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Fair Scheduling for the Optimal Link of Ad hoc Network Based on Graph Theory

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Abstract: Using a wireless multi-hop networks multi-link transmission to improve the system throughput, consider the priorities and fairness of the link scheduling optimization model and propose a fair scheduling for the optimal link, then design a link optimal fair scheduling algorithm based on graph theory. The mathematical model is based on links conflict, use node back- off time multi bandwidth to maximize the objective function, by solving the optimal solution of the model get the largest set of solution space, that is the best link scheduling strategy. Then according to the strategy with graph theory, designed a fair scheduling algorithm for the wireless multi-hop network link. The simulation proved that the algorithm is the link in ensuring fairness, at the same time, compared to existing algorithms it can get more than 10% system capacity gain.

Key words: Ad hoc networks, link transmission, fairness, graph theory

INTRODUCTION

Channel access has been proposed in the cellular network research. The information theory has proved that, the base station schedules the uses who have the best channel condition at every moment, then the system will acquire the maximum channel capacity (Ket and Awale, 2011; Cai *et al*., 2003). The channel access is located at the bottom of the protocol stack in the wireless multi-hop network, it controls the nodes access the wireless channel at the right time and it also controls the message sent and received in the channel (Wang *et al*., 2010).

Hung and Marsic (2010) has used the RTS-CTS control messages to solve the network hidden terminal and exposed terminal problems, the core idea of this channel access protocol is: the sender and receiver have taken the handshake by using RTS-CTS control messages before sending the first data packets, the main purpose is to inform the receiver ready to receive the data. Based on this, Lai *et al*. (2011) has improved the corresponding channel access algorithm and reduced the cost of measuring channel. However, the above algorithms do not consider the mutual interference between nodes, they are unable to obtain the optimal system performance. Meanwhile, some algorithms (Gong *et al*., 2007; Huang *et al*., 2011) can improve the network performance under the situation that there has one sender node and multiple receiver nodes, it can not use the multilink diversity that existing multiple competition but has no one common sending link.

In general way, the different competitive level nodes in the Ad Hoc network need to be considered, because the nodes distribution is random, it makes some part nodes in the network carrying large traffic load, in order to reduce the congestion influence on the Ad hoc network performance, the routing nodes access level can be increased, so that the routing nodes will transmit the received packet as soon as possible. Yoo *et al*. (2010) and Akyol *et al*. (2009) has considered the nodes conflict in the link scheduling process but it makes the nodes who win in the channel competition will have a greater advantage, so the other nodes will be starved to death because they can't grab the channel, this method can't guarantee the links fairness.

Present study considers the links priority relationship and the system fairness requirement, establishes a wireless multi-hop network link scheduling model, solves it and then to design a fair scheduling algorithm for the optimal link.

SYSTEM MODEL

In the one-hop network, we consider the routing select problem between senders (I) and receivers (J), as

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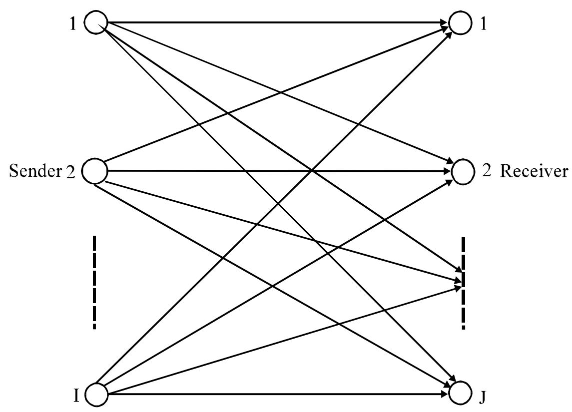

Fig. 1: Graph model

shown in Fig. 1. The time-delay and bandwidth constraints of each node are considered, they are used as the weights of edges in the graph, we should determine an optimal routing algorithm. Here in order to analyze conveniently, a precondition for load balancing is supposed. For the load imbalance problems, setting virtual senders and virtual receivers are used and the original problem can be changed into balance model, then we could solve it.

Assumption N = I+J-1 network links (S_i, i∈N) are already selected which reference (Chen *et al*., 2004) has researched. Channel access protocol is used, let's define the maximum transmission rate of link i at time slot t is r_i (t).

