Network Coding Scheme Behavior in a Vehicle-to-Vehicle Safety Message Dissemination

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***Abstract*—Message dissemination is considered as a challenging task in Vehicular Ad-hoc network (VANET). In particular, safety messages, such as, road accident warning, traffic congestion warning, etc., are the most critical messages type that need to be efficiently transmitted in a wireless and mobile network where the topology changes dynamically. Many protocols have been proposed for the sake of disseminating information with a high data reachability and a low end-to-end delay in a limited bandwidth. In this work, we focus on a new trend of dissemination protocols based on the "Network Coding" (NC) scheme. Precisely, we intent to study the NC gain toward safety message dissemination and deduce its suitability in accordance to such application requirements. To this end, three NC-based protocols are proposed for the aim at thoroughly studying the impact of such technique on the safety message dissemination performance. The gain of NC scheme is studied under different traffic densities (from low to high dense network). The simulation results show that NC could be an efficient solution to overcome the intermittent connectivity in sparse network mainly for comfort applications but not suitable for safety message dissemination, especially in high dense network, since it may introduce a high transmission delay.**

Keywords—Vehicular Ad hoc Networks, Network Coding, Data Dissemination, Vehicle-to-Vehicle Communication, Intelligent Transportation System

I. Introduction

One of the major driving forces for implementing the Vehicular Ad-hoc Networks is ensuring an efficient and safe Intelligent Transportation systems (ITSs). Composed of mobile vehicles connected via wireless links, VANETs are designed to support a wide variety of applications ranging from safety applications to infotainment and entertainment applications. Since they are meant to save loss of live and protect the road users, safety applications are considered as the most valuable and critical applications category. For the sake of ensuring such applications, an efficient data exchange through Vehicle-to-Vehicle communications should be guaranteed. However, due to the challenging features of VANET (i.e., highly dynamic change in the network topology, high node mobility, etc.), tremendous efforts have been devoted on the data dissemination design that should overcome the intermittent connectivity problem between vehicles in low traffic density and the collision and contention problems in high dense traffic due to an excessive rate of data transmissions.

Among the proposed data dissemination protocols we distinguish a new paradigm design recently applied in the vehicular environment called "Network Coding" [1] [2]. The NC scheme aims to go beyond the traditional transmission techniques by enabling intermediate nodes to mix different packets before re-forwarding. This means that instead of broadcasting each packet via a separate transmission, the node is able to combine all the packets that need to be transmitted in one combined packet, typically using an Xor or a Random Linear Network Coding (RLNC) techniques. In such a way, the number of transmission should be theoretically reduced since less transmissions are needed in order to transmit more information. Upon the reception of the coded packet, the receiver tries to decode it according to specific packets previously received.

At first glance, this technique seems to be a promising solution for data dissemination since it is able to improve the data transmission efficiency with respect to the network throughput, wireless resources capacity, energy consumption and reliability issues. Despite these prominent properties, NC technique have shown some limits due to its design that will be depicted in the present work.

Indeed, our main focus is to reveal the impact of the NC technique on the safety message dissemination performance and conclude its suitability for such critical message dissemination requirements. In this context, we propose three NC solutions based on a combination between known data broadcast protocols and the NC scheme. The NC behavior is studied under different network traffic densities (sparse and dense network).

The reminder of this paper is organized as follows. In Section II, we report previous works with relation to their application domain. Section III describes the proposed protocols design and mainly the NC scheme integration. Section IV, is dedicated to present the simulation environment and discuss the performance evaluation. Finally, concluding remarks and future works are presented in Section V.

II. Related Works

In a previous work [3] we have given an overview of data dissemination protocols based on the Network Coding technique appeared in the literature. Furthermore, we have classified them in order to investigate the gain that can be reached whenever this technique is applied in a vehicular environment. In particular we have mainly addressed the NC-based protocols designed for a Vehicle-to-Vehicle (V2V) communication since it is considered as the most relevant communication mode for safety data dissemination. Based on this review we have concluded that NC is an efficient technique that is able to mainly improve the network reliability, throughput and energy consumption but for a specific type of applications.

Therefore, although its benefits, the NC technique could not be perfectly applied for different context. Here we mention some NC-based solutions with relation to the targeted application.

