Improved Sequential Vertex Colouring Algorithm for the TDMA Dynamic Time Slot Allocation Protocol

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***Abstract*—The design of the media access control (MAC) layer protocol has been considered a key technical issue in ad hoc research in recent years. Considering the demands and feasibility of engineering practice, a new dynamic time-slot allocation (TSA) protocol based on the improved sequential vertex coloring (SVC) algorithm is proposed in this study according to the characteristics of the MAC protocol in ad hoc networks. We analysed the frame structure, interactive process of the protocol, and the dynamic time-slot allocation algorithm. The NS2 software was employed to simulate the performance of the system in three different scenarios. The results demonstrated that parameters such as slot utilisation, throughput, average delay, and fairness were better than those using the IEEE 802.11 and TDMA protocols.**

***Index Terms*—Ad hoc network, dynamic slot allocation, NS2 simulation, sequential vertex coloring, TDMA.**

I. Introduction

In mobile ad hoc networks, media access control (MAC) performance is critical for improving the entire network, Thus the design of the protocol for this layer is a key issue. TDMA has once again become a research hotspot due to the need for time slot synchronisation. Compared with the generic IEEE 802.11 protocol, TDMA is simpler and more practical for engineering applications, and the instrument and equipment life cycles are longer. An effective MAC layer protocol for broadband mobile ad hoc networks is proposed in the present study.

Various TDMA protocols have different frame structure designs and time-slot scheduling modes. The TDMA protocols are classified as follows [1, 2]: (1) Fixed dynamic time-slot allocation (TSA) mode: The total number of nodes in the network determines the frame length in this mode and the access delay is related to the frame length. If the traffic load varies, it is not possible to follow the changes dynamically, thereby resulting in the waste of time slots or overloading. As a result channel utilisation rate decreases. However, this allocation mode has good node fairness and it is easy to implement in engineering applications. Therefore, it is suitable for medium or small scale networks with homogeneous traffic loads. (2) Dynamic TSA mode: The TSA protocol is self-adaptable to the topology and instantaneous traffic. Depending on the reservation or competition mechanism used to resolve the TSA strategy, the typical representative protocols include the five-phase reservation protocol [3], E-TDMA [4], and HRMA [5]. The channel utilisation is increased but the system load is higher, and implementing the project also becomes more complicated.

Manuscript received September 8, 2017; revised July 27, 2018.This work was supported in part by the Education and Scientific Research Foundation of Education Department of Fujian Province for Middle-aged and Young Teachers [grant number JAT170352]

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There are two existing types of dynamic allocation algorithms: centralised and decentralised algorithms [6]. In the centralised algorithm, a node selected as the central control node can obtain information from all the nodes in the entire network and manage the TSA [7]. The channel utilisation efficiency improves. However the central control node becomes overloaded because it needs to access information from the entire network. If the central control node function is abnormal, the whole network may crash. In the decentralised algorithm, according to specified principles, each node in the network reserves a transmission time slot sequentially or simultaneously. Thus, as the scale of the network increases, the time consumed for time slot distribution will also increase. In addition, the network scale, node ID, and other information regarding the entire network should be obtained in advance. Therefore, the decentralised algorithm is unsuitable for large-scale and variable-size networks [8, 9]. In addition to these two methods, a dynamic TSA algorithm that conforms to the necessary engineering application requirements is described in the follow sections.

II. PROTOCOL ANALYSIS

A. Design Objectives

The proposed protocol is capable of accessing four to 32 nodes. Any node can act as a central station. The central station obtains all of the network topology states using an interaction method and implements time-slot multiplexing and dynamic allocation with the improved sequential vertex coloring (SVC) algorithm. Several assumptions are proposed for the network model before we consider its design and analysis, i.e. the time slots for all nodes are synchronised with a reference benchmark, each node has a unique MAC address, the node operates in the half-duplex mode where the data are transmitted or received asynchronously, and the link is a symmetric link.

B. Frame Structure

According to the practical broadband adhoc network project requirements, the frame structure is shown in Fig. 1. The structure comprises the control channel (CCH), access channel (RCH), and traffic channel (TCH). The *CCH* field can be divided into K sub-slots, which are numbered from 1 to *K*. The *RCH* field only has one-time slot. The *TCH* field comprises *M* time slots, which are numbered from one to *M*.

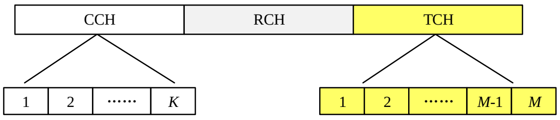

Fig. 1. Frame structure of the TDMA protocol.

