Network coding approach for vehicle-to-vehicle communication: Principles, Protocols and Benefits

Imen Achour
IEEE Student Member
Mediatron Lab. SupCom
Imen.achour@supcom.tn

Tarek Bejaoui
IEEE Senior Member
University of Carthage
Tarek.bejaoui@yahoo.fr

Sami Tabbane
IEEE Senior Member
Mediatron Lab. SupCom
Sami.tabbane@supcom.rnu.tn

***Abstract*— Information dissemination in vehicular networks is becoming a hot topic of research in the field of Vehicle-to-Vehicle (V2V) communications, since efficient data exchange is needed for most crucial applications (road accident warning, traffic congestion warning ...). Many protocols have been then proposed for the sake of disseminating information with high reachability and low end-to-end delay in limited bandwidth. In this work, we propose to review the design of some of dissemination protocols based on the network coding technique. Newly adopted in wireless ad hoc networks, network coding paradigm seems to be a promising solution for data dissemination in vehicular environment. The goal of this work is then to classify the different network coding based protocols appeared in the literature and reveal the gain achieved once this technique is applied. To this end, a summary table for a comparative study of the numerous retained protocols is presented.**

Keywords— Vehicular Ad hoc Networks; Network Coding technique; V2V communcation; Data dissemination.

I. INTRODUCTION

Similar to Mobile ad hoc networks (MANETs), Vehicular ad hoc networks (VANETs) are self-organizing networks composed of mobile nodes connected via wireless links. Nevertheless, in VANETs, these mobile nodes are particularly represented by smart vehicles leading to new characteristics that distinguish VANET from other networks. Therefore, nodes' trajectory is almost predictable since vehicles only move on predetermined roads. However, vehicles' mobility vary within the traffic conditions variation, such as during traffic jams, accidents, traffic lights, rush hours, etc, which results in highly dynamic change in the network topology. Moreover, vehicles nodes do not have the problem of resources limitation in terms of data storage and power.

Such particular features often make standard networking protocols behave differently in VANETs. Thus, specific data dissemination protocols should be particularly designed to fit the different requirements of various VANETs' applications [1]. Moreover, in recognition of the specific characteristics of VANETs, researchers have defined a new wireless standard, known as IEEE 802.11p or WAVE (Wireless Access for Vehicular Environments). This mode of operation (WAVE) is designed to support the Intelligent Transportation Systems (ITS) application. For this purpose, the Federal Communications Commission (FCC) has allocated 70 MHz of wireless spectrum in the 5.9 GHz band for a new Dedicated Short Range Communication (DSRC) service.

Based on DSRC/WAVE, data dissemination in VANET may be processed through two different communication modes, as depicted in Fig. 1: V2I (Vehicle-to-Infrastructure) communication mode and V2V (Vehicle-to-Vehicle) communication mode. In the first mode, vehicles are communicating with roadside infrastructure based unit (RSU) and/or cellular infrastructure (3G/4G) in order to collect data information. Nevertheless, when no infrastructure is deployed for VANETs applications or when vehicles are beyond the coverage of road side unit, the V2V mode is applied. Hence, vehicles equipped with wireless IEEE 802.11p antenna are able to inter-communicate leading to a host of new applications [1], ranging from safety applications (e.g., curve speed warning, hard braking notification, road congestion warning, collision risk warning, lane change assistance) to comfort applications (e.g., traffic information exchange, web surfing, content distribution, advertisement). Besides, data in VANETs is basically disseminated upon two transmission strategies, namely unicast and broadcast/multicast.

In this context, many researchers have provided several strategies to address the dissemination issue in vehicular environment. Most of these strategies were reviewed in the literature [2] [3] [4]. In [2], authors have given a survey of the VANETs routing mechanisms especially designed for a V2V communications. However, [3] [4] provides a review of broadcast protocols dealing essentially with the contention and collision problems. Yet, adding to that, vehicular networks are suffering from limited resource bandwidth. In fact, according to the FCC, the DSRC in USA provides seven channels with 10 MHz in bandwidth: 1 control channel and 6 service channels. Only, the control channel is deployed for safety messages exchange. The dissemination of this sort of messages is a critical issue in VANETs since they should be efficiently transmitted (i.e. by achieving high packet delivery within certain time limit and acceptable overhead). Besides, these messages are useful for safety application (preventive messages) as they are valuable for non-safety applications (e.g., traffic monitoring). Therefore, all vehicles have to handle the control channel often enough in order to successfully receive safety information within the limited bandwidth.

