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Timeslot allocation algorithm for collision free data fusion tree

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Abstract. With continuous development of information-based war, tactical data chain plays an increasing important role. On the basis of analyzing timeslot allocation algorithm of typical tactical data chain, a kind of combined static and dynamic timeslot allocation algorithm is proposed. It can dynamically adjust timeslot allocation strategy according to different business features to satisfy users' communication demands and its performance is tested through simulation experiment. It can be seen from simulation results that timeslot allocation algorithm in the Thesis can not only improve timeslot utilization rate, but also drastically reduce average time delay and better satisfy actual application demand of communication system for tactical data chain.

Key words. Tactic data chain, Business prediction, Extreme learning machine, Static timeslot allocation algorithm.

1. Introduction

With rapid development of information technology, tactical data chain is increasingly applied widely in modern war and has become a key technology of information-based war[1]. Tactical data chain has a complete set of communication facilities to enhance information acquisition, processing and transmission capacity. According to network management system of data chain, tactical commanders can continuously adjust operation parameters to adapt to change on the battlefield and command & control the network at optimal performance and status [2]. Medium Access Control (MAC) protocol directly influences performance of tactical data chain system and controls message sending and receiving on wireless channel[3]. Time Division Multiple Access (TDMA) is the main access mode of current tactical data chain and it has good capacity to resist interception and interference. In addition, the network structure is flexible and can satisfy the need of complexity in modern battlefield environment[4]. However, in actual application, battlefield situation is changing constantly and timeslot demands of network nodes in different areas var. How to

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effectively allocate timeslot becomes especially important in TDMA application[5].

At present, there is mainly static timeslot allocation, competing timeslot allocation and dynamic timeslot allocation algorithms. Static timeslot allocation algorithm fails to dynamically adjust allocation scheme according to business demand at nodes and resource wasting is serious, with poor practicability[6-8]; competing timeslot allocation algorithm allocates timeslots in the form of timeslot groups and timeslots are pre-designed. It is also a kind of static timeslot allocation mode. Hence, there is difficulty in many conflicts, small throughput and serious timeslot wasting[9]; dynamic timeslot allocation algorithm allocates required timeslot when it is necessary to send data at the node. After data are sent, the node cancels occupation for the timeslot and channel utilization rate is improved. However, there are also some deficiencies, such as not high utilization rate of free timeslot[10].

To improve timeslot utilization rate of tactical data chain, a TDMA allocation algorithm integrating static and dynamic timeslot is proposed. Firstly, static timeslot allocation algorithm is used to allocate some timeslots and extreme learning machine (ELM) is used to predict business volume. In addition, required number of timeslot is determined according to predicted result. Finally, OPNET simulation software is used to test algorithm performance.

2. Analysis of typical timeslot allocation algorithm

2.1. *Classification of timeslot allocation algorithm*

How to reasonably allocate timeslot resources of TDMA is the key to improve system performance of data chain. Static timeslot allocation and competing timeslot allocation belong to static allocation and dynamic timeslot allocation is divided to centralized mode and distributed mode by realization mode, specifically as shown in Fig. 1 below[11].

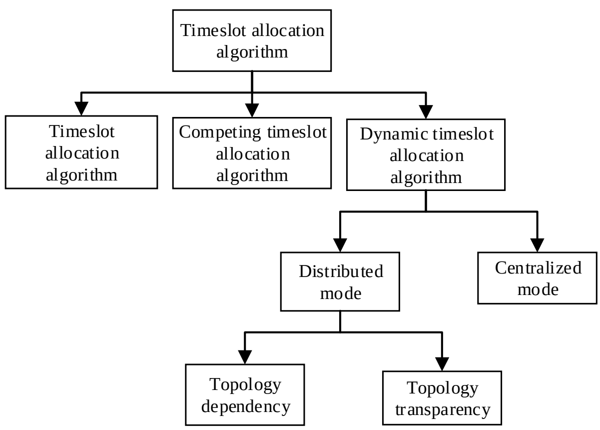

Fig. 1. Classification of timeslot allocation algorithm

2.2. Static timeslot allocation

In static timeslot allocation algorithm, the shortest timeframe length is adopted to prevent conflicting transport between nodes, realize reasonable timeslot allocation and improve channel utilization rate. Suppose there are n nodes in tactical data chain, its connection matrix R can be described with Equation (1).

$$R = (r_{ij})_{n\times n}, i, j = 1, 2, \cdots, n\,. \tag{1}$$

Where

$$r_{ij} = \begin{cases} 1 & e(i,j) \in E, i \neq j \\ 0 & others \end{cases} \tag{2}$$

Where $e(i,j)$ indicates link and E is link set.

