A Receiver-Driven Loss Recovery Mechanism for Video Dissemination over Information-Centric VANET

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Abstract

Information-Centric Vehicular Ad Hoc Network (IC-VANET) is a promising network architecture for the future intelligent transport system. Video streaming applications over IC-VANET not only enrich infotainment services, but also provide the drivers and pedestrians real-time visual information to make proper decisions. However, due to the characteristics of wireless link and frequent change of the network topology, the packet loss seriously affects the quality of video streaming applications. In this paper, we propose a REceiver-Driven loss reCOvery Mechanism (REDCOM) to enhance video dissemination over IC-VANET. A Markov chain based estimation model is introduced to capture the real-time network condition. Based on the estimation result, the proposed REDCOM recovers the lost packets by requesting additional forward error correction packets. The REDCOM follows the receiver-driven model of IC-VANET and does not require the infrastructure support to efficiently overcome packet losses. Experimental results demonstrate that the proposed REDCOM improves video quality under various network conditions.

Keywords: Information-centric network, vehicular ad hoc network, video streaming

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1. Introduction

As the increasing evolution of mobile and wireless communication technology, Vehicular ad hoc network (VANET) is becoming an essential part of the future intelligent transport system [1][2]. Due to its self-organized nature, instant deployment and low cost, VANET is a promising solution to realize ubiquitous connectivity to all participants on the road which include vehicles, pedestrians, traffic control systems, etc. A wide range of emerging applications over VANET (such as collision-avoidance system, intelligent traffic management and online infotainment) are expected to tremendously enhance the driving experience and safety [3][4]. Especially, the real-time video streaming plays an important role in the integrated service platform for the future intelligent transport system [5]. The video streaming applications can not only deliver entertainment services but also provide the drivers and pedestrians intuitive and visual information of highway conditions to make proper and timely decisions [6].

VANET is a special type of mobile ad hoc network (MANET), which is capable of interconnecting moving vehicles to construct a dynamic multi-hop wireless network without infrastructure support [7]. Vehicular nodes usually have high computing power, constant power supply, multiple network interfaces, and high moving speed. The wireless connections between vehicular nodes are affected by signal interference, multipath fading, shadowing effect and channel fluctuation. In addition, the frequent movement of vehicular nodes will cause continuous change of topology and intermittent connectivity. Therefore, VANET is more vulnerable to packet loss or error than MANET [8]. These characteristics impose design challenges to video streaming applications over VANET.

Recently proposed Information Centric Network (ICN), as a novel Internet architecture, can greatly improve the video streaming services in VANET environment [9][10]. ICN changes the end-to-end communication model of TCP/IP architecture to information centric scheme. The main features of ICN include receiver-driven transmission approach, data-centric communication model, in-network caching, and built-in multicasting [9]. Named data is the core building block of ICN. The data-centric communication model separates the content from the location where the content is stored. ICN nodes only use the name to identify, transmit and route the data [10]. The characteristics of ICN architecture are well suited for the essence of VANET, which is information dissemination [11].

Although ICN based VANET (IC-VANET) has high potential significance for the future intelligent transport system, few studies have been conducted on video content dissemination over IC-VANET. Due to the receiver-driven transmission approach, it is the obligation of receiving nodes to control the transmission strategy and adapt to the frequent network condition variations. However, every node of IC-VANET has in-network caching capability. Intermediate nodes are allowed to reply to a data request if the nodes temporarily store the requested content. Because of the in-network caching and topology changes, it is hard for the receiving nodes to measure the network conditions such as transmission delay. Moreover, the ad-hoc property makes IC-VANET nodes difficult to acquire the overall network information and adaptively control the video transmission.

In this work, we propose a REceiver-Driven loss reCOvery Mechanism (REDCOM) to facilitate video dissemination over IC-VANET. The REDCOM adopts Forward Error Correction (FEC) method to compensate the video packet losses [12][13]. By using standard error correction algorithm, additional redundant packets are generated along with original video packets. Certain number of packet losses during the transmission can be recovered from received original video packets and redundant packets [12]. Since it does not need to retransmission, the FEC method is suitable for the video streaming applications [13]. In order to promptly detect the change of network conditions, a Markov chain based estimation model is built to estimate the packet transmission results of each video block. Based on the estimation, the proposed scheduling algorithm calculates the number of FEC packets required to recover the lost packets. Our proposed REDCOM follows the receiver-driven transmission approach and can adapt to the variation of the network conditions.

The remainder of this paper is organized as follows. Section 2 presents the background and related work on ICN and VANET. Section 3 discusses our proposed REDCOM. The experiment settings and result analysis are described in Section 4. Finally, the concluding remarks and our future work are given in the Section 5.