The message collision problems which caused by hidden terminal and exposed terminal can be expressed by the conflict graph, as follows:

Definition 1: We import the conflict limit function conflict (i, j, t), equals to 1 means link i and link j have conflicted with each other at time slot t, otherwise equals to 0:

$$\text{conflict}(i,j,t)=\begin{cases}1 & \text{if clash}\\ 0 & \text{else}\end{cases} \tag{1}$$

The timeline is colored to mark the conflict and non-conflict time slots, so it constitutes the solution space, the messages are not conflicted in the solution space, they can transmit, i.e., there is no direct connection edge between any two vertices in the graph theory.

In order to improve the system throughput, our objective is to find the largest set of solution space (Maximum Solution Space, MSS), make the link scheduling optimal. It is the largest link collection on timeline.

Before definition 2, we import L (t) is the link collection at time t. Because it is the set of solution space at a certain moment on the timeline, therefore it is the subset of MSS, L (t)∈(MSS).

Definition 2:

$$I_x=\begin{cases}1 & \text{if true}\\ 0 & \text{else}\end{cases} \tag{2}$$

We import the symbolic function, equals to 1 means constraint condition is true, otherwise equals to 0. Here the constraint condition means those time slots which content conflict (i, j, t) = 0 in the link collection L (t) at time t, i.e., time slots which messages are not conflicted.

Definition 3: Import R_{it} is the average throughput of link i at time t.

$$R_i(t+1)=\frac{t_c-1}{t_c}R_i(t)+\frac{1}{t_c}r_i(t)I_{i\in L(t)} \tag{3}$$

where, t_c means the size of average statistical window. R_i (t)、I_x、L (t) have been defined.

The messages conflict and the fairness of channel access are both considered, we import the backoff algorithm (MILD) .

$$\text{MILD}=\begin{cases}\min(\alpha\times\text{COUNTER},\max)\\ \max(\text{COUNTER}-\beta,\min)\end{cases} \tag{4}$$

α and β can be set according to different applications. COUNTER is the value of backoff counter, max, min are, respectively the maximum and minimum values of backoff counter and they have the same meaning, this formula is expressed as: In order to avoid messages conflict, a timer is set in each node, when the timer countdown is completed, then the messages are re-sent, because each node's MILD values are different, so the conflict problem can be resolved.

After import the backoff algorithm, so long as we set the suitable α, β values, then the system fairness could be guaranteed to some extent.

Finally, we give the objective function F (x) for solving and make the objective function value minimal, i.e., solve minF (x). The link scheduling is optimized and the fairness between nodes is guaranteed.

$$\min F(R_j)=\sum_{i\in N}\sum_{j\in N}\text{MILD}_i\times R_j \tag{5}$$

s.t. conflict (i, j, t) = 0 ∀I, j∈L (t), i≠j

From the graph theory, we can know that solving the minimum of F (x) is the optimal path solution, this is a linear optimization problem. The resulting path is like this: The fair factor and system throughput are both get the optimal.

OPTIMAL STRATEGY AND GRAPH THEORY ANALYSIS

Solving Eq. 5's optimal solution to get the optimal link scheduling strategy.

Theorem 1: When statistics window $t_c \to \infty$, the system optimal solution content:

$$L^*(t) = S_{m^*}(t) \tag{6}$$

Where:

$$m^* = \underset{m}{\arg\max} \sum_{i \in N} MILD_i$$

Proof: First, we proof by contradiction, when $t_c \to \infty$, for any time t, the following equation can be set up:

$$\sum_{i \in N} F(R_i^*(t)) \geq \sum_{i \in N} F(R_i(t)) \tag{7}$$

i.e.:

$$\sum_{i \in N} MILD_i \sum_{j \in N} R_j^*(t) \geq \sum_{i \in N} MILD_i \sum_{j \in N} R_j(t) \tag{8}$$

where, $R_j^*(t)$ is the optimal link bandwidth and $R_j(t)$ is the bandwidth of the link scheduling at any time. Meanwhile, the optimal solution should content that the MMS is always called, i.e., $L^*(t)\ S_{m^*}(t)$.

