Stable Transmission Algorithm for 5G Wireless Sensor Networks Based on Energy Equalization-delay Reduction Mechanism

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Abstract

Wireless sensor network (WSN) is mainly through the distribution of cheap nodes in a specific range of monitoring areas, self-organization, and other ways to build a data acquisition-transmission-processing network. The node collects the data information in the covered area by a cycling mechanism. The relay link node transmits the data information to the sink node to realize data. When a node fails to send, or the winner receives data, it must adopt a retransmission mechanism. If the jitter of the transmission link occurs at this time, the node must carry out frequent data re-transmission to ensure that the data can be completely transmitted to the sink node. The re-transmission mechanism will result in data congestion, generating more serious node energy limitations and transmission bandwidth limitations. To solve congestion control problems and cluster head node limitation in the 5G wireless sensor network, a stable transmission algorithm for wireless sensor networks based on an energy equalization-delay reduction mechanism is proposed. The channel state control index is designed, and a data transmission model is proposed to evaluate the stability of the data transmission process. A cluster head updating method based on energy equalization and delay reduction mechanism is constructed to enhance the probability of high-energy nodes being selected as cluster head nodes. The simulation results show that the proposed algorithm has higher network transmission bandwidth, lower average network delay, and lower network throughput frequency than the current wireless sensor network transmission algorithms.

Keywords: 5G Wireless Sensor Network; Cluster Head Updating Method; Energy Equalization-Delay Reduction Mechanism; Stable Transmission Algorithm

1 Introduction

Under the background of 5G, current researchers try to improve the stability of data transmission in wireless sensor networks by improving link layer, network layer, network management and other aspects [14–16]. For example, Zbigniew [6] based on the reasonable allocation of the remaining energy of cluster head nodes, adopted the unified management of sink node to conduct inter-region energy balanced scheduling, and used the optimal energy polling mechanism of nodes in the cluster to realize the stability of regional topology structure and the rapid convergence of regional re-formation process. However, the scheme did not fully consider the distance and node density factors, so that the duration of regional stable transmission was short, and it was difficult to adapt to the practical application scenarios of 5G UWB transmission. Shan *et al.* [4] proposed a regional stable transmission scheme based on the disequilibrium clustering mechanism. By adopting the disequilibrium clustering method, the nodes with higher energy were deployed in the hot region, and the nodes were updated by the polling method, thus improving the stability performance of regional transmission. However, the proposed algorithm took little consideration of data delay, which made the algorithm prone to serious data congestion in the 5G UWB deployment environment, and reduced the transmission stability of the algorithm. Yin *et al.* [12] inserted mobile high-energy nodes into the region and replace cluster head nodes with low energy in real time by trajectory routing, which effectively satisfied the problem of high energy consumption of cluster head nodes under the 5G UWB transmission condition and significantly improved the quality of network data transmission. However, the algorithm had low adaptability to node movement and was difficult to be deployed in the actual scene with high node movement speed.

In order to improve the network transmission perfor-

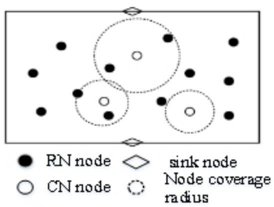

Figure 1: Network deployment

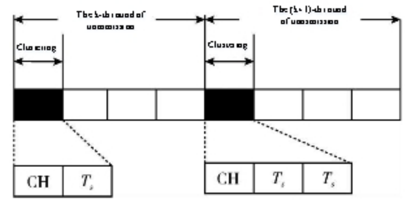

Figure 2: Cluster head node replacement and data update

mance and improve the node limitation, a stable transmission algorithm based on energy equalization-delay reduction mechanism is proposed. Firstly, a data transmission model is designed based on data segment transmission and channel slot distribution to adapt to the high flow characteristics of wireless sensor network topology under 5G conditions. The preset mode is adopted to deploy high-energy nodes, optimize the selection process of cluster head nodes, and achieve the purpose of suppressing the limitation of cluster head nodes. Combined with the sleep mode, the efficiency of data packet transmission is further improved. Then, feedback is used to improve the communication confirmation efficiency between the sink node and the cluster head node, so as to optimize the quality of region segmentation and realize the stable transmission of data. Finally, the performance of the proposed algorithm is verified by simulation experiments.