2. Related Work

2.1 Information-Centric Network

The primary design goal of the ICN is to change the traditional host-to-host transmission scheme to data-centric communication model. The rationale behind the ICN design is that the main use of the current Internet is becoming information dissemination. To enable the network entities (client, server, routers, and forward nodes, etc.) understand the content that they deal with, the named data is carefully decided as core building block of the ICN architecture [9]. The name of data is the unique identifier in the whole process of the transmission.

The ICN protocols specify two packet types, interest and data packet as shown in **Fig. 1**. When the content provider produces a content item, the content item is segmented to chunks. The content provider packetizes each chunk into a data packet, and assigns a global unique name to the data packet.

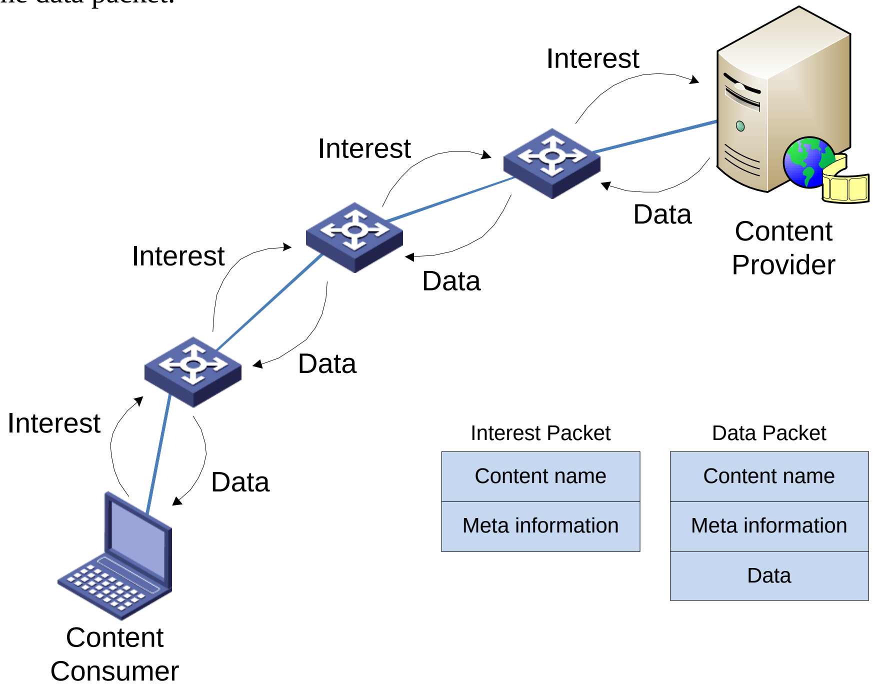
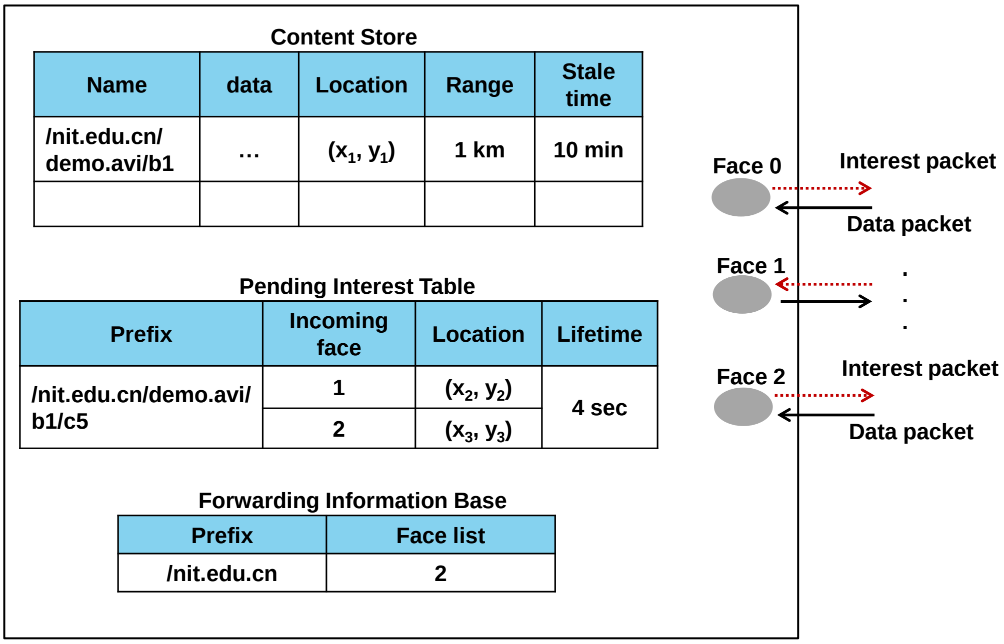


Fig. 1. The receiver-driven transmission model in ICN

Although there is no fixed rule, the ICN protocols recommend the naming structure following the uniform resource identifier scheme [14]. Fig. 1 presents the receiver-driven transmission approach of the ICN. According to different roles, we can classify the ICN nodes into three types: content consumer, intermediate node and content provider. When the content consumer wants to acquire certain content, it will initiate a transmission by broadcasting an interest packet. The name of the interest packet is the key identifier for the desired content. The intermediate nodes transfer the interest packet to the content provider based on forwarding policy. When an interest packet is arrived, the content provider finds the matched data packet and sends it back to the content consumer.