For this purpose, recent research efforts have adopted a new way of information dissemination based on the network coding (NC) technique [5] [6]. This technique, that recently caught the attentions of many researchers in the field of wireless communications in MANETs, has proven its efficiency and robustness in vehicular environment.

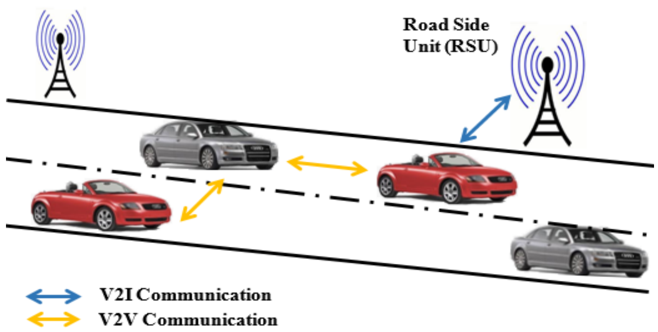

Fig. 1. Communication modes in Vehicular ad hoc network.

In this work, we are focusing on the review of this class of dissemination protocols based on network coding strategy that is essentially designed for a V2V communication mode.

To the best of our knowledge, no prior work has already thoroughly discussed the network coding-based dissemination protocols particularly designed for VANETs. To this end, we propose this work for the sake of classifying the protocols reported in literature and investigating the gain that can be reached by applying the network coding technique in VANETs. The NC-based protocols designed for a V2I communication are out of the scope of this work. Mainly, we are interested in vehicle-to-vehicle communication since it is considered as the most relevant communication mode for safety data dissemination (most significant applications category).

This paper is organized as follows. In Section II, we briefly describe the network coding principle and its impact on data dissemination performance. Section III presents the classification of the retained protocols for this study, illustrates some related protocols with a brief description of their strengths and limitations, and finally compares the different classes. At the end, concluding remarks and future works are presented in Section IV.

II. Network coding Based Dissemination Protocols: Principles And Classification

In this section we present the network coding technique and its intended benefits in network dissemination. Then, we define the criteria used for the protocols' organization and hence our classification's result.

A. What is the network coding ?

Network coding [5] [6] is a new dissemination paradigm. The core idea of NC is to provide each intermediate node the capability to mix different received packets before forwarding. This technique is expected to yield a significant improvement in data transmission efficiency through various crucial metrics such as network throughput, wireless resources capacity, energy consumption, reliability issues and data transmission delay. Indeed, [5] have proved that the intermediate nodes built on the theory of network coding lead to make optimal use of the available network resources. Hence a source node can disseminate information to a set of receivers at the broadcast capacity of the network.

In order to make it simple, the network coding approach and its distinction from the traditional transmission approach can be best described through the famous "Butterfly" Network example [7]. However, this topological configuration is not possible in real world vehicular ad hoc networks. To this aim, we propose to explain the network coding concept and its major benefit through a simple example, shown in Fig. 2. In this example we consider three vehicles (V1, V2 and V3); both vehicles V2 and V3 are waiting for packets P1 and P2 from V1. Assuming that from prior transmission, V2 and V3 have respectively received P1 and P2. Hence, two more transmissions for each packet are needed from V1 to complete the transfer. Yet, by applying the network coding technique (combining P1 and P2 in the same packet) V1 can achieve the maximum data dissemination efficiency. In another word, thanks to NC technique, V1 has reduced the number of transmissions and so enhanced the network throughput. This is not the only benefit, NC can offer other desirable properties such as reliability in lossy networks.

