Ant Colony Optimization Based Delay-Sensitive Routing Protocol in Vehicular Ad Hoc Networks

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Abstract. Vehicular Ad Hoc Network (VANET) is a multi-hop autonomous system that consists of vehicular nodes. VANETs aim to perform an efficient wireless communication in vehicular environments, and vehicular communication scenario is one of the typical high reliability and low delay scenarios in 5G networks. However, the special situations in VANETs like frequent link failure, unstable network topology and random change of vehicle mobility pose a number of challenges in routing protocol design. In this paper, we propose a delay sensitive routing protocol for VANETs to address these serious problems by using ant colony optimization (ACO) and we aim to find a path with a low average end-to-end delay from source to destination. We transform the next hop selection into a probability problem according to ACO concept. There are two mechanisms applied in routing discovery process which utilize pheromone information of transmission delay and heuristic information of vehicles. Two Mathematical models are proposed in pheromone deposit and evaporation prodecure to estimates transmission delay. Performance analysis and simulation results show that the proposed scheme has better performance.

Keywords: VANET · Ant colony optimization · Routing protocol · GPSR

1 Introduction

With the development of wireless communication technology and the popularization of vehicular electronic equipments, the study of vehicular communication network has become a trend. Vehicular Ad Hoc Network (VANET) is a emerging network which enables communications among vehicles (Vehicle-to-Vehicle,

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V2V), between vehicles and roadside infrastructures (Vehicle-to-Infrastructure, V2I) and between vehicles and pedestrians (Vehicle-to-Pedestrian, V2P) [1–3]. Unlike from Mobile Ad Hoc Network (MANET), VANETs show some different features compared with MANETs to some extent. The most commonly difference in VANETs is the high speed and unstable network topology which makes the link situation more complex and difficult to control. In addition, the best effort delivery in traditional networks can not meet the applications in VANETs, since most of the emergency applications in VANETs are delay-sensitive which guarantees traffic safety. Usually, we prefer a lower transmission delay rather than a higher transmission rate as far as the emergency messages. The fundamental architecture of VANETs is shown in Fig. 1. In VANETs environment, communication range of vehicle is small compared to cellular networks. Besides, channel conditions are relatively poor due to the obstruction of the roadside buildings and the low altitude of the vehicle antenna. Therefore, the typical route from source vehicle to destination vehicle consists of multiple hops and middle node on the path acts as a forwarding node. Consider the important role of multi hop communications and the special characteristics in VANETs, its necessary to develop efficient routing protocol for VANETs. A variety of studies have been done on MANETs in order to propose efficient routing protocols since last century. Such as AODVGPSR and DSR [4,5]. However, these famous routing protocols are dedicated to solve basic requirements in MANETs and can hardly meet the harsh requirements in VANETs. Researches have focused on routing design to improve routing performance over VANETs. The authors in [6] proposed a geographical routing protocol which takes advantage of the road conditions to improve QoS performance. Each forward node selection guarantees delay, bandwidth usage and error bit while satisfying the Qos constraints. In [7], authors developed a propagation strategy and a delay analytical framework in routing algorithm using bidirectional vehicles to forward messages. The authors in [8] designed an algorithm for cluster head and gateway node selection which is combined with AODV routing protocol to provide efficient and secure communications among vehicles by grouping vehicles into different clusters. In this paper, the well-known theory of ant colony optimization (ACO) is adopted to optimize transmission delay in VANETs. The newly research is done on the basis of our previous work in [9]. We in [9] analyse the access mechanism of MAC layer and propose a mathematical model for estimating the delay consumed in the MAC layer. Consider that only the MAC delay is optimized which only is a part of end-to-end delay in our previous work. Therefore, we propose an improved scheme in this work to optimize not only MAC delay but also transmission delay by using ACO. What is expected is that the performance of the new scheme has been improved. The theory of ant colony optimization originates from the study of real ant colony behavior in nature [10–12]. Due to the strong robustness of ant colony algorithm and the convenience to combine with other algorithms, ant colony algorithm is widely applied to address all kinds of NP hard problems. We notice that the transmission process of packets is similar to the process that ants seek paths from nest to food. Hence, as similar as ants lay pheromone along the path, data packets will also lay information during transmission. Commonly, packet delay of each transmission can be recorded as pheromone information. Moreover, this information can be fed back to the transmitter. So we combine the heuristic knowledge of end-to-end delay in the packet transmission process with the characteristics of vehicles to optimize routing algorithm. The remainder of this paper is organized as follows. In Sect. 2, the principle of ACO is introduced. Section 3 presents the proposed adaptive delay-sensitive routing protocol based on ACO concept. Performance evaluations and simulation results are presented in Sect. 4. In the end, the conclusions are derived in Sect. 5.