Content Store

Name	data	Location	Range	Stale time
/nit.edu.cn/ demo.avi/b1	…	(x_1, y_1)	1 km	10 min

Pending Interest Table

Prefix	Incoming face	Location	Lifetime
/nit.edu.cn/demo.avi/ b1/c5	1	(x_2, y_2)	4 sec
	2	(x_3, y_3)	

Forwarding Information Base

Prefix	Face list
/nit.edu.cn	2

Fig. 2. The ICN node structure: CS, PIT and FIB

Fig. 2 depicts the structure of an ICN node. The in-network caching capability is realized by the Content Store (CS) and named-data scheme. After sending a data packet, the ICN node will temporarily store the data packet in the CS. If the same request is received, the node can retrieve the data packet from its CS and send to the content consumer. The Pending Interest Table (PIT) records the incoming face of each interest packet and forms a forwarding path. The intermediate nodes use this information to transmit data packets back the content consumer. The Forwarding Information Base (FIB) contains the routing information for transmitting interest packets [9][14].

2.2 Information-Centric VANET

The main function of VANET is to deliver the road related information to the neighboring vehicles, pedestrians, traffic control systems. However, traditional IP based transmission scheme is inadequate to the dynamic nature of VANET. Amadeo et al. [11] reviewed state-of-the-art of ICN and proposed a new architecture that integrates ICN and VANET. The content dissemination over VANET has different properties from MANET. Because the road related information is valid within particular region, it is unnecessary to broadcast the information over the whole network. In addition, the road conditions are constantly changing, it is important to efficiently update the information.

According to the spatial, temporal and regional properties of the content transmission, Bai et al. [15] designed an ICN based VANET framework to support various types of applications. TalebiFard et al. [16] proposed a transmission model to improve the efficiency of content delivery in IC-VANET. Bouk et al. [17] described the benefits of the integrated IC-VANET architecture. Amadeo et al. [18] proposed Content Centric Vehicular Network (CCVN) scheme to enhance content dissemination and reduce packet forwarding load.

Despite many researchers proposed the solution approaches to integrate ICN with VANET, few studies have been conducted on video content dissemination over IC-VANET. Since the unique features of ICN, the video streaming mechanisms for IC-VANET environment need to be reconsidered.

3. Efficient Receiver-Driven Video Dissemination Mechanism

3.1 Video Streaming Architecture over IC-VANET

Because the communication models of ICN and traditional TCP/IP network are fundamentally different, the video streaming system designed for IP-VANET cannot be directly applied to IC-VANET. In this section, the new architectures for video content provider and video content receiver are described.

3.1.1 The architecture of video content provider for IC-VANET

The prime architectural difference from the IP based video streaming system is that the video content provider works reactively in IC-VANET. As depicted in Fig. 3, the path between video content receiver and video content provider consists of multiple vehicular nodes.