Now, we establish another scheduling $L^{\hbar}$ which content $L^{\hbar}(\tau) = S_{m^{\hbar}}(\tau)$, $\forall \tau < t$ and $L^{\hbar}(t) = S_{m^{\hbar}}(t)$ ($S_{m^{\hbar}}(t)$ is an arbitrary value of MSS). From Eq. 8, there has:

$$\sum_{i \in S_{m^*}(t) \cup i \in S_{m^{\hbar}}(t)} MILD_i \sum_{i \in S_{m^*}(t) \cup i \in S_{m^{\hbar}}(t)} R_j^*(t+1) \geq \sum_{i \in S_{m^*}(t) \cup i \in S_{m^{\hbar}}(t)} MILD_i \sum_{i \in S_{m^*}(t) \cup i \in S_{m^{\hbar}}(t)} R_j^{\hbar}(t) \tag{9}$$

where, $R_j^{\hbar}$ is the bandwidth when scheduling $L^{\hbar}$ is happened.

We use first-order Taylor expansion to $R_j^*(t+1)$, due to $t_c \to \infty$, then (constant terms are divided out):

$$R_j^*(t+1) = R_j^*(t) + (R_j^*(t+1))' \cdot \frac{r_j(t)}{t_c} + o\left(\frac{r_j(t)}{t_c}\right) \tag{10}$$

where, $o\left(\frac{r_j(t)}{t_c}\right)$ means first order infinitesimal of $\frac{r_j(t)}{t_c}$. The two sides of equal sign in Eq. 9 add:

$$\sum_{i \in S_{m^*}(t) \cap i \in S_{m^{\hbar}}(t)} MILD_i \sum_{i \in S_{m^*}(t) \cap i \in S_{m^{\hbar}}(t)} R_j^*(t)$$

then:

$$\sum_{i \in S_{m^*}(t)} F'(R_j^*(t)) \frac{r_j(t)}{t_c} \geq \sum_{i \in S_{m^{\hbar}}(t)} F'(R_j^{\hbar}(t)) \frac{r_j(t)}{t_c} \tag{11}$$

Proof over.

In practical situations, we generally use a larger measurement window t_c, so the Theorem 1 is consistent with the optimal link scheduling program. Now, we use the values $MILD_i$ ($i \in N$) which obtained by backoff algorithm, as the weight of link i, then the optimal scheduling program is one maximum solution space at any time and the weight values are largest in the maximum solution space. This is a NP hard problem in Mathematical, in order to find the approximate optimal solution, graph theory provides some algorithms, here we use the Linear Programming Algorithm which based on "punishment" by Lu and Hua-ming (2009) and Zhou (2009). First, by:

$$MILD = \begin{cases} \min(\alpha \times COUNTER, max) \\ \max(COUNTER - \beta, min) \end{cases} \tag{12}$$

We maintain the counter of each node, the calculated result is the node's weight, then calculate the node's weighted degree at a certain moment t. The calculation is as follows:

$$w_i = |MILD_{is} - MILD_{is'}| \tag{13}$$

Where:

$$MILD_{is} = \min_j \{MILD_{ij}\}, MILD_{is'} = \min_{j \neq s} \{MILD_{ij}\} \tag{14}$$

In all neighbor nodes of vertex w, the D-value of two smallest counter is the "penalty value". Then according to the following steps to find MSS:

Step 1: Calculate each node's "penalty value" and find the largest "penalty value" node

Step 2: Use the optimal link scheduling strategy to calculate the initial feasible solution and put the resulting vertices into the solution space L, then delete all the neighbors of this vertex in the original graph

Step 3: Repeat the above process, until the original graph is empty, The resulting solution space is the suboptimal largest solution

FAIR SCHEDULING FOR THE OPTIMAL LINK

Ad Hoc network has not a central base station, the optimal strategy formula (Eq. 6) is generally difficult to realize. Based on the theory of above "punishment" algorithm and Eq. 6, present study presents the Fair Scheduling for the Optimal Link (FSOL) algorithm. The core idea of this algorithm is: take the backoff algorithm of node's counter as the node's weight and take the node's bandwidth as the parameter of Eq. 6 to calculate the optimal link scheduling model. This can guarantee the optimization and fairness of channel access.