Suppose one timeframe is composed of m timeslots and at least one timeslot is allocated to each node, then:

$$S = (s_{ki})_{m\times n}, k = 1, 2, \cdots, m; i = 1, 2, \cdots, n\,. \tag{3}$$

Where

$$s_{ij} = \begin{cases} 1 & slot_k \to i \\ 0 & others \end{cases} \tag{4}$$

Suppose channel utilization rate of node i is ρ_i, then channel utilization rate of data chain system ρ can be expressed as:

$$\rho = \frac{1}{n}\sum_{i=1}^{n}\rho_i = \frac{1}{n\times m}\sum_{k=1}^{m}\sum_{i=1}^{n}s_{ki}\,. \tag{5}$$

On the whole, static timeslot allocation model is:

$$\begin{aligned} &\min(m)\ and\ \max(\rho) \\ &s.t. \\ &\begin{cases} \sum\limits_{k=1}^{m} s_{ki} \geq 1 \quad i \in (1,n) \\ r_{ij} + s_{ki} + s_{kj} \leq 2 \ \ i,j \in (1,n), k \in (1,m) \\ r_{il}s_{ki} + r_{lj}s_{kj} \leq 1 \ \ i,j,l \in (1,n), k \in (1,m) \end{cases} \end{aligned} \tag{6}$$

During static timeslot allocation, binary tree algorithm is generally adopted. Suppose each timeframe is composed of $2N$ timeslots and binary tree has N layers, specific relationship is shown in Fig. 2.

When channel capacity is large enough, conflict probability of static timeslot allocation is small and channel utilization rate is low. Timeslot allocation scheme cannot be adjusted according to change of operation demand in a real time way and resource wasting is serious, with limited application scope[12].

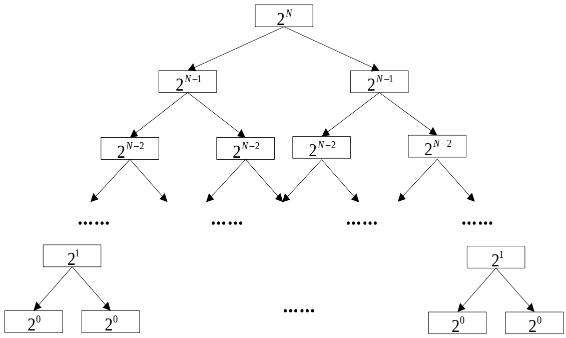

Fig. 2. Binary tree of static timeslot allocation

2.3. Competing timeslot allocation

In competing timeslot allocation algorithm, all nodes obtain timeslots through competing and the node which is the nearest to receiving point has the biggest probability to obtain timeslot. Timeslot bandwidth is adjusted randomly with big flexibility; however, it is actually a static timeslot allocation method. Hence, when there are many nodes, the success rate of information sending drops sharply. In particular, when there are many conditions to compete for timeslot nodes, the collision is especially obvious[13].

2.4. Dynamic timeslot allocation

Dynamic timeslot allocation algorithm can be adjusted according to dynamics of users' signal transmission demand and has strong adaptability, with relatively high resource utilization efficiency. As the performance of distributed dynamic timeslot allocation algorithm is superior to centralized dynamic timeslot allocation algorithm, and the application scope is more extensive, distributed dynamic timeslot allocation algorithm is mainly introduced. Timeslot conflict is defined as that node i and other nodes occupy the same timeslot and the calculation formula of timeslot conflict probability η_i is:

$$\eta_i = \frac{\sum\limits_{k=1}^{m} s_{ki} \times \left(\sum\limits_{k=1}^{m} s_{ki} - 1 \right)^{+}}{m}. \tag{7}$$