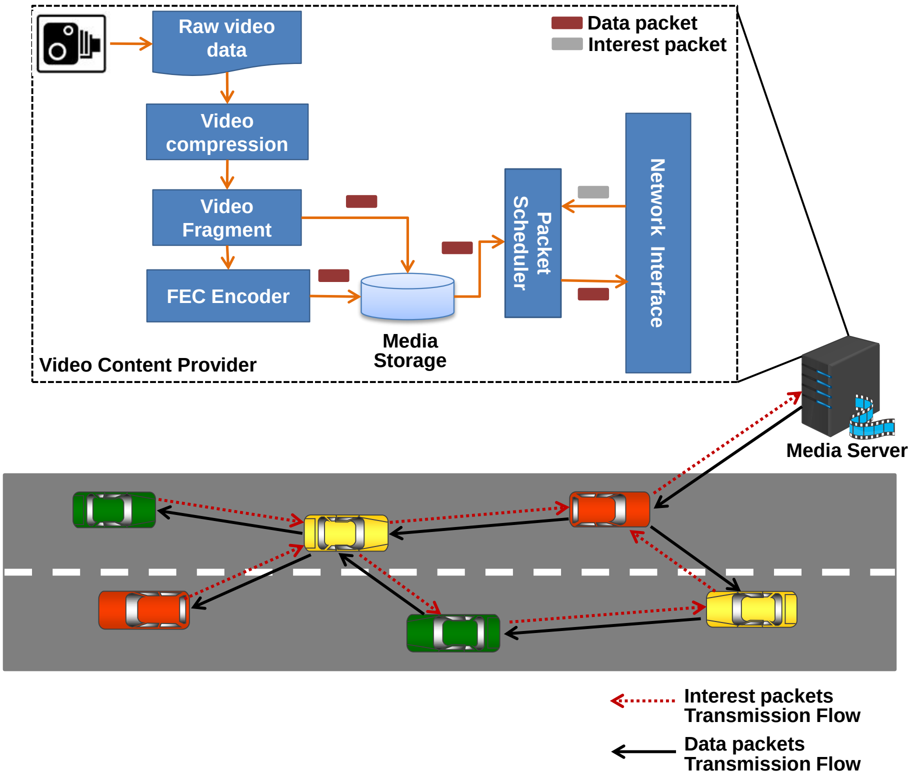


Fig. 3. Architecture of video content provider in IC-VANET

After compression, the video data are divided into fragments and encapsulated as data packets of IC-VANET. In order to overcome packet loss, the FEC encoder uses the video data to produce additional FEC packets. The generated video data and FEC packets are stored into the media storage, rather than immediately sending out to the receivers. Only when an interest packet is arrived, the packet scheduler searches the media storage, and responses with the matched data packets.

Due to the end-to-end communication model of IP based VANET (IP-VANET), the two communication parties are required to establish a session before transmitting video data. In order to cope with the high link condition variation, the video receiver periodically sends feedback to the video provider to maintain the session. Based on the link conditions, such as transmission delay, packet loss rate, jitter and throughput, the video provider regulates the transmission rate, loss recovery and video quality. Because the sessions are processed separately, the video provider needs to consume huge resources for the session management when the number of the receivers increases.

The features of IC-VANET significantly relieve the workload of the video provider. The video receivers do not have to retrieve all data from the video provider. The in-network caching capability allows that any intermediate nodes that hold the request data to reply the video receiver. Because of the receiver-driven transmission approach, the video receiver proactively sends requests to recover the lost packets and controls the video quality adaptation. From the video receiver's point of view, the video provider is an ordinary network node which happens to keep all video data. As a result, it is unnecessary to set up and maintain the session at the video provider.

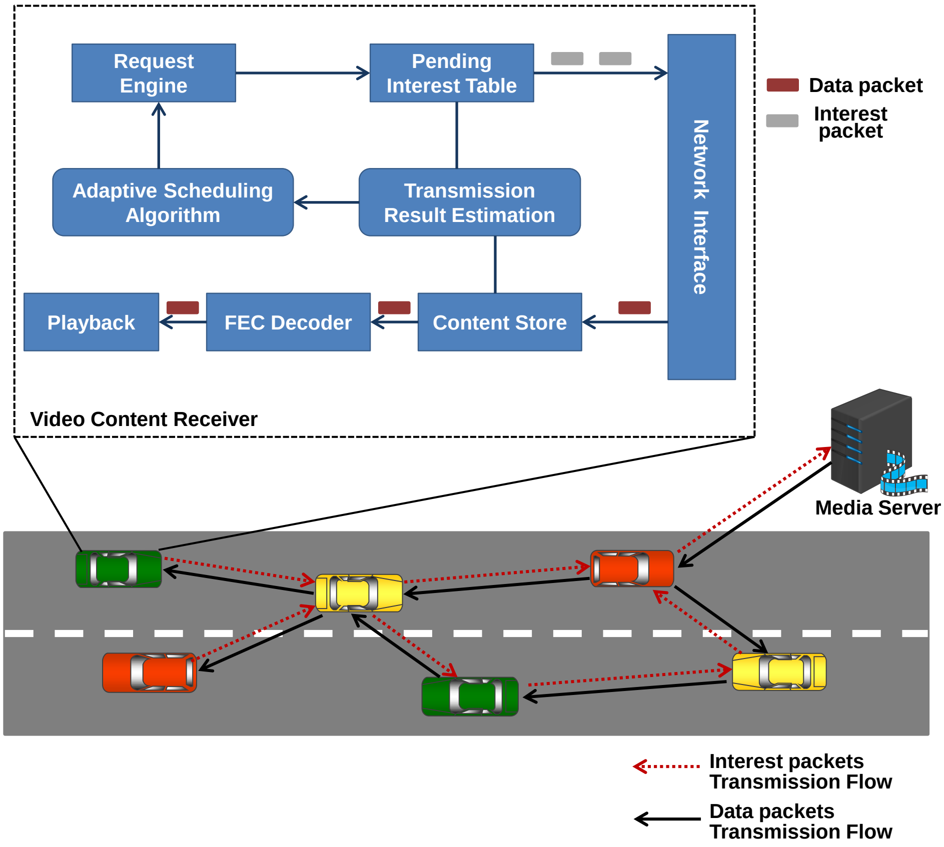


Fig. 4. Architecture of video content receiver in IC-VANET

3.1.2 The architecture of video content receiver for IC-VANET

In IC-VANET, the video content receiver plays more important role than in IP-VANET. **Fig. 4** presents the architecture of video content receiver. According to the video frame rate and packetization profile, the request scheduler generates interest packets. In the process of waiting for the corresponding replies, the interest packets are temporarily buffered in the PIT as the unresolved packets. When the playback point is reached, the video packets are retrieved from the data buffer and delivered to the video decoder.