Step 1: According to the "punishment" linear programming algorithm on the definition of weighted degree, every node should maintain a level value table. The level value table records the weight values of node and neighbor nodes. In Ad Hoc network, because the node generally only know the other node's situation within nod-hop range, so each node interact the level value table with other nodes in nod-hop range and the nodes can calculate their own weighted values. The specific algorithm is shown in Fig. 2

Where the sender and receiver nodes are, respectively load their level value table on the DATA, CTS and BI messages and the nodes can interact the level value table with other nodes in nod-hop range, here the cost of loading level value table can be ignored.

Step 2: Fair scheduling for the optimal link. According to the above calculation, we select the maximum "penalty value" node, that is the first link which have the priority to be selected

Step 3: After the nodes complete a series data sending, the channels use multiple increase, linear decrease (MILD) algorithm to realize backoff, the channels are no longer involved in competitive for a period time, then the algorithm end

SIMULATION RESULTS AND ANALYSIS

Random distribution scenario: In order to validate this paper's algorithm FSOL (Fair Scheduling for the Optimal Link) effectiveness, we build up the simulation experiments to verify the analysis. We use NS-2 and the CMU (Carnegie Mellon University) which providing the wireless expansion modules to simulate. Simulation uses NS-2 modules to generate the node, the mobile nodes are average distributed in 2000×2000 m area. We set the link available bandwidth average distributed from 1~10 Mbps Link transmission rate is set to 1 Mb sec^{-1} according to IEEE 802. 11 b standard, then according to the dual-path model, we calculate the node's carrier wave monitor distance is 1.78 km, the average transmission distance is 0.80 km. And the Rice fading channel model is used. As compare with this studies algorithm, we use the OSAR (Wang *et al*., 2004) algorithm.

First, we take the system throughput performance analysis and compare the results. They are divided into the following two situations:

- **Situation one:** Each sender node only corresponds to one receiver node. That means the signals which transmitted from the sender only send to one node receiving. Figure 3 shows the system throughput