B. Network coding based protcols in Vanet

Although multiple protocols that are based on delay and probability solutions were presented in the literature, only few, based on network coding and adapted to vehicular environment were proposed. The NC technique can be applied for both V2V and V2I communication, except that in this work we are focusing on surveying inter-vehicle communication based protocols. The classification of the retained protocols in this study can be done in different ways and according to several aspects. Up to now, none of NC-based protocols developed for a V2V communication deploys a multicast strategy. Most of which are using either a unicast data mode or a broadcast feature. In Fig 3, we classify the considered protocols, according to the transmission strategy, basically into two protocol types: unicast and broadcast protocols. For further comparison between the different protocols we propose **Error! Reference source not found.**Related works for each category will be briefly described in the two next sections. Moreover, the strengths and limitations of each protocol will be investigated.

III. Network Coding-Based Unicast Protocols

This section introduces the NC-based unicast routing protocols in VANETs. The main objective of unicast routing in VANETs is to transmit data from a single source to a single destination via wireless multi-hop transmission. These protocols are defined on the basis of the area and the application for which they are most suitable.

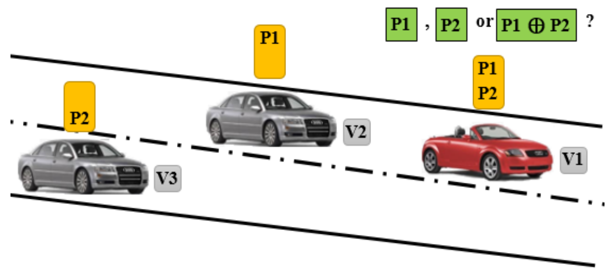

Fig. 2. A 3-vehicle example.

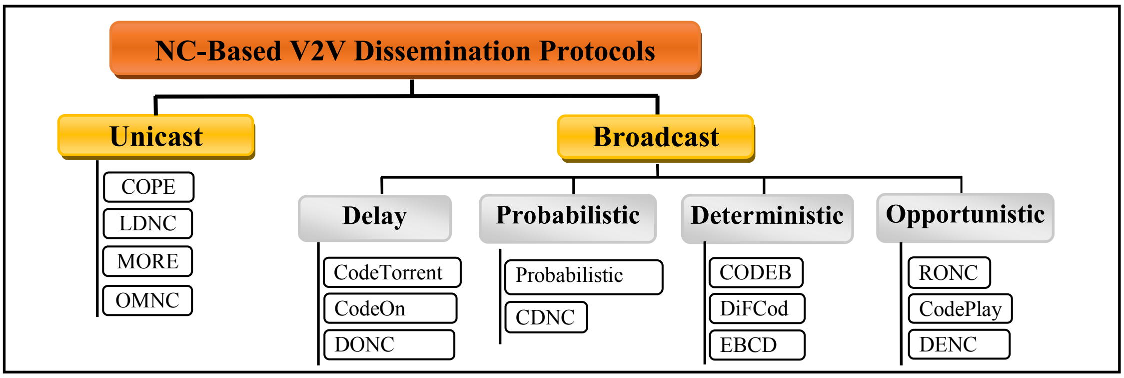

Fig. 3. Classification of NC-Based protocols in V2V data dissemination.

A. COPE

Although it is a NC-based unicast routing protocol, COPE is a base upon which many protocols are built [7]. It aims at extending the benefit of network coding concept, in term of throughput, beyond the simple duplex flows example presented in the "Butterfly" Network. COPE principle relies on three fundamental techniques: (a) "opportunistic listening" by snooping all the transmitted packets in the wireless broadcast medium that the node can overhear, (b) "opportunistic coding" by encoding packets with the guarantee that the combination will be decoded at the destination and (c) "neighbor state learning" that is achieved through the reception reports, periodically broadcasted by each node. However, the fact of exchanging node state, may lead to a high network overhead which is not suitable for time sensitive applications.

B. LDNC

The idea of COPE was specifically adapted for VANETs in a new protocol called Local-directed Network Coding (LDNC) [8]. The foremost contribution of this work is that it takes into account the packet propagation directions (forward and backward) throughout the encoding process. Hence, when a node has the opportunity to send, it looks for an efficient XOR combination of packets useful for both direction. Experiment results have shown that LDNC is able to improve the throughput and get higher performance in dense network. Despite that, LDNC remains a unicast routing protocol.

