame based on the position information contained in the received RTB frame. This is possible since each vehicle broadcasts its periodic status message which contains its address, position, moving speed, and direction of movement. Hence, using the LAA after receiving an RTB frame, a node is able to know if there are other nodes within the radio transmission range of the source node ahead of itself. However, if the node's position is between the source vehicle and other vehicles in radio coverage of the sender vehicle, it will not reply with a CTB frame because there is no distance gain along the encoded message desired propagation direction. Hence, the node's NAV will be updated in accordance with the *duration* field in the received RTB frame. Otherwise, a backoff timer will be started for replying with a CTB frame, after which the node keeps sensing the channel in the meantime to receive the encoded message for a rebroadcast. For instance, in Fig. 1, node *B* will not reply with a CTB frame after learning that there are other vehicles with higher distance gain using the LAA algorithm but rather updates its NAV. Likewise, vehicle *C* will also update its NAV after receiving the RTB since the direction information contained in the *direction* field of the RTB frame shows a different intended propagation direction.

If there exist only node $i$ with the highest distance gain within the transmission coverage and in the desired propagation direction of the source vehicle, then node $i$ becomes the eligible candidate and will start a backoff timer upon receiving an RTB frame for replying with a CTB frame to the source node. However, if there exist more than one eligible station as is the case of Fig. 1 (see node *D* and *E*), each eligible node will start a backoff timer for replying with a CTB frame with the help of the following metrics: 1) the gain in distance $\Delta d$ between node $i$ and the source node; 2) the received signal-to-noise-ratio (SNR) and packet error rate (PER) $e$, which can be estimated from the received RTB frame, and 3) the relative velocity between node $i$ and the source node. Depending on these criteria, the rebroadcasting metric η is evaluated and used to determine and select the most suitably qualified candidate for rebroadcasting the encoded packets to enable the nodes outside the radio coverage of the source node to receive the encoded packets. Mathematically, this metric is given by

$$\eta = \frac{e}{E_{max}} + \left[\frac{\Delta v}{V_P} + \left(1 - \frac{\Delta d}{R}\right)\right] \tag{13}$$

where $\Delta d$ is the encoded packet transmission distance given by $\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$, $R$ is the maximum IEEE 802.11p radio signal transmission coverage defined in [12], an IEEE standard drafted to support wireless access in vehicular environments (WAVE) [13], $e$ is the PER of the encoded packet which is determined based on the calculated SNR, $E_{max}$ is the maximum acceptable PER as defined in [14], $\Delta v$ and $V_P$ is the relative and maximum velocity respectively.

CARER protocol requires the selected vehicle to reply the source vehicle with a CTB frame within the DIFS interval in order to prevent interruption of an RTB/CTB handshake mechanism between itself and the selected node from other flows. Finally, the station with the minimum value of η will reply the source node with a CTB frame first and, then becomes the chosen node to rebroadcast the encoded message. In general, a mobile station with the longest distance gain, small relative velocity, and better channel conditions is the most suitably qualified candidate for rebroadcasting the encoded message. Eventually, other vehicles will end up updating their NAVs accordingly whenever they receive or overhear other RTB/CTB frames.

By applying the concept of mini-slot [15-17], the DIFS interval is further divide into a number of mini-slots. Hence, in the proposed CARER scheme, vehicles start a timer in terms of mini-slots to enable them to contend for medium access. Currently, to the best of our knowledge, there has not been a harmonized agreement on fading and shadowing models so far for vehicular communication systems [18]. In order to determine the received signal power, we adopt the Friis free-space model [19] in our theoretical analysis. In line with the work of Proakis [20], the bit error rate (BER) of the encoded messages over an additive white Gaussian noise channel with binary phase-shift keying modulation is taken as $Q\left(\sqrt{(2\mathcal{E}_b/N_0)}\right) = Q\left(\sqrt{(2P_r/r_b N_0)}\right)$, where $Q(x) = \left(1/\sqrt{2\pi}\right)\int_x^{\infty} e^{-t^2/2dt}$, $N_0$ is the noise power spectral density, $\mathcal{E}_b$ is the received energy per bit, $r_b$ is the basic rate and $P_r$ is the received power. In [21], it is given that $e = 1 - \left(1 - Q\left(\sqrt{(2P_r/r_b N_0)}\right)\right)^L = 1 - \left(1 - Q(I/\Delta d)\right)^L$, where $I = \sqrt{(2P_t G_t G_r (c/f_c)^2)/(r_b N_0 (4\pi)^2)}$, $P_t$ is the transmission power, $G_t$ is the transmitter antenna gain, $G_r$ is the receiver antenna gain, $c$ is the measured speed of light, and $f_c$ is the carrier frequency. Using the definition of PER $e$ as given above, the rebroadcasting node selection metric (1) can be rewritten as