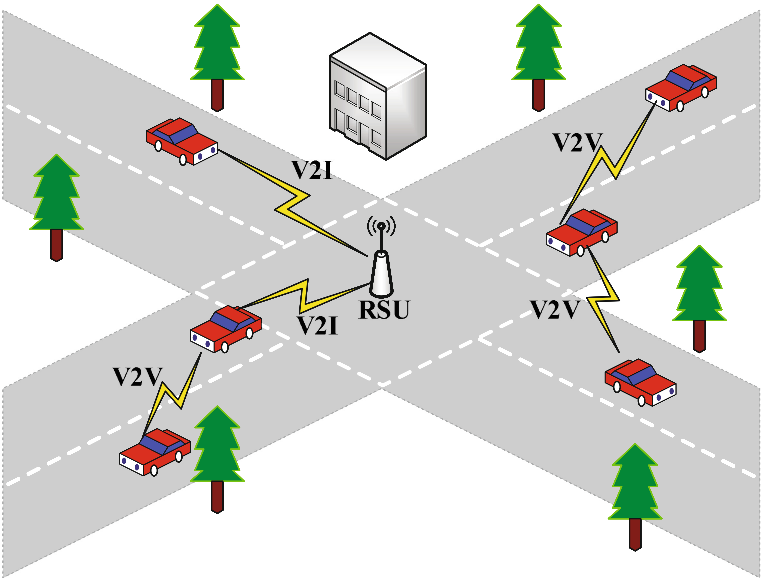
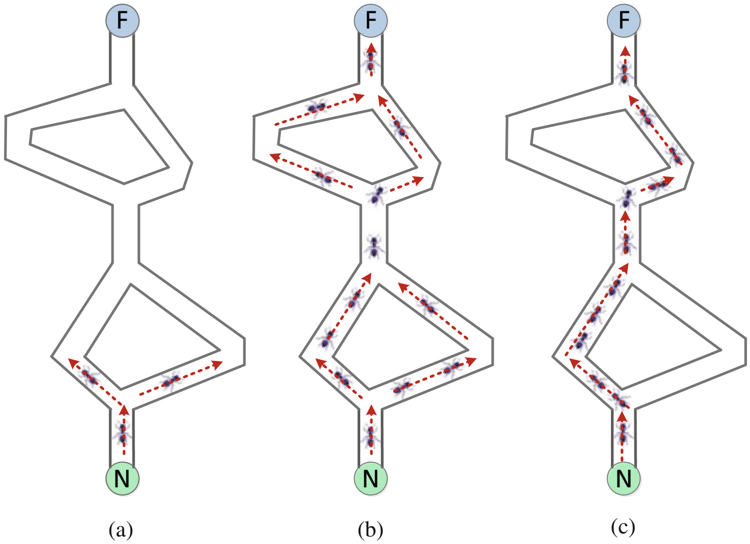


Fig. 1. The fundamental architecture of VANETs, including vehicle to vehicle communications and vehicle to infrastructure communications.

2 Ant Colony Optimization

In the early 1990s, Goss et al. proposed the concept of ant colony optimization algorithms after a long period of study on the behavior of real ants [13]. ACO is a branch of swarm intelligence (SI) and has been proved to be able to solve the complex combinational optimization problems. Figure 2 presents the behavior of ants when searching for food. As shown in Fig. 2(a), ants randomly select a path when in the beginning of finding food from their nest. After a period of time, ants are distributed on the every path from nest to food as shown in Fig. 2(b). Finally, almost all ants go through the shortest path after a long research which is shown in Fig. 2(c). Unlike human, ants lay a chemical substance called pheromone when searching the route. When ants reach a intersection, they tend to select the way with more pheromone. When a plenty of ants searching the food on different paths, ants that pass the shortest path will be the most after a period of time because shortest path takes shortest time. Therefore, the amount of pheromone on the shortest path will be the most, so all the ants will select the shortest path in the end. The characteristics of real ants will provide an idea for solving actual optimization problems.