C. MORE

MORE, proposed in [9], is a distributed multipath opportunistic routing mechanism built on the theory of Network Coding. It is also a unicast routing protocol. According to MORE principle, intermediate nodes are allowed to forward random linear combinations of packets going to the same destination, instead of solely forward each received packet. So, the problem of "which packet to transmit" is circumvented by random packets mixing. Whereas, in order to determine "when to transmit", MORE adopts a centralized algorithm that prescribes for each intermediate node how many packets it should receive before generating a new coded packet. Besides, MORE can achieve 100% packet delivery ratio since it continuously sends coded packets until the destination collects a sufficient number of packets for decoding. However, this approach does not account for the bandwidth resource competition among neighboring nodes attempting to transmit new packets. The problem is more accentuated when multiple unicast sessions are running at the same time.

D. OMNC

In order to alleviate MORE limits, authors in [10] have proposed OMNC. The aim of this protocol is to optimize MORE to work in a distributed environment. Hence, for each node, OMNC assign an encoding and broadcast rate in a decentralized manner. Indeed, distributed environment leads to avoid congestion and to decrease the generation of redundant packets. Intermediate nodes continue encoding packets and broadcasting them, until the source node receives an acknowledgment (ACK) sent from the destination. OMNC achieves significant throughput improvement over traditional routing and existing network coding protocols such as COPE and MORE under both single-unicast and multiple-unicast scenarios. Yet, in safety applications critical metrics such as message success probability and delay should also be taken into account. This is not the case within this protocol. Moreover, the fact that OMNC is built on an ACK exchange between the source and the destination nodes (since it is adapted to unicast networks) makes it impractical for critical message dissemination.

After overviewing the related works of the NC-based unicast category, investigating their achievements and also their limits, we next move to present, in the following section, the classification adopted to the various protocols proposed for broadcast transmission mode on the bases of NC technique.

IV. NETWORK CODING BASED-BROADCAST PROTOCOLS

NC-based Broadcast protocols aim at disseminating broadcast message from a source vehicle to all other vehicles in the network. In this class, a data packet propagates through the network by way of flooding where each vehicle is allowed to blindly rebroadcast the packet. However, this technique is not scaled with the network density. Hence, in dense networks flooding becomes very costly and will result in serious redundancy, contention, and collision. This is typically referred to as a broadcast storm problem [11].

So, many studies have addressed this issue in order to alleviate the impact of this problem on dissemination performances. As a common solution employed by the most of researchers is reducing the number of redundant rebroadcast packets. To this purpose, only some of the vehicles should be chosen to relay the packet in contrast to flooding. To this end, we have classified the different NC-based broadcasting protocols with reference to their adopted broadcasting technique in combination with the network coding approach. As a result, we can basically distinguish four types: deterministic-based, delay-based, probabilistic-based and opportunistic-based.

A. Delay based Broadcasting Protocols

1) Code Torrent: It is a pull-based scheme for content distribution application in VANETs using NC, where vehicles need to explicitly initiate requests to download a piece of content [12]. CodeTorrent is a single hop broadcasting protocol. The peer selection and content delivery is maintained to the one-hop neighborhood of a vehicle, thus the need of multi-hop routing management is discarded. Also, the use of NC alleviates the peer and content selection problems. In this protocol, a small random delay, called broadcast jitter, is applied before each transmission to reduce collisions and mitigates the broadcast storm.

2) *CodeOn:* CodeOn offers a novel scheme for push-based content distribution protocols designed for VANETs [13]. An access point (AP) or a source broadcasts the content file to all the vehicles in its range. Outside the ranges of APs, receiver vehicles distribute the file cooperatively by selecting a set of relay nodes for broadcasting. CodeON is particularly designed for vehicles beyond the AP range. In CodeOn, nodes exchange "content reception status", calculate their "utility" and then compute a transmission backoff delay which is inversely proportional to their utility (i.e. the amount of useful content they possess). As a result, the node with the most useful content gets to relay. This protocol has well solved the problems of lossy wireless transmissions in VANETs. In fact, CodeOn, takes advantage of symbol level network coding (SLNC) which exploits the benefits of both network coding and symbol-level diversity (much better resiliency to transmission errors compared to packet level).