C. CCHs

It is assumed that the network includes *N* active nodes, which are numbered from one to *N*. The CCHs schedule the time slots with fixed assignments and allocate unique control time slots to each node. Assuming that the control time slot *K* is less than the total number of node *N*, the nodes not assigned to a time slot will be allocated sequentially in the next frame until all of the nodes have been allocated. No allocations will be made if the control frame has idle time slots. A new round of allocation begins sequentially with a new frame and the process cycle continues.

In the control time slot, each node broadcasts its saved neighbourhood states list and transmits the received TSA list to its neighbours. In addition, if the neighbourhood information list changes on other node, the received list should be transmitted in this time slot. After multiple interactions, the time allocation list for the central station will finally converge.

D. RCH

The RCH is a public channel employed by the node access network. The conflict probability is low when few nodes access the network. During conflicts, the nodes compete in order to obtain a time slot to access the network. The protocol uses the S-ALOHA method to request a new node to issue an access request message. After the central station receives a request, a new control slot is assigned to it and this information is then broadcast. If the new node fails to receive this message subsequently, then it is considered that sending the network access request message has failed. The access request message will be issued again after some time to avoid collisions.

E. TCH

TCHs are the traffic data transmission channels. Each channel determines its own TCH based on the STA list transmitted by the central station. At least one time slot is assigned to each node. Each node transmits information during its own traffic time slot, and then listens and receives information within the traffic time slots of the other nodes.

F. Control Interaction Frame Structure

Information exchange between nodes is implemented in the CCH. The interaction information comprises two components: the neighbour state list and the TSA list. Figure 2 shows the structure of the state list for the neighbourhood nodes. The *Index* field represents the node number($1 \leq Index \leq 32$) The *Seq* field is the newness degree for the neighbour nodes status list, where the list is newer when the value is larger. *Node i state* ($1 \leq i \leq 32$) indicate whether the Index node and node i are one-hop neighbour nodes. If the value is 1, they are one-hop neighbour nodes; otherwise, the value is 0.

Index	Seq	Node1 State	Node2 State	……	Node32 State
5bit	16bit	1bit	1bit		1bit

Fig. 2. Structure of the state list for the neighborhood nodes.

Table start	TTL	Slot num	Slot_1	……	Slot_8
16bit	8bit	5bit	32bit		32bit

Fig. 3. Structure of the TSA list.

The structure of the TSA list is shown in Fig. 3. The *Table Start* field represents the time when the central station transmits the time slot list, i.e. the effective time of the TSA list. *TLL* field is the survival period, i.e. the valid time. If the time set for receiving the list is beyond the valid time, then the list is rejected. The *Slot num* field is the number of traffic time slots, where eight is used in the protocol.The *Slot_i* field ($1 \leq i \leq 8$) has 32 bits in total, which indicate the details of time slot *i* occupied by the nodes. If node *n* occupies time slot *i*, then the corresponding bit *n* is set to one; otherwise, it is set to zero.

Each node needs to maintain and transmit the two lists in its own control time slot. The interaction of the entire protocol is explained in the following.

G. Protocol Interaction Process

The interaction process is operated in the time frame of the CCH. Each frame in the protocol includes eight control time slots. The TDMA protocol interaction process is shown in Fig. 4. Each node maintains a transmission queue, which records the neighbour status list that needs to be updated.

In the listening state, after receiving the data packet, the node first determines that the destination address of the packet belongs to itself or broadcast address.The head sequence number is then analysed to determine whether the neighbour state has changed. An assessment is made to determine whether to join the sending queue and update its neighbour state table. The survival time of the TSA list is used to determine whether to update its own TSA list.

If the node is in its own time slot, it first checks whether the transmission queue is empty. If it is not empty, a record in the queue will be fetched back, which is then combined with the TSA list to construct and transmit a data packet; otherwise, the neighbour state record and TSA list are delivered.

Each four frames comprise a round. Each node updates its neighbour state record every round. Every 10 rounds, according to the received node state list, the central station obtains the topology information for the entire network and updates the TSA list. Each node can obtain the topology information for the whole network so any node can be selected as the central station.

