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Anti-Congestion Algorithm for Multiple Data Unicast Transmission in the Internet of Brain Things

XIAODAN YAN[1], WEI YAN[2], AND LIANG ZHANG[3]
[1]School of Cyberspace Security, Beijing University of Posts and Telecommunications, Beijing, 100876, China
[2]Laboratory LE2I, CNRS, Arts et Métiers, University of Bourgogne Franche-Comté (UBFC), Dijon, France
[3]Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao 266237, China

Corresponding author: Liang Zhang (zhang.l@sdu.edu.cn)

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ABSTRACT Aiming at the problems of traditional cross-talk, channel competition, and data transmission congestion in the brain Internet of Things transmission, a new anti-congestion algorithm for multi-data unicast transmission is proposed. The algorithm calculates the congestion probability of multiple data unicasts by establishing a multi-dimensional conflict model for multiple data transmission channels in the brain Internet of Things. According to the crosstalk characteristic of the network data transmission channel path in the space, the congestion condition of multiple data unicast transmission is detected, and the congestion state of the unicast transmission in the brain Internet of Things is reversed to detect the congestion channel, thereby reducing the congestion-prone data transmission. To achieve anti-congestion transmission, the simulation experiment is carried out on the method. The experimental results show that the method can accurately detect channel path conflict information in multiple data unicast transmissions. It has high-data transmission performance and contributes to the congestion transmission of various data in the brain of the Internet of Things in the future.

INDEX TERMS The Internet of Brain Things, data unicast transmission, anti-congestion, channel conflict.

I. INTRODUCTION

In the Internet of Brain Things, the congestion control of network data transmission has attracted increasing attention [1]. As we all know, due to the huge amount of data, in the process of multiple data unicast transmission, the data transmission will suffer from problems such as channel competition, channel conflict and channel crosstalk, so that data transmission congestion may be easily caused. Congestion will cause packet loss, delay increase, and decrease of network resource utilization rate and network throughput. Among existing congestion control method, the artificial neural network technology has good fault tolerance, self-organization and adaptability. At the same time, the fuzzy theory has made remarkable progress in its own field. Fuzzy logic imitates human brain, and can be used to deal with the unknown or inaccurate control of the model [2], [3]. However, these traditional congestion control mechanisms used in data transmission cannot better solve all kinds of data transmission congestion. Therefore, the transmission control mechanism which is suitable for the data transmission is required [4]. In recent years, researchers have proposed a lot of congestion control mechanisms for transmission resistance. All these methods solve the present congestion control problem in the transmission in a certain extent [5]. In reference [6], a data transmission rate adjustment method was proposed by adding a data encoder to the data source. This method can dynamically adjust the coding parameters according to the network conditions, so as to realize the adaptive transmission rate adjustment. However, due to the channel conflict in the transmission process of data, it is easy to cause data congestion.In reference [7] a TCP throughput model was proposed to implement stable-state adaptive coding strategy in the server side, without bringing large scale rate oscillation.However, this method can cause channel crosstalk.

TABLE 1. Several common causes, results and recovery methods of path crosstalk in data transmission.

Type of congestion	Failure cause	Failure result	Recovery policy
Channel competition	Node failure	Channel selection is not effective	Select the optimal channel
Operation failure	Incorrectly input	Return error	Result substitution
Channel conflict	Node collapse	Transmission interruption	Retrial and local reconfiguration

Besides the above-mentioned methods, TCP friendly anti-congestion control mechanism is the focus of research on network traffic control. Many different methods have been put forward, but their packet loss rates are not stable [8]. Although some progresses have been made in previous researches, the research in this field is still not mature enough, and the methods used are also subjected to limitations Most of the methods are affected by human factors. For current methods, the most important thing is to control the network traffic after the data transmission congestion and reduce the real-time data transmission in the Internet of Brain Things. Therefore, how to analyze the rate of congestion, probability distribution and execution efficiency of different types of data transmission without affecting the packet loss rate and throughput is the key in the design of a reasonable and effective anti-congestion method for data transmission. In other words, the use of anti-congestion mechanism of multiple data unicast transmission should be limited by internal resources. Therefore, in the process of modeling and analysis of data transmission performance, this paper not only takes into account the effect of transmission congestion caused by various channel conflicts or channel competition, but also concerns the impact of the channel competition risk on the quality of data transmission in the mathematical space, in order to provide a theoretical basis for the anti-congestion selection of multiple data unicast transmission channel in the Internet of Brain Things.

II. MATERIAL AND METHODS

A. PROOF OF PATH CROSSTALK IN DATA TRANSMISSION CONGESTION

In the Internet of Brain Things, the multiple data unicast transmission refers to a separate data channel between sender and receiver. Therefore, in the process of multiple data transmission, the selection of congestion channel is of great importance to the security of the whole network and the application of data transmission system. If a transmission channel path is randomly selected, the overall data transmission task will be broken down upon the occurrence of channel congestion occurs during the data transmission. Due to the random selection of the traditional data unicast transmission, the probability of congestion in the channel selection is random, so it is difficult to directly model and analyze the congestion status of the data transmission channel. The whole data transmission includes 4 parts, including data input, waiting for transmission, transmission process and data output [9]. In the whole process, data is continuously input to the channel, and then input to the next channel after completion of transmission. In the stage of congestion, the influences of different channel types and strategies on data transmission are different. Table 1 shows the basic classification and hierarchy of congestion in the process of data transmission.

As can be seen from Table 1, the common data transmission congestion is related to the channel error selection. The recovery strategies include retry, replace, partial reconstruction and so on. Retry strategy can not only involves the re-execution of single data transmission task, but also the reboot and reset of the whole data transmission network. After the congestion, the task of the forerunner data transmission is dispatched to the new alternative service and output to the subsequent transmission task specified in the data transfer process after the completion [10]. Local reconstruction refers to the partial reconstruction of the transmission channel, which is affected by a single failure. Since local reconfiguration can be regarded as a replacement of larger scope and more times, its evaluation way of data transmission efficiency is consistent. The data characteristics after the transmission congestion are the focus of the research. In the front end of the congestion process, the transmission network is only the initial congestion, and a large number of transmission channels will be retried, replaced, and local reconfigured, leading to the significant increase of the nonlinear component of the network transmission data [11]. There is an opposite between the data processing process and the normal data, which leads to the highly random load imbalance of the data. Using the channel competition to express the random load imbalance will make the data transmission network suffer from a certain path crosstalk in the early stage of congestion. The reasons are as follows:

(1) In the Internet of Brain Things, the unification of the deterministic and contradictory of multiple data transmission channels is one of the basic concepts of path crosstalk. Once the channel selects the competition conflict, the data path will select a feature which is seemingly random but not really random, also known as path crosstalk.