3) Delay-based Opportunistic Network Coding protocol (DONC): By design, DONC, proposed in [14], aims at improving network reliability and loss recovery without the need for costly control protocol. The main idea behind this work is to combine the central mechanism of delay based protocols with the use of network coding. For the delay-based broadcasting mechanism, it is built on the bases of the distance between the transmitter and the receiver. Hence, the waiting time assigned to each receiver is a decreasing function of this distance. With regard to the network coding, this protocol adopts the random lineaire network coding (RLNC) technique. Results illustrate that the DONC protocol outperforms classical delay-based broadcast protocols thanks to the NC benefits.

B. Probablistic based Broadcasting Protocols

In such protocol type, each node rebroadcasts a packet with a given probability.

1) *Probabilistic NC:* The protocol proposed in [15], is a combination of the network coding technique with probabilistic forwarding algorithm. In our work, we refer to this protocol as "Probabilistic NC". Authors in [15] have proven that network coding can offer a constant factor of benefits, in terms of energy efficiency over a fixed network, and a log(n) factor over a network where the topology dynamically changes and "n" is the number of nodes in the network. Random linear mixing of original packets is used to perform the encoding. Whereas, the decoding process is performed by solving linear equations. The drawback of this approach is that it presents a relatively high decoding complexity. In addition, the number of encoded packets that the node have to transmit is probabilistic. This may subsequently decrease the packet delivery ratio.

2) Content Distribution in VANETs using Network Coding (CDNC): In order to assess the performance of NC application in vehicular networks and its impact on the limited ressources, authors in [16] have developped an abstract model and implemented it in a content distribution systems. Based on the generated model, some investigated strategies were proposed to enhance the NC efficiency in resources consumption. To demonstrate the effectiveness of the generated model, extensive simulations were performed using a probabilistic approach in data coding.

C. Deterministic-based Broadcasting Protocols

Deterministic approaches are based on pre-selecting some forwarding nodes that are able to achieve a full delivery within the entire network.

1) CODEB: In this work [17], authors show how the NC can be applied to a deterministic broadcast approach, leading to an outstanding results in term of reducing the number of transmissions throughout the network. An XOR and a Reed-Solomon (RS) coding techniques are then applied to the Partial Dominant Pruning (PDP), the deterministic approach presented in [18]. Inspired by COPE, CODEB inserts a coding layer between the IP and MAC layer which detects coding opportunities in order to reduce the number of required transmissions. Amongst the two proposed algorithms, the RScode-based optimal algorithm performs better than the XOR-based algorithm by up to 15%.

2) DiFCode: It is an other relevant work in the network coding area [19] which reduces the number of transmissions needed to disseminate packets in an ad hoc wireless network. The efficiency of network coding is further enhanced by applying the deterministic approach called "Multiple Point Relays" (MPR)[20]. In opposition to CODEB, where the received encoded packets should be dropped whevere they are not immediately decoded, DifCode allows to store temporarily incoming combinations in a specific buffer until receiving enough information to decode them. DiFCod outperforms the "probabilistic NC" protocol proposed in [15] in term of number of transmissions either in dense or sparse networks.

3) Efficient broadcasting using network coding and directional antennas (EBCD): The main objective of this work [21], is to achieve an efficient broadcasting. To this end, authors combine the network coding based broadcast approch with broadcasting using directional antennas. The network coding based broadcast is exploited to reduce the number of transmissions. However, the usage of directional antennas to network coding-based broadcasting is to further reduce energy consumption. The technique used for this purpose is DDCDC (Dynamic Directional Connected Dominating Set).