2 Proposed Network Model

2.1 Network Deployment Model

Typical deployment scenarios of wireless sensor networks under 5G conditions are shown in Figure 1. 5G wireless sensor nodes are deployed in a random distribution mode in the rectangular region. Nodes are divided into regional nodes (RN) and cluster nodes (CN). Both RN node and CN node are in a wandering state, but within the data transmission cycle, RN node and CN node will be within the same node coverage radius. As master control nodes (MCN), the sink node controls the status of RN nodes and CN nodes through the frequency-invariable control channel, records and updates the geographical coordinates of RN nodes in real time.

Cluster head nodes need to be replaced before the start of the next transmission cycle. During the replacement process, the network topology and node coverage will be optimized. After the completion of the replacement process, data will be transmitted in a stable way, as shown in Figure 2. After the selection is completed, the cluster head node will broadcast data to the node within its own coverage radius. After receiving the data message, the regional node will give feedback to the cluster head node nearest to it and update its geographical coordinate position. After receiving the data packets fed back by the regional nodes, the cluster head node will fuse all the data packets within the transmission cycle and send them to the sink node through a specific frequency channel. In the process of region formation, both the original RN node and CN node have a chance to be selected as cluster head nodes in the new round of selection. In general, the node with the highest energy should be selected as the new CN node. In this paper, the random number method is adopted to determine the CN node, and only when the random number of a node is higher than the threshold value $W(s)$, it can be selected as a cluster head node. $W(s)$ is obtained as follows:

$$W(s) = \frac{1 - k(r \quad mod(1/k))}{k}. \tag{1}$$

Where k represents the probability of the current node being removed from the CN node, and r represents the number of data transmission times. If the random number of a node is higher than the threshold $W(s)$, it will be selected as the cluster head node (CH) in the current round, and the threshold $W(s)$ will be set to 0. Cluster head node selection will continue to operate on the remaining nodes in the next transmission cycle.

2.2 Data Transmission Model

As can be seen from Section 2.1, network energy consumption can be reduced to some extent through cluster head node replacement and data update, and the stable cycle in the process of data transmission can be improved. However, as can be seen from the process of node replacement, repeated data feedback is required for node replacement, and the probability of data delay phenomenon will be significantly increased when network fluctuations occur [13]. In the actual application, due to the random distribution characteristics of cluster head election process [10], each node has a certain probability to become a new cluster head node in the data transmission process. In addition, wireless sensor network nodes in 5G environment also have high density characteristics [7]. With the continuous increase of network size, the energy balance performance must be fully considered to improve the network quality and prevent serious fluctuations in data transmission.

Considering that the RN node is generally in a dormant state, the data transmission process is started when the transmission channel is in an idle state [3], as shown in Figure 3. After the data transmission process is started,

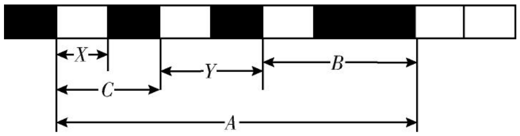

Figure 3: Data transmission

the length of the idle channel is , and the transmission period is T. In the data transmission process, three situations will occur: the cluster head node successfully receives the transmitted data, denoted as A; The network is congested and the data packet transmission is blocked, denoted as B; The channel is idle, it is ready for data transmission, denoted as C. According to the working state of the transmission channel, the channel state can be set to two states, X and Y: 1) X represents the successful data transmission of the channel (denoted as K) and data congestion (denoted by M). Obviously, the X and Y states will alternate occur throughout the working week.

Suppose that in the whole working week, the occurrence number of X and Y are m and n respectively. The total number of nodes in the network is H, and the probability that network nodes are in hibernation state is P_i. The data packet reachable probability is P, which can be obtained by the following equation,

$$P = (1 - P_1) + \cdots + (1 - P_H) = \sum_{i=1}^{H}(1 - P_i). \tag{2}$$

The probability $P(X, Y)$ of the simultaneity occurrence of the two states X and Y within the transmission week can be obtained as follows:

$$P(X, Y) = (1 - e^{-xP})^m (e^{-xP})^n. \tag{3}$$

Where x represents the length of idle channel, and P represents the data packet reachable probability. The occurrence frequency $E(X)$ in the whole working week satisfies:

$$E(X) = 1/e^{-xP}. \tag{4}$$

According to Equation (4), the average time $T(X)$ of a node in the idle state satisfies:

$$T(X) = xE(x) = x/e^{-xP}. \tag{5}$$

The occurrence frequency of $E(Y)$ in the whole working week satisfies:

$$E(Y) = 1/(1 - e^{-xP}). \tag{6}$$

Therefore, it can be seen that the average duration $T(Y)$ of a node in a busy state satisfies:

$$T(Y) = (T_s - x)E(Y) = \frac{T_s - x}{e^{-xP}}. \tag{7}$$

Where, T_s represents the data transmission cycle.