Owing to the receiver-driven transmission approach, the video content receiver is responsible for packet loss recovery, video quality adjustment and adaptation of network condition variation. When the timeout occurs for an unresolved packet, the interest or data packet is lost. With the observation of the transmission result pattern, the video content receiver estimates the network condition variation and adjusts the transmission policy on the basis of the estimation. The intermediate nodes also manage the CS with their geographical location and content properties. The transmission result estimation and adaptation policy are explained in the following sections.

3.2 Transmission Result Estimation Model

The packet losses over wireless links often occur in bursts. For example, if one packet suffers communication error, then there is a high probability that subsequent packets suffer errors as well. In addition, because the movement of vehicular nodes causes frequent change of topology and interrupts the transmission between nodes, the packet losses in IC-VANET also occur in bursts. In order to capture the property of transmission result, the estimation model is constructed by using the Markov process.

Since the PIT buffers the unresolved packets, we use the sequence counter of the unresolved packets leaving the PIT as the state index of proposed model. There are two mutually exclusive cases for an unresolved packet leaving the PIT: (1) the corresponding data packet is received and (2) the timeout occurs. If the i^{th} unresolved packet leaves the PIT because of the data packet arrives, then the process is in state G_i. On the other hand, if the timeout occurs, the process is in state B_i. Let the random variable X_i represents the transmission result of the i^{th} unresolved packet:

$$X_i = \begin{cases} 0 & \text{denotes that the data packet is received successfully} \\ 1 & \text{denotes that the timeout occurs} \end{cases} \tag{1}$$

$\{X_i\}$ forms a Markov chain, and the state transition is shown in **Fig. 5**.

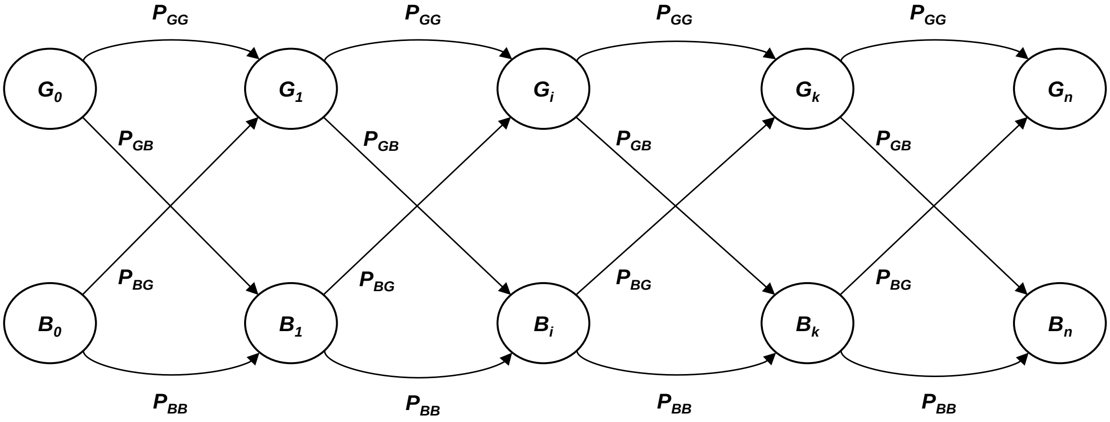


Fig. 5. The state diagram of the transmission result

Because the packet losses in IC-VANET have the burst property, we use random variable W_B to denote the number of consecutive packet losses. Given that the n^{th} transmission result is loss, which means that the chain is in the state B_n, then the $(n+1)^{th}$ transmission result is loss with probability P_{BB}. Therefore, the $(n+1)^{th}$ transmission result is success with probability $1\text{-}P_{BB}$. The probability mass function (pmf) of W_B is:

$$P(W_B = k) = (1 - P_{BB}) P_{BB}^{k-1} \tag{2}$$

where k is the number of consecutive losses. Using the properties of the geometric distribution, the expected packet losses are:

$$E[W_B] = \frac{1}{1 - P_{BB}} \tag{3}$$

and the corresponding variance is:

$$Var[W_B] = \frac{P_{BB}}{(1 - P_{BB})^2} \tag{4}$$

Given the current state vector $V_0 = (G_0, B_0)$ and the transition probability matrix A, the pmf of the n^{th} transmission result is given by:

