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# A Research and Review for Temporal Slots Division Algorithms of Tactical Data Link

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Abstract
Tactical data links have been an important symbol of modern digital warfare, whose research and innovation can represent the technology level of informatization equipments. Numerous data links generally employ the time di-

vision multiple access (TDMA) scheme with a certain temporal slots division algorithm. Thus the system quality of the TDMA-based data link mainly depends on the performance of the used division one. In this paper, we categorize and review a series of existing slots allocation ones for the purpose of promoting its further development.
Keywords: TACTICAL DATA LINK; TIME DIVISION MULTIPLE ACCESS (TDMA); TEMPORAL SLOTS DIVISION ALGORITHM

**1. Introduction**

Tactical data link is a comprehensive battlefield information system integrating the communications, navigation and identification. It is a typical application of the digital transmission technology in the military aspect, in which, through single or multiple network structure and media, tactical data exchanges with standardized formats among nodes including sensors, command centers, weapons platforms and combat troops [1]. This link is responsible for transmitting and processing data to extract information and guide further tactical action, achieving a seamless connection from sensors to weapons. Its research began in the 1950s. Then, in different historical periods, US-led western countries have developed a wide range of tactical data links, e.g. Link-1, Link-4/4A, Link-11, Link-14, Link-16 and Link-22, etc [1]. These ones play a significant role and become one of the crucial technologies in modern information warfare. However, the gradual deepening of information warfare makes the number of nodes and the amount of messages increasing, and different types of information have distinguishing demands of quality of service (QoS), thus promoting the further study of tactical data links. Besides, currently, as for the demands of the network-centric warfare, there have been emerging data links based on the self-organizing networking [2]. For instance, as a representative of the next generation data link, tactical targeting network technology (TTNT) uses a fully distributed, real-time and dynamic flat self-organizing network structure, showing great flexibility and simplicity [3]. Overall, on the basis of incorporating existing equipments, the general aim is to build an all-in-one comprehensive tactical data link through employing such the aircraft, satellite or terrestrial repeater station as advanced communication carriers and technologies to increase the system capacity and enhance the data transfer rate as well as the ability of resisting the jamming and interception [1].

For realizing efficient real-time information transmission, time division multiple access (TDMA) is extensively employed in a variety of tactical data links. Using the time channel resources, the TDMA behaves in its specific pattern of burst communication, which can effectively resist the interception and interference. Moreover, its flexible networking ability makes it suitable for field operations. The TDMA partitions the communication path into numerous temporal slots which are then assigned different nodes by means of a certain allocation algorithm. Thus how to effectively allocate slots to achieve desirable system performance is one of the key issues of realizing a TDMA scheme.

According to the operating strategy, we can mainly divide the existing temporal slots assignment algorithms into three types, i.e. the static, dynamic and hybrid ones. Moreover, in the light of the specific allocation pattern, the static schemes can be divided into the fixed and competitive methods, the dynamic the centralized and distributed ones which can be further divided by the topology transparent and dependent ones [4], and the hybrid the slots borrowing and divide-and-conquer ones [5], as depicted by Fig. 1.

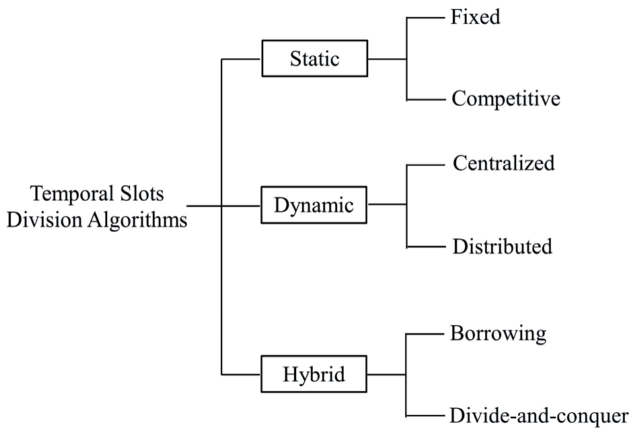


**Figure 1**. The categories of the temporal slots division algorithms of tactical data links

**2. Static temporal slots division algorithm**

For the fixed static temporal slots division algorithm, predefined temporal slots are allocated to corresponding nodes before communication. This one is applicable to the condition of small number of nodes or sufficient channel capacity, and can avoid conflicts of multiple accesses. However, using this algorithm, idle network traffic can cause low channel availability. Moreover, lack of time slot resources could occur with large number of nodes. Even S et al. reported that the fixed time slots assignment issue is a classic NP-complete problem [6]. Thus for most studies, researchers applied heuristic time slots division methods to obtain suboptimal solutions [7]. For instance, reference [8] and [9] proposed meanfield annealing and mixed neural-genetic algorithms, respectively, which can minimize the length of time frame and then attain relatively satisfactory solution. However, large computational complexity and the dependence on the extent of understanding network topology can affect their practicability. Besides, Liu X et al. recently designed a minimum delay jitter indicator-based fixed algorithm, and simulation tests showed that this one could meet the needs of transmitting high real-time tactical information [10].