$$\eta = \left[1 - \left(1 - Q\left(\frac{I}{\Delta d}\right)\right)\right]^{L} (E_{max})^{-1} + \left[\frac{\Delta v}{V_P} + \left(1 - \frac{\Delta d}{R}\right)\right] \quad (14)$$

Therefore, η is a function of $\Delta v$, $V_P$, and $\Delta d$ once the values of the parameters such as $I$, $L$ and $R$ are obtained. Consequently, it shows that the selection of mini-slots for network channel access contention solely depends on difference in distance as well as relative velocity to the source vehicle.

### C. Media Access Delay

The delay $T_r$ caused by the process of choosing a vehicle to rebroadcast the encoded messages is the function of the time interval between the transmission of an RTB frame by the source node and successful selection of a vehicle that will rebroadcast the encoded messages. Hence, this delay $T_r$ is computed as the addition of the two delays experienced due to an RTB?CTB handshake, and we have

$$T_r = AIFS[4] + T_{RTB} + T_{CTB} \quad (15)$$

If we denote w as the average time interval it took the backoff timer of a broadcast vehicle to reach 0, then

$$T_{RTB} = \sum_{m=0}^{\infty} 4p^m(1-4p)\left[m\left(w + t_{rtb\_r}\right) + (w + t_{rtb})\right] \quad (16)$$

where $4p^m(1-4p)$ is the probability that the source node successfully transmits an RTB frame at backoff stage $m$ with average corresponding delay of $m\left(w + t_{rtb\_r}\right) + (w + t_{rtb})$. Since our protocol enables nodes to start a timer in terms of mini-slots to enable them to contend for channel access, if the $i^{th}$ time slot is selected then $w$ can be represented with $w|i \left(i \in \left[0, CW[4]\right]\right)$ which then allows the source node to uniformly select a time slot from $\left[0, CW[4]\right]$ so that

$$w = \sum_{i=0}^{CW[4]} \left(\frac{1}{1 + CW[4]}\right) . (w|i) \quad (17)$$

and

$$w|i = \begin{cases} \sum_{d=1}^{i} \bar{X}_t\,, & i \in \left[0, CW[4]\right] \\ 0, & i = 0 \end{cases} \quad (18)$$

where $X_t$ represents the average time delay in the $i^{th}$ time slot of $CW[4]$ and $\bar{X}_t$ denotes the mean of the average time delay. This time delay may have been caused by the frozen time owing to a successful message transmission, collisions or simply an idle time slot.

The total access delay $T$of the encoded message is a function of the time interval between the arrival of the message at the head of the queue and its acknowledgement. This time interval consists of 1) an arbitration inter-frame space (AIFS); 2) the delay $T_{RTB}$ due to backoff procedure, the frozen time as a result of other ongoing transmissions, the retransmission time due to an RTB collisions and the successful RTB transmission time; 3) delay $T_{CTB}$ due to retransmission as a result of a CTB collision and its successful transmission; and 4) the delay $T_{XOR}$ due to the encoded message collision, successful transmission and acknowledgement. Accordingly, the overall encoded message access delay $T$ becomes

$$T = AIFS[4] + T_{RTB} + T_{CTB} + T_{XOR} \quad (19)$$

Let $X_{ic}$ represent the incidence that a station's encoded message transmission ended in collision in the $i^{th}$ time slot while $X_{is}$ represents the incidence of a successful transmission in the $i^{th}$ time slot and $X_{ij}$ represents the event that there is no transmission in the $i^{th}$ time slot. Therefore, the probability that there is no attempt of transmitting the encoded message in the $i^{th}$ time slot can be shown as

$$p_{(X_{ij})} = \prod_{i=0}^{4} (1 - p_i)^{(n_i)(x_j),i} \quad (20)$$

While the probability of successful transmission of the encoded message in the $i^{th}$ time slot can be shown as

$$p_{(X_{is})} = \prod_{i \in [0,4]}^{4} (1 - p_i)^{n_i} . \sum_{j=0}^{4} x_{j,}i \,.\, p_i . \binom{n_i}{1} . (1 - p_i)^{(n_i - 1)} \quad (21)$$