The NC is essentially used for content distribution of multimedia data [4] [5] [6] [7]. Only few works have addressed the safety applications by applying the NC scheme. In [8], the authors propose a Repetition-based MAC protocol for beacon-message exchange in order to improve the network reliability. Based on neighbors feedback (about their location, speed, etc.), each node repetitively broadcast the generated message according to a repetition pattern. The content of the message is no longer the own message of the sender but it is a combination of received messages using the Network coding scheme.

In the same line, authors in [9] propose an opportunistic scheme for beacon-message dissemination, while assuming a more realistic V2V channel model and considering that the perfect feedback is obtained. Their goal is to maximize the safety messages reachability and minimize the reception delay in a lossy vehicular network. Simulation results have shown that this opportunistic scheme outperforms the Random Linear Network Coding (RLNC) in terms of average delay and packet loss probability. Though this reached performance, the average delay considered in [9] measures the delay between two consecutive successful received messages for a specific node. However, the end-to-end delay of a packet to reach the maximum of receivers within a specific area of interest is not addressed.

Moreover, authors in [10] combined a delay-based broadcasting protocol with the Network coding scheme. Their aim is to reduce the packet loss effect. This protocol is dedicated for short alert message however its delay performance was not studied.

On the other hand, authors in [11] have addressed non-safety applications, namely advertising applications. Their aim is to improve the network throughput (bandwidth utilization) by applying the network coding. Therefore, according [11] each relaying node combines the packet received from the two considered sources before rebroadcasting which reduces the bandwidth consumption and leads to improve the throughput about 38%.

III. THE NC-BASED PROTOCOL DESIGN

We should emphasize that the objective of this paper is not to study the network coding algorithm, but rather to investigate the main gain that we can reach by applying the network coding for safety message dissemination generated whenever a critical situation is detected on the road.

To do so, we combined three broadcast protocols with the NC scheme, for which details are given below.

- BFP-NC: is a combination between a typical broadcasting technique named "Blind Flooding Protocol" (BFP) and the NC scheme. In BFP, each receiver checks the packet novelty. If it is new, then it is immediately rebroadcasted. Otherwise, it is discarded.
- S1PD-NC: is a combination between the Slotted 1-persistence Dissemination protocol (S1PD) [12] and the NC scheme. S1PD is a delay-based broadcasting protocol. The core idea of such protocol is to assign to each receiving vehicle a waiting time before reforwarding the message further in the network. Typically, the waiting time is inversely proportional to the distance separating the sender and the receiver. Thus, the longer the distance, the shorter the waiting time period is. The objective of such technique is to overcome the "Broadcast storm" [13] problem generated in dense networks. S1PD is considered as the basic strategy upon which further modifications and enhancements are conducted [14] [15] [16] [17].
- SEAD-NC: is a combination between a Simple and Efficient Adaptive data Dissemination protocol (SEAD) [16] and the NC scheme, where SEAD is an adaptive data dissemination protocol, based on a hybrid strategy (delay + probability). SEAD takes implicitly into account the network density to define the probability of broadcast. Moreover, thanks to its adaptivity feature, SEAD may behave efficiently either for safety or non-safety messages exchange.

These combinations are made according to the following design, that may be described through two main blocks, illustrated in Fig. 1 and Fig. 2. To better understand the NC-based protocols design, we first define the following terminology used throughout the remaining of this work:

- *Coded Packets*: is a set of packets mixed together into a linear combination using the Random Linear Network Coding (RLNC) scheme. The decoding of such packets is performed via Gaussian elimination. Noting that the complexity of decoding "n" packets through linear equations is $O(n^3)$. The decoding process is triggered whenever the node receives enough independent linear equations of the different coded packets. We assume in our work that the independence condition is always fulfilled.
- *Native Packet*: is an original data packet either locally generated by the node application unit or extracted from coded Packets.
- *Data Buffer*: a buffer that includes successfully received native packets.
- *Decoding Buffer*: a buffer in which the vehicle temporarily stores encoded packets waiting for further packets to be decoded.

A. NC-Reception block

The NC-Reception block is intended to deal with the decoding process and to save received packets in the appropriate buffer as depicted in Fig. 1.