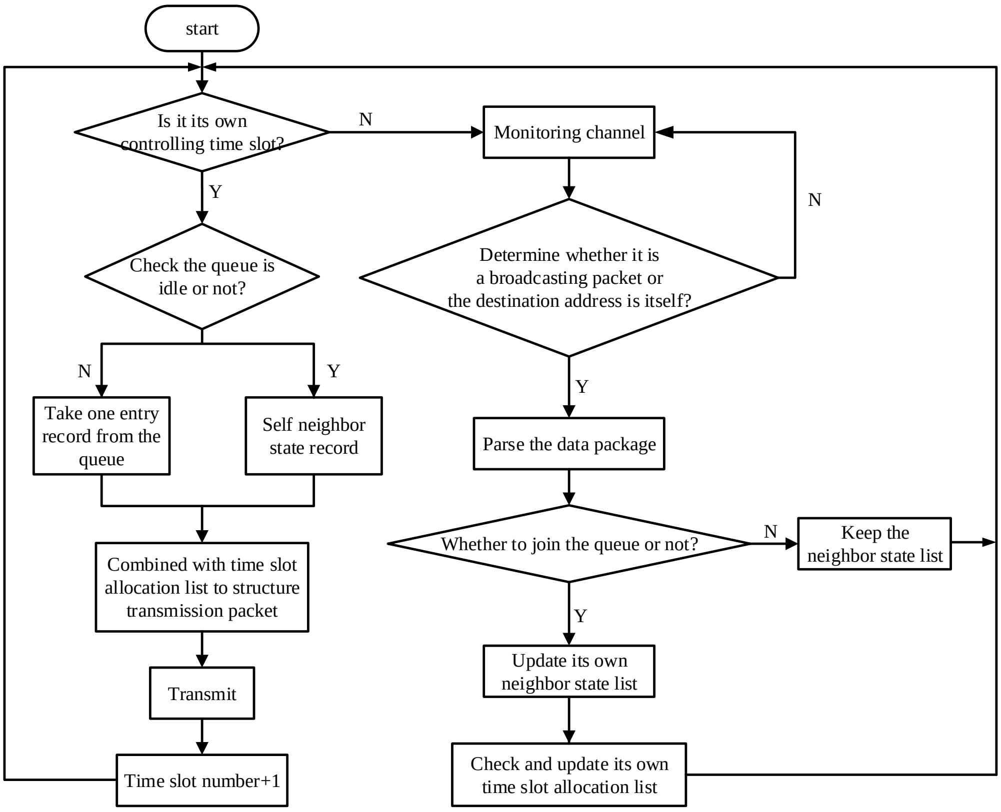

Fig. 4. Interaction process of the TDMA protocol.

H. Dynamic Time Slot

The graph-colouring algorithm from graph theory is employed to solve the TDMA scheduling schemes. In graph theory, the graph-colouring algorithm applies different colours to any adjacent regions. TSA is regarded as a graph-colouring problem and the channel utilisation is increased under conditions where it is necessary to avoid collision as much as possible [10–15].

In graph theory, the graph-colouring problem is a classic NP hard problem. The static topology structure of an adhoc network is considered to be a graph G(V,E) , where the vertices V (1,2,3...n) represents the nodes in the network, n is the total number of nodes in the network, and the edge E represents the assembly of all the links in the network. Assuming that nodes i and j in the network can communicate with each other, then there is an undirected edge $e_{i,j}$ between the two vertices, $e_{i,j} \in E$, i.e. nodes i and j are one-hop neighbours. Collisions occur when one-hop neighbours transmit data simultaneously in the same time slot. Two-hop neighbour nodes may also cause collisions when transmitting data to the same node in the same time slot. The nodes beyond the two-hop neighbours can share the same time slot for communication and implement space multiplexing.

In 2002, Yeo proposed the typical TSA algorithm based on graph theory, i.e. SVC [16–18]. According to the premise of ensuring the minimum frame length, the algorithm can maximise channel utilisation. Based on the SVC algorithm and practical engineering requirements, an improved SVC (I-SVC) algorithm is proposed in the present study. In simulations with NS2 software, we demonstrate that the protocol satisfies the dynamic TSA requirement, and the channel utilisation is superior to that with the conventional SVC and MFA algorithms. The algorithm is explained in the next section.

III. I-SVC ALGORITHM

A. SVC Algorithm

The channel utilisation in an adhoc network comprising N nodes is represented by equation (1):

$$\rho_i = \frac{Allocated\ number\ of\ time\ slot\ of\ node\ i}{Number\ of\ time\ slot\ in\ TDMA\ time\ slot} = \frac{\sum_{m=1}^{M} t_{mi}}{M} \tag{1}$$

where t_{mi} is time slot m occupied by node i.

