LoRaSense: An Interference-aware Concurrent Transmission Model

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Abstract

LoRa, one of the most potential LPWAN (Low-Power Wide Area Network) techniques, has received widespread attention for its far transmission distance and long battery life. These characteristics make it successfully applied in target tracking, water level monitoring, fire alarm, smart c-ity, etc. Since these applications mainly require tens of hundreds of access devices to collect data, different LoRa networks will overlap, so an interference-free network is badly needed. Current collision avoidance scheme, however, could cause collisions again, especially when the the duty cycle of interference source is high. In other words, current scheme is not interference-free.

Motivated by the exist interference, this paper presents an interference-aware concurrent transmission model: LoRaSense. Specifically, LoRaSense estimates the idle cycles of interference source through interference-aware model based on RSSI, and then achieves concurrent transmission of access devices and interference sources combining with collision model. Our LoRaSense increases channel utilization while resisting interference. To demonstrate the utility of LoRaSense, we build a prototype of LoRaSense in one LoRa gateway and three LoRa nodes. Our real-world experiments show that LoRaSense can achieve 10%-15% packet reception ratio improvement compared to LoRaWAN.

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1 Introduction

LoRa [1] has successfully facilitated some IoT applications such as target tracking, water level monitoring, fire alarm, smart city [1]. In these applications, collision created by plenty of access devices and multipath often occurs. Large amounts of interference will lose important data and cause massive data retransmission, which greatly reduces the throughtput of LoRa network, and energy consumption of n-odes increases accordingly [2]. A key issue is how to achieve interference-free transmission. Current devices, however, avoid collision only through automatically retransmitting after waiting a time interval, which is useless for the problem. While the realization of interference-free will bring many benefits to information collection and distribution in LoRa network. [3]

The traditional collision avoidance scheme Aloha [4] is used in LoRaWAN. The key approach is to automatically retransmit the data packet after waiting a randomly selected time interval when collision occurs. However, this method is likely to create a new collision. Especially when the duty cycle of interference source is high, its channel occupation ratio is higher, so the probability of successful transmission is lower with randomly backing off under the interference source. Therefore, it is very important for the whole network to guarantee interference-free of transmission under high duty cycle interference sources.

This paper introduces LoRaSense, an interference-aware concurrent transmission scheme that effectively solves collision problem and realizes concurrent transmission. Based on that transmission of interference source has a certain idle cycle, LoRaSense predictes the idle cycle according to RSSI value collected by LoRa node. Then the node transmits data in the idle cycle which will ensure interference-free transmission. The challenge however is to accurately predict the idle cycle of interference sources.

Considering that different interference sources have different transmission characteristics, LoRaSense samples interference sources according to RSSI value, and then uses the sampled data to establish interference sources fingerprint database. Thus, the channel idle information of each interference source can be known.

Challenges:

- How to accurately predict the idle period of the interference source?
- How to use the predicted idle period for concurrent transmission?

Contributions:

- LoRaSense can accurately identify the LoRa interference source and predict the idle period information of the interference source;
- LoRaSense can realize the concurrent transmission of data in the network;
- Experiments shows that the interference source identification rate can reach more than 90% in our system. when there are strong interference souces around the LoRa network, the decoding rate in our system is increased by 10%-15% compared with in LoRaWAN.

2 Related Work

There are three interference avoidance in traditional interference avoidance schemes:collision avoidance (ie, MAC layer protocol), interference cancellation (using physical layer separation collisions), and interference perception.

2.1 Collision Avoidance

We usually use carrier sense or MAC layer control to avoid collisions. The classic ways of collision avoidance include: B-MAC [5] X-MAC [6] EM-MAC [7] But LoRa can not directly use the RSSI threshold to determine whether the channel is idle like the traditional ways, that is because sometimes LoRa signals power is lower than noise.

2.2 Interference Cancellation

Interference cancellation is said the signal does not need to be retracted when collides, because it can collision signal to separate at the physical layer. This part of the research can be divided into three categories: continuous signal cancellation [8], ANC (Analog Network Coding) [9] and ZigZag [10].

However, continuous interference [8] cancellation requires a fixed deployment or environment (such as temperature, i.e.). And the synchronization in ANC and ZigZag is too energy intensive for the low power network like LoRa.