$$[P(X_n = 0), P(X_n = 1)]^T = A^n V_0^T \tag{5}$$

Based on equation 5, we define the short-term packet loss probability for the next k packets:

$$P_l(k) = \frac{\sum_{i=1}^{k} P(X_i = 1)}{k} \tag{6}$$

3.3 Adaptive Receiver-Driven Video Scheduling Algorithm

Due to the dynamic characteristics of IC-VANET, the packet loss rate is changing during the video transmission process. Because video streaming applications are sensitive to the delay, it is important to promptly detect the changes and adjust the transmission. In order to support adaptive video streaming in IC-VANET, we propose the receiver-driven video scheduling algorithm to overcome packet losses. As shown in **Fig. 3** and **Fig. 4**, the video content provider will generate additional FEC packets along with video packets. Different with IP-VANET, the video content provider will not send video and FEC packets until explicitly receiving the interest packets.

The video content receiver continuously monitors the transmission results of unresolved packets, and updates the transition probability matrix. If a PIT entry for interest packet expires, the interest packet will be retransmitted. The maximum number of retransmissions is decided by:

$$r = \left\lfloor \frac{T_{delay}}{RTO} \right\rfloor - 1 \tag{7}$$

where T_{delay} is the tolerant video delay and RTO is Retransmission TimeOut value [10].

After transmitting interest packets for one video block, the expected burst loss length and average packet loss probability for the next video block are calculated by using equation 6. Let h denotes the number of packet in the next video block, m denotes the number of requests for FEC packets. Then m can be calculated as:

$$m = \frac{P_l(h) \times h}{1 - P_l(h)} \tag{8}$$

When the playback point is reached, the FEC decoder will try to recover the lost or corrupted packets from received FEC packets. If the recovery is failed, then the data packet will be dropped. Because video content receiver detects the actual number of packet losses in each block, the proposed algorithm is capable of effectively producing relevant amounts of FEC packets for various quantities of packet loss. **Table 1** illustrates the detailed process of our proposed algorithm.

Table 1. Adaptive receiver-driven video scheduling algorithm

```
send the interest packets for one video block
monitor the transmission results
calculate maximum number of retransmission $r$
if timeout then
    record the loss information
    if retransmission allowed then
        resend the request
    end if
end if
if packet arrived then
    save to the CS
    update the received packet list
    if one video block received then
        recover lost or corrupt packets
        send to playback buffer
    end if
end if
calculate the number of FEC packets
send the interest packets for FEC
```

4. Simulation and Results

In order to verify our study, the NS2 network simulator is adopted to evaluate the performance of the proposed mechanism [19]. The “Bridge” Common Intermediate Format (CIF) sequences are used as the video traces [20], and encoded using H.264/ Advanced Video Coding standard. Sending FEC packets require addition network bandwidth and resources. Too many FEC packet transmissions will cause network congestion and decrease the loss recovery rate. As demonstrated in [13], maximum four FEC packets for each video block are produced.

Table 2. Parameters of the simulation

Parameter	**Setting**
Antenna height	1.5m
Antenna gain	1dB
MAC protocol	IEEE 802.11p
MAC bandwidth	24 Mbit/second
Payload size	1500 bytes
Mobility model	Manhattan Grid Model
Propagation loss model	Nakagami
CS size	5000 entries
PIT size	5000 entries
CS replacement policy	Least Recently Used (LRU)

We use the Bonnmotion tool to generate a bi-directional two lanes highway scenario [21]. The 100 vehicular nodes are uniformly positioned in the 10km length highway. The detailed parameters of the simulation are shown in **Table 2.** We consider three traffic randomness levels as: for low randomness level, the speed of vehicular nodes is uniformly distributed from 20km/h to 40km/h. For middle randomness level, the node speed is uniformly distributed from 20km/h to 60km/h. And for high randomness level, the node speed is uniformly distributed from 20km/h to 80km/h.

The Peak Signal to Noise Ratio (PSNR) is used as the evaluation matrix for video quality. The frame PSNR is calculated as:

$$PSNR = 10\log_{10}\frac{L^2}{\frac{1}{M*N}\sum_{m=1}^{M}\sum_{n=1}^{N}[x(m,n)-y(m,n)]^2} \tag{9}$$

where x is the original frame and y is the distorted frame. M and N are width and height of a frame. L represents the maximum pixel value in the $N\times M$ pixels. Then, the average PSNR is calculated as the mean PSNR value of all frames.