On the other hand, as for the competitive temporal allocation algorithm, prior to communication, time slots and battle platforms are divided by group, respectively. Then each group of slots is assigned to its predefined corresponding one of battle platforms. For each platform in every group, a certain amount of slots are competitively obtained within the assigned group of ones to transmit messages. With the predefined slot groups planning, this algorithm is also a static time slots division one. It can simplify the complicated work within the network design phase and reduce the management burden during the network operation [4]. In this respect, Custy J and Shum A designed this type of protocol called SHUMA. With respect to this one, the posture sensing data of the link-16 terminal is utilized to adjust the sending slots, which can reduce channel collisions. In addition, the SHUMA also facilitates the dynamic entry and exit of each platform [11]. Although as compared with the fixed protocol, the competitive one is flexible and advantageous to some extent, it cannot entirely avoid conflicts with the competition. When two platforms simultaneously send messages within the same time slot in one network, the receiver can only get the information from the closer platform [4].

**3. Dynamic temporal slots division algorithm**

For this algorithm, time slots are assigned dynamically to the corresponding nodes. Only when a node need to send information, it attempt to obtain temporal slots by means of submitting requests or competition. Despite of the network expenses for control messages to dynamically assign slots, this protocol can markedly improve the channel utilization rate, thus overcoming the shortcoming of the static one. Moreover, the tactical environment is unpredictable as well as intricate and several lines of significant messages demand the assurance of QoS. However, in the static allocation protocol, it is difficult to obtain high QoS performance, especially at busy network load, while using appropriate dynamic division schemes can provide a QoS guarantee.

In the centralized dynamic algorithm such as typical polling one, there generally exists a central node working as a relay for the other nodes' communications, as presented in Fig. 2 (a). This central one can collect the global information of the whole network to be responsible for allocating time slot resources for all the nodes, thereby being able to get the enhanced channel utilization. However, a high cost required for mastering the conditions of all the nodes and poor invulnerability limit this protocol's application in the tactical data link [4]. For the disadvantages of traditional polling protocol, several explorers did numerous improvements. For instance, Wang Y proposed two dynamic polling slots allocation algorithms for the transmission demands of large volume data and sudden messages [12]. Wang WZ designed an adaptive polling medium access control protocol. Through the adaptive scheduling mechanism based on packets' queue length and priority as well as the delay requirements, this one can select nodes having more high-priority packets with a higher probability to poll, thus heightening the channel utilization and providing the ability of distinguishing services [12].

In addition, in comparison to the military communication system, the employment of the centralized protocol in civil one is broader. In the background of different applications, researchers designed a train of polling algorithms. For example, aimed at the IEEE802.11 as a widely used wireless network standard, Lagkas T D et al. made the best of the service features of nodes and the number of successful polls to get over the empty packet polling problem, effectively heightening the channel utilization rate [13]. For the Bluetooth mechanism, balancing the fairness, signal path utilization and time delay, Yang F et al. proposed an adaptive polling strategy [14]. Besides, in the ad hoc network of clustering structure, Tseng C-C and Chen K-C gave a priority polling scheme with reservation, attaining certain guarantee of QoS. Nevertheless, the synchronous existence of multiple high priority messages may lead to the packets conflicts [15].

For the distributed dynamic assignment algorithm, all the nodes are mutually equal as demonstrated in Fig. 2 (b) and compete by turn for their respective slots in the light of a certain rule, therefore elevating the invulnerability of the tactical data link in the battlefield environment. Moreover, the existing distributed method can be divided by two types, i.e. topology transparent and dependent schemes [4].

The former does not rely on the local topology information and can provide a performance assurance for nodes at assigning slots, e.g. the time spread multiple access scheme designed by Chlamtac I and Farago A [16], whereas without reference to the topology, much conflicts may be induced and further this protocol cannot deal with the variation of the network structure and load.

The topology dependent strategy commonly employs the interactive control messages to gather local topology content, furthermore assigning slots for nodes. Thus this scheme can avoid conflicts and take full advantage of channel resources. For example, Young C D proposed a unifying dynamic distributed multichannel TDMA slot assignment protocol (USAP) and gave a two-hop adjacent nodes information gathering method [17], while the fixed number of frames and slots within one loop result in that the channel is difficult to be effectively used, and this algorithm cannot quickly adapt to the change of the topology. In order to make up for these shortcomings, Zhu C and Corson M S designed a five phase reservation protocol, in which the right to use slots is obtained by competition [18]. However, the above schemes still cannot realize satisfactory performance due to employing a changeless frame length. Thus investigators proposed a series of strategies with variable frame length. For instance, Young C D designed a USAP multiple access protocol [19], but how to alter the frame length did not be given. For solving this problem, multiple schemes were presented including an adaptive slots assignment protocol [20] as well as a train of enhanced versions [21][22][23]. In these algorithms, the frame length can change with the nodes density and load, which is able to adapt to the variation of nodes in the competitive domain and further heighten the channel utilization. Besides, Lee JK et al. proposed a fast dynamic algorithm to decrease time slot access delay for newly arrived nodes in ad hoc networks. This one can simplify the allocation procedure through employing mini-slots to share control packets for short periods [24]. Recently, Muhammad HC and Bart S designed a distributed protocol formulating the channel scheduling as an optimization problem to maximize the slots reuse rate, and whereby they jointly optimize the slots allocation and the frame lengths. Further, they gave a greedy heuristic scheme through which nodes realize slots assignment in a progressive decentralized way. Tests showed that with respect to the slots reuse rate, this one could obtain better performance than previous ones [25].