(a) (b) (c)

Fig. 2. The behavior of ant colony from nest N to food F. (a) The initial state of ant colony; (b) The intermediate state of ant colony; (c) The final state of ant colony.

3 The Proposed Routing Protocol

In this section, we introduce the proposed routing protocol in detail. The kernel concept of routing is to measure the reasonableness of each forward node and then choose the most reasonable node. Hence, the routing problem can be transformed into the design of probability model. Recall the process of ants searching for food, ants follow the pheromone rule to explore the network. We take the pheromone concept into routing algorithm and combined with the characteristics of vehicles in VANETs. Commonly, the probability model can be represented as follows [14]:

Where τ_{ij} is the density of pheromone from vehicle node i to vehicle node j; η_{ij} is the heuristic information between vehicle i and vehicle j, including link expiration time, distance and MAC backoff times. N_i is the set of neighbors belong to vehicle i; α is the weight parameter of pheromone and β is the weight parameter of heuristic information; P_{ij} represents the probability that vehicle i choose vehicle j as forward node. Therefore, the density of pheromone and the heuristic information of vehicles are the two main mechanisms in our proposed routing protocol. They will be introduced in the following subsections.

3.1 Pheromone Deposit and Evaporation

Consider that most applications in VANETs require a low end-to-end delay, so we can transform packet delay as pheromone information. In the packet transmission process, each packet will experience a delay from source node to destination node. We assume vehicle i transmits n packets to vehicle j in time interval Δt. Then we can get the average delay of a single packet as pheromone information from vehicle i to vehicle j as follows:

$$\tau_{ij}^{D}(\Delta t) = \frac{1}{n}\sum_{k=1}^{n} D_{ij}^{k} \tag{1}$$

where D_{ij}^{k} represents the delay of k?th packet from vehicle i to vehicle j. If the transmitter adds transmission time to the packet, the receiver can get the delay of the packet based on the receive time. According to the transmission control protocol, the transmitter will wait a acknowledge (ACK) message after send a packet. If the ACK message isnt received in a certain time, the transmitter will resend the packet. Therefore, the transmitter can collect the delay of each packet which send to the receiver according to the ACK message. Just like the pheromone information laied by real ants, it will expirence a evaporation process as time passed. In VANETs environment, the network topology will change with time passed. Therefore, the pheromone information of delay between two vehicles will gradually become valueless. In general, we assume the evaporation rate of pheromone is a constant. Then the evaporation process of pheromone can be represented as follows:

$$\tau_{ij}^{E}(\Delta t) = (1-\rho)\cdot\tau_{ij}(t) \tag{2}$$

where ρ is the constant evaporation rate of pheromone; $\tau_{ij}(t)$ is the level of pheromone between vehicle i and vehicle j at time t. Consequently, the pheromone information of delay collected between vehicle i and vehicle j at time $t + \Delta t$ is as follows:

$$\tau_{ij}(t+\Delta t) = \tau_{ij}^{D}(\Delta t) + \tau_{ij}^{E}(\Delta t) = \frac{1}{n}\sum_{k=1}^{n} D_{ij}^{k} + (1-\rho)\cdot\tau_{ij}(t) \tag{3}$$

As we prefer a low end-to-end delay, we normalize the result as follows:

$$\tau_{ij} = \frac{\tau_{max} - \tau_{ij}(t+\Delta t)}{\tau_{max}} = \frac{\tau_{max} - \frac{1}{n}\sum\limits_{k=1}^{n} D_{ij}^{k} + (1-\rho)\cdot\tau_{ij}(t)}{\tau_{max}} \tag{4}$$

where τ_{max} is the maximum value of pheromone between vehicle i and its neighbors.

3.2 Heuristic Information of Vehicles

With the utilization of modern vehicular electrical equipments, the mobility information can be collected by these devices, such as speed, location, move direction and so on. We assume that vehicles can get the mobility information of neighbors and destination under the assistance of Global Positioning System (GPS). These information has an important influence on the performance of routing protocol to a large extent. For example, the well-known GPSR routing protocol selects the forwarding node with the forwarding regulation of shortest distance. Hence, we take distance into consideration as heuristic information. In addition, the number of MAC backoff times and link expiration time can be considered as well.