Upon the reception of coded packets, a first test (T1) is performed to check whether these packets could be decoded or not. This test depends on the packets already stored in both Data and Decoding buffer. Since we are applying RLNC, a node should receive "N" independent linear equations in order to decode "N" native packets. If this condition is not fulfilled,

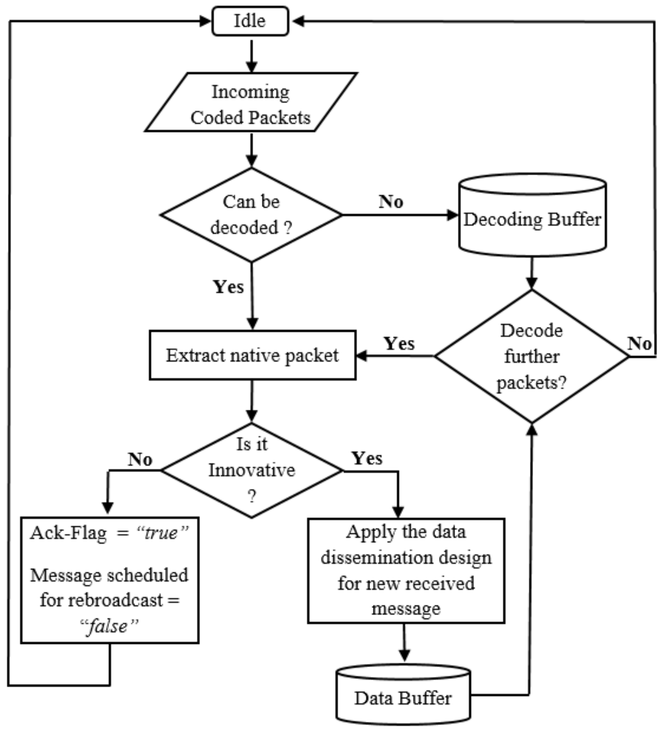

Fig. 1. NC-Reception Block.

the coded packets are temporarily stored in the Decoding buffer. Elsewhere, all native packets are extracted. Thereafter a second test (T2) is executed regarding the novelty of each extracted packet, i.e., whether it carries a new information or not. If it is the case, the packet is stored in the Data buffer and is scheduled for a rebroadcast according to the adopted data broadcast technique (i.e., BFP, S1PD or SEAD). Therefore, a waiting timer is assigned and an acknowledgement flag is initialized *"ACK-Flag = False"*. If it is an already seen packet coming from the backward side, then it is discarded and considered as an implicit acknowledgement *"ACK-Flag = True"*. Hence, such message will be no longer scheduled for an upcoming rebroadcast.

Each time a new native packet is extracted, a third test (T3) is made in order to check whether this packet is useful to decoded further packets already stored in the Decoding buffer or not. If a coded packet is decoded, then we return to the second test (T2) and the decoded packets are automatically removed from the Decoding buffer. Noting that the native packets in the Data buffer are sorted with respect to the waiting time and the acknowledgement Flag. The packets that are not yet acknowledged (*"ACK-Flag = False"*) and having the shortest period of waiting time have the highest priority to be coded and rebroadcast.

B. NC-Transmission block

The NC-Transmission block, presented in Fig. 2, is designed to handle the issue "Which packets need to be encoded" and "When encoded packets should be rebroadcast" by a forwarding vehicle. The transmission process is triggered whenever the waiting timer of a Native packet expire. Therefore, the "d" first packets stored in the data buffer (i.e., assigned to the shortest waiting time) are coded together and transmitted

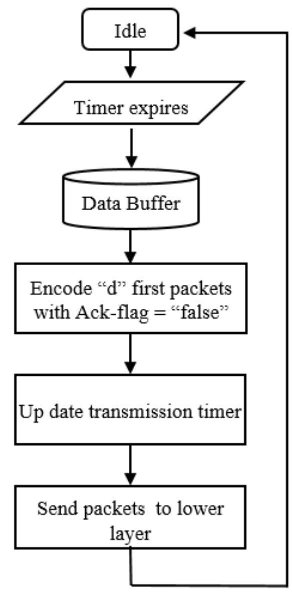

Fig. 2. NC-Transmission Block.

according to the data broadcast technique, either immediately or respecting a probability of broadcast. We note, that "d" is a fixed parameter that represents the coding degree, which means the maximum of packets that could be encoded. The timer of each chosen packet is updated according to the retransmission timeout. Only the packets which are not yet acknowledged, i.e. *"ACK-Flag = False"*, are considered.

