A Fair TDMA Scheduling Based on Weight of Flows

Xiaoying Shuai

1 College of Computer Science and Technology, Taizhou University, Taizhou, China

E-mail: xyshuai@163.com

Abstract. Nodes in wireless ad hoc networks transmit data to 1-hop neighbour nodes through broadcast channel. Conflicts occur when multiple nodes within the communication range send data at the same time or when one node receives data sent by multiple nodes at the same time. For broadcast scheduling problem (BSP), many researchers used TDMA (Time Division Multiple Access) scheme based on SVC (Sequential Vertex Colouring) in ad hoc networks to achieve conflict-free scheduling. However, SVC is related to the order of nodes. To improve the fairness of network, the slots of nodes are adjusted by changing the order of nodes. In this paper, we proposed a fair scheduling algorithm for TDMA, which takes into account the number of flows, the size of the flows and the bandwidth of each node. The simulation and analysis results show that this scheduling algorithm can enhance the fairness of the ad hoc compared with the traditional algorithm based on SVC.

1. Introduction

Wireless ad hoc is temporary dynamic topology structure using shared wireless channel to interconnect many nodes, and it don’t rely on any fixed network infrastructure. Nodes can transmit directly with 1-hop neighbors. When a target node is located far away, a sequence of intermediate nodes will store and forward packets to the destination. Since nodes share broadcast channel, collision will emerge when a node transmits with its 1-hop or 2-hop neighbors simultaneously, as shown by figure1.

Figure 1. Collision in ad hoc.

To collision-free broadcast schedules, TDMA is widely used in ad hoc. BSP is referred as the TDMA scheduling problem to minimize time slots of a frame [1]. BSP to schedule at least one slot for each node and maximize the throughput in an ad hoc is a NP-complete problem. For BSP, papers [2][3] proposed many TDMA schemes. The result of scheduling is related to the order of nodes. Therefore, different order will result in different slots of nodes, which will lead to fairness in ad hoc.
2. Related work

2.1 SVC algorithm

Vertex coloring method is efficient algorithm to deal with BSP [4]. An undirected graph is represented as \( G = (V, E) \). Nodes \( u, v \in V \) are 1-hop neighbors, then undirected edge \( e = (u, v) \in E \). If vertex \( u \) is assigned color \( C_u \), vertex \( v \) is \( C_v \), then \( C_u \neq C_v \). The slots schedule in TDMA is considered as vertex color allocation. So, ad hoc achieves high channel utilization without collision. SVC orders node by specified criterion.

SVC algorithm

Order nodes as 1, 2, ..., \( N \)

Color \( i = 1 \);

Repeat

For vertex \( = 1 \) to \( N \) do

If vertex can color with \( i \) then color

Color \( i++ \)

Until all vertices colored

An efficient algorithm for BSP based on SVC is proposed in paper3. VCP (Vertex Coloring Problem) is NP-hard. The algorithm includes two phases. The first phase assigned only one slot to a node to minimize the frame length. To maximize the total number of slots in a frame, the algorithm in the phase 2 allocated an exist available slot to other nodes that are not 1-hop and 2-hop neighbors. This algorithm has the property of greedy selection, the fairness of which is related to the order of nodes. Aggeliki Sgora et al. [5][6] proposed fair TDMA scheduling based on the active flows in ad hoc networks.

2.2 Model

\( G = (V, E) \) represents an ad hoc. If nodes can hear each other, we consider they are 1-hop neighbor. The connectivity table \( A_{nm} \) as follow, where \( n \) represents the number of nodes.

\[
A_{ij} = \begin{cases} 
1 & \text{if node } i \text{ and } j \text{ can communicate directly} \\
0 & \text{otherwise} 
\end{cases} \quad (1)
\]

If a common neighbor of node \( i \) and \( j \) is node \( k \) is, then \( A_{ik} = A_{kj} = 1 \). And if \( A_{ij} = 0 \), 2-hop neighbor of node \( i \) is node \( j \). The matrix \( B_{nm} \) as follow:

\[
B_{ij} = \begin{cases} 
1 & \text{if node } i \text{ and } j \text{ have a common neighbor} \\
0 & \text{otherwise} 
\end{cases} \quad (2)
\]