1. Link Expiration Time: Link expiration time (LET) measures the lifetime of a link, and wireless links with a long LET will maintain a longer communication time. If the locations of vehicle i and vehicle j are (x_i, y_i) and (x_j, y_j), the velocity of vehicle i and vehicle j are v_i and v_j respectively. Then we can calculate the distance and angel between vehicle i and vehicle j. According to communication range R and locations, we can get $\varDelta d_{ij}$ as the relative distance which maintenances the wireless link. In addition, the relative velocity $\varDelta v_{ij}$ between vehicle i and vehicle j can be calculated by speed. As a result, the LET between vehicle i and vehicle j can be simply written as follows:
$$LET_{ij} = \frac{\varDelta d_{ij}}{\varDelta v_{ij}} \tag{5}$$
2. MAC Backoff Times: According to the MAC layer protocol of VANETs, vehicles must experience a contention process before transmission in a cluster. Thus, the delay in MAC contention process is a part of end-to-end delay. Its essential to reduce MAC delay because it influence the ultima performance of delay. Regard that the basic backoff algorithm in MAC layer is the Binary Exponential Backoff (BEB) algorithm, therefore, node has a low MAC delay if the number of backoff times is less. First, we analysis the procedure of MAC contention. In MAC layer contention process, nodes will start a backoff process before transmission. The backoff time is generated randomly. Only the backoff ends, node can start a transmission. The problem is how to estimate the successful probability in a contention process. We assume the packet arrival rate follow the Poisson distribution and the probability that vehicle i has n packets to be transmitted during a time interval t is written as follows:
$$P_i(t, n) = \frac{(\lambda t)^n}{n!} e^{(-\lambda t)} \tag{6}$$
where λ is the packet arrive rate of a vehicle. Then we can get the successful probability $P_i(t, 0)$ and failure probability $1 - P_i(t, 0)$ of each contention.

Consequently, the average number of backoff times following the above analysis is calculated as follows:

$$\bar{N_i} = \lim_{n \to -\infty} \sum_{k=1}^{n} k \times (1 - P_i(t, 0))^{k-1} \times P_i(t, 0) = \frac{1}{e^{-\lambda(j) \times t}} \tag{7}$$

where $\lambda(j)$ is the overall packet arrival rate in cluster j. We normalize the results of heuristic information (distance, LET and extimated MAC backoff times) between vehicle i and vehicle j and we get the weight value of heuristic information is as follows:

$$\eta_{ij} = w_1 \frac{\bar{N}_{max} - \bar{N}_j}{\bar{N}_{max}} + w_2 \frac{LET_{ij}}{LET_{max}} + w_3 \frac{D_{max} - D_i}{D_{max}} \tag{8}$$

where $\bar{N}_{max}$, LET_{max} and d_{max} are the maximum value of backoff times, LET and distance; D_j is distance between vehicle j and destination; w_1, w_2 and w_3 are weight value and $w_1 + w_2 + w_3 = 1$. Finally, we combine pheromone information with heuristic information and apply Eq. (5), Eq. (9) to Eq. (1). Then we get the mathematical model of forward probability between two vehicles. Following the analysis, we develop the routing algorithm by solving the following problem:

$$\max_{j \in N_i} P_{ij} = \max_{j \in N_i} \frac{[\tau_{ij}^{\alpha}] \cdot [\eta_{ij}^{\beta}]}{\sum\limits_{l \in N_i} [\tau_{il}^{\alpha}] \cdot [\eta_{il}^{\beta}]} \tag{9}$$

The procedure of the proposed ACO based delay-sensitive Routing Protocol can be summarised as follows. Firstly, measure the delay of pheromone information by flooding RREQ packets. Secondly, measure the heuristic information including LET, backoff times and distance. Thirdly, combine these two mechanisms by the method of ACO using Eq. (1). The detailed ACO based delay-sensitive routing algorithm is shown in Algorithm 1.