As we can note, COBED, DifCode and EBCD are NC-based protocols initially proposed for Wireless ad hoc networks. Simulation results in [17] [19] [21] have proven that they have significantly decreased the number of transmissions, and therefore reduced collision effects under static nodes. At first glance, we can say that these protocols may be efficiently applied for data dissemination in VANET, since it is considered as a special case of MANET. Yet, VANET has several characteristics that distinguish it from MANET. One of the most valuable characteristics of vehicular networks is the high mobility of the nodes (vehicles). So, we can admit that the aforementioned protocols are not yet well suitable for vehicular environment and need some adjustment to fulfill the VANETs requirements. In fact, CODEB and EBCD have proven their fragility in the presence of node mobility. While, DiFCode performance is not studied in a dynamic network.

D. Opportunistic based Broadcasting Protocols

In such protocols, an intermediate node performs the encoding process and subsequently the broadcast process, once it has the opportunity of sending. The major difference that distinguishes an opportunistic protocol from another is the criteria according to which a node may decide if it is the relevant node to send or not.

1) Reliable Opportunistic Network Coding (RONC): The goal of the proposed opportunistic scheme, presented in [22], is to maximize the safety message reachability and minimize the reception delay in a lossy vehicular network. In order to facilitate the presentation of the protocol, we refer to this scheme as RONC. The specific applications for which RONC is tailored are cooperative driver assistance and collision warning systems applications in vehicular environment. In [22], each node tries to find the best message combining strategy from the already received packets based on a feedback information exchanged between neighboring nodes. The most significant result that can be noticed from RONC is shown through extensive simulations, done in [22], where the proposed opportunistic NC scheme outperforms the random linear network coding (RLNC) in term of average delay.

2) CodePlay: It is specifically designed for an essential vehicular networks' application called "Live Multimedia Streaming" (LMS) [23]. The main objective of CodePlay is improving the performance of LMS service in terms of streaming rate, service delivery delay and bandwidth efficiency. For this aim the protocol fully exploits the benefits of SLNC in vehicular environment. Moreover, the region of dissemination in [23] is divided into segments, and each segment selects a coordinator which designates a relay node for that segment in a centralized way.

3) Data Dissemination Efficiency based on Network Coding (DENC): It is a reference that we have proposed for the work presented in [24] in order to facilitate its presentation. Authors in [24] have studied the V2V data dissemination effeciency using the network coding approach. Hence, while most of the reported works explore the V2V design via simulation, the authors in [24] provide analytical results for V2V data dissemination under a simple scheduling model. The aim of this study is to investigate the limits (in upper bound) of the benefits from network coding. For this, the probability mass functions pmf's of dissemination completion time in three-node case for both random broadcast and NC based broadcast are explicitly derived. It has been proved that NC based broadcast reaches steady-state, which had been validated through simulation results [24].

V. CONCLUDING REMARKS

In summary, we have reviewed in depth the various inter-vehicle dissemination protocols relayed on network coding technique and systematically classified them. The network coding technique, recently adopted in vehicular context, has proven its efficiency (reliability, throughput, availability…) in information dissemination. However, some critical limits have been witnessed in some described protocols. These protocols may be strongly enhanced while taking into account different parameters (resources constrains, transmission delay, delivery ratio, coding rate, content dissemination completion…) with relation to the vehicular applications' requirements. In future works, we intend to include NC-based protocols for V2I and hybrid communication mode (V2V2I).

ACKNOWLEDGMENT

This work is a part of the MOBIDOC project achieved under the PASRI program, funded by the European Union and administered by the ANPR.

REFERENCES

[1] Srephan Olario, Michele C.weigle, Vehicular Network From Theory to Practice, A champman and Hall Book, Section II, 2009

[2] Marwa Altayeb and Imad Mahgoub, "A Survey of Vehicular Ad hoc Networks Routing Protocols," International Journal of Innovation and Applied Studies Vol. 3 No. 3, pp. 829-846, July 2013.

[3] Rakesh Kumar1 and Mayank Dave, "A Review of Various VANET Data Dissemination Protocols, " International Journal of u- and e- Service, and Technology Vol. 5, No. 3, September, 2012.

[4] Sooksan Panichpapiboon, Wasan Pattara-atikom, "A Review of Information Dissemination Protocols for Vehicular Ad Hoc Networks, " IEEE Communications Surveys and Tutorials, vol. 14, no. 3, pp. 784-798, Third Quarter, 2012.