IV. Performance Evaluation

In this section, we present the performance evaluation of the studied broadcast protocols in their original versions and in combination with the NC scheme, carried out by means of extensive simulations, using NS3 [18] simulator. These simulations aim to evaluate the impact of the NC scheme on the data dissemination efficiency in a vehicular environment. To this purpose we have used a micro-traffic simulator called "SUMO - Simulation of Urban Mobility" [19] for a realistic mobility trace in a highway environment. A three-lanes unidirectional road is considered with 6 km of length. The maximum of speed is set to 30 m/s while taking into account the speed variation during overtaking or at the presence of the traffic light. We set the bit rate to 6 Mbit/s in the MAC layer. We adjust the transmission power to achieve roughly 700 meters of transmission range, assuming a Nakagami propagation model. For the warning messages we assume the presence of two source nodes in the front responsible for a new packet generation each second. We assume in our simulation that the maximum of packets that could be encoded by a forwarding node is "d=2". Since, it allows us to give a lower bound on the dissemination delay. Elsewhere, a greater value of d will lead to a higher delay which may have an impact on the warning message dissemination efficiency as the coding technique will be more complicated. Each plotted result is an average of 20 runs of 100 s. We computed a 95% confidence interval, but it is not shown here since its range is very small. Further details about the simulation parameters are given in Table I. In order to study the network scalability, we have considered two traffic scenarios, as presented in Fig. 3:

- Scenario 1: Low dense network (sparse network) where vehicles are suffering some intermittent connectivity. In this case, we pretend the presence of a communication gap. Some vehicles are out of the reach of both the source vehicle and the nodes blogging to its transmission range.
- Scenario 2: High dense network where all vehicles are continuously connected. In such case, no communication gap is present, and all vehicles are connected through multi-hop communications.

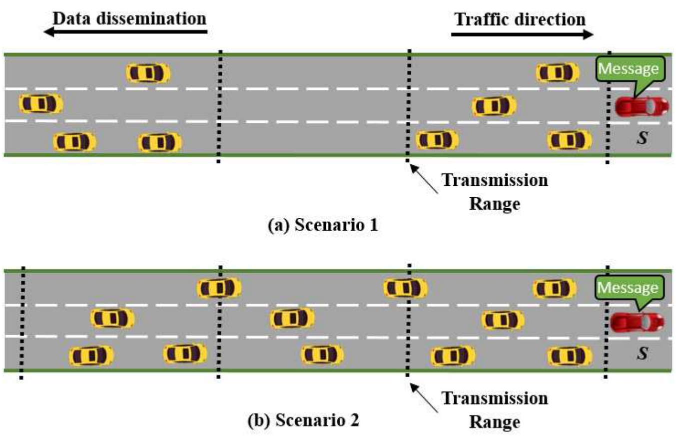

Fig. 3. NC Simulation Scenarios.

Our evaluation considers the following metrics:

- *Redundancy Ratio (R):* the proportion of the total received messages (new messages + redundant messages) to the number of original received messages (new messages).
- *Packet Delivery Ratio (PDR):* the average number of original packets successfully received by a vehicle, compared to the total number of generated messages.
- *Forwarding Ratio (FR):* the proportion of vehicles in the network that are involved in the rebroadcast of a source packet.
- *End-to-End Delay (E2EDelay):* the average difference between the data packet generation time by the source vehicle and the reception time of this packet by the last reached vehicle.
- *Link Load (bit/s):* the average of broadcast traffic (in terms of bits) received by each vehicle over a unit of time.

A. NC Performance in Sparse Network

Based on the simulation results presented in Fig. 4, we can deduce, from the first scenario, that both the BFP and the NC-BFP outperform the S1PD, SEAD and their combination with the NC scheme in terms of packet delivery ratio. This result is expected since these latter protocols (S1PD, SEAD) are particularly designed to deal with the "Broadcast Storm" in dense network. So their main goal is to reduce the number of

TABLE I. SIMULATION PARAMETERS

Parameters	Specifications
Simulation times	100 s
Number of source nodes	2
Vehicles' density	Scenario 1 : 5 veh/km Scenario 2 : 65 veh/km
Highway length (1 direction)	6000 m
Max speed	30 m/s
Transmission range	700 m
Bit Rate	6 Mbit/s
Propagation model	Nakagami
Data packet generation frequency	1 Hz
Data packet size	500 bytes
Number of runs	20
Number of coded Packets	2