Where

$$x_j, i = \begin{cases} 1, & \text{if } AIFS[i] \leq AIFS[4] + k \\ 0, & \text{otherwise} \end{cases}$$

and $x_j, i$ cross-checks whether the nearby stations of AC[$i$] will be contending with the source node for the channel access in the $i^{th}$ time slot of CW[4], and $n_i$ represents the total number of neighbouring stations belonging to AC[$i$] which are contending for channel access. Consequently, the probability of collision at the attempt of transmission of the encoded message in the $i^{th}$ time slot can be shown as

$$p_{(X_{ic})} = 1 - p_{(X_{is})} - p_{(X_{ij})} \quad (22)$$

### D. Location-Aware Algorithm (LAA)

In VANETs, nodes are aware of their location (or coordinates) by the help of the embedded global positioning system (GPS). Vehicles also discover the location of their neighbor vehicles from the status messages broadcasted periodically by each node which contains vehicle direction, velocity, position and MAC information. Given that the coordinates of the destination vehicle are known, the distance from the source to the receiving nodes is calculated by using vector formulae where the magnitude of vector $\bar{AB}$ is the distance between node A and B as shown in Fig. 3. Mathematically, the distance is given as

$$\bar{AB} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (23)$$

Where $(x_1, y_1)$ and $(x_2, y_2)$ stands for initial and final coordinates of the vehicle respectively. In the same manner, if the direction information is not clearly obtained from the RTB frame, then, the it will be given by $\theta$ which is the formation of horizontal angle between point A and B as

$$\theta = tan^{-1}\left\{\frac{y_2 - y_1}{x_2 - x_1}\right\} \quad (24)$$

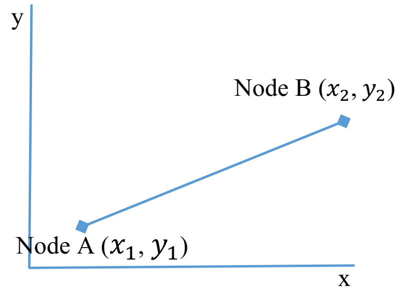

Fig. 3: Graphical representation of Vector $\overline{AB}$

TABLE I. VALUE OF PARAMETERS USED IN OUR SIMULATIONS

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Frequency | 5.9GHz | Data rate | 3Mbps |
| Bandwidth | 10 MHz | DIFS time | 64$\mu s$ |
| Modulation | BPSK | TX power | 2mW |
| Packet size | 512 byte | $AR$ | 37 byte |
| $E_{max}$ | 8% | $AG$ | 17 byte |
| $f_c$ | 2.4G | $V_P$ | 50 $m/s$ |
| $G_t$ | 1 | $P_t$ | 15 dBm |
| $CW_{min}$ | 15 | $G_r$ | 1 |
| $CW_{max}$ | 1023 | $R$ | 300m |
| $L$ | 1024 byte | $r_b$ | 1M |

## III. SIMULATION SETUP

The simulation was performed using NS-2 [22] which is a well-used simulator in analyzing vehicular networks [23], to validate our analytical model. The choice of suitable vehicular movement pattern for the experiments is significant to enable us to achieve close-to-real-life scenarios with dynamic vehicular network topology. We use a highway road network with 2000m edge length and Bonn-Motion tool [24] to generate suitable node mobility model. In our simulations, there are random distribution of 200 vehicles in a two opposite directions along two-lane road pattern with a minimum average of 30m space between any given pair of adjacent vehicles that are in the same lane. The Rayleigh model is used with the vehicles velocity randomly distributed in the range of the discrete set $V = \{(30 + 10 * k)m/s,\ \forall k \in [0,3]\}$ for the simulation of channel fading effect. Five data flows were set up at the rate of 100 packets p/s as a default setting. The rest of the parameters used this simulation are shown in Table III.

### A. Results and Discussion

We analyse and calculate the packet recovery probability and the percentage of collision probability as a function of the packet loss rate and generation probability, respectively. The $x$-axis of the graphs shown in Fig. 4 (a) – (c) and (d) – (f) indicate packet loss rate and generation probability obtainable in the network. The performance metrics used in our evaluation were measured in a saturated vehicular network[3]. We compare both the analytical and simulation results of the proposed CARER with the simulation results of a Simple Repetition-based (SR) error recovery scheme that does not apply the network coding technology. Different results of packet recovery probability obtained from the simulations and the analytical model are shown in Figs. 4 (a) – (c) for the values of varying numbers of retransmissions, $m = 4$, 5 and 7 respectively. Packet recovery probability is defined as the ratio of the total number of lost packets recovered through $m$ number of retransmissions to the total number of packets lost. Figs. 4 (a) – (c) show both the analytical and simulation results of the recovery probability for both CARER and SR when the value of $m = 4$, 5 and 7 respectively.