Algorithm 1. The Proposed Routing Algorithm

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Collect neighbor vehicles of transmit vehicle in set M;
Calculate and update pheromone information of delay $\tau_{ij}$ by Eq.(5);
Calculate heuristic information (link expiration time, MAC backoff times
    and distance) $\eta_{ij}$ by Eq. (9);
Apply Eq.(5) and Eq. (9) to calculate forward probability $P_{ij}$;
Select the vehicle with maximum value of $P_{ij}$ in neighbor vehicle set M;
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4 Performance Evaluations

The performance evaluation of the proposed routing protocol has been investigated and compared with GPSR routing protocol and AODV routing protocol. In addition, we compare the proposed scheme with the scheme in [9] as well. The simulation scenario is a 1000 m 25 m highway area. Vehicles move with a average velocity 50 km/h. The number of vehicles is variable from 12 to 60. The communication range of vehicle is 250 m. Table 1 shows the detailed simulation parameters. Figure 3 presents the average throughput among different routing protocols versus the number of vehicles. In this figure, the average throughput increases as the number of vehicles increases, which is expected because numerous nodes provide connectivity as the number of vehicles increases. Hence, the probability that packets transmitted to the destination increases which leads to a higher average throughput. Also, Fig. 3 shows that the average throughput of our proposed routing protocol outperforms the scheme in [9], GPSR routing protocol and AODV routing protocol, which can be explained according to the following reasons. In our proposed routing protocol, we select each forward node with better delay and connectivity performance as we estimated the transmission delay and MAC delay (MAC backoff times represents the delay in MAC layer), and consider the influence of vehicle mobility. However, GPSR only select the forward node according to distance which results in a terrible link connectivity. AODV selects the path with minimum hops which causes network congestion easily, result a bad performance. The above observations demonstrate that our routing protocol has a better performance than GPSR and AODV.

Table 1. Simulation Parameters.

Parameters	value
Scenario layout	Highway
Terrain size	$1000\,\mathrm{m} * 25\,\mathrm{m}$
Packet size	512 bytes
Transmission power	23 dBm
ρ	0.1
(α, β)	$(1/2, 1/2)$
(w_1, w_2, w_3)	$(1/3, 1/3, 1/3)$
Speed of vehicles	10–30 km/h
Vehicle density	Up to 60
Transmission range	250 m
Bandwidth	10 MHz
Comparison schemes	The Proposed, Scheme in [9], GPSR, AODV
Simulation time	500TTI

Figure 4 compares average end-to-end delay of different routing protocols against the number of vehicles. As shown in Fig. 4, average end-to-end delay increases both in all protocols with the increase of vehicle density. This is because MAC layer contention becomes intensely competitive, which determined by the fact vehicles in a cluster use channel resource through competition according to the 802.11 DCF (Distributed Coordination Function) mechanism. In addition, we can see that delay of our proposed routing protocol is lower than scheme in [9], GPSR and AODV, which demonstrates our routing protocol has better

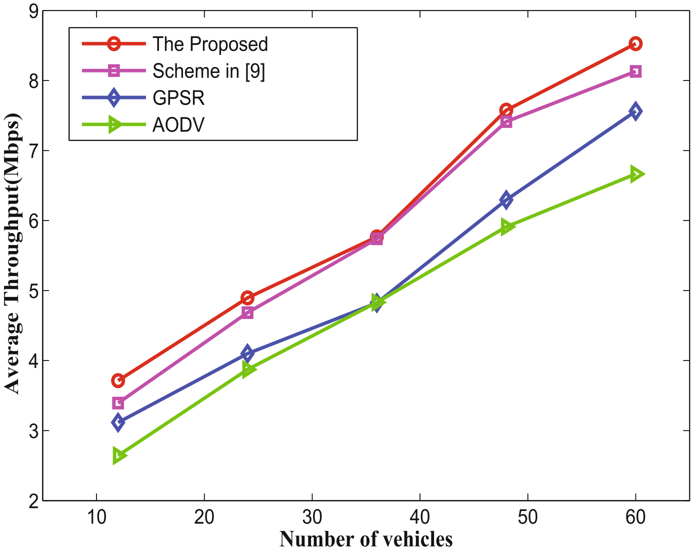

Fig. 3. Average throughput vs vehicle density.