Where

$$(x)^{+} = \begin{cases} 1 & x > 0 \\ 0 & x \leq 0 \end{cases} \tag{8}$$

At this time, channel utilization rate ρ_i and average message time delay t_i of node I can be expressed as:

$$\rho_i = \frac{1}{m} \sum_{k=1}^{m} s_{ki}. \tag{9}$$

$$t_i = \frac{1}{\theta_i}\tau \sum_{k=1}^{m} (s_{ki} \times k)\,. \tag{10}$$

Then dynamic timeslot allocation model is:

$$\begin{array}{l} \min(\eta_i)\ and\ \min(t_i)\max(\rho_i) \\ s.t. \\ \sum\limits_{k=1}^{m} s_{ki} \geq \theta_i \quad i \in (1, n) \end{array} \tag{11}$$

Dynamic timeslot allocation algorithm can fully utilize timeslot resources and timeslot allocation is more reasonable. In case of conflict, it is hard to guarantee that each node can obtain timeslot[14].

3. Combined static and dynamic timeslot allocation algorithms

3.1. Integration thought

As single static timeslot allocation and dynamic timeslot allocation algorithm has their own deficiencies, based on competition theory, the advantages of two algorithms are used to overcome their own disadvantages. A combined static and dynamic timeslot allocation algorithm is proposed in the Thesis. Its basic thought is that: timeslot of each timeframe is divided to two parts. One part is subject to static timeslot allocation strategy and others are subject to dynamic allocation strategy. Therefore, under the condition of satisfying basic timeslot, remaining timeslot resources can be flexibly allocated.

3.2. Users' business prediction

In the tactical data chain system, due to comprehensive influence of various factors, users' business is characterized with stability, periodicity and burstiness and time sequence and neural network are mainly adopted to predict business. In addition, time sequence is actually a linear modeling method and can only accurately describe stability and periodicity business and it is hard to accurately predict burstiness; traditional neural network can accurately predict burst business and it has deficiencies such as complicated network structure and slow convergence speed. It is hard to satisfy real-time communication requirements of tactical data chain system. ELM is a new feed-forward neural network and training iteration process is converted to linear system of equations for solution according to Moore-Penrose generalized inverse matrix theory. Network training can be completed at one time and the performance is superior to traditional neural network[15]. Hence, ELM is used in the Thesis to model business volume of observation mode at present and in the past and predict next business volume in a real time way.

Suppose training set of collected node business is $\{(x_1, y_1), (x_2, y_2), \cdots, (x_n, y_n)$

and regression model of ELM is:

$$\begin{cases} \sum\limits_{i=1}^{L} \beta_i f(\alpha_i x_1 + b_i) = t_1 \\ \sum\limits_{i=1}^{L} \beta_i f(\alpha_i x_2 + b_i) = t_2 \\ \qquad\qquad \vdots \\ \sum\limits_{i=1}^{L} \beta_i f(\alpha_i x_n + b_i) = t_n \end{cases} \tag{12}$$

Where, α_i is input weight of nerve cell i; b_i is derivation of nerve cell $i; \beta_i$ is output weight of nerve cell i.

Equation (13) is converted to the following through matrix:

$$f(x) = h(x) \cdot \beta \tag{13}$$

Where: T_k is output vector; $h(x)$ is nerve cell matrix, and

$$h(x) = \begin{bmatrix} f(\alpha_1 x_1 + b_1) & f(\alpha_2 x_1 + b_1) & \cdots & f(\alpha_L x_1 + b_1) \\ f(\alpha_1 x_2 + b_1) & f(\alpha_2 x_2 + b_1) & \cdots & f(\alpha_L x_2 + b_1) \\ \vdots & \vdots & & \vdots \\ f(\alpha_1 x_k + b_1) & f(\alpha_2 x_k + b_1) & \cdots & f(\alpha_L x_k + b_1) \end{bmatrix}. \tag{14}$$

Least square is used to solve Equation (14) to obtain output weight.

$$\min \sum_{i=1}^{N} \|\beta \cdot h(x) - y_i)\| . \tag{15}$$

With above output weight, trained business prediction model of ELM is:

$$y = \sum_{i=1}^{L} \beta_i f(\alpha_i x + b_i) . \tag{16}$$

Where, x and y are respectively input and model output.