Channel utilisation in the whole network is described by equation (2):

$$\rho = \frac{1}{N}\sum_{i=1}^{N}\rho_i = \frac{1}{MN}\sum_{m=1}^{M}\sum_{i=1}^{N} t_{mi} \tag{2}$$

The broadcasting scheduling problem for the nodes can be described in the following math mode by equations (3)-(6).

$$Minimize\ M\ and\ Maximize\ \rho \tag{3}$$

$$s.t \qquad C1: \sum_{m=1}^{M} t_{mi} \geq 1 \qquad (i = 1,\ ..., N) \tag{4}$$

$$C2: c_{ik}t_{mi} + c_{kj}t_{mj} \leq 1; \\ (i, j, k = 1, \cdots N, i \neq j, j \neq k, k \neq i, m = 1, \cdots, M) \tag{5}$$

$$C3: c_{ij} + t_{mi} + t_{mj} \leq 2; \\ (i, j = 1, ..., N, i \neq j, m = 1, ..., M) \tag{6}$$

In the equations above, *M* is the number of time slots, t_{mi} is the time slot *m* occupied by node *i*, and c_{ij} indicates whether nodes *i* and *j* are one-hop neighbours or not, where 1 denotes that they are one-hop neighbours and 0 that they are not.

The descriptions given above show that we must search for the minimum frame length and maximum channel utilisation rate under the following restrictive conditions:

(1) Any node in the time frame is assigned at least one time slot, i.e. restrictive condition C1.

(2) Two-hop neighbour nodes cannot be assigned to the same time slot, i.e. restrictive condition C2.

(3) One-hop neighbour nodes cannot be assigned to the same time slot, i.e. restrictive condition C3.

(4) In the adhoc network, collisions can be avoided if nodes within two-hop distances are assigned to different time slots.

The scheduling problem can then be converted into a graph-colouring problem. The time slots are equivalent to colours in graph theory. Colouring the graph with the minimum number of colours is equivalent to constructing the frame structure with the minimum time slots.

Mean field annealing (MFA) [19] is a dynamic TSA algorithm based on colouring theory. However, the MFA algorithm has two disadvantages because it cannot minimise the lengths of frames sufficiently and it lacks a method for determining the optimal parameters.

The SVC algorithm is an improved algorithm based on MFA. According to some rules, *N* nodes in the network are numbered as 1, 2 $\cdots$ *N*. The first node is coloured and numbered as colour No. 1. Next, the node list is scanned downwards and the minimum colour number is assigned to a non-one-hop neighbour node. The process is repeated until all the nodes have been coloured. According to the variable ordering criterion, the best performance is achieved by reducing the number of one-hop and two-hop neighbours, i.e. nodes with the maximum number of one-hop and two-hop neighbours should be written in the list first.

The algorithm comprises two stages: determining the minimum frame length *M* and maximising the channel utilisation.

The algorithm is described by the following SVC algorithm pseudo code, shown in Fig.5.

Fig. 6- Fig. 8 is a topology in three scenarios.The random topology structure of scene 3 in Fig. 8 is considered. According to the analysis in Section III.A, the nodes are sorted twice by the SVC algorithm but without considering the priority algorithm for sorting nodes with the same number of neighbours .

Table I shows the TSA results obtained by the conventional SVC allocation algorithm. According to the analysis in the figures and tables, TSA can be continued for nodes

Algorithm 1 SVC Algorithm pseudo-code

Define:
N: Number of nodes in the network.
NH(i): Assembly of node *i* with the one-hop or two-hop neighbours.

CHECK(m,i): Checking whether the m^{th} time slot can be assigned to node *i*. In the node assembly *NH(i)*,determine whether the node is assigned to the time slot *m*.If not, set to 1; otherwise,reset to 0.
M: Time frame length obtained from stage 1.
x_{mi}: Time slot m is occupied by node *i*.

Stage I:

1: Descend the one-hop and two-hop neighbour nodes;
2: *m* = 1, *i* = 1;
3: If(*CHECK*(*m*,*i*)= 1), then x_{mi} = 1, go to Step 5;
4: Else, go to Step 7;
5: If(*i*=N), STOP;
6: Else m= m+1, *i* = *i*+1, go to Step 3.
7: m=m+1,go to Step 3.
Stage II :
8: Ascend the one-hop and two-hop neighbour nodes;
9: *m* = 1, *i* = 1;
10: If(*CHECK*(*m*,*i*)= 1 and x_{mj}=0), then x_{mi} = 1;
11: If(*m*=*M* and *i* = *N*), STOP.
12: Else if(*m*= *M* and *i* < *N*)
13: then *m* = 1; *i* = *i* + 1, go to Step 10.
14: Else *m* = *m* + 1, go to Step 10.