2.3 Interference-aware

Interference Interference-aware [11] is a compromise between conflict avoidance and interference cancellation. It classify and pre-judge the interference sources by the receiving signal. With this method we can effectively shorten the time of carrier monitoring and improve the success rate of concurrent transmission. But unfortunately there is no currently interference-aware approach to LoRa.

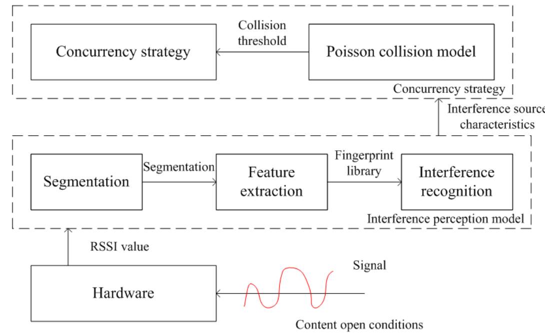

Figure 1. Concurrent transmission scheme framework

3 INTERFERENCE-AWARE MODEL DESIGN BASED ON RSSI VALUELoRaSense

3.1 SYSTEM OVERVIEW

The system framework is shown in Figure 1. After turning on interference-aware, nodes can establish interference source fingerprint database by sampling and segmenting the RSSI value, so that the channel idle information can be known. In the subsquent transmission, nodes identify the interference source through the feature and fingerprint database extracted from sampling, and use the channel idle information of interference source to predict idle cycle. Then it combines the idle cycle with established Poisson collision model to realize concurrent transmission under interference source.

3.2 THE CONDITION OF TURN ON THE INTERFERENCE PERCEPTION

We consider that interference-aware is turned on only in large interference environment . Because if the environmental interference is small, then using interference-aware model is completely meaningless. When the interference around node is large, the existing LoRaWAN protocol cannot ignore the interference. In this section, interference-aware is not directed to all nodes in the whole network, but to the node with relatively serious interference and relatively important in the network.

For a node, it is very difficult to sense the surrounding interference without increasing power consumption. In LoRaWAN network, for the sake of power consumption, the node enters sleep state after completing transmission, only waking up to receive an ACK after 1s and 3s. In order to estimate the interference, this section uses the interference standard for evaluation.

Set S_t is the number of packets sent by the sending node and S_a is the number of ACKs received. The interference level IS is expressed as:

$$IS = \frac{S_t}{S_a} \tag{1}$$

It can be known from formula (1) that when the number of ACKs received by the node is low and the number of transmitted packets is high, it indicates that the interference level is high. Because several transmissions may cause large errors, this section sets the interference level to enable interference perception on when $S_t > 50$.

The threshold depends mainly on the gateway's tolerance for packet loss. We should note that the distance will also affect interference standard. For farther nodes, the packet loss tolerance should be higher. Therefore the tolerance of distancecan be expressed as:

$$\delta = \frac{1}{P_L}\delta \tag{2}$$

Among them, P_L is the transmission success rate measured in an open environment for a node with distance d.

According to [12], this section sets the interference level threshold δ that the user can tolerate as follows:

$$\delta = \begin{cases} 1.136\delta, 0 \leq d \leq 2 \\ 1.17\delta, 2 \leq d \leq 5 \\ 1.49\delta, 5 \leq d \leq 10 \\ 3.85\delta, 10 \leq d \leq 15 \end{cases} \tag{3}$$

d is the distance of node from gateway, and the unit is kilometer.

After deployment, nodes calculate the interference standard threshold δ through the value and distance given by the server and save it locally. Before each transmission, nodes calculate the interference standard IR and compare it with δ . When the interference standard is greater than δ , the interference-aware is turned on. When it is smaller, the interference-aware is turned off. In this way, nodes can autonomously choose the time to turn on interference-aware using a low-cost method.

3.3 SAMPLING AND SEGMENTATION

In this section, it is mainly necessary to determine the sampling time and the method of interference source segmentation.

Each type of different spreading factor corresponds to a different rate, so different sampling times need to be determined. The sampling time $T_{sample,i}$ with a spreading factor of i can be expressed as:

$$T_{sample,i} = T_d \bullet \max T_{packet} \tag{4}$$

Max T_{packet} is the maximum time transmitting the packet and T_d is the sampling interval. When the payload takes the maximum value, that is, the payload is equal to 51 bytes, the transmission time is the longest. Using the transmission time of the packet equals the packet length divided by the bit rate,T_{packet} can be calculated accurately.