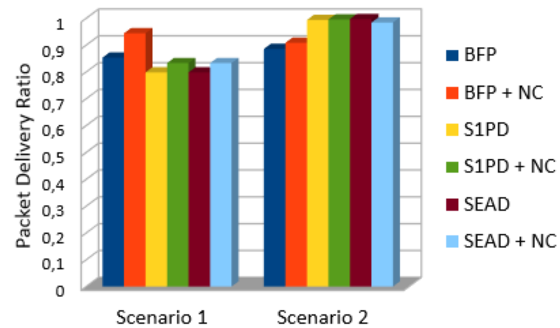

Fig. 4. Packet Delivery Ratio behavior under NC scheme.

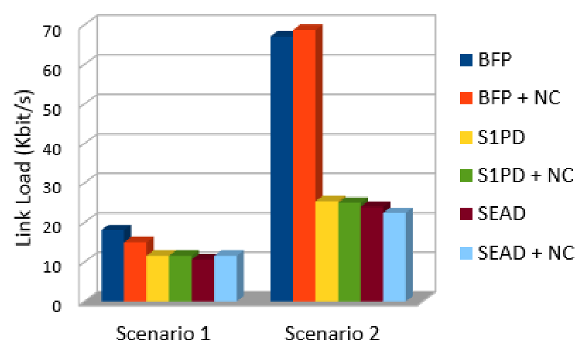

Fig. 5. Link Load behavior under NC scheme.

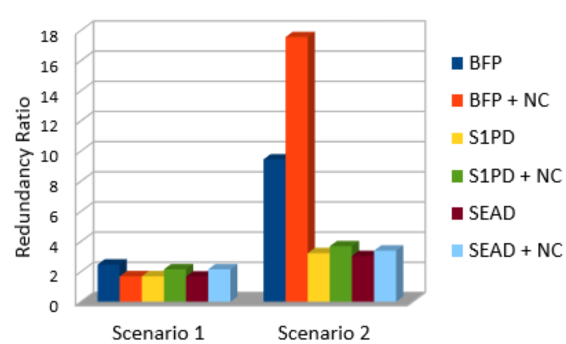

Fig. 6. Redundancy Ratio behavior under NC scheme.

redundant transmissions and therefore minimize the network resources consumption, as it is shown in Fig. 6 and Fig. 5 through the second scenario. However, in such scenario (sparse

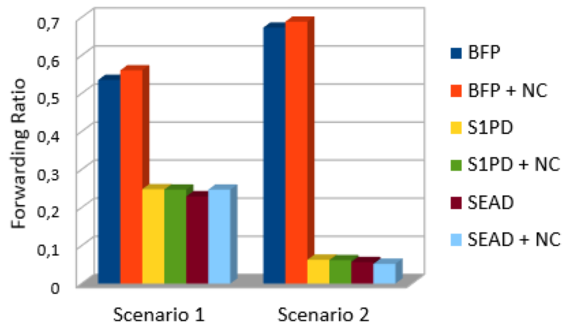

Fig. 7. Forwarding Ratio behavior under NC scheme.

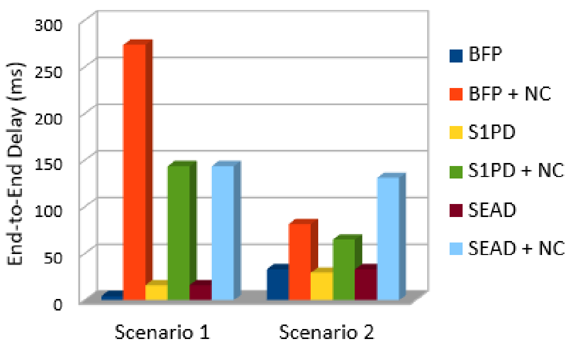

Fig. 8. End-to-End Delay behavior under NC scheme.

network) redundant transmissions are needed to overcome the packet loss due to intermittent connectivity.