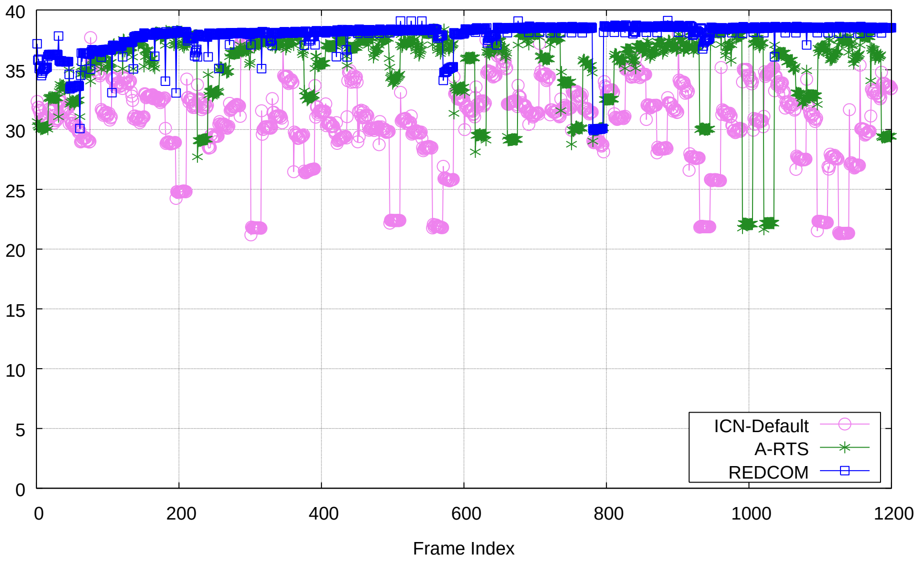


Fig. 6. The achieved video quality under low randomness traffic

We compare our REDCOM with the default ICN approach [9] and the adaptive retransmission algorithm (A-RTS) proposed in [10]. The default ICN approach adopts static retransmission approach to response the packet loss. After sending an interest packet, the IC-VANET node will add an entry in the PIT. A timer with four seconds is associated with each entry [9]. If the data packet does not return before the timer expires, the Interest packet will be retransmitted. **Fig. 6** shows the achieved video quality by three approaches under low randomness traffic. Because the network topology is relatively stable, the packet loss rate is not high. The video quality is satisfactory in this case.

The initial positions of the vehicular nodes are evenly distributed at the beginning of the experiments. The deviation of node movement becomes larger with the increasing randomness level. As a consequence, the node density is varying on the road during the experiment process. Because of the regional and temporal properties of IC-VANET, many neighboring vehicular nodes will request same content in the high density scenario. If an intermediate node receives an interest packet and finds out that the entry with the same name already exists in the PIT, this means that the request has been sent for the same content. Instead of forwarding the interest packet, the intermediate node only registers the incoming face. When the requested data packet is received, the intermediate node will send the data to all the faces registered in the PIT entry. The support of multicasting and in-network caching greatly improves the performance of content dissemination in the high density scenario.