(2) In the case of congestion in multiple data unicast transmission, the target transmission data will have a sensitive dependence on the initial state of the long-term behavior within the corresponding parameter space range.

(3) The crosstalk feature is a very important prerequisite for early judgement of data transmission congestion.

To verify whether the early path of data transmission congestion has crosstalk, we can verify whether the maximum lyapunov exponent of these channel sequences is greater than 0 [12]. Figure 1 shows the lyapunov exponent graph simulation of the obtained channel sequence by using Matlab

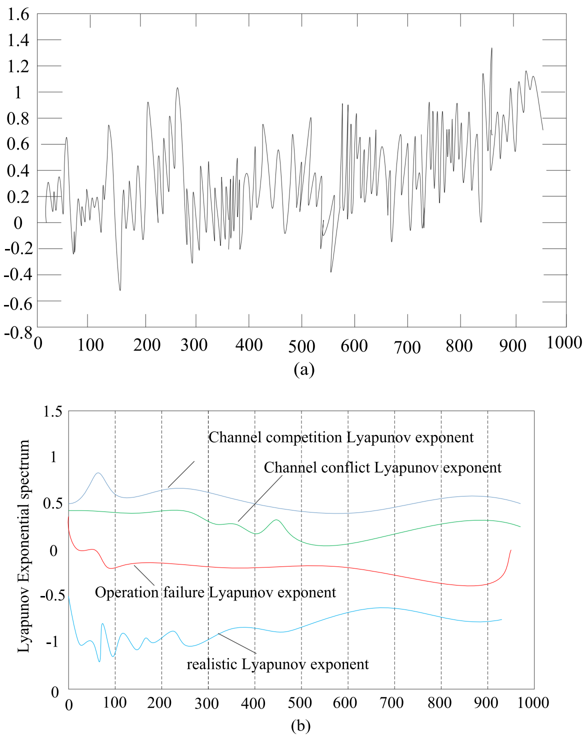

FIGURE 1. Crosstalk of channel sequence in early stage transmission congestion. (a) The domain waveform under transmission cogestion. (b) Lyapunov exponential spectrum of channel sequence under transmission cogestion.

under the congestion of multiple data unicast transmission in the Internet of Brain Things.

As can be seen from Figure 1, the maximum Lyapunov exponent of the congestion channel sequence is greater than 0, so it can be proved that in the early congestion of data transmission, the congestion channel sequence has crosstalk.

The time domain waveform diagram of the transmission congestion in Fig. 1(a) is analyzed, and it is found that the waveforms are mostly greater than 0. By analyzing the trend of the time domain waveform when the transmission is congested, the time domain wave exceeding 0 is counted, and then the classification calculation is performed to obtain the Lyapunov exponent of the congested channel sequence.

B. CLASSIFICATION AND EXTRACTION OF PATH CROSSTALK FEATURE UNDER DATA TRANSMISSION CONGESTION

The characteristics of path crosstalk can be used as a data source for judging the symptoms of transmission congestion. Through searching the features of data crosstalk in the network, the features of the channel, the internal change law and the internal relationship were analyzed [13]. In the nonlinear time series, the correlation between the crosstalk path features reflecting the characteristics of the data transmission congestion was found. Moreover, the corresponding crosstalk path features were extracted to form the congestion judgment data set. The methods are as follows:

Using the data classifier, the classification error rate of channel path classification after data transmission congestion was mapped into a set of probability density functions. Through this set of probability density functions, the probability of use in each classification frequency point was allocated. Based on probabilistic analysis, a generation sequence of specific random number with significant crosstalk characteristics was generated, and the crosstalk characteristic path was extracted.

The congestion path satisfies the random frequency modulation demand of probability density. Supposing that the congestion transport channel sequence $x(n)$ and τ are the time delays for phase space reconstruction. According to the reconstruction embedding theorem, a m dimensional vector can be formed in the reconstructed m dimensional phase space.

$$X(n) = \{x(n), x(n+\tau), \cdots, x(n+(m-1)\tau)\} \tag{1}$$

Where $n = 1, 2, \ldots, N$. In the reconstructive mapped m dimensional phase space, a dimension vector X_n is obtained, which is expressed as a point in the phase space. The nearest neighbor point is $X_{\eta(n)}$. The Euclidean distance is taken as the distance scale, and the distance R_{mn} between the two adjacent channel paths is measured, that is to say:

$$\begin{aligned} R_{mn} &= \left\|X_{\eta(n)} - X_n\right\|_2^{(m)} \\ &= \min_{j=N_0,\cdots,N,j\neq n} \left\|X_n - X_j\right\|_2 \\ &= \sqrt{\sum_{l=0}^{m-1} \left(x_{\eta(n)+l\tau} - x_{n+l\tau}\right)^2} \end{aligned} \tag{2}$$

In the mapping phase space of data transmission congestion channel sequence, as m increases to $m+1$, the distance between the nearest neighbor point and the nearest neighbor point in the phase space is:

$$\begin{aligned} R_{(m+1)n} &= \left\|X_{\eta(n)} - X_n\right\|_2^{(m+1)} \\ &= \sqrt{\sum_{l-0}^{m} \left(x_{\eta(n)+lz} - x_{n+lz}\right)^2} \\ &= \sqrt{\left[\left\|X_{\eta(n)} - X_n\right\|_2^{(m)}\right]^2 + \left[x_{\eta(n)+mz} - x_{n+mz}\right]^2} \end{aligned} \tag{3}$$