The recovery probability of both CARER and SR starts to reduce significantly when data loss rate increases towards $10^1$ (see Fig. 4 (a) – (c)). This rapid degradation in loss recovery probability (LRP) caused by increased change in data loss rate from $10^0$ to $10^1$ is due to the fact that fast retransmission of both the raw and encoded packets tends to congest the channel thereby resulting to excessive network overhead and the consequent quality of service (QoS) deterioration. Generally, UDP which resides at the transport layer shows increasing poor performance across the network whenever the overall data loss rate exceeds $10^0$ towards $10^1$. Therefore, as the rate of packet loss increases, more data transmissions are lost and even their retransmissions tend to be lost as well either due to channel congestion, increased network overhead or distance between the sender and the receivers.

In Figs. 4 (a), there is a significant improvement (over 20% in maximum) in packet loss recovery ability of CARER over SR scheme. This can be explained by the fact that conventional error recovery techniques based on retransmission of packets repeat each transmission separately thereby congesting the channel excessively as opposed to CARER which combines two or more packets into one, without increasing the size of the encoded packet through the assistance of network coding technology. In Fig. 4 (b), the performance gap between CARER and SR gets even wider due to increase number of retransmission from $m = 4$ to 5. This increased performance gap is expected considering that every retransmission of the encoded message by CARER provides higher chances of data loss recovery given the increased data content of the encoded message as opposed to SR which retransmits every packets separately.

More interesting result is witnessed in Fig. 4 (c) where there is a clear significant improvement (over 50% in maximum) in loss recovery probability of CARER over SR scheme. What is noteworthy in Fig. 4 (c) is not only the fact that the performance of CARER (both analytical and simulation results) increased accordingly with the increase in number of retransmission from $m = 5$ to $m = 7$, but the packet recovery probability of SR decreased from 0.74 to 0.63 (over 10% decline in performance). This significant decline of packet recovery probability of SR can be explained by the fact that, though, retransmission-based loss recovery techniques increase the chances of recovering packets not received or correctly received in the previous transmission, the repeated packets increase network overhead and after a given number of consecutive repeats may lead to excessive channel congestion and consumption of a substantial amount of the channel

[3] Saturated network is standard in network performance evaluation and analysis [25] and it provides a practical estimation of the optimal performance achievable.