Considering that in the process of data transmission, when A happens with k times, then B occurs with $(m-k)$ times, so the probability $E(k)$ that the network successfully sends the data packet satisfies:

$$E(K) = \sum_{i=1}^{m}\sum_{j=1}^{i} C_i^k e^{-xP}(1 - xPe^{-xP})^k. \tag{8}$$

Therefore, the data length $L[E(K)]$ in the process of the event K execution satisfies:

$$L[E(K)] = \frac{x(1-x)P}{1 - xPe^{-xP}}. \tag{9}$$

According to Equations (7), (8), and (9), the probability T of network node successfully sending data message satisfies:

$$T = \frac{x(1-x)Pe^{-xP}}{1 + x - xPe^{-xP}}. \tag{10}$$

3 The Proposed Regional Stable Transmission Algorithm for WSN

As can be seen from the mentioned above network model, network nodes may encounter a variety of events during data transmission. The occurrence of each event has a certain probability, and the probability that the network node can transmit data stably satisfies Equation (10). In the process of data transmission, it is necessary to fully consider the phenomenon of energy limitation and data delay existed in nodes, so that data transmission can be carried out with a high transmission success rate [17]. Therefore, a delay reduction mechanism based on energy balance is designed in this paper, the data can be transmitted stably on the basis of energy balance. The scheme consists of two parts: cluster head updating method based on energy equalization-delay reduction mechanism and region division method based on stable transmission mechanism. The following is detailed introduced them.

3.1 Cluster Head Renewal Based on Energy Equalization-delay Reduction Mechanism

Due to the frequent data forwarding of cluster head nodes in the process of data transmission, and the frequent channel competition in the process of data transmission, serious energy loss will occur. In order to improve the life cycle of network nodes, all network nodes are divided into high energy nodes (HEN) and general nodes (GN) [11]. Wherein, the initial energy of HEN node and GN node can be expanded according to a certain proportional coefficient, and the expansion coefficient can be set as 1. The probability of HEN node being selected as cluster head node is significantly higher than that of GN node, so as to ensure the stable performance of cluster head node and regional topology.

Let the weight of HEN and GN to be selected be P_{HEN} and P_{GN}.

$$P_{HEN} = \frac{\mu\omega}{1+\mu\omega+P}. \quad (11)$$

$$P_{GN} = \frac{(1+\mu)\omega}{(1+\mu)\mu\omega+P}. \quad (12)$$

Where ω represents the proportionality coefficient between HEN node and GN node. Since the general expansion coefficient can be set as 10 20, P_{HEN} will be higher than P_{GN}.

Suppose that the energy consumption value of the m-th node in the network is $E(i)$, and the initial energy of the network node is E. The total number of nodes currently in hibernation state is N, and the total number of nodes in the network is L, then the average energy residual $E(last)$ of the network nodes satisfies:

$$E(last) = \frac{\sum_{i=1}^{N} E - E(i)}{L-N}. \quad (13)$$

With Equations (1), (11), (12), and (13), the update thresholds T_{HEN}, T_{GN} of HEN node and GN node are set as:

$$T_{HEN} = \frac{1-(1-P_{HEN})(rmod[1/(1-P_{HEN})]}{1-P_{HEN}} \quad (14)$$

$$T_{GN} = \frac{1-(1-P_{GN})(rmod[1/(1-P_{GN})]}{1-P_{GN}} \quad (15)$$

Where T_{HEN}, T_{GN} denote the update thresholds of HEN node and GN node, respectively. r is the number of data transmission.