The classified congestion channel path is defined as Q_s, and the original path is defined as Q_0. Thus, it can determine whether the probability analysis mapping classification of transmission congestion is established [14]. A batch of congestion probabilities are taken to analyze the average value $\langle Q_s \rangle$ of mapping path Q_s, which is compared with the first path Q_0. In addition, the influence of the deviation size of these Q_s values should be considered, which is identified as the standard deviation σ_s. When $\langle Q_s \rangle$ is constant, the greater the deviation σ_s is, the more dispersed these Q_s are. Moreover, some Q_s may be very close to Q_0. On the other hand, the smaller the σ_s is, the more significant the difference between $\langle Q_s \rangle$ and Q_0 is. Therefore, the difference prominence

S can be defined as the difference between the probability analysis mapping path and the original path.

$$S = \frac{|\langle Q_S \rangle - Q_0|}{\sigma_S} \tag{4}$$

Where $\langle Q_s \rangle$ represents the mean value of the discriminant statistic value of N batch probability analysis mapping path, and σ_s represents the standard deviation of the discriminant statistic value of the N batch probability analysis mapping path [15], that is:

$$\sigma_s = \sqrt{\frac{1}{N-1} + \sum_{i-1}^{N} (Q_i - \langle Q_S \rangle)^2} \tag{5}$$

In order to confirm whether the original path is nonlinear, Sigma test was conducted to decide the value of S. For each probability analysis, the probability distribution of the Q_s value in the congestion path is a normal distribution, then.

$$p(Q_S) = \frac{1}{\sqrt{2\pi}\sigma_S} \exp\left[-\frac{(Q_S - \langle Q_S \rangle)^2}{2\sigma_S^2} \right] \tag{6}$$

$$\int_{-\infty}^{\infty} p(Q_S) dQ_S = 1 \tag{7}$$

The optimization of confidence interval and rejection interval in congestion path classification model probability analysis is shown in Figure 2. in which the $p(Q_S) \sim (Q_S)$ curve can be seen. To negate probability analysis mapping classification, S must be large enough to make the distribution of Q_s away from Q_0, or that Q_0 should be distributed outside of most distributions of Q_s. Since the normal distribution $p(Q_s)$ extends to Q_s, and the value is positive and negative infinity. It is impossible to make Q_0 distributed completely outside of the $p(Q_s)$ distribution. Generally, the confidence of the scientific community is recognized as 95%. In other words, in the statistical test, the chance for the rejection probability analysis of the mapping classification is $\alpha = 5\%$, that is, if the difference between Q_0 and $\langle Q_s \rangle$ exceeds a certain critical value Q_c, there is:

$$p(|Q_0 - \langle Q_s \rangle| > Q_c) \leq 0.05 \tag{8}$$

In Figure 2, Q2 is the data transmission signal opening, Z1, Z2 transmission signal classification rejection area, and the shaded part in the figure is the congestion range.It can be known that only Q_0 (1) of the shadow area that is less than 5% in Figure 1 is not different from Q_s. The small coincidence probability of Q_0 and Q_s indicates that the difference between all Q_s and Q_0 is significant. Since the normal distribution is symmetric on the two sides of $\langle Q_s \rangle$, the shadow part on both sides (i.e., the rejection region of probability analysis map classification) accounts for 2.5% of the probability in Figure 1. For standard normal distribution ($\sigma_s = 0$, $\langle Q_S \rangle = 0$), there is:

$$0.025 = \int_{-\infty}^{Z_2} p(Q_S) dQ_S = 1 - \int_{-\infty}^{Z_1} p(Q_S) dQ_S \tag{9}$$

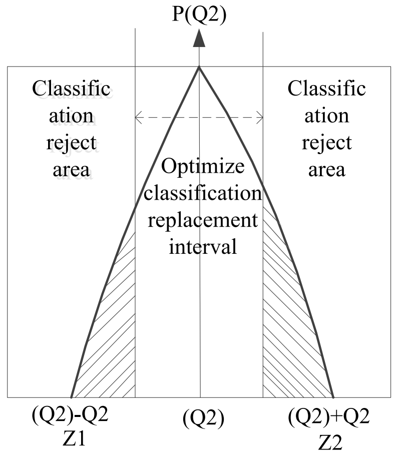

FIGURE 2. Optimization of the confidence interval and rejection interval in classification model probability analysis.

Where, $z_2 = -z_1$ indicates the intersection of the so-called confidence interval established by the rejection region and the crosstalk probability analysis mapping. From the standard normal distribution, it can be obtained that the $z_2 = -z_1 = 1.96$ in formula (9). Therefore:

$$|\langle Q_s \rangle - Q_\tau| / \sigma_S = Z_1 = 1.96 \approx 2.00 \tag{10}$$

The resulting criteria are as follows:

(1) $S \geq 2.00$, the 95% probability indicates that the probability analysis mapping classification is false, and the original congestion path is the crosstalk path.

(2) $S < 2.00$, probabilistic analysis mapping is established, and the original congestion path is not a crosstalk path.

The time series of the similar mapping is set to $i = 1, 2, \cdots N$, and can be regarded as the channel time sequence after the path transmission congestion [16]. The m dimensional phase space was reconstructed by the phase space reconstruction method. The number of points from x_j to x_i, except x_i itself, is less than the points of x_j of r.

$$Q = \sum_{j \neq i} H(r - \|x_i - x_j\|) \tag{11}$$

Where, $H(\cdot)$ represents the Heavside function. The concept of association function is set here, which is defined as the point that is smaller than the given distance r. The ratio of the logarithm of the total point is called the correlation function, which is expressed as:

$$C_N(r) = \frac{2}{N(N-1)} \sum_{i=1}^{N} \sum_{j=i+1}^{N} H(r - \|x_i - x_j\|) \tag{12}$$

Where, molecule is 2. In order to eliminate repeated counts, the norm is used to represent the distance between two points. The maximum difference between two points can be obtained as two vectors.

$$\|x_i - x_j\| = \max_{1 \leq k \leq m} |x_{i-(k-1)\tau} - x_{j-(k-1)\tau}| \tag{13}$$

Vectors which are not greater than r are called associated vectors, and the association rules were established to extract