Moreover, Lewis A M and Pizzi S V proposed a demand-assigned multiple access protocol, promoting the exploration of the QoS issue in tactical data links [26]. On the basis of a new frame format, this scheme can achieve dynamic on-demand slots allocation. However, for low priority requests, it may produce a greater time delay. Thereby, this protocol cannot obtain desirable QoS performance. As to this problem, Zhang Z and Zhang X gave a QoS-based dynamic slots allocation algorithm for the distributed tactical network, in which the frame length can be adaptively shrunk or increased with reference to the number of requests [27]. The simulation results showed that this scheme could achieve acceptable delay for messages of multiple priorities such as the high and low ones, etc. Thus this protocol can enhance the QoS performance and channel utilization. Nevertheless, this method only applies to the one-hop network, in which all the nodes are within the scope between each other [27]. Therefore, the OoS-based slots allocation scheme for the multi-hop one needs further study.

**4. Hybrid temporal slots division algorithm**

In general, the hybrid allocation algorithm mainly works in slots borrowing or divide-and-conquer modes. The former is on the basis of the static protocol. As one node has obtained several slots yet its communication demand still cannot be met, it can borrow ones not employed by other nodes. For the latter, within the whole network, some nodes operate by means of the static algorithms, the other ones run with the dynamic methods [5]. Farago A et al. indicated that integrating multiple time slots allocation algorithms is able to enhance the efficiency of the network system [28]. Therefore, numerous researchers proposed a series of hybrid protocols incorporating the advantages of the static and dynamic ones to overcome the deficiencies of the existing algorithms [29][30][31][32].

For the first time, Ephremides A and Mowafi O A proposed a hybrid slots allocation design named PTDMA. Based on the TDMA mechanism, this protocol assigns a unique slot to each node, and then probabilistically decides how to utilize available and occupied slots [30]. Further, combining the TDMA and carrier sense multiple access (CSMA) strategy, Sharp B A et al. and Chlamtac I et al. designed separately the hybrid TDMA/CSMA [29] and ABROAD [31] protocols. Employing the technology of carrier sense, the hybrid TDMA/CSMA allocation method can ensure that each node has priority to use its assigned slots. In comparison to the PTDMA, this algorithm can guarantee stable performance. Moreover, aimed at avoiding the conflicts caused by hidden platforms, the ABROAD protocol uses collision detection mechanism [31]. Nevertheless, the above methods don't introduce the effective backoff algorithm, and the employed competition mechanism likewise needs to be further improved [5]. In response to these shortcomings, Rhee I proposed a protocol called Z-

MAC. This one makes use of the advantages of the TDMA and CSMA tactics. At low network load, the Z-MAC utilize the competition strategy of the CSMA to reuse the bandwidth, then being able to obtain a high channel usage rate, while as the network is busy, via dynamically converting to the operation mode of the TDMA, the Z-MAC can reduce the instability of the CSMA [32]. Thereby, even in the worst condition, this performance of the CSMA can be attained as well. In order to improve the adaptation of the dynamic allocation algorithm to the change of network load and nodes density, Wang WZ analyzed the service features of tactical data links and designed a message-streams oriented hybrid slots assignment protocol. They partitioned the message-streams into fixed and random ones, and adopted fixed and dynamic allocation modes, respectively. The test results showed that even under heavy load or great changes of nodes density, this scheme could likewise ensure the QoS demands of a part of services [5]. Besides, Ren H et al. proposed a multi-layer network-based hybrid algorithm, in which, different layers use their respective allocation strategies [33]. Simulation results showed that this one could take full advantage of the multi-layer structure and achieve desirable overall performance.

**5. Conclusions**

The quality of temporal slots division algorithms greatly affects the performance of the TDMA-based tactical data links. This paper investigates a train of ones and elucidates their respective advantages and shortcomings. So far, there does not exist an assignment one that can meet all operational requirements. The complexity of battlefield in the modern warfare brings the diversity of the needs of allocation ones. Thereby, how to build a reasonable and efficient assignment one to adapt to varied battlefield environments is one of the important directions of further researches. Furthermore, tactical data links faces more severe safety challenges as compared to general communication systems. Therefore, it is also imperative to explore appropriate security mechanism while studying allocation algorithms for meeting future operational needs.

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