Fig. 5. SVC Algorithm pseudo-code

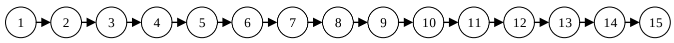

Fig. 6. Topology structure figure of scene 1

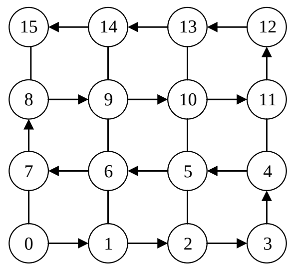

Fig. 7. Topology structure figure of scene 2

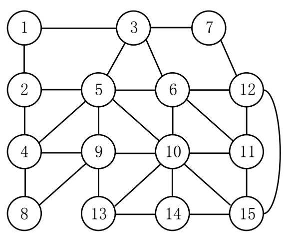

Fig. 8. Topology structure figure of scene 3

7 and 8 without affecting the TSA for the other nodes in the network. Thus, the conventional SVC algorithm is not suitable for allocating time-slot. On the other hand,the allocation algorithm with variable frame length is not feasible for engineering applications. Therefore, the algorithm needs to be improved. So we propose an SVC algorithm based on a fixed frame length.

TABLE I
TIME SLOT ALLOCATION TABLE FOR THE SVC ALGORITHM

Node	Slot 1	2	3	4	5	6	7	8
1				■				■
2							■	
3					■			
4						■		
5	■							
6		■						
7			■					
8		■						■
9				■				
10			■					
11						■		
12				■				
13					■			
14								■
15							■	

B. I-SVC STA Algorithm with Fixed Frame Length

1) I-SVC STA Algorithm: Stage II of the algorithm is improved in order to address the issues that affect the SVC algorithm. In Step 1, ascending ordering is performed according to the total number of one-hop neighbours and two-hop neighbours of each node in the NH(*i*) assembly.

For the nodes with the same numbers of one-hop and two-hop neighbours, according to the total numbers of one-hop neighbours, in decreasing order, we then obtain the new sorting of i_1, i_2, $\cdots$, i_N. Similarly, the random topology in Scene 3 is considered and the TSA results obtained by the I-SVC algorithm are shown in Table II.

TABLE II
TIME SLOT ALLOCATION TALBE FOR THE I-SVC ALGORITHM

Node	Slot 1	2	3	4	5	6	7	8
1				■				■
2							■	
3					■			
4						■		
5	■							
6		■						
7			■				■	
8		■			■			■
9				■				
10			■					
11						■		
12				■				
13							■	
14								■
15					■			

Clearly, nodes 7 and 8 are reassigned to new time slots and the defects with the SVC algorithm are eliminated, where the colours are more suitable and the channel utilisation is increased.

For the three topological scenes shown in Fig. 6 to Fig. 8, the total number of time slots and the channel utilisation obtained using I-SVC, SVC, and MFA are compared in Table III. The comparisons show that for some scenes, the I-SVC algorithm was superior to SVC and it was generally better than MFA.

TABLE III
COMPARISON OF THE PERFORMANCE OF THE CONVENTIONAL SVC ALGORITHM AND I-SVC ALGORITHM

Scene	Total number of time slots required			Channel utilization		
	I-SVC	SVC	MFA	I-SVC	SVC	MFA
1	3	3	3	0.333	0.333	0.333
2	6	6	6	0.1875	0.1875	0.0625
3	8	8	8	0.1583	0.1417	0.125

2) I-SVC TSA Algorithm with Fixed Frame Length: In the section above, the variable TSA algorithm is introduced. The TSA algorithm with a fixed frame length is more suitable for practical engineering applications. If we select the number of time slots with a fixed frame length as *Z*,then the problem with TSA is how to achieve the maximum channel utilisation rate with *N* nodes when the frame length is *Z*. The channel utilisation is described as follows.

$$\rho = \frac{1}{N}\sum_{i=1}^{N}\rho_i = \frac{1}{ZN}\sum_{m=1}^{Z}\sum_{i=1}^{N}t_{mi} \tag{7}$$

The integer programming is represented by equation (8).

$$Maximize \quad \rho \tag{8}$$

The following are the corresponding restrictive conditions.

$$s.t. \quad C1: \sum_{m=1}^{Z} t_{mi} \ \geq 1 \quad (i = 1, ..., N) \tag{9}$$

$$\begin{aligned} &C2: c_{ik}t_{mi} + c_{ik}t_{mj} \leq 1; \\ &(i, j, k = 1, ..., N, i \neq j, j \neq k, k \neq i, m = 1, ..., Z) \end{aligned} \tag{10}$$

$$\begin{aligned} &C3: c_{ij} + t_{mi} + t_{mj} \leq 2; \\ &(i, j = 1, ..., N, i \neq j, m = 1, ..., Z) \end{aligned} \tag{11}$$

The algorithm 2 and the symbols used are described as follows, shown in Fig.9.