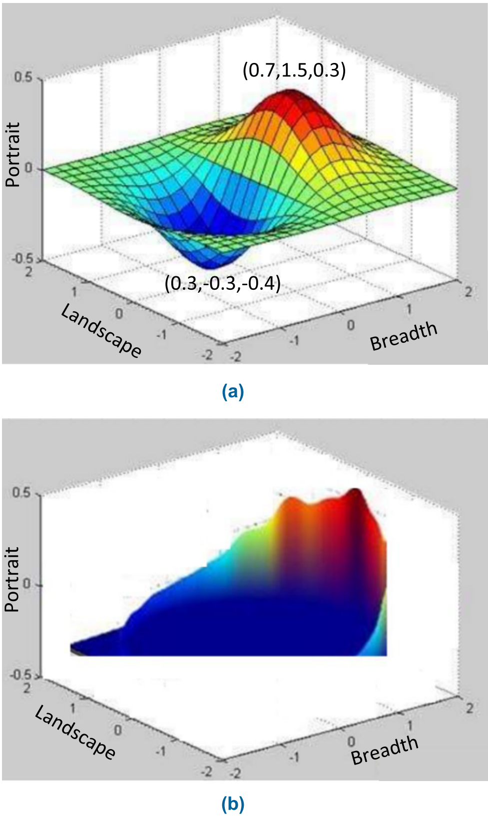

FIGURE 3. Schematic diagram of smooth filtering effect of congestion path crosstalk. (a) The effect map before smooth filtering. (b) The effect map after smooth filtering.

the association rules [17]. After the data transmission congestion probability classification was carried out, we can see that the data transmission path was different from the congestion state, namely the so-called smoothing filtering effect. The smoothing filtering effect formed by data transmission congestion channel sequence is shown in Figure 3.

Analysis of the above figure shows that when the lateral distance from the center position is 0.3m, the longitudinal distance from the center point is 0.3m, and the horizontal depth is 0.4m downward, the smoothing filter has the lowest position, and the reverse transmission blockage occurs; The position is 0.7m, the longitudinal distance is 1.5m in the forward direction, and the horizontal depth is 0.3m upward. The smoothing filter has the highest position, and positive congestion occurs at this time.The smooth filtering effect is the result of the path difference in the congestion state of the data transmission. This effect is arranged disorderly in the space. Through detecting the crosstalk of multiple data transmission paths, we can determine whether the smooth filtering effect is expanded or not.

C. DATA TRANSMISSION CONGESTION DETECTION BASED ON THE INTRODUCING OF PATH CROSSTALK AREA

1) THE FEASIBILITY ANALYSIS OF DETECTION IS DETERMINED BASED ON PATH CROSSTALK

The path crosstalk in multiple data transmission is firstly used in the field of network video stream transmission, and the problem solved in video stream transmission is similar to the problem to be solved in this paper. The space in video stream transmission is determined according to the collected path, which is consistent with the application conditions of this paper. If the channel conflict of video channel is formed, the following requirements must be satisfied.

(1) the solution exists;

(2) the solution is the only one;

(3) the solution is continuously dependent on the input path

To meet the above requirements, the channel conflict can be formed in the video stream transmission. The smooth filtering effect of the spatial crosstalk feature mentioned in the last chapter satisfies these characteristics very well, so the channel conflict will be formed. The reasons are as follows: [18]:

(1) when the path of generating smoothing filtering effect is independent and identically distributed, the maximum A-posteriori probability solution exists;

(2) by using the MRF method, a priori distribution model is used to constrain the solution of the smooth filtering effect, and the smoothing constraint can be used to ensure that the conflict in the smooth filtering effect is the only solution;

(3) in addition, the formation of smoothing filtering effect depends on the continuous congestion path of path transmission, so that it satisfies the requirement of congestion input path.

Therefore, the early congestion process of data transmission can be well detected using path crosstalk theory, so as to deal with the channel conflict in data transmission.

2) THE VALIDITY OF CONGESTION TIME IN MULTIPLE DATA TRANSMISSION CHANNELS

The first step of channel conflict judgement is to form a multidimensional conflict area based on three data crosstalk information. Each data transmission crosstalk information in multidimensional space is represented by X and Y coordinates on the coordinate axis. One is the congestion information value of data transmission, and the one is the time value of congestion. In this way, the real-time congestion status of data transmission can be transformed into a mathematical two-dimensional space coordinate system.

Using the above data to transmit the actual crosstalk signal, two adjacent signals before and after congestion are used as examples to make up two triangular regions, which are set to $\Delta A_k B_k C_k$ and $\Delta D_{k+1} E_k F_k$, called crosstalk congestion regions. The vertex of triangle is represented as the actual two-dimensional coordinate of data information in triangle area [13], [19]. Point D_k is the intersection of middle line in the crosstalk congestion area, it has the area $\Delta A_k B_k C_k$ crosstalk path congestion. The crosstalk path can be used as the compensation path for the time span error of the congestion region. However, it is necessary to ensure that the time coordinates of the congestion area at the point of the congestion are less than the minimum value of the vertex coordinates, that is to ensure that the congestion information has occurred in the time domain. With this mathematical

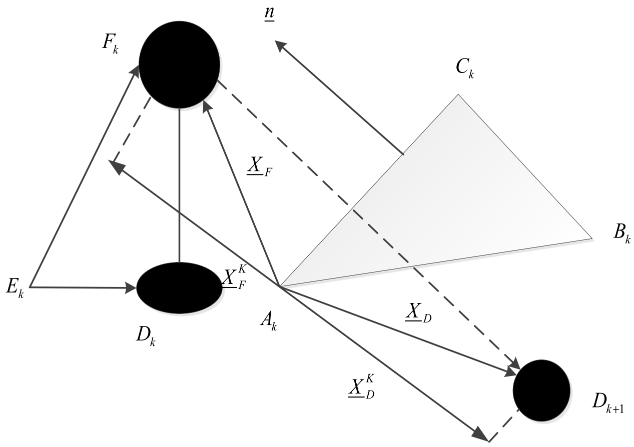

FIGURE 4. **Analysis of path crosstalk in data transmission congestion area.**

method, the congested time of a channel can be estimated by vector. The method of judgement is as follows.

$$\begin{cases}\underline{X}_F=\underline{F}_k-\underline{A}_k\\ \underline{X}_D=\underline{D}_{k+1}-\underline{A}_k\end{cases}\begin{cases}\underline{X}_F^n=(\underline{X}_F\cdot\underline{n})\underline{n}\\ \underline{X}_D^n=(\underline{X}_F\cdot\underline{n})\underline{n}\end{cases}\tag{14}$$

Where, $\underline{X}_F^n$, $\underline{X}_D^n$ are the components $\underline{X}_F$ and $\underline{X}_D$ of normal $\underline{n}$ in the congestion virtual area. Then, we can determined whether the direction between $\underline{X}_F\cdot\underline{n}$ and $\underline{X}_F\cdot\underline{n}$ is consistent. If it is consistent, it shows that the calculated data transmission crosstalk and congestion time domain information are invalid, because this time has not happened. If inconsistent, it shows that the calculated transmission path of time effective area has been congested, which is the time effective area that has occurred.