[5] R. Ahlswede, N. Cai, S. R. Li, and R. W. Yeung, "Network Information Flow," In IEEE Transactions on Information Theory, 2000.

[6] R. W. Yeung, "Network coding: A historical perspective," Proc. IEEE, vol. 99, no. 3, pp. 366–371, Mar. 2011.

TABLE I. COMPARISON OF VARIOUS NETWORK CODING-BASED DATA DISSEMINATION PROTOCOLS IN VANET

Network coding protocol	**Transmission Technique**	**Coding Technique**	**Combination**	**Evaluation Models**	**Network Coding gain**
COPE [7]	Unicast	Xor	-	Experiment	Throughput
LDNC [8]	Unicast	Xor	-	Simulation	Throughput
MORE [9]	Unicast	RLNC	-	Experiment	Throughput and reliability
OMNC [10]	Unicast	RLNC	-	Experiment	Throughput
Code torrent [12]	Broadcast	RLNC	NC + random amount of waiting time before each transmission	Simulation	File downloading delay
CodeOn [13]	Broadcast	SLNC	NC + transmission backoff delay	Simulation	Average downloading rate
DONC [14]	Broadcast	RLNC	NC+ Delay based	Simulation	Packet reception ratio in lossy networks
Probabilistic NC[15]	Broadcast	RLNC	NC+ Probabilistic based	Analysis and Simulation	Energy efficiency
CDNC [16]	Broadcast	RLNC	NC+ Probabilistic based	Analysis and Simulation	Resources consumption efficiency
CODEB [17]	Broadcast	Xor and RS	NC+ PDP	Analysis and Simulation	Number of transmissions
DifCode [19]	Broadcast	Xor	NC + MPR	Simulation	Number of transmissions
EBCD [21]	Broadcast	Xor or RS	NC+DDCDC	Simulation	Number of transmissions Energy efficiency
RONC [22]	Broadcast	Xor	NC + Opportunistic based	Simulation	Reliability for safety message
CodePlay [23]	Broadcast	SLNC	NC+ opportunistic transmission scheduling algorithm	Simulation	Bandwidth efficiency
DENC [24]	Broadcast	RLNC	NC + opportunistic Broadcast	Analysis and Simulation	Dissemination completion duration Dissemination Velocity
VanetCode [25]	Broadcast	RLNC	NC + simple broadcast	Simulation	Content distribution Delay
CCD [26]	Broadcast	Xor	NC + single-hop broadcasting	Simulation	Data secrecy
ENCDA [27]	Broadcast	RLNC	NC+ carry and forward technique	Analysis and Simulation	Data Availability

[7] S. Katti, H. Rahul, W. Hu, D. Katabi, M. Medrad, and J. Crowcroft, “XORs in the air: Practical wireless network coding,” IEEE/ACM Trans. Netw., vol. 16, no. 3, pp. 497–510, Jun. 2008.

[8] L. Haojie, Z. Dongdong, and Y. Chen, “Local-directed network coding in vehicular ad-hoc networks,” in Proc. IEEE on Intelligent Signal Processing and Comm. Sys. (ISPACS), China, Dec. 2010, pp. 1–4.

[9] S. Chachulski, M. Jennings, S. Katti, and D. Katabi, “MORE: A Network Coding Approach to Opportunistic Routing,” Massachusetts Institute of Technology, Computer science and Artificial Intelligence Laboratory, Tech. Rep., June 2006.

[10] X. Zhang and B. Li, “Optimized Multipath Network Coding in Lossy Wireless Networks,” in Proceedings of the 2008 The 28th International Conference on Distributed Computing Systems, ser. ICDCS ’08. Washington, DC, USA: IEEE Computer Society, 2008, pp. 243–250.

[11] S. Ni, Y. Tseng, Y. Chen and J. Sheu. “The Broadcast Storm Problem in a Mobile Ad Hoc Network,” Proc. of ACM Int’l Conf. on Mobile Computing and Netw. MOBICOM, pp. 151–162, 1999.