IV. NS2-BASED PROTOCOL SIMULATION

The proposed TDMA protocol was simulated and validated using NS2 software. NS2 is one of the most extensive open source software systems in the network simulation field, where it was developed and operated with the C++ and OTcl languages. NS2 includes a simulation event scheduler, network assembly object library, and other structures. The network components are used to simulate communication between network devices or nodes, and different environments can be established for simulations [20].

The protocol employed in the simulation could have a variable or fixed frame length, and it was compared with the IEEE 802.11 and TDMA protocols. Figure 8 shows the simulation topology, where the network included 15 random

Algorithm 2 I-SVC Algorithm with Fixed Frame Length

Define:
M: Number of time slots obtained with the I-SVC algorithm.
Z: Number of traffic time slots.

1: According to the number of nodes allocated to each time slot, the TSA result from the I-SVC algorithm is sorted in descending order to obtain the new ranking of i_1, i_2, $\cdots$, i_M;
2: If (M>Z), then jump to step 4;
3: else, go to step5.
4: The time slot for part *M-Z* is assigned to the next frame and the process is repeated until the traffic time frame is full.
5: For the time slot of part *Z-M*, repeat for the sorting results from step 1 until the traffic time frame is filled.

Fig. 9. Pseudo-code of I-SVC Algorithm with Fixed Frame

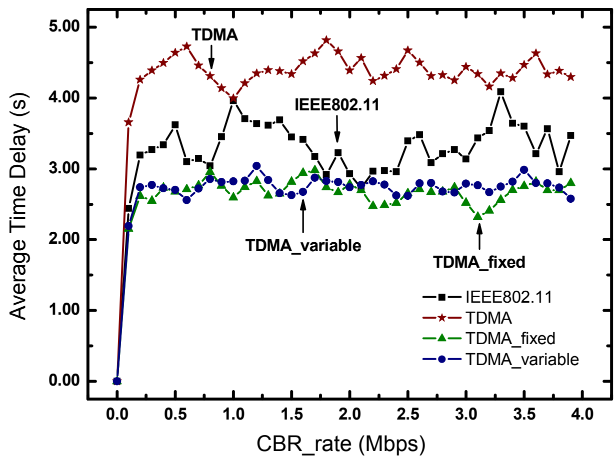

Fig. 11. Average time delay simulation.

nodes (Node 1 to Node 15), and Node N transmitted data to Node N+1. In the simulation, the data flow generation probability for each node conformed to a Poisson data distribution, the data packet size was 1200 B, the route protocol was AODV, and the simulation duration was 100 s. The saturated throughput, average delay, and access fairness were simulated [21].

Figure 10 shows a diagram of the simulated system throughput with changes in the traffic load. As shown in Fig. 10, the throughput tended to saturate as the traffic load increased.

tended to become saturated as the traffic load increased. The scenario had a random topology structure and the average time delays were longer for all the protocols. The average time delays were equivalent for the TDMA protocols with variable frame length and fixed frame length. The delay jitter was severe for IEEE 802.11 protocol due to the back-off mechanism. When using the original TDMA protocol, the frame cycle and delay were maximised because the number of time slots was the same as the number of nodes.

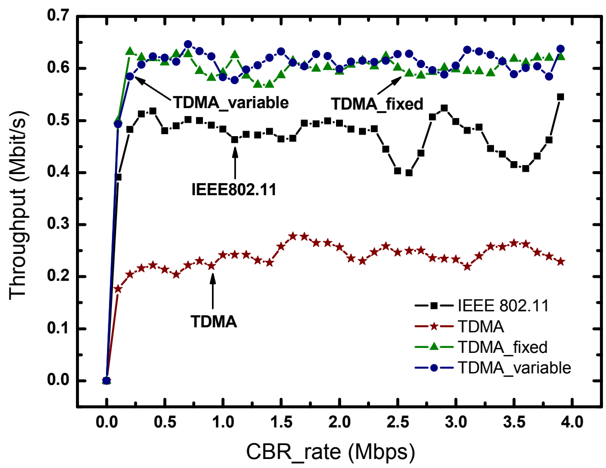

Fig. 10. Throughput simulation.