3) CONFLICT JUDGEMENT OF CROSSTALK PATHS

After calculating the congestion area of data transmission and confirming the effective congestion time, it needs to further determine whether the specific path meaning information have congestion, and then the detailed calculation is made as far as possible to ensure the synchronization in the time domain. The time domain value in data transmission congestion is still expressed by two-dimensional coordinate. That is, once the data transmission congestion, the plane of triangle area $\Delta A_kB_kC_k$ and $\Delta D_{k+1}E_kF_k$ will have the crosstalk path coordinates, to determine whether the coordinate value of the crosstalk path coordinates Q is in the congestion area, so as to complete the congestion judgment. The calculated 2-D coordinate information contains the specific value of the time domain information and data transmission congestion information of crosstalk path. The schematic diagram is shown in Figure 4.

The congestion area of data transmission can be represented by the following linear equation.

$$\left(\underline{P}-\underline{A}\right)\cdot\underline{n}=0\tag{15}$$

Where, P is a vector of any crosstalk path coordinate points in data transmission congestion area, which can be expressed as:

$$P=\underline{P}=x\underline{i}+y\underline{j}+z\underline{k}\tag{16}$$

$\underline{A}=x_A\underline{i}+y_A\underline{j}+z_A\underline{k}$ is the vector representation of data transmission congestion path coordinate A; $\underline{n}=a\underline{i}+b\underline{j}+c\underline{k}$ is the normal vector representation, which can be transformed as follow.

$$a\left(x-x_A\right)+b\left(y-y_A\right)+c\left(z-z_A\right)=0$$

The two-dimensional coordinate of crosstalk vertex F as well as the two-dimensional coordinates of another two crosstalk vertexes D are used to calculate the linear equation expression between them. First of all,

$$\begin{cases}\underline{r}=l\underline{i}+m\underline{j}+n\underline{k}\\ l=x_D-x_F,\qquad m=y_D-y_F\end{cases}\tag{17}$$

The parameter equation of different crosstalk path coordinate points is obtained.

$$x=lt_Q+x_F,\quad y=mt_Q+y_F$$

Where

$$t_Q=-\frac{p}{s}p=\underline{n}\cdot F-\underline{n}\cdot\underline{A},\quad s=al+bm+cn$$

Through substituting it into the upper formula, there is.

$$x_Q=lt_Q+x_F,\quad y_Q=mt_Q+y_F\tag{18}$$

After the Q(x,y) coordinate is obtained, it needs to detect whether the channel path is in the congestion area and to detect the channel conflict through the data transmit congestion area information solved by the above methods. According to the calculated channel conflict information, we can realize the accurate scheduling of the late transmission congestion response and ensure the real-time data transmission.

III. RESULTS

A. DESIGN OF EXPERIMENTAL ENVIRONMENT

The QPME simulation software was applied to simulate the proposed algorithm, and realize the anti-congestion performance of multiple data unicast transmission in the Internet of Brain Things. The metric attributes include the throughput X of the task s, the mean response time T of system, the utilization rate of the channel path node U, the packet loss rate L of the data transmission s and the accomplish probability A in the steady-state data transmission. The confidence interval of the simulation data (c, i) was set to 95%. In the Internet of Brain Things, the simulation scenario for the overall channel path of multiple data unicast transmission is shown in Figure 5. The black line represents congestion in the figure. From Figure 5, it can be seen that in the Internet of Brain Things, multiple data unicast transmission from input point to destination output location went through different paths. Due to the huge amount of data, if the transmission path cannot be chosen independently in multiple data unicast transmission, or the transmission channel of the selected transmission is congested, it is easy to cause the failure of the whole data.