From another side, by comparing the network coding versions to their original broadcasting protocols, we can obviously note that by integrating the NC scheme, the data dissemination protocol is able to improve the packet delivery ratio, more than 10% for the BFP. This means that the NC seems to be an efficient solution to overcome the intermittent connectivity problem between vehicles, due to the transmission range limits and the high node speed (highly dynamic topology), in the absence of road infrastructure from which broadcasted packets could be relayed.

Adding to that, if we focus on the BFP, as it is the most suitable protocol for such scenario, we can note that by applying the NC scheme the number of received messages per vehicle is reduced while offering a higher rate of packet reachability. This means that through one received coded packet we can extract more than one information and may be considered as a recover for some lost packets. Furthermore, even if these information are already known, they could be treated as an implicit acknowledgement for some packets that should not be re-forwarded. As a result, the NC improves the networks reliability while reducing the link load. This result is highlighted trough Fig. 4 and Fig. 5.

Although, these salient properties, the NC suffers from a high end-to-end delay, as depicted in Fig. 8. This result may be explained by the decoding process design on itself since in order to decode N new coded packets we necessarily need to receive N coded packets linearly independent. To meet this requirement, an extra time is required to receive enough coded packets. As a result, even it is considered as an acceptable and legitimate fact, the NC scheme could be efficient for delay tolerant applications (such as comfort applications), but not suitable for safety applications where the end-to-end delay is a critical metric.

B. NC Performance in Dense Network

For the dense scenario (scenario 2), we can obviously deduce the efficiency of S1PD and SEAD compared to the traditional transmission design BFP. They are able to significantly reduce the number of redundant packets and therefore the link load while achieving better data reachability within the same transmission delay.

Regarding the NC-based protocols, we can deduct from the Figures, that as opposed to what was theoretically mentioned in previous works, in dense networks, no perceptible benefit could be noted. The network coding does not reduce excessive transmissions, on the contrary, it may induce high link load as it is noticed with the BFP. This result is explained by the NC design that does not ensure an immediate packet decoding, since a specific number of combined packets should be earlier received. Also, as previously mentioned, some dissemination protocols (S1PD and SEAD here) may behave efficiently to mitigate the broadcast storm problem while ensuring a high delivery rate and a low delay. In the dense case, these protocols offer performances that are close to the optimal: a delivery rate equal to 100% and a redundancy ratio close to 2 (note that the latter cannot be lower than 2 as a node receives a packet from backward and forward). In this context, the contributions of the NC techniques become marginal.

In dense network, the NC technique is becoming more complicated and less efficient especially in terms of transmission delay. In fact, NC techniques have to face a complicated trade off that rises with the number of coded packet. On one hand, “Which packets to transmit ?” that means how many packets and what is the best combination of packets that should be mixed together before forwarding in order to achieve a high packet delivery. On the other hand “When to transmit?” which means how much time incoming packets should wait before generating a new coded packet. According to the NC technique, a node is allowed to combine only successfully decoded packets. However, the success of this latter procedure relatively depends on the received packets. So, the forwarding nodes have to wait the reception of a certain number of native packets in order to decode the new received packet. This condition may have a great impact on the packet transmission delay and hence the end-to-end delay overall the network. As a result, we consider that the NC scheme is not an outstanding solution that could be applied for critical message dissemination.

V. Concluding Remarks

In this work, we proposed three NC-based dissemination protocols. Our aim was to study the suitability of the NC technique for safety message dissemination mainly in terms of transmission delay, redundancy ratio, delivery ratio and link load. To this end we compared the proposed protocols to their original design in an attempt to thoroughly extract the gain that could be reached by applying this technique. Simulation results, conducted under different traffic densities revealed that the NC technique could be an efficient strategy to overcome the connectivity problems in sparse networks but this is at the cost of the delay transmission, which is legitimate. However, under a high dense traffic, no noticeable gain is detected. On the contrary, extra transmitted packets and transmission delay are observed.

Although its salient properties and numerous benefits toward content distribution, NC could be merely considered efficient for comfort applications which are more tolerant in transmission delay, especially in sparse networks. However, this scheme could not be an outstanding solution for safety message dissemination.

In future work, we will try to enhance these protocols performance in combination with the NC scheme by making a trade off between the protocol complexity (i.e. coding degree) and the network density. Therefore, it would be interesting if we could determine a dynamic coding degree in accordance with the network traffic density.

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