The compatibility matrix \( D_{nm} \) as follow:

\[
D_{ij} = A_{ij} \cdot V \cdot B_{ij} = \begin{cases} 
1 & \text{if node } i \text{ and } j \text{ are within 2 hops} \\
0 & \text{otherwise} 
\end{cases} \quad (3)
\]

Let \( S \) represent the slots of per frame. Let \( s : S \times N \rightarrow \{0,1\} \) to express a transmission schedule, is defined by

\[
s_{ij} = \begin{cases} 
1 & \text{if slot } i \text{ assigned to node } j \\
0 & \text{otherwise} 
\end{cases} \quad (4)
\]

So, TDMA scheduling in ad hoc can be formulated as multi-objective optimization problem [7]. Minimize \( S \)
\[ \text{Maximize } \sum_{i=1}^{S} \sum_{j=1}^{N} S_{i,j} \quad (5) \]

Subject to:
\[ \sum_{i=1}^{S} S_{i,j} \geq 1 \quad i = 1, 2, \ldots, S \quad (6) \]
\[ \sum_{i=1}^{S} \sum_{j=1}^{N} \sum_{k=1,k\neq j}^{N} S_{i,j}d_{jk}S_{i,k} = 0 \quad (7) \]

Equation (6) shows each node must broadcast at least once. Equation (7) prevents collisions, means that nodes within 1-hop or 2-hop can’t transmit in the same slot.

3. TDMA scheduling based on weight of flows

A new TDMA scheduling scheme is proposed to improve fairness. Different bandwidth or size of the flow will lead to the actual data transmission time of the node is different. The node has lager number of flows or data will give priority to more slots. Nodes are ordered according to three parameters: the number of flows, the size of each flow and bandwidth of a node. Firstly, the weight of the flow at the nodes are calculated based on these three parameters. Then, the nodes are sorted according to the weights to minimize the frame length. Finally, maximize the total number of slots in a frame.

3.1 Weight of flows

Let \( F_{ij} \) represent the weight of the flow \( j \) in node \( i \).
\[ F_{ij} = \begin{cases} \frac{sf_{ij}}{(BW_i \times tslot)} + 1 & \text{if } sf_{ij} > 0 \\ 0 & \text{otherwise} \end{cases} \quad (8) \]

Where \( sf_{ij} \) is the size of \( F_{ij} \), \( BW_i \) represent the bandwidth of node \( i \), \( tslot \) is unit time of the slot. Weight vector \( W \) is follow, where \( T \) is the number of flow in the node \( i \).
\[ W_j = \sum_{j=1}^{T} F_{ij} \quad (9) \]

3.2. Minimize frame length

This stage minimizes the frame length and ensures that each node with data has at least one slot. First, the nodes are ordered by descending according to the weights. Then, an available slot is searched to assign to each node until all nodes are allocated.

Algorithm minimize frame length as follow

- Compute \( W \);
- Sort node by \( W_j \);
- Different slots \( (m1) \) are allocated to the first node and its 1-hop neighbors;
- \( i=1, j=m1+1, S=m1 \);
- While \( (j \leq N) \) //the remaining nodes
  - If \( W_j \neq 0 \)
    - If slot \( i \) can be allocated to node \( j \)
      - Then \( sij=1, j++, i=1; \)
    - Else \( i++ \);
  - Else \( j++ \);
  - If \( i > S \) then \( S=i; \)

3.3 Maximize throughput

In this stage, a slot is allocated to as many collision-free nodes as possible to maximize channel utilization. Because the scheduling scheme is related to the order of nodes, the phase 2 sorts the nodes
by the weights. It is possible for those nodes that need more slots to get more slots. The algorithm improves the fairness of the system.

Algorithm maximize throughput as follow

Sort node by $W_j$;

$j=1$;

While ($j \leq N$)

If $W_j \neq 0$

$i=1$;

While ($i \leq S$)

If slot $i$ can be assigned to node $j$

Then $s_{ij}=1$;

$i++$;

$j++$;

4. Simulation

A simulation C program has been created to compute and analyze the fairness of my algorithm. By simulations and analysis, we compared our algorithm with the algorithm in paper [3][5]. The simulation network topology of 15 nodes is introduced by Wang and Ansari, shown in figure2 [8]. The bandwidth of each node in the ad hoc can randomly select the following data: 1M,2M,5M,10M, etc. Nodes randomly produce several flows and the size of each flow.