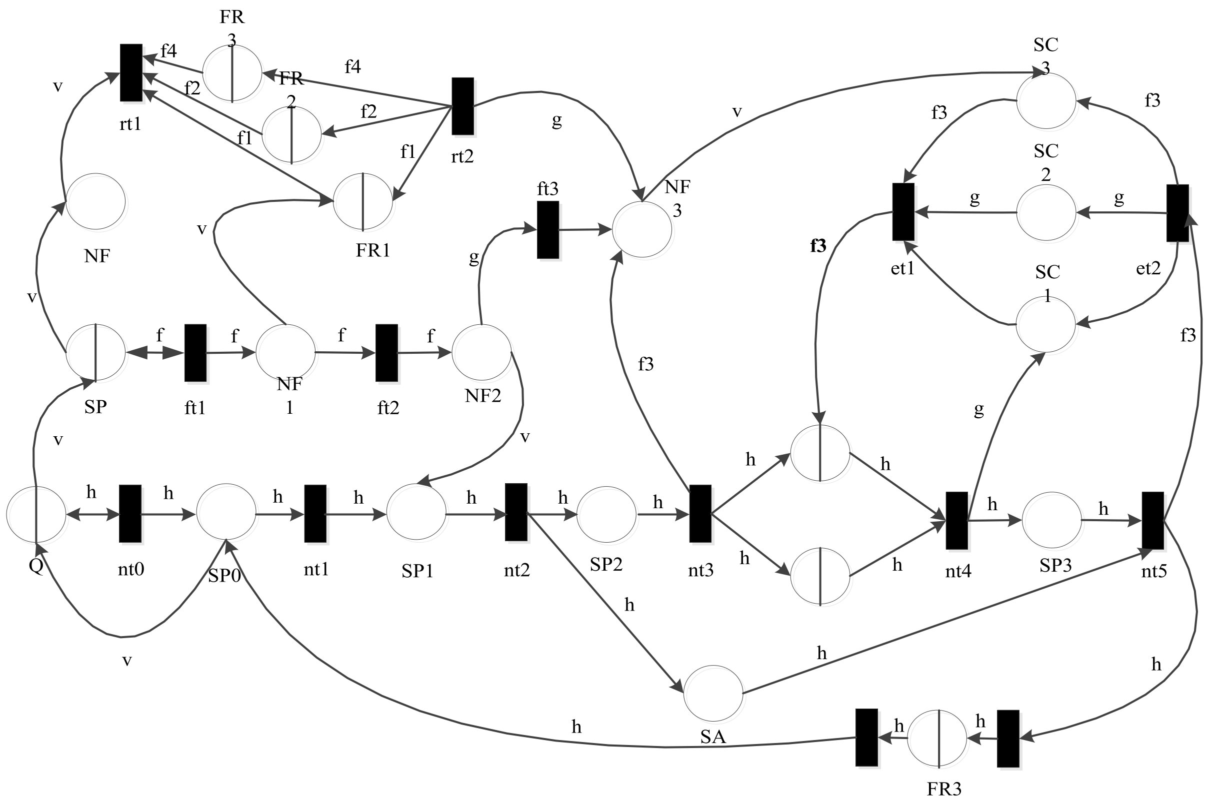

FIGURE 5. Experimental QPN modeling of overall channel path in data transmission in the Internet of Brain Things.

Therefore, in the whole the Internet of Brain Things, an anti-congestion algorithm for multiple data unicast transmission is proposed in this paper. By using the characteristics of channel crosstalk when the data transmission is congested, the congestion of the transmission path is judged, so that the congestion is avoided and the path of the transmission channel is selected reversely. To this end, an open channel queue model was used to simulate the source of a stable data transmission task through the queue library Q (G/M/ infinity /IS) and to test the anti-congestion performance of the proposed algorithm in the Internet of Brain Things.

Since the existing versions of QPME do not support the direct use of time changes, a combination of queue repository (G/M/1/PS) and transient changes is used to replace the transition model of time transition. When the transmission congestion of class I data occurs, the zero queue processing mode of IV congestion recovery is used to simulate the replacement of the data transmission channel. FRi is used to simulate the recovery time distribution of class I $\sim$ IV congestion. Repository SA is used to track and describe the overall execution status of data transmission test model. The probability of competing paths for data transmission is:

- $pN(1) = 5\%$;
- $pN(2) = 45\%$;
- $pN(3) = 36\%$;
- $pN(4) = 14\%$.

B. ANALYSIS OF CONGESTION TEST RESULTS IN TRANSMISSION PATHS

To realize the congestion test of data transmission channel path, two experiments were designed and completed.Among them, the article selected a total of 50 samples for experiments.

1) EXPERIMENT 1

crosstalk features are used to detect data transmission congestion and to calculate its impact on data transmission congestion performance. The experimental method is to keep the probability distribution of the competing conflict type unchanged, adjust the incidence of the data transmission channel competition (that is, the p1 of the queue library SF), and observe the change trend of the selected data transmission channel. The result of Experiment 1 is shown in Figure 6, in which the transverse axis of each subgraph indicates the parameter p1 of the queue library SF. When P1 is reduced, the rate of channel competition is reduced; the longitudinal axis of each subgraph is marked with different performance parameters and the response time is logarithmic.

The experimental results show that when p1 is reduced, the incidence of the data transmission channel, the overall throughput, the response time, the utilization of the network resources, and the data packet loss rate are reduced, and the completion probability of the whole data transmission is improved. The congestion detection model in this paper can

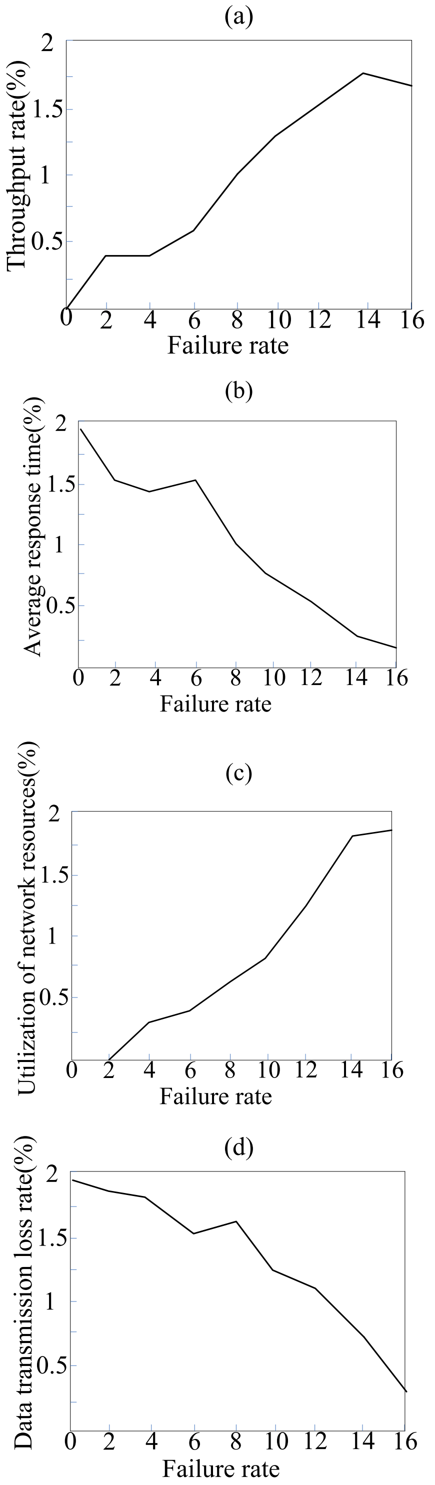

FIGURE 6. Simulation results of Experiment 1. (a) The throughput. (b) The average response time. (c) Network reource utilization time. (d) Data packet loss rate.

reflect the change trend of the performance indexes of data transmission with the channel competition rate.

2) EXPERIMENTAL 2

the impact of all kinds of competitive conflicts on data transmission congestion performance is analyzed. The experimental method is to let only one channel congestion occur in data transmission, and investigate the impact of the channel competition rate change on data transmission performance. The specific steps are described as follow. First, the probability of three types of competing conflicts is 0, and the remaining one is 100%. Then, the channel competition rate (that is, the p1 of the queue library SF) is adjusted to observe the change trend of the performance of the data transmission test model.