Next, the node performs RSSI sampling in CAD mode with a sampling interval of 10 ms.

For any interference source, the RSSI signal collected during $T_{sample,i}$ period can be represented by a set of arrays $S = [s_1, s_2, ..., s_k]$. This section uses the threshold method for cutting. Unlike other related work, the threshold is determined by the instantaneous RSSI value when CAD is interrupted. Assuming that there are m RSSI values under CAD in S, that is, all RSSI values greater than 0 in S, are denoted as $F = [f_1, f_2, ..., f_m]$. Then the thresholds range σ can be expressed as:

$$\sigma = [-\frac{\sum_{i=1}^{m} f_i}{m} - \theta, -\frac{\sum_{i=1}^{m} f_i}{m} + \theta] \tag{5}$$

Among them, θ is the deviation of RSSI and is taken as 5dBm in this chapter.

The time taken by each interferer transmission is called duty cycle, and the non-work cycle is called idle cycle. The sampling points are divided by the threshold range to obtain the sampling points at the beginning and end of each duty cycle, which are stored in two arrays I_b, I_e respectively. If the element in S is in range σ or in F, the serial number corresponding to this element is placed in I_b, otherwise it is placed in I_e. Then I_b and I_e can be expressed as $I_b = [b_1, b_2, ..., b_{N_b}]$, $I_e = [e_1, e_2, ..., e_{N_e}]$ where N_b and N_e indicate the number of starting points and the number of ending points, respectively. When the sampling point is sampled from the idle cycle time it satisfies $e_1 > b_1$: Then the kth duty cycle can be expressed as: $S_k^{busy} = [s_{I_b(k)+1}, s_{I_b(k)+2}, s_{I_e(k)}]$. The kth idle period can be expressed as: $S_k^{idle} = [s_{I_e(k)+1}, s_{I_e(k)+2}, ..., s_{I_b(k+1)}]$.

3.4 THE ESTABLISHMENT OF FINGERPRINT DATABASE

We use the three arrays S, I_b and I_e, to build a fingerprint library F_{sam}.For a fingerprint library with N_f eigenvalues,F_{sam} can be represented by a set of arrays, and we denote it as $F_{sam} = \{f_1, f_2, ...f_{N_f}\}$.

The average transmission time $T_{on\_air\_time}$. Average time interval $T_{occupation}$ and channel idle ratio μ are used to characterize the temporal characteristics of interference source.

$$T_{on\_air\_time} = \frac{\sum_{i=1}^{\min(N_b,N_e)} (e_i - b_i) \bullet T_d}{N_e} \tag{6}$$

The average time interval $T_{occupation}$ is mainly calculated by calculating the interval value at the beginning of each work cycle.

$$T_{occupation} = \frac{\sum_{k=2}^{N_b} (b_k - b_{k-1}) \bullet T_d}{N_b - 1} \tag{7}$$

The channel occupancy ratio is expressed by the ratio of the total duration of the duty cycle to the total sampling time, so the channel idle ratio can be expressed as:

$$\mu = 1 - \frac{\sum_{i=1}^{\min(N_b,N_e)} (e_i - b_i) \bullet T_d}{T_{sample,i}} \tag{8}$$

The characterization of the energy signature is represented by the average energy value E_{avg} and the energy change value E_{avg} of the duty cycle:

$$E_{avg} = \frac{\sum_{j=1}^{\min(N_e,N_b)} S_j^{busy}}{N_e} \tag{9}$$

$$E_{\text{var}} = \max(S^{busy}) - \min(S^{busy}) \tag{10}$$

In addition, there is also a CAD flag F_{cad}. F_{cad} is true if there is a value greater than 0 in the RSSI value of the duty cycle, otherwise false.