As the network transmits data, when the energy of HEN node and GN node trigger the update threshold as shown in Equations (14) and (15) respectively, the network will set the corresponding HEN node and GN node as sleep state, and contact the sink node for energy supplement. In this way, the nodes that reduce excessive energy consumption are selected as cluster head nodes, and node replacement can be carried out in time, which can effectively improve the network life cycle. In addition, due to differentiation factors between HEN node and GN node, HEN node has a higher probability of being selected as cluster head node, thus reducing the probability of network transmission interruption caused by node energy limitation.

3.2 Region Partitioning Based on Stable Transmission Mechanism

The cluster head updating method based on energy equalization-delay reduction mechanism can select the nodes with the best energy with a high probability for data transmission. According to Equation (10), HEN node can be selected as cluster head node to effectively improve the sending efficiency of data packets. However, due to the high mobile speed of each node under the 5G network condition, this paper builds a regional division method based on the stable transmission mechanism to realize the stable transmission of data. The details are as follows:

Step 1. Region partitioning stage. The sink node broadcasts the nodes that trigger model (14) and model (15) in the network. If the corresponding HEN node and GN node can meet the transmission requirements in the transmission cycle, the information will be fed back to the sink node and the remaining energy in the node will be updated.

Step 2. The sink node obtains the average residual energy of network nodes according to model (13), and sets the nodes in the network whose energy surplus is lower than the residual energy of the bottleneck as dormant state, as shown in Figure 4.

Step 3. According to model (11) and model (12), HEN node and GN node are initialized and assigned. If HEN node and GN node satisfy model (14) and model (15) respectively, they will be selected as cluster head nodes.

Step 4. After the cluster head node is elected, the data will be broadcast. After each regional node receives the data broadcast, the cluster-head node with the strongest energy is taken as the subordinate node and incorporated into the control region of the cluster-head node.

Step 5. Network nodes execute data transmission until the accuracy rate triggered by the corresponding cluster head nodes is lower than 50% in accordance with model (14). The selection process of cluster head nodes is re-conducted. So this round of transmission is ended. After the region segmentation is completed, cluster head nodes start to enter the data transmission state, and each regional node aggregates its own data to cluster head nodes and transmits it to the sink node through cluster head nodes. When regional nodes complete data collection and aggregation, each cluster head node will enter a dormant state. At this time, the accuracy rate of cluster head nodes will decline sharply. Therefore, the region segmentation process will need to be re-conducted, and Step 1 will be started to perform region partition.

4 Experiments and Analysis

In order to compare the performance, NS2 simulation experiment environment is adopted [9]. The network deployment environment is as follows: the node distribution area is a rectangle, and both the sending node and the receiving node of the network are located at the edge of the

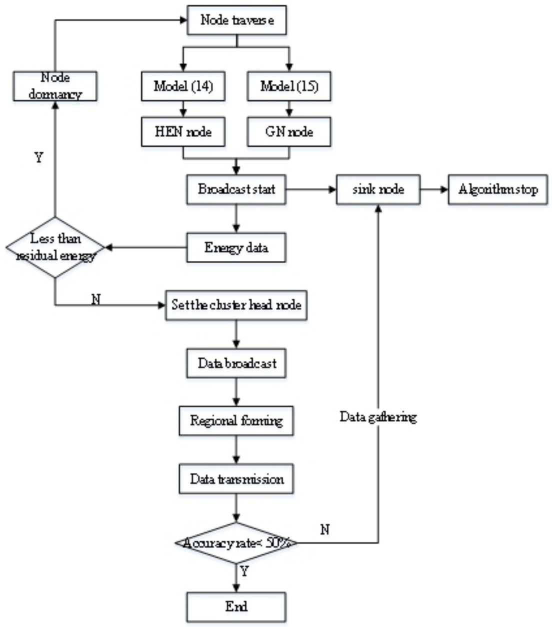

Figure 4: Region partitioning method based on stable transmission mechanism

Table 1: Comparison parameter

Parameter	Value
Network node density	Not less than 10 units(100 square meters)
Energy expansion coefficient μ of high energy nodes	Not less than 5
Node layout	Random distribution
Channel noise	Standard white Gaussian noise
Initial energy of the node	10J
Data packet packet probability	0.5
Node minimum transmission bandwidth	Not less than 1 Mbps

rectangular area with a random walk state. The node signal uses 5G signal [1]. The signal pre-emission molding technology as shown in the literature [2] is adopted. In the signal molding process, the spectrum sharpening and clearing mechanism based on the zero mode mentioned in the literature is utilized.