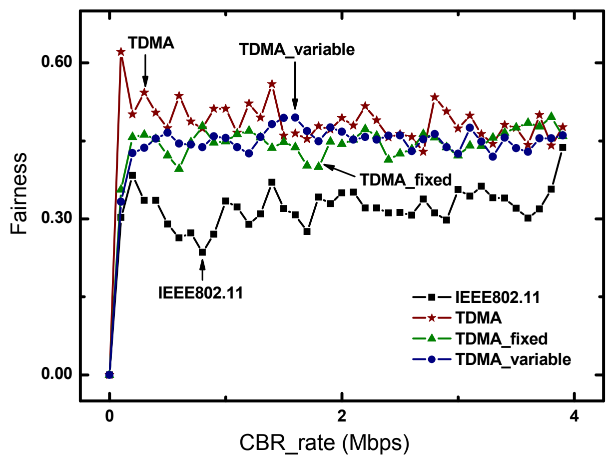

Fig. 12. Fairness simulation.

When the I-SAC algorithm was employed, the TDMA protocol with variable frame length and the TDMA protocol with fixed frame length obtained optimal performance. As the traffic load increased, the collisions between interaction information also increased, so the throughput performance with IEEE 802.11 was moderate [22, 23]. Without time slot multiplexing, the throughput of the traditional TDMA protocol was minimal.

As shown in Fig. 11, the average time delay in the network

Figure 12 compares the fairness using the four protocols. In the conventional TDMA protocol, each node had a time slot, and thus the fairness was optimal. The TDMA protocol with variable frame length and the TDMA protocol with fixed frame length included time slot multiplexing, so the fairness was poor. The IEEE 802.11 protocol employed a competition mechanism so it was impossible to assign a channel to each node in advance. Thus, as the traffic load increased, the collisions increased and the fairness decreased.

V. Conclusion

In this study, we proposed an I-SVC dynamic TSA algorithm based on the conventional colouring algorithm, which is suitable for adhoc networks. To address the practical engineering requirements, the protocol frame has a fixed frame length structure, including CCH, RCH, and TCH. According to the topology of the overall network, the time slots are dynamically allocated to the nodes. NS2 software was employed to simulate the performance of the proposed algorithm in terms of the throughput, average time delay, and fairness in three different scenarios. The experimental results demonstrated that the time slot utilisation rate was optimal with the I-SVC protocol, and it performed better than the IEEE 802.11 and TDMA protocols. In future research, we will improve the system convergence time and the random selection algorithm for the central station [24, 25].

References

[1] A. Sgora, D. J. Vergados, and D. D. Vergados, "A survey of tdma scheduling schemes in wireless multihop networks," *ACM Computing Surveys (CSUR)*, vol. 47, no. 3, p. 53, 2015.

[2] R. Jurdak, C. V. Lopes, and P. Baldi, "A survey, classification and comparative analysis of medium access control protocols for ad hoc networks," *IEEE Communications Surveys & Tutorials*, vol. 6, no. 1, 2004.

[3] C. Zhu and M. S. Corson, "A five-phase reservation protocol (fprp) for mobile ad hoc networks," *Wireless networks*, vol. 7, no. 4, pp. 371–384, 2001.

[4] J. Yeo, H. Lee, and S. Kim, "An efficient broadcast scheduling algorithm for tdma ad-hoc networks," *Computers & operations research*, vol. 29, no. 13, pp. 1793–1806, 2002.

[5] A. Nasipuri, J. Zhuang, and S. R. Das, "A multichannel csma mac protocol for multihop wireless networks," in *Wireless Communications and Networking Conference, 1999. WCNC. 1999 IEEE*, vol. 3. IEEE, 1999, pp. 1402–1406.

[6] Z. Yang and J. Garcia-Luna-Aceves, "Hop-reservation multiple access (hrma) for ad-hoc networks," in *INFOCOM'99. Eighteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*, vol. 1. IEEE, 1999, pp. 194–201.

[7] J. P. de Carvalho, H. Veiga, C. R. Pacheco, and A. Reis, "Extended research on performance of ieee 802.11 a, b, g laboratory wpa2 point-to-multipoint links," *Engineering Letters*, vol. 23, no. 1, pp. 8–13, 2015.