According to the above eigenvalues, the fingerprint of a particular interferer F_{sam} can be described as:

$$F_{sam} = \{T_{on\_air\_time}, T_{occupation}, E_{avg}, E_{\text{var}}, F_{cad}\} \tag{11}$$

3.5 INTERFERENCE SOURCE IDENTIFICATION

For a node with m interference sources around it, its interference source can be expressed as $I = \{I_1, I_2, ..., I_m\}$. For each element I_i in I, there is a specific $F_{sam,i}$ corresponding to it, so the interference source fingerprint library is recorded as $F = \{F_{sam,1}, F_{sam,2}, ..., F_{sam,m}\}$. It should be noted that since only LoRa transmitted at the same rate will cause interference, the value $F_{cad,i}$ in each $F_{sam,i}$ is true. After each sampling, the interference source identification is performed in two steps. First, it is first judged whether it is an interference source, that is, the CAD flag of the interference source is checked. If $F_{sam,i}$ is true, it indicates that the interference source is the interference between the same spreading factors in the networks, and the second step is to identify the interference source. Otherwise, the duty cycle is not considered to be the source of interference.

This section mainly uses k-means [13]for interference source identification. Each time a distance d from each interfering source fingerprint library in I and $F_{sam,x}$ is calculated to obtain a one-dimensional matrix D:

$$D = \{d_1, d_2, ..., d_m\} \tag{12}$$

Since each eigenvalue here is a one-dimensional coordinate, the distance d_k between the interference source x and the interference source k in the interference source fingerprint database can be expressed as:

$$d_k = \sum_{i=1}^{N_f} \left| f_{i,k} - f_{i,x} \right|, f_{i,k} \in F_{sam,k}, f_{i,x} \in F_{sam,x} \tag{13}$$

When d_k is the smallest and less than the threshold $d_{threshold}$, x is considered as the source of interference k. In order to ensure the real-time nature of the interference source, we use $F_{sam,x}$ to calculate moving average for $F_{sam,k}$, that is:

$$F_{sam,k} = \rho F_{sam,k} + (1-\rho) F_{sam,x} \tag{14}$$

Among them, ρ take 0.9.

If d_k is the smallest and greater than the threshold $d_{threshold}$, x is treated as a new source of interference and placed in I.

3.6 CONCURRENT TRANSMISSION STRTEGY DESIGN

As shown in Figure 2, the transmitting node selects to transmit in the idle period of the interference source. At this time, because the gateway is not transmitting when the gateway receives the data of the transmitting node, it does not interfere with the data receiving of the transmitting node at the gateway. Where, T_{idle} is the idle time, $T_{on\_air\_time}$ is the transmission time.

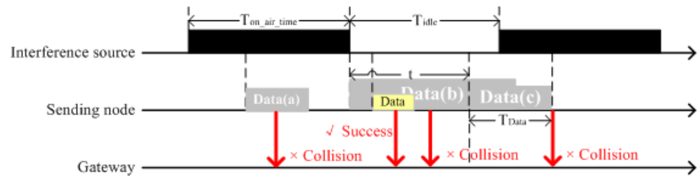

Figure 2. Concurrent transmission scheme framework

However, in case (a), case (b) and case (c) of Figure 2, the transmitting node may not be successfully received due to collision with the interference source.

In case (a), the start time transmitted by the transmitting node is in the working period of the interference source. Therefore, no matter how long the data is transmitted by the transmitting node, the two will collide, resulting in failure to be received at the gateway end. Therefore, the probability P_A of a collision occurring in case (a) is equal to the probability that the transmitting node chooses to transmit data during the work cycle which is $P_A = 1-\mu$. Among them, μ is the channel idle ratio which is obtained by the formula (8).

In case (b) and case (c), the nodes each select to start transmitting data when the idle period of the interference source. The probability of selecting to send in the idle period is $p = \mu$.

For case (b), when the idle period $T_{idle} < T_{on\_air\_time}$, the node will collide whenever it chooses to send. Therefore, the probability of collision probability P_B under case (b) can be expressed as:

$$P_B = P(T_{idle} < T_{data}) = 1 - P(T_{idle} > T_{data}) \tag{15}$$

In case (c), the idle period $T_{idle} > T_{on\_air\_time}$. When the start time $t > T_{idle} - T_{data}$, a collision occurs. Because in this case, $t + T_{data} > T_{idle}$. Therefore, $P[t > (T_{idle} - T_{data})] = \frac{T_{data}}{T_{idle}}$.