Figure 2. Topology of 15-nodes network.

4.1 Fairness index

The fairness is a key factor in ad hoc. Unfair channel allocation may lead to starvation, waste of resources and others, thus reducing channel utilization. Therefore, many researchers have studied how to alleviate the unfairness in ad hoc [9][10]. The proposed algorithm hopes to provide TDMA scheduling in a fair way. Consider not only the number of actual flows in the ad hoc, but also the length of each flow. To measure fairness, the Jain’s Fairness Index [11] was adopted in this paper, defined as:

$$f(x) = \frac{\left( \sum_{i=1}^{n} x_i \right)^2}{n \sum_{i=1}^{n} x_i^2}$$

(10)

Where $x_i$ represents the amount of slots allocated to node $i$, $n$ is the number of nodes.

4.2 Result analysis

After more than 100 simulations, the average simulation result shows that the proposed scheduling algorithm surpassed the algorithm ordered only by the number of neighbor nodes or by flows in fairness. The result is shown as figure3.
5. Summary
An ad hoc network is a self-organizing and dynamic topology wireless network without infrastructure. Nodes in the communication range transmit data through broadcast channel. To achieve collision-free scheduling, TDMA is widely used in ad hoc. BSP on TDMA ad hoc networks is a multi-objective optimization problem, that is, the shortest frame length, maximizing channel utilization. TDMA based on SVC is closely related to order of nodes. This paper proposed a fair scheduling algorithm for TDMA, which calculated the weights of each node's flow. Then the nodes are ordered according to its weight. The algorithm improves the fairness of ad hoc network.

The time complexity of my algorithm is \( O(n^3) \). In the future, we will enhance the performance of the scheduling algorithm in the following: reduce computation time and optimize slot allocation.

Acknowledgement
This research was supported by the Taizhou University Foundation for the Talents (QD2016035).

References
[1] Clayton W. Commander and Panos M. Pardalos 2009 A combinatorial algorithm for the TDMA message scheduling problem *Computational Optimization and Applications* 43 p 449
[2] A. Ephremides and T. V. Truong 1990 Scheduling broadcast in multi-hop radio networks *IEEE Transactions on Communications* 38 p 456
[3] Jaehyun Yeo, Heesoo Lee and Sehun Kim 2002 An efficient broadcast scheduling algorithm for TDMA ad-hoc networks *Computers & Operations Research* 29 p 1793
[4] Ernico Malaguti and Paolo Toth 2009 A survey on vertex coloring problems *International Transactions in Operational* 17 p 1
[5] Aggeliki Sgora, Dimitrios J. Vergados and Dimitrios D. Vergados 2007 Efficient Fair TDMA Scheduling in Wireless Multi-Hop Networks *Proceedings of the 4th IFIP International Conference on Artificial Intelligence Applications and Innovations* (USA) 247 p 279
[6] Dimitrios J. Vergados, Aggeliki Sgora and Dimitrios D. Vergados et al 2010 Fair TDMA scheduling in wireless multihop networks *Telecommunication Systems* 30 p 1
[7] Clayton W. Commander 2007 *Broadcast Scheduling Problem* (Boston: Springer Press)
[8] Gangsheng Wang and Nirwan Ansari 1997 Optimal broadcast scheduling in packet radio networks using mean field annealing *IEEE Journal on Selected Areas in Communications* 15 p 250
[9] Jun He and Hung Keng Pung Fairness of medium access control protocols for multi-hop ad hoc wireless networks *Computer networks* 48 p 867
[10] Huazhou SHI, R. Venkatesha Prasad and Ertan Onur et al 2014 Fairness in Wireless Networks Issues, Measures and Challenges *IEEE Communications Surveys & Tutorials* 16 p 5
[11] Jain Raj 1991 *The art of computer systems performance analysis: techniques for experimental design, measurement, simulation, and modeling* (New York: John Wiley & Sons Inc)