Weibull distribution is used to simulate burst business of data chain system and generate 1000 sample data of business volume. Then ELM is used to train samples and finally 100 business volume values are predicted to obtain predicted result as shown in Fig. 3. It can be known from Fig. 3 that for burst business, ELM can better describe its change trend and there is small deviation between predicted value and actual value. Hence, ELM can be used to accurately predict users' communication business.

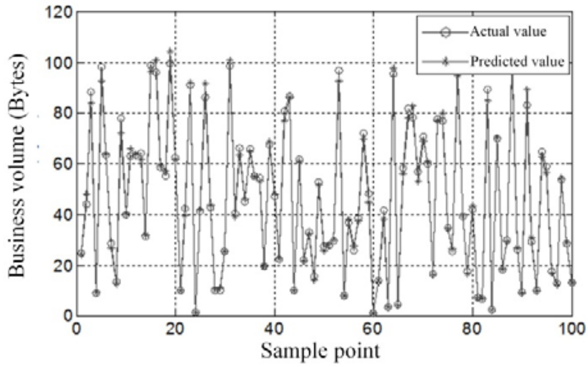

Fig. 3. Prediction for burst business of extreme learning machine

3.3. Working steps of algorithm

(1) Static timeslot allocation stage. One timeframe is divided to two parts and static allocation strategy is used to allocate some timeslots to all members and provide the most basic access guarantee for all members. In addition, static timeslot data are adjusted according to number of current active nodes.

(2) Dynamic timeslot allocation stage. Firstly, required number of business timeslot in all nodes is predicted through ELM and business prediction result is converted to required timeslot number. Suppose total required number of timeslot for all members in the network participation group is $Stotal(i, j)$, static allocation timeslot number of all members is $Sfix(i, j)$. Then dynamic timeslot allocation number is:

$$S_{reserve}(i,j) = S_{total}(i,j) - S_{fix}(i,j)\,. \tag{17}$$

Where i indicates number of network participation group and j indicates number of members in the network participation group.

After the network participation group collects timeslot demands of members in the network participation group, ordering is made from high to low according to priority before allocating timeslot to network participation group and allocating to members in the network participation group as per demand priority.

4. Simulation experiment

4.1. Simulation environment and parameter setup

To test rationality and superiority of timeslot allocation algorithm proposed in the Thesis, famous network simulation software OPNET Modeler is used for simulation experiment and it is compared with static timeslot and dynamic timeslot algorithms for analysis. Suppose 8 sites are distributed in the 500×500Km square network, simulation parameters of network environment are shown in Table 1.

Table 1. Network environment parameters

Parameters	Values	Parameters	Values
Frame size	128 ms	Bandwidth	1 Mbps
Timeslot number per frame	64	Load magnitude	150Bytes
Static timeslot number per frame	30	Package length	200 Bytes
Dynamic allocation timeslot number	2	Simulation time	1000s
Timeslot length	2	Package generation interval	0.01s

4.2. Result and analysis

(1) Comparison of timeslot utilization rate

Comparative results for timeslot utilization rate of static timeslot allocation, dynamic timeslot allocation and timeslot allocation algorithms in the Thesis are shown in Fig. 4. It can be seen from Fig. 4 that static timeslot allocation algorithm cannot dynamically adapt to business change, its timeslot utilization rate is the lowest and timeslot utilization rate is less than 60%, causing serious timeslot wasting; compared with static timeslot allocation algorithm, dynamic timeslot allocation is more flexible and it adjusts free timeslot to users with insufficient timeslots, improving timeslot utilization rate and making timeslot utilization rate up to 78%. The timeslot utilization rate of timeslot algorithm in the Thesis is up to 86%, which is mainly due to that algorithm in the Thesis fully utilizes advantages of static timeslot allocation and dynamic timeslot allocation and introduces ELM to predict burst business to improve timeslot utilization rate and reliability of data transmission.