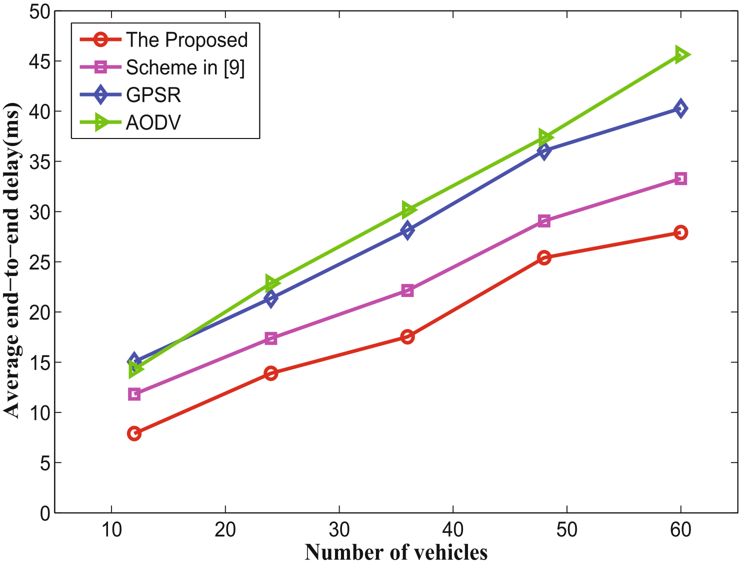

Fig. 4. Average end-to-end delay vs vehicle density.

performance again. Two reasons explain the result. Firstly, recall the pheromone information applied in our routing protocol, this is a positive feedback which guides us to select a forward node with a lowest delay. Secondly, we estimated the backoff times in MAC layer according to the vehicle density in a cluster, which further optimize the delay.

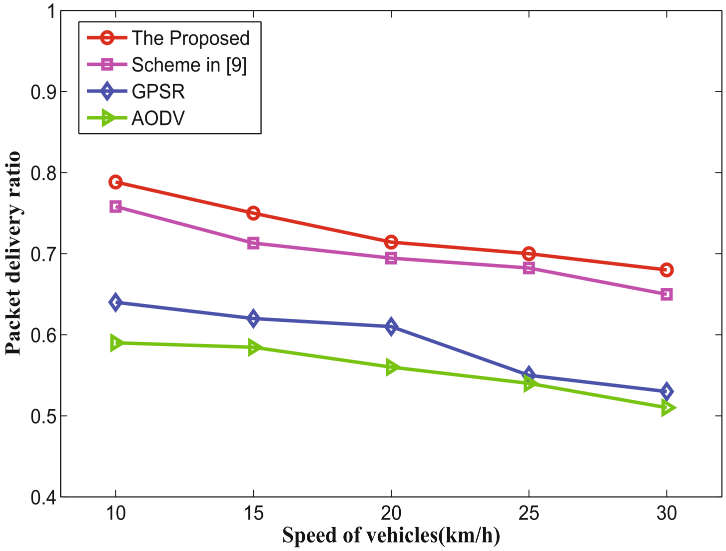

Fig. 5. Packet delivery rate vs speed of vehicles.

Figure 5 depicts the packet delivery rate of different routing protocol versus the speed of vehicles, and once more, our proposed routing protocol performs better than other three schemes. As mentioned previously, we apply link expiration time as heuristic information which influenced by vehicle speed and direction. Therefore, the path in our proposed routing protocol has better connectivity and less broken than GPSR and AODV. On the other hand, from this figure the packet delivery rate of all these protocols decreases while vehicle speed increases from Fig. 5 This is because link reliability and stability decreases when the speed of vehicles increases which causes link interruption more easily.

5 Conclusions

In this paper, we propose an ant colony optimization based delay-sensitive routing protocol in VANETs. We investigate two mechanisms of ACO to be applied to the routing protocol. For pheromone information, we take the estimated transmission delay between two nodes as pheromone and propose the pheromone deposit and evaporation process. For heuristic information, we develop the scheme combining the link expiration time, MAC backoff times and distance to estimate the connectivity and reliability of a node. The abundant and religious simulation results verify that the proposed routing protocol performs much better than GPSR and AODV and can efficiently support the routing requirements in VANETs.

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