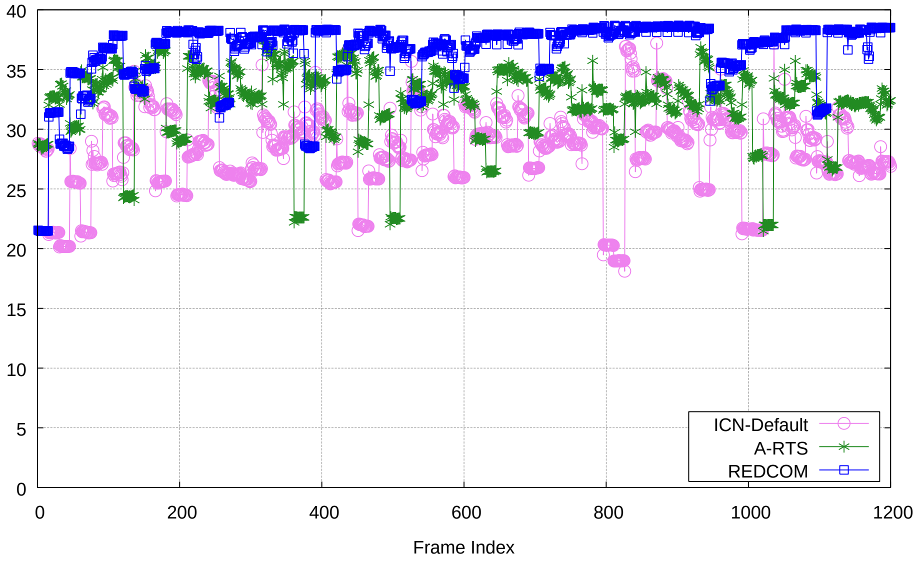


Fig. 7. The achieved video quality under middle randomness traffic

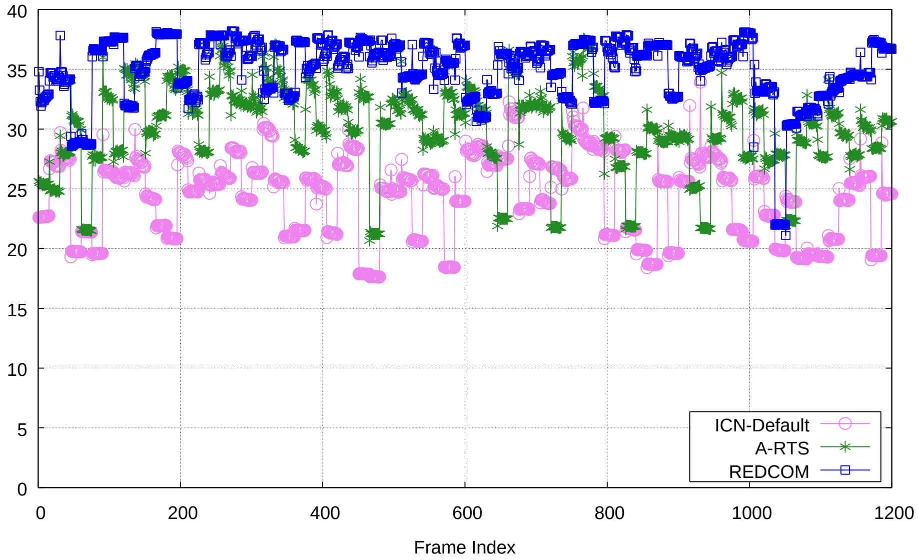


Fig. 8. The achieved video quality under high randomness traffic

However, with the increasing changes of the network topology, the packet loss is becoming more severe. The default ICN approach cannot detect the variations and timely recover the lost packets. A-RTS is based on automatic repeat-request mechanism. Resending of an interest packet requires a delay of at least one round-trip time. Since each video frame has a timestamp for playback, the delay caused by multiple retransmissions can result in the late arrival of video packets at the playback point. Because the proposed mechanism estimates the network variations and generates requests for FEC packets accordingly, REDCOM achieves higher video quality than the default ICN approach and A-RTS as shown in **Fig. 7** and **Fig. 8**. The proposed REDCOM maintains the higher PSNR and the PSNR gradually decreased with the increasing rate of packet loss as depicted in **Fig. 9**.

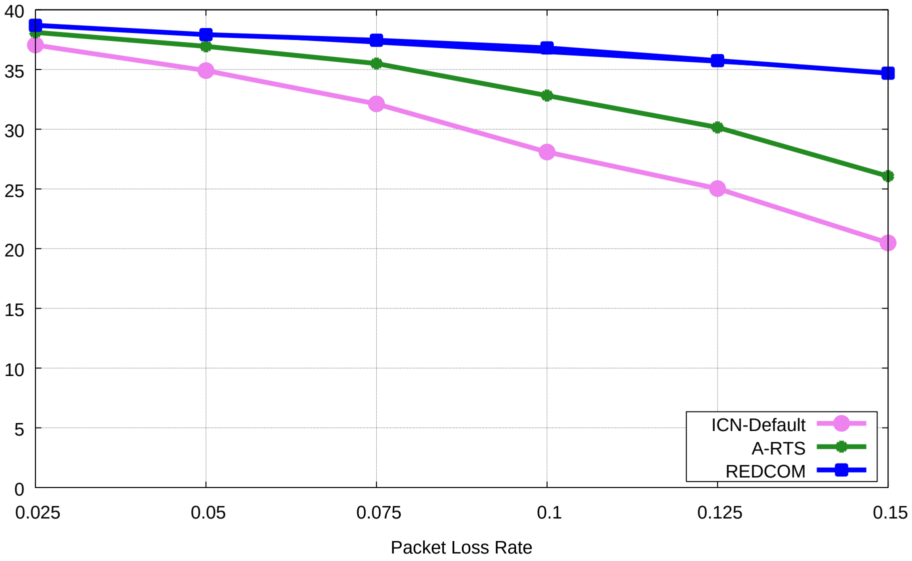


Fig. 9. The achieved video quality under different packet loss rates

5. Conclusion

In this study, we propose a receiver-driven loss recovery mechanism (REDCOM) to overcome high packet losses in IC-VANET. Although IC-VANET has high potential significance for the future intelligent transport system, few studies have been conducted on video content dissemination over IC-VANET. Because of the characteristics of wireless link (such as signal interference, multipath fading, shadowing effect and channel fluctuation) and frequent changes of the network topology, the packet loss seriously affects the quality of video streaming application. In order to timely recover lost packets, a Markov chain based estimation model is built to estimate the packet transmission results of each video block. Based on the estimation, the proposed REDCOM calculates the number of FEC packets required to compensate the packet losses. Experimental results demonstrate that REDCOM is able to efficiently overcome packet losses under various network conditions. We will perform sensitivity analysis for maximum and minimum number vehicles per kilometer to keep good Quality of Service in the future.

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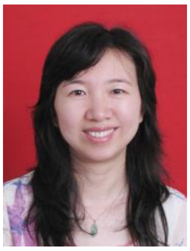

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