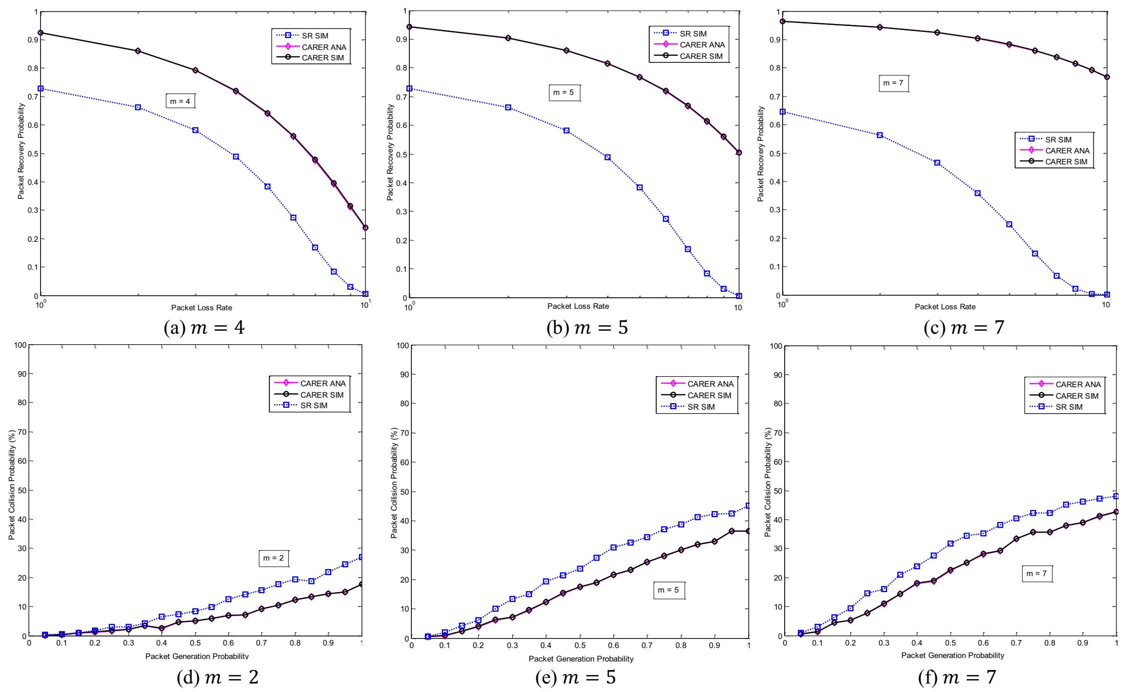


Fig. 4. Performance comparisons between the CARER and the SR scheme using (a) – (c) packet recovery probability, (d) – (f) percentage of packet collisions probability as a function of packet loss rate and packet generation probability, respectively.

bandwidth thereby giving rise to excessive increase of network overhead and further loss of data due to QoS deterioration. In other words, indiscriminate retransmissions generally proofs counter-productive after a certain number of consecutive repetition in most cases.

Fig. 4 (d) – (f) shows the results of packet collision probability for both CARER and SR schemes for different values of $m$. The percentage of packet transmission collision probability obtained from the simulations and the analytical model for varying numbers of retransmissions ($m = 2$, 5 and 7) were measured and the results shown in Fig. 4 (d) – (f). In general, CARER shows a performance gain (10% improvement) over SR as is evident in Fig. 4 (d) – (f) in terms of reduced data transmission collision probability. This can be explained by the fact that the defined parameter set for the EDCA used in WAVE standard is capable of prioritizing messages; hence, under heavy network density (increased packet generation rate) with increasing number of nodes sending AC3 packets especially, the collision probability tends to increase significantly. Therefore, the reduction in the percentage of packet collision probability that exist between the CARER and SR is expected given that an increased traffic density will undeniably lead to increased channel load especially for SR scheme when the total number of packet retransmission increases as opposed to CARER which uses network coding technology to combine several packets without necessarily increasing the encoded packet size. In other words, the total number of individual packets contention is reduced using CARER as a result of the coding technology applied in contrast to SR protocol.

The percentage of data collision probability of both CARER and SR starts to increase considerably as packet generation probability increases towards 1.0 (see Fig. 4 (d) – (f)). This rapid increase in the percentage of collision rate is caused by increased contention for access to the medium caused by high network saturation as the rate of packet generation increases under heavy network density. In the same manner, Fig. 4 (e) – (f) shows a gradual increase in the percentage of packet collision probability across the results of both the simulations and analytical model for the CARER and the SR protocol as the number of data retransmission increases from $m = 2$ (see Fig. 4 (d)) to $m = 5$ (see Fig. 4 (e)) and when $m = 7$ (see Fig. 4 (f)). This observed increase in percentage of collision rates for both schemes is as a result of increased channel congestion and contention due to high number of packets retransmissions to ensure high level of lost packet recoverability. However, the increased collision rate can be minimized with proper adjustment of contention window (CW) according to access categories (ACs) of the packets to meant to be transmitted. In other words, adjustment mechanism for CW and AIFSN should be finely tuned when traffic load increase with its associated high packet collision probability. Hence, dynamically adjusting the CW minimizes the internal and external collision of IEEE 802.11e [26].

## IV. CONCLUSIONS

In this paper, we present an analytical model to achieve a reliable packet broadcast in vehicular networks using network coding technology. We developed a rebroadcasting metric η which is used to determine and select the most suitably qualified candidate for rebroadcasting the encoded packets to enable the nodes outside the radio coverage of the source node to receive the encoded packets. The proposed CARER model computes the successful packet recovery probability as a function of packet loss probability and packet collision probability within vehicular networks. Both the theoretical and simulation results show that the analytical model is accurate in calculating both the recovery of lost packet(s) and packets collision probability for both periodic status and emergency (safety) packets. The performance evaluation of CARER protocol in urban environments comprising of short road segments with intersections will form an interesting future work to complement our proposed scheme. Part of our future work will also require adequate analysis of the end-to-end QoS performance of the proposed CARER scheme.

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