The result of Experiment 2 is shown in Figure 7.The four curves in each sub graph represent different kinds of competition conflicts and data transmission congestion. The cross axis of each subgraph indicates the parameter p1 of the queue library SF. When p1 is reduced, the channel competition rate is reduced; the longitudinal axis of each subgraph indicates the different transmission parameters and the response time is logarithmic.

The experimental results show that as p1 decreases, the occurrence rate of data transmission channel competition decreases. For the class I congestion, the throughput of data transmission will be improved, the transmission response time is shortened, the packet loss rate is reduced, and the completion rate of data transmission will be improved. For class II congestion, the throughput rate will be improved rapidly at the beginning of the high incidence rate. When the incidence is reduced to a certain extent, the speed of throughput increases slowly and then tends to be stable. The reduction of class II's channel competition rate has little effect on the data transmission time, but will improve the utilization of data transmission channel resources, reduce the packet loss data and improve the success probability of data transmission completion. For class III congestion, the retry strategy makes the transmission of data increased, although it improves the utilization of network resources; the data transmission queue causes longer waiting time, thus prolonging the transmission time. When the congestion rate is reduced, the transmission time is shortened and the utilization rate of network resources is reduced, which improves the completion probability of data transmission, without causing data packet loss or affecting the throughput [20]–[22].

C. DATA TRANSMISSION CONGESTION AFTER EMERGENCY RESPONSE TEST RESULTS ANALYSIS

Experiment 3: emergency method of queue model for data transmission congestion is adopted, and a queue library G/M/ /IS is used to describe the corresponding emergency response performance after data congestion in data transmission. In order to simplify the emergency model, assuming that each data transmission node Ni represents the congestion occurrence rate, the probability distribution of the channel path competition conflict type and the parameter p1 of the recovery time distribution function. The initial value of the transmission node Ni in Experiment 1 is taken as N4, and the repetition number is $k = 3$. The conditional selection probability is $p = 30\%$ for N7. Besides N2, all nodes' I class congestion probability is $pN(1) = 0$, and Nr is the replacement node of N2 [23].

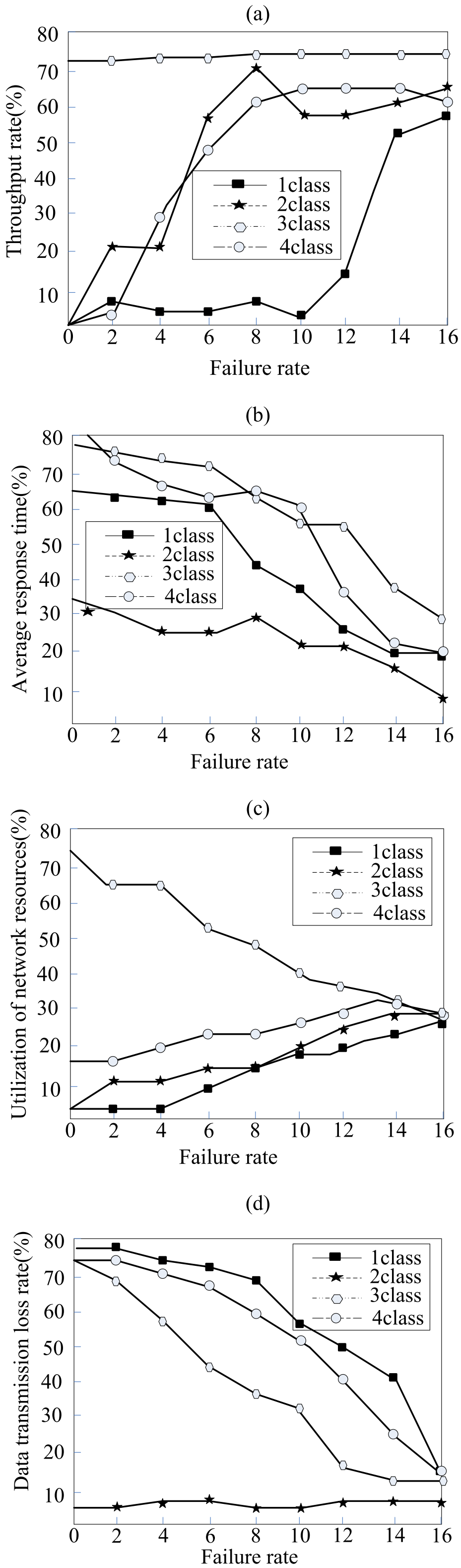

FIGURE 7. **Simulation results of Experiment 2. (a) The throughput. (b) The average response time. (c) Network reource utilization time. (d) Data packet loss rate.**

The specific steps of Experiment 4 are as follows:

(1) The channel competition rate of N2 is adjusted, to maintain the same configuration of other parameters, and investigate the impact of congestion's emergency measures on system performance.

(2) The channel competition rate of N4 is adjusted, to maintain the same configuration of other parameters, and investigate the impact of congestion's emergency measures on system performance.

(3) The channel competition rate of N5 is adjusted, to maintain the same configuration of other parameters, and investigate the impact of congestion's emergency measures on system performance.

(4) The channel competition rate of N7 is adjusted, to maintain the same configuration of other parameters, and investigate the impact of congestion's emergency measures on system performance.

The results of Experiment 4 are shown in Figure 8, where,

(1) Four curves in each sub graph represent the influence of channel competition rate on data transmission congestion performance, respectively.

(2) the transverse axis of each sub graph indicates the parameter p1 of the queue library SF. When p1 is reduced, the occurrence rate of channel competition corresponding to data transmission is increased.

(3) The performance parameters of longitudinal axis data transmission of sub graphs are expressed by the logarithmic of the response time.

Through analysis of Figure 8, it can be known that when the parameter p1 of SF in the data transmission node Ni is reduced, the incidence of channel competition is reduced, the emergency response time is reduced, and the probability of data transmission is increased. However, the impact of congestion recovery of Ni on data transmission is different under different interactions. The specifics are as follows:

(1) The influence of channel competition rate change on data transmission in N2 is divided into two stages. The p1 value of library SF (N2 and N3) is 0.00002 as bounded. When the p1 value of N2 is greater than 0.00002, the average response time of data transmission is reduced and the probability of data transmission is increased with the decrease of channel collision rate of N2. When the p1 value of N2 is less than 0.00002, the average response time of data transmission varies little with the decrease of the channel conflict rate of N2, but the probability of data transmission is improved significantly. Thus, when the incidence of channel competition in N2 is higher than that of N3, the average response time of N2|N3 is mainly determined by N2, and the probability of data transmission is determined by N2 and N3.