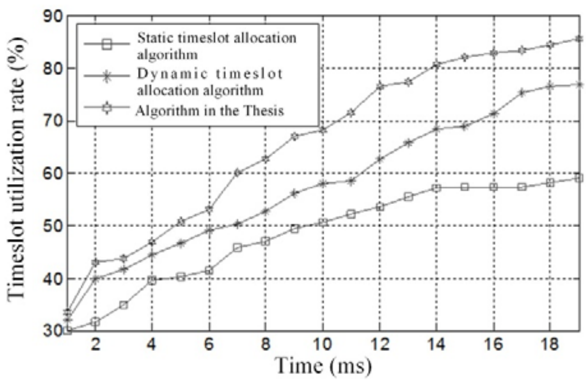

Fig. 4. Comparison of timeslot utilization rate of different allocation algorithms

(2) Comparison of timeslot conflict rate

As static timeslot allocation algorithm is appointed and static, timeslot conflict will not occur generally. Therefore, it is not involved in comparative experiment of timeslot conflict rate. The comparative results of dynamic timeslot allocation and combined timeslot allocation algorithm in the Thesis are shown in Fig. 5. It can be known from Fig. 5 that dynamic timeslot allocation algorithm is subject to random allocation timeslot. Business volume increases as time goes by and increase range of timeslot conflict rate is obvious; the timeslot conflict rate of combined timeslot allocation algorithm in the Thesis is small and has no significant influence on performance of data chain communication system.

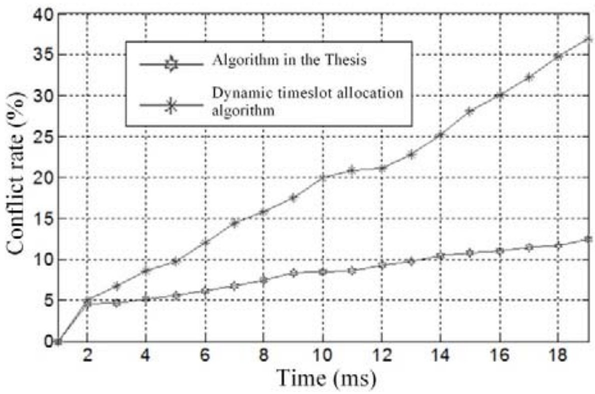

Fig. 5. Comparison of timeslot conflict rate of different allocation algorithms

(3) Comparison of average time delay

Average time delay change curves of 3 timeslot allocation algorithms are shown in Fig. 6. It can be seen from Fig. 6 that as time goes by, average time delays of 3 algorithms increase accordingly and increase of average time delay of static time delay allocation algorithm is the most drastic, followed by dynamic timeslot allocation algorithm. However, increase of average time delay of timeslot allocation algorithm in the Thesis is slow and stable, which is mainly due to that static timeslot allocation algorithm cannot apply for surplus timeslot with business change and free timeslot cannot be fully utilized. In addition, algorithm in the Thesis adds dynamic timeslot allocation strategy on the basis of some static timeslots and timeslots are fully utilized to improve system throughput and drastically reduce average time delay.

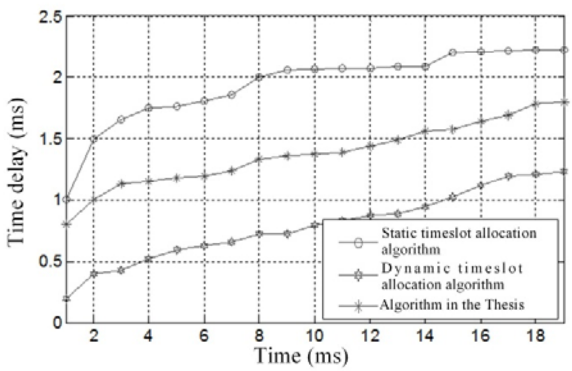

Fig. 6. Comparison of average time delays of different allocation algorithms

5. Conclusion

To improve timeslot utilization rate of data chain system, a TDMA allocation algorithm integrating static and dynamic timeslot appointment is proposed. Firstly, static timeslot allocation algorithm is used to allocate some timeslots and extreme learning machine is used to predict users' business volume. In addition, required number of timeslot is determined according to predicted result. Therefore, timeslot allocation strategy can be dynamically adjusted according to different business features to satisfy users' communication demand. Finally, OPNET simulation software is used to test algorithm performance. Results show that compared with other timeslot allocation algorithms, algorithm in the Thesis can improve utilization rate of timeslot and drastically reduce average time delay.

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