The network sending nodes are independent of each other, and the relevant data packet also satisfies the Poisson distribution. The remaining parameter settings are shown in Table 1. In addition, we select two newest control mechanisms in 5G sensing technology: optimized transmission algorithm of 5Gsignal bandwidth based on cross layer coding plus multiple-xing mechanism (OT-CLCPM) [8] and data transmission algorithm of mobile wireless sensor network based on power loss equalization control mechanism (DT-PLEC) [5] to make comparison. The comparison parameters select network transmission bandwidth, network average delay and network throughput frequency as shown in Table 1.

After the start of the simulation experiment, the network transmission bandwidth, network average delay and network throughput frequency at the end of the transmission cycle are recorded round by round according to the number of data transmission rounds. Considering the moving characteristics of 5G nodes, moving speeds 5m/s and 50m/s are taken as experimental control parameters to test the performance of network parameters under low/high mobile conditions.

4.1 Network Transmission Bandwidth

Table 2 shows the network transmission bandwidth tested with node moving speeds of 5 m/s and 50 m/s as experimental environment control parameters. As can be seen from Table 2, the network transmission bandwidth of the proposed algorithm is higher than that of the OT-CLCPM algorithm and the DT-PLEC algorithm. Because the proposed algorithm fully considers the network energy consumption and time delay in the process of data transmission. The cluster-head updating method based on energy equalization and delay reduction mechanism is designed to promote the stable updating of cluster-head nodes, and reduce the transmission congestion caused by the limited cluster-head nodes, so it has a high network transmission bandwidth. OT-CLCPM algorithm mainly adopts a crosstalk elimination scheme based on cross-layer coding channel interactive multiplexing mechanism. By reducing the crosstalk phenomenon caused by channel noise in the transmission process, the transmission efficiency of nodes can be increased. However, this algorithm does not suppress the transmission paralysis of cluster head nodes due to energy limitation. Therefore, the cluster head node has a high probability of limitation, which reduces the performance of network transmission bandwidth.

DT-PLEC algorithm constructs the goal sink-regional child node control packet transmission mechanism, the regional node threshold flow control mechanism and the limited bandwidth secondary confirmation mechanism to make regional transmission stable. However, since the algorithm mainly controls the data flow, it does not carry out targeted region segmentation for the energy limitation of cluster head nodes. Therefore, the failure of cluster head nodes is easy to cause data transmission paralysis in a large area, so the network transmission bandwidth is also lower than that of the proposed algorithm.

4.2 Mean Delay of Network

Table 3 shows the mean delay of network tested with node moving speeds of 5 m/s and 50 m/s as experimental en-

Table 2: Network transmission bandwidth test results

Node moving speeds=5m/s			
Number of data transmission rounds	OT-CLCPM	DT-PLEC	Proposed
50	3385/Mbps	3400/Mbps	3482/Mbps
150	3000/Mbps	3100/Mbps	3396/Mbps
250	2000/Mbps	1950/Mbps	2500/Mbps
350	1200/Mbps	1100/Mbps	1800/Mbps
450	1150/Mbps	1050/Mbps	1500/Mbps
550	1120/Mbps	1020/Mbps	1500/Mbps
Node moving speeds=50m/s			
Number of data transmission rounds	OT-CLCPM	DT-PLEC	Proposed
50	1250/Mbps	1250/Mbps	1350/Mbps
150	1000/Mbps	900/Mbps	1300/Mbps
250	1050/Mbps	870/Mbps	1200/Mbps
350	800/Mbps	600/Mbps	800/Mbps
450	600/Mbps	450/Mbps	700/Mbps
550	500/Mbps	400/Mbps	700/Mbps

vironment control parameters. As can be seen from the Table 3, the network average delay of the proposed algorithm is significantly lower than that of the OT-CLCPM algorithm and the DT-PLEC algorithm. Because the proposed algorithm fully considers the node energy limitation and data delay phenomenon, it introduces the dormancy mechanism of cluster nodes to reduce the energy consumption, reduces the number of data packet retransmission, improves and upgrades the network congestion control capabilities, so the network average delay is low. OT-CLCPM algorithm optimizes signal preforming and weakens the channel noise method to improve the network transmission capacity. However, because OT-CLCPM does not considers the way of optimizing the cluster nodes update to improve the network congestion control ability. Due to the failure of cluster head nodes, the network delay is likely to increase, so the network average delay performance of this algorithm is lower than that of the proposed algorithm. DT-PLEC algorithm constructs the goal sink-regional child node control packet transmission mechanism, the regional node threshold flow control mechanism and the limited bandwidth secondary data confirm system to optimize the regional transmission quality. However, because this algorithm also does not consider energy constrained factors of cluster nodes, only considers traffic overload on the impact of network average delay, so in the network bottleneck delay, the performance of the algorithm is also lower than the proposed algorithm in this paper.