And because of $T_{data} = \frac{L_{data}}{r_{data}}$, therefore:

$$P_C = P[t > (T_{idle} - T_{data})] \bullet P(T_{idle} > T_{data}) = \frac{L_{data}}{T_{idle} \bullet r_{data}} \bullet P(T_{idle} > T_{data}) \tag{16}$$

Meanwhile the LoRa network satisfies the Poisson distribution, the probability $P(T_{idle} > T_{data})$ that the idle period of the interferer is greater than the packet transmission time can be expressed as:

$$P(T_{idle} > T_{data}) = e^{-\lambda T_{data}} \tag{17}$$

Where, the load λ is available

$$\lambda = \frac{r_{\text{interference}} \bullet T_{on\_air\_time}}{T_{occupation}} \tag{18}$$

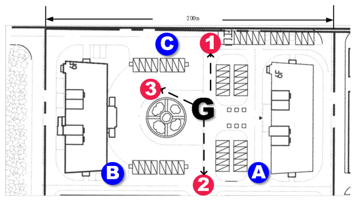

Figure 3. Experimental deployment diagram

Because the interference source is consistent with the physical layer configuration of the node itself, therefore $r_{interference} = r_{data}$. which is:

$$\lambda = \frac{r_{data} \bullet T_{on\_air\_time}}{T_{occupation}} \quad (19)$$

Among them, the data transmission rate r_{data} can be obtained according to the Poisson distribution characteristics. Therefore:

$$P(T_{idle} > T_{data}) = e^{-\frac{r_{data} \bullet T_{on\_air\_time} \bullet T_{data}}{T_{occupation}}} \quad (20)$$

Therefore, the probability of this part of the probability P_I is

$$P_I = p \bullet (P_B + P_C) = \mu \bullet (\frac{T_{data}}{T_{idle}} - 1) \bullet e^{-\frac{r_{data} \bullet T_{on\_air\_time} \bullet T_{data}}{T_{occupation}}} \quad (21)$$

Given a threshold C_{th} for the probability of collision, let $P_{total} < C_{th}$, then solve:

$$L_{data} < \frac{T_{occupation}}{T_{on\_air\_time}} (\frac{1 - C_{th}}{\mu(1 - \frac{1}{r_{data} \bullet T_{idle}})}) \quad (22)$$

4 Evaluation

In this section, we mainly use DRAGINO's LoRa nodes and gateways to conduct experiments, and verify the performance of LoRaSense by three aspects: interference source identification rate, decoding rate and throughput.

4.1 Experimental configuration

We build a prototype model with a LoRa Gatway(Dragino LG01-S IoT Gateway) and three LoRa nodes (Dragino Lora Shield v95, antenna gain are 2dBi) to experiment and evaluate. The topology is in Figure 3, G is gatway; the red circles(1,2,3) are nodes; A and B are interference sources. Table 1 is some parameter setting of the nodes and interference sources.In the experiments, the three nodes send an 13 bytes package in every one minute and each experiments continue 60 minutes. We only open the Interference-aware on node 2.The RSSI collected from nodes will be processed after experiments.

There is mainly three different interference avoidance system used in our experiments:

1.Without any protocol on node(Pure LoRa)

2.Use Aloha protocol.

3.Use LoRaSense.

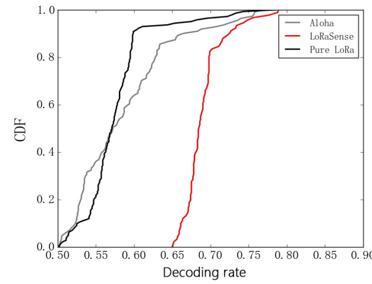

Figure 4. Cumulative distribution function graph of transmission success rate

Table 1. Parameter setting for nodes and interference sources

Parameter	Value
Bandwidth(BW)	125KHz
Carrier frequency	915MHz
Spreading factor(SF)	7
Code rate	4/5

4.2 The Effect of Interference Sources Power

In order to test the perceptual performance of interference sources under different interference source nodes transmission power, three groups of experiments were conducted. In each group, the interference sources A,B,C transmit power are =[0, 5, 14](dBm). Each interference sources send an 13 bytes package in every one minute .