[12] Lee, J. Park, J. Yeh, G. Pau, M. Gerla, “Code torrent: content distribution using network coding in vanet”, in Proc. of the 1st international workshop on Decentralized resource sharing in mobile computing and networking, pp. 1- 5, 2006.

[13] Ming Li, Zhenyu Yang and Wenjing Lou, “ CodeOn: Cooperative Popular Content Distribution for Vehicular Networks using Symbol Level Network Coding,” IEEE Journal On Selected Areas In Coomunications, VOL. 29, NO. 1, JANUARY 2011.

[14] Farhan H. Mirani, Anthony Busson, Cedric Adjih, “Improving Delay-Based Data Dissemination Protocol in VANETs with Network Coding,” REV Journal on Electronics and Communications 2, 3-4, 2013.

[15] C. Fragouli, J. Widmer, and J.-Y. L. Boudec, “Efficient broadcasting using network coding,” IEEE/ACM Trans. Netw, vol. 16, no. 2, pp. 450– 463, 2008.

[16] LEE, Seung-Hoon, LEE, Uichin, LEE, Kang-Won Lee and Mario Gerla, “Content distribution in VANETs using network coding: the effect of disk I/O and processing O/H,” 5th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks, SECON'08, 2008, p. 117-125.

[17] L. Li, R. Ramjee, M. Buddhikot, and S. Miller, “Network Coding-Based Broadcast in Mobile Ad-hoc Networks,” in INFOCOM 2007. 26th IEEE International Conference on Computer Communications. IEEE, May 2007, pp. 1739 –1747.

[18] W. Lou and J.Wu, “On reducing broadcast redundancy in ad hoc wireless networks,” IEEE Transactions on Mobile Computing, 2002.

[19] N. Kadi and K. A. Agha, “MPR-based flooding with distributed fountain network coding,” in Ad Hoc Networking Workshop (Med-Hoc-Net), 2010 The 9th IFIP Annual Mediterranean, June 2010, pp. 1 –5.

[20] A. Qayyum, L. Viennot, and A. Laouiti, “Multipoint relaying for flooding broadcast messages in mobile wireless networks,” in Proc. IEEE Hawaii Int’l Conf. on Sys. Sciences (HICSS), Big Island, HI, Jan. 2002, pp. 3866–3875.

[21] S. Yang and J. Wu, “Efficient broadcasting using network coding and directional antennas in MANETs,” IEEE Trans. Parallel Distributed Sys., vol. 21, no. 2, pp. 148–161, Feb. 2010.

[22] B. Hassanabadi and S. Valaee, “Reliable Network Coded MAC in Vehicular Ad-Hoc Networks”. In Proc. IEEE 72nd Vehicular Technology Conf. Fall (VTC 2010-Fall), 2010.

[23] Z. Yang, M. Li, and W. Lou, “Codeplay: Live multimedia streaming in vanets using symbol-level network coding,” in Proc. 18th IEEE int’l conf. on Network Protocols (ICNP),, 2010, pp. 223–232.

[24] Fei Ye, Sumit Roy, Haobing Wang, “Efficient Data Dissemination in Vehicular Ad Hoc Networks”, IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 30, NO. 4, MAY 2012.

[25] S. Ahmed and S. Kanhere, “VANETCODE: network coding to enhance cooperative downloading in vehicular ad-hoc networks,” in Proc. int’l conf. on Wireless Communications and Mobile Computing (IWCMC), 2006, pp. 527–532.

[26] Gerla, Mario, Cascella, Roberto G., Cao, Zhen, Crispo, Bruno and Battiti, Roberto, “An efficient weak secrecy scheme for network coding data dissemination in VANET,” in PIMRC, 2008. 19th International Symposium on. IEEE, 2008, pp. 1-5.

[27] Zhenni Feng, Yanmin Zhu, Qian Zhang, Min Gao, “Exploiting Network Coding for Data Availability in Vehicular Networks: Issues and Opportunities,” msn, pp.24-30, 2012 8th International Conference on Mobile Ad-hoc and Sensor Networks (MSN), 2012.