4.3 Network Throughput Frequency

Table 4 shows the network throughput frequency tested with node moving speeds of 5 m/s and 50 m/s as experimental environment control parameters. As can be seen from the table, the network throughput frequency of the proposed algorithm is significantly lower than that of OT-CLCPM algorithm and DT-PLEC algorithm, which shows superior network throughput performance. Because the proposed algorithm in this paper takes the energy and region division into account, and combines the differentiation characteristics of HEN node and GN node, improves the probability of HEN node being selected as cluster head node and improves the data throughput performance of transmission node. Therefore, the probability of network jitter is low, which reflects the low network throughput frequency. OT-CLCPM algorithm only uses optimized signal preforming to improve the performance of the network, it does not improve the network jitter phenomenon of cluster nodes. Therefore, more data packets need to be re-transmitted, which reflects higher network throughput frequency. DT - PLEC algorithm optimizes the performance of data transmission mainly through flow control method to design goal sink-regional child node control packet transmission mechanism, the node threshold flow control mechanism and limited bandwidth node secondary qualification. Although the network throughput capacity is enhanced to a certain extent, the algorithm does not further stabilize the data transmission quality between regions by optimizing cluster head node update, so the network throughput performance is also lower than the proposed algorithm in this paper.

5 Conclusions

In order to solve the regional stable transmission problem of wireless sensor networks in 5G deployment environment, a regional stable transmission scheme based on energy equalization-delay reduction mechanism is proposed. Firstly, the network deployment model and data transmission model are analyzed, and the data transmission can be stabilized by energy balance and delay reduc-

Table 3: Network mean delay test results

Node moving speeds=5m/s			
Number of data transmission rounds	OT-CLCPM	DT-PLEC	Proposed
50	80/ms	70/ms	60/ms
150	83/ms	75/ms	55/ms
250	135/ms	140/ms	60/ms
350	150/ms	180/ms	100/ms
450	160/ms	190/ms	120/ms
550	190/ms	220/ms	130/ms
Node moving speeds=50m/s			
Number of data transmission rounds	OT-CLCPM	DT-PLEC	Proposed
50	120/ms	110/ms	90/ms
150	125/ms	120/ms	100/ms
250	160/ms	180/ms	110/ms
350	240/ms	320/ms	120/ms
450	320/ms	500/ms	200/ms
550	380/ms	530/ms	250/ms

Table 4: Network throughput frequency test results

Node moving speeds=5m/s			
Number of data transmission rounds	OT-CLCPM	DT-PLEC	Proposed
50	100	105	50
150	400	500	290
250	800	1200	600
350	1000	1300	900
450	1100	1350	950
550	1300	1500	1000
Node moving speeds=50m/s			
Number of data transmission rounds	OT-CLCPM	DT-PLEC	Proposed
50	600	700	300
150	800	1500	600
250	1500	2400	1400
350	2500	3000	2000
450	2600	3200	2200
550	2800	3500	2500

tion. The cluster head update method based on energy equalization-delay reduction mechanism and the region partition method based on stability transmission mechanism are designed to improve the adaptability of the proposed algorithm to ultra-wideband and high jitter existing in 5G environment, it significantly improves the network congestion control ability, and has better network adaptation performance. In the next work, the proposed algorithm will adopt the node topology optimization mechanism to enhance the network congestion control performance and UWB data transmission ability of the proposed algorithm under the condition of low-density topology, and further improve the deployment value of the proposed algorithm in complex environments, in view of the difficulty in realizing low-density node deployment.

Acknowledgments

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Biography

Bo Wu biography. Bo Wu was born in 1987.08 in Zhengzhou City. His main interests include data mining, data security, information processing.