The interference source recognition rate is shown in Table 2. As shown in Table.2, the interference recognition rate will raise when this node use interference perception. Comparatively speaking, the interference recognition rate of B is lower than other node. The cause of this phenomenon is that C is further from node 2 than B so its RSSI collected by node2 is not accurate. Figure 5 shows the interference source recognition with the different interference source transmit power in system. When the power increases, the recognition rate of the interference source increases, but because the recognition rate is relatively high, the increase is not obvious.

LoRaSense can increase the decoding rate by about 10% compared with the other two system, as shown in Figure 4. Further, we can find that the Aloha protocol is useless to decoding rate under the high load in our experiment. The main reason of this phenomenon is that in our experiment the interference load is set high and the channel occupancy time is long. When the collision occurs in Pure LoRa system, the possibility of collision can not be reduced even using Aloha protocol.

Table 2. Interference source recognition rate

Recognition rate \ Interference source	A	B	C
A	92.1%	5.4%	2.5%
B	7.2%	86.8%	6%
B	2.9%	5.3%	91.8%

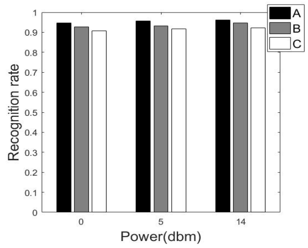

Figure 5. Recognition rate of three interference sources at different powers

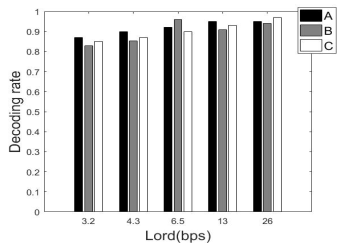

Figure 6. The relationship between the recognition rate of three interference sources and the load

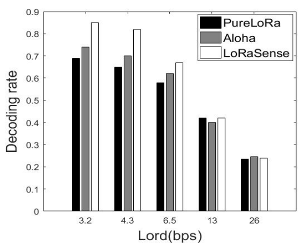

Figure 7. Three methods with the transmission success rate of the interferes source under different loads

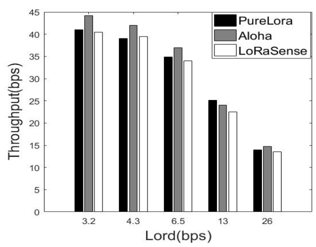

Figure 8. Comparison of throughput of three methodes under different loads of interference sources

4.3 The Effect of Channel Load

In this section, five groups of experiments were conducted. In each group, we use different package rates to simulate different channel load. T_p is the package sending period,T_p = [0.5,1,2,3,4] (s),The corresponding load is ,The transmission power of all nodes is NL = [3.4,4.3,6.5,13,26] 14 dBm.

As shown in Figure 6 when the channl load increases, the decoding rate increases. This is because the interference perception can obtain more information of the interference source under the high load, so the fingerprint database can depict the transmission characteristics of the interference source more clearly and decoding rate increased.

As shown in Figure 7, with the increase of load, the decoding rate in all three system decreased. In the case of high load, LoRaSense can increase the transmission success rate by 10%-15%. However, when the load is very high ($<$ 13bps), the LoRaSense can not select the appropriate transmission time for the node because the channel is overcrowded.

As shown in Figure 8, the throughput of all nodes decreases with the increasing load because of the channel is more and more crowded. Although the decoding rate in LoRaSense system is higher than the other two system,it does not improve throughput.This is because the LoRaSense chooses to send shorter packages to avoid conficts when there have interference, so the throughput does not improve. However, it should also be noted that throughput is not important criterion for LoRa transmission. LoRa achieves long-distance transmission through low speed, that is, the throughput is already very low. Although LoRaSense can not improve the throughput, it can improve the decoding rate and reduce the data re-transmission, thus ensuring the interference-free of data transmission.

5 Conclusion and Future Work

This paper makes theoretical analysis and experiments on the existing problems in LoRa transmission, and presents a concurrent transmission strategy based on interference perception.This paper presents LoRaSense. LoRaSense estimates the idle cycles of interference source through interference-aware model based on RSSI, and then achieves concurrent transmission of access devices and interference sources combining with collision model. Our LoRaSense increases channel utilization while resisting interference.

There are still some works need to be down: in the concurrent decision of interference awareness, we may consider reducing the overhead of the existing interference perception in the future.

6 ACKNOWLEDGEMENTS

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