(2) under repeated relationship, the reduction of channel competition rate of N4 will lead to a significant reduction in the average response time of data transmission and a fast increase of data transmission probability. It can be seen that the repeated number of N4 ($k = 3$) amplifies its impact on data transmission congestion.

(3) under the conditional relationship, the decrease of the channel competition rate of N7 will result in the decrease of the average response time of the data transmission and the increase in the probability of data transmission, but the

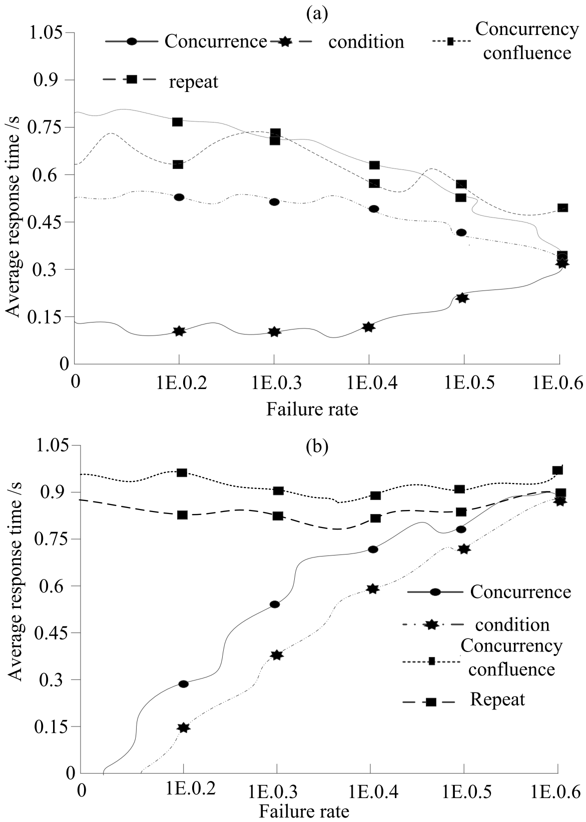

FIGURE 8. **Simulation results of Experiment 3. (a) Average response time. (b) Completion probability of data transmission.**

trend of the change is slow. Thus, under such conditions, the influence of N7 on data transmission will be reduced.

IV. CONCLUSIONS

Under the influence of uncertain and complex external factors, multiple data unicast transmission cannot always run stably and reliably in the Internet of Brain Things. Due to the crosstalk between adjacent paths in multiple data transmission as well as channel competition and channel conflict, data transmission congestion is very easy to occur. For this reason, this paper proposes a comprehensive data transmission congestion analysis method based on the crosstalk conflict detection of the channel region data. The method takes account of the interaction relationship between data generated after data transmission congestion, and considers the impact of different channel path competition types on data transmission. A crosstalk model based on the influence of congestion on channel path is built, and a detectable multidimensional conflict mathematical model is established based on the interaction relationship in crosstalk. On this basis, the QPME 1.01 software package is applied to verify the quantitative analysis ability of the congestion detection model. The experimental results show that the method can quantitatively analyze the data transmission congestion, recovery time and interaction, and can effectively detect the congestion of data transmission, with good feasibility and effectiveness. This study provides a theoretical basis for the reverse path selection of multiple data unicast transmission in the Internet of Brain Things. Compared with the existing anti-congestion methods of data transmission, the advantages of the proposed method can be summarized as follows:

(1) Considering the congestion of data transmission in many aspects, the congestion and recovery strategy caused by different channel competition conflicts are analyzed, and the real-time transmission mechanism of data under the influence of congestion recovery is clearly expressed.

(2) The congestion characteristics of data transmission are expressed intuitively in the way of crosstalk, especially in the description of the calculation process of data transmission effectiveness. Through converting the problem of congestion judgment into the problem of conflict detection on the mathematical model, the proposed method can effectively solve the problem of quantitative analysis of data transmission congestion.

(3) Compared with other methods, it can judge the applicable conditions of different congestion recovery methods of data transmission, with the accuracy of quantization being significant improved. It is helpful to guide the design of the implementation scheme of data transmission congestion recovery strategy under the uncertain environment.

In this paper, the repair time after data transmission congestion has not been further studied. In the next step, we will continue to improve the anti-congestion model of data transmission, refine the channel conflict type and the quantitative analysis method of the recovery strategy. In addition, we will study how to optimize and control the smooth channel selection of data transmission, and develop corresponding update models based on the proposed analysis model.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this article.

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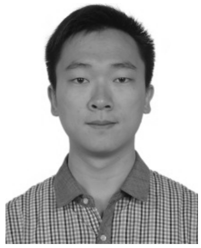

XIAODAN YAN is born in 1991. He received the B.Sc. degree from Qufu Normal University. He is currently pursuing the PhD degree with the Beijing University of Posts and Telecommunications. His research interests include network and system security, distributed systems, and networking.

WEI YAN received the Ph.D. degree in computer science from the University of Strasbourg, France, in 2014. From 2014 to 2018, she has been an Assistant Professor with the School of Information Science and Engineering, Shandong Normal University. Since 2018, she has been with the Laboratory LE2I, University of Bourgogne, France. She has published 28 papers, including 9 peer-reviewed journal papers and 19 peer-reviewed conference papers. Her research interests include knowledge engineering, semantic similarity, ontology modeling and inventive design.

LIANG ZHANG received the B.S. degree in electronic science and technology and the M.S. degree in microelectronics and solid state electronics from the Harbin Institute of Technology, Harbin, China, in 2007 and 2009, respectively, and the Ph.D. degree in instrumentation and microelectronics from the Institut Pluridisciplinaire Hubert CURIEN and the University of Strasbourg, Strasbourg, France, in 2013. He is currently an Assistant Professor with the Key Laboratory of Particle Physics and Particle Irradiation, Institute of Frontier and Interdisciplinary Science, Shandong University, Qingdao, China. His current research interests include particle detection technology.