[8] R. Zhang, X. Cheng, L. Yang, X. Shen, and B. Jiao, "A novel centralized tdma-based scheduling protocol for vehicular networks," *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 1, pp. 411–416, 2015.

[9] A. Kanzaki, T. Uemukai, T. Hara, and S. Nishio, "Dynamic tdma slot assignment in ad hoc networks," in *Advanced Information Networking and Applications, 2003. AINA 2003. 17th International Conference on*. IEEE, 2003, pp. 330–335.

[10] W. Guo, L. Huang, L. Chen, H. Xu, and J. Xie, "An adaptive collision-free mac protocol based on tdma for inter-vehicular communication," in *Wireless Communications & Signal Processing (WCSP), 2012 International Conference on*. IEEE, 2012, pp. 1–6.

[11] C.-K. Park, M.-W. Ryu, and K.-H. Cho, "Survey of mac protocols for vehicular ad hoc networks," *SmartCR*, vol. 2, no. 4, pp. 286–295, 2012.

[12] H. Kang, Y.-n. Zhao, and F. Mei, "A graph coloring based tdma scheduling algorithm for wireless sensor networks," *Wireless personal communications*, vol. 72, no. 2, pp. 1005–1022, 2013.

[13] M. Hadded, P. Muhlethaler, A. Laouiti, R. Zagrouba, and L. A. Saidane, "Tdma-based mac protocols for vehicular ad hoc networks: a survey, qualitative analysis, and open research issues," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2461–2492, 2015.

[14] I. Rhee, A. Warrier, J. Min, and L. Xu, "Drand: Distributed randomized tdma scheduling for wireless ad hoc networks," *IEEE Transactions on Mobile Computing*, vol. 8, no. 10, pp. 1384–1396, 2009.

[15] T. Yin, Y. Wang, M. Zhao, and J. Xiao, "A modified dynamic tdma slot allocation algorithm in ad hoc network," in *Computer Communication and the Internet (ICCCI), 2016 IEEE International Conference on*. IEEE, 2016, pp. 124–128.

[16] J. Yeo, H. Lee, and S. Kim, "An efficient broadcast scheduling algorithm for tdma ad-hoc networks," *Computers & operations research*, vol. 29, no. 13, pp. 1793–1806, 2002.

[17] H. J. Ning, "Vertex coloring model and algorithm research of computer distribution," in *Intelligent Systems Design and Engineering Applications (ISDEA), 2014 Fifth International Conference on*. IEEE, 2014, pp. 1113–1116.

[18] G. Kim, S. S. Kim, I.-H. Kim, D. H. Kim, V. Mani, and J.-K. Moon, "An efficient simulated annealing with a valid solution mechanism for tdma brodcast scheduling problem," *International Journal of innovative Computing Information and Control*, vol. 7, no. 3, pp. 1181–1191, 2011.

[19] G. Wang and N. Ansari, "Optimal broadcast scheduling in packet radio networks using mean field annealing," *IEEE Journal on selected areas in Communications*, vol. 15, no. 2, pp. 250–260, 1997.

[20] T. Issariyakul and E. Hossain, *Introduction to network simulator NS2*. Springer Science & Business Media, 2011.

[21] D. J. Vergados, A. Sgora, D. D. Vergados, D. Vouyioukas, and I. Anagnostopoulos, "Fair tdma scheduling in wireless multihop networks," *Telecommunication Systems*, vol. 50, no. 3, pp. 181–198, 2012.

[22] F. Alassery and W. K. Ahmed, "Toward energy efficient wireless sensor networks using pilot periods for collision detection." *Engineering Letters*, vol. 24, no. 1, pp. 113–124, 2016.

[23] F. Alassery, W. K. Ahmed, M. Sarraf, and V. Lawrence, "A low computational complexity statistical discrimination algorithm for collision detection in wireless sensor networks," *IAENG International Journal of Computer Science*, vol. 41, no. 3, pp. 204–211, 2014.

[24] N. Vattikuti, H. Sindhwal, M. Dasari, and B. R. Tam-

ma, “Delay sensitive tdma slot assignment in ad hoc wireless networks,” in *Communications (NCC), 2015 Twenty First National Conference on*. IEEE, 2015, pp. 1–5.

[25] C. Röhrig, C. Kirsch, J. Lategahn, M. Müller, and L. Telle, “Localization of autonomous mobile robots in a cellular transport system.” *Engineering Letters*, vol. 20, no. 2, pp. 148–158, 2012.

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