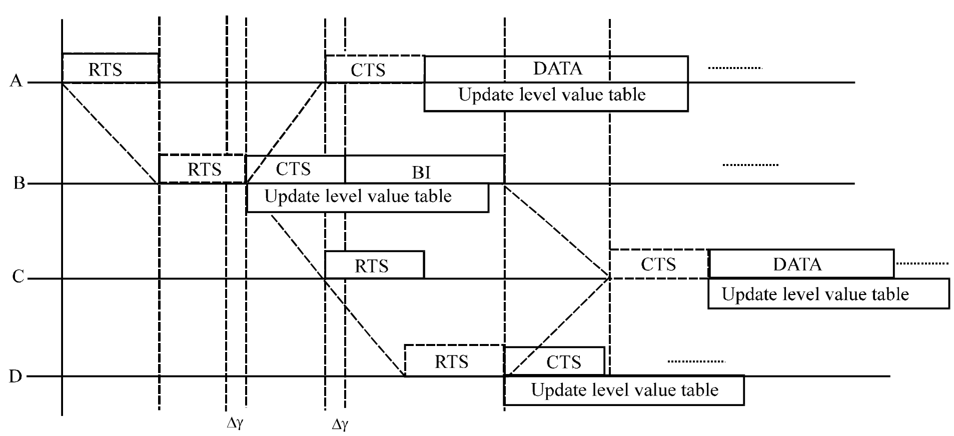

Fig. 2: Time sequence diagram of calculating bandwidth

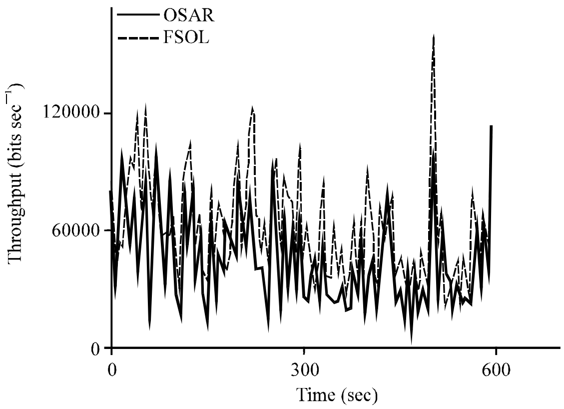

Fig. 3: System throughput

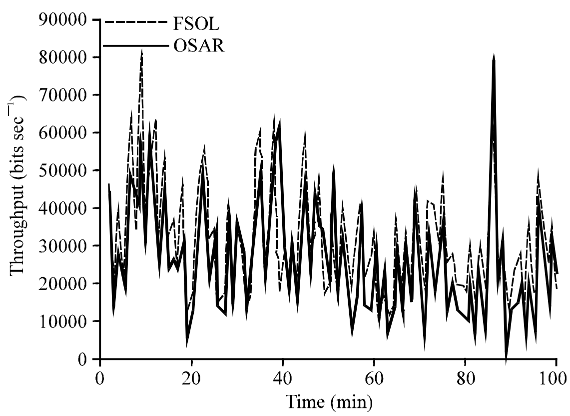

Fig. 4: System throughput

curves with the link number changes in this scenario. Present studies algorithm is better than OSAR and the capacity gain can get more than 20%. With the link number increasing, the system capacity will also increase, this is because the link diversity is gradually increasing and the OSAR algorithm can not use the multi-link diversity

- **Situation two:** Each sender node corresponds to multi receiver nodes. This means the signals which transmitted from the sender should send to many nodes receiving and the result is shown in Fig. 4. Because the FSOL algorithm fully consider the priority of scheduling link and the node's fairness and it can make use of multi-user diversity, so the FSOL algorithm improve the system throughput further. Meanwhile, FSOL is better than OSAR on the system throughput performance as can be seen in Fig. 4

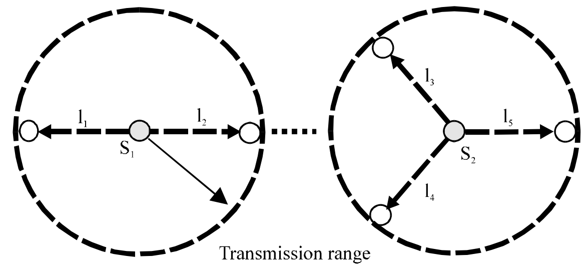

Fig. 5: Two sending nodes scenario

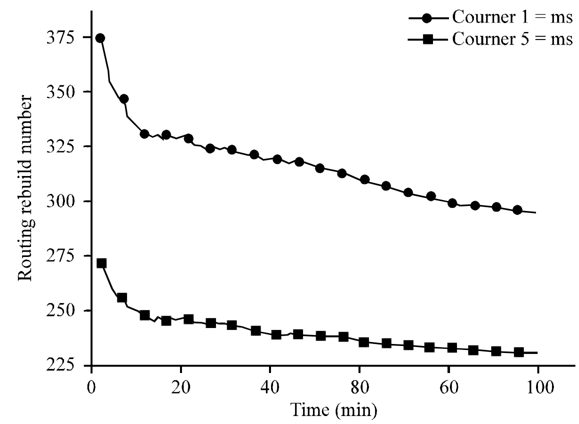

Fig. 6: Routing rebuild number

Two sending nodes scenario: Now we simulate a two sending nodes scenario (as shown in Fig. 5). The simulation parameters are the same with fair scheduling for optimal link, the distance of each link is 500 m, the distance of two sending nodes (S_1, S_2) is 2 km which is longer than the carrier wave monitor distance. The conflict relation of links (l_1, l_2, l_3, l_4, l_5) can be obtained by chapter 1. Now, we set different counter to compare the routing rebuild number, order COUNTER1 = 1 ms, COUNTER2 = 5 ms, then according to the above sections analysis, we get the routing rebuild number under these two counters, as shown in Fig. 6.

As can be seen from Fig. 6, Present study has reduced the link's end-to-end rebuild number, effectively and it reduces the cost of establishing paths. According to the different counter values in nodes, the MSS will be different when select the links and the small counter value, the more routing rebuild numbers. Meanwhile, the routing rebuild number will be decreased with the time increasing, in this way, the establishing paths will be stable. This result also shows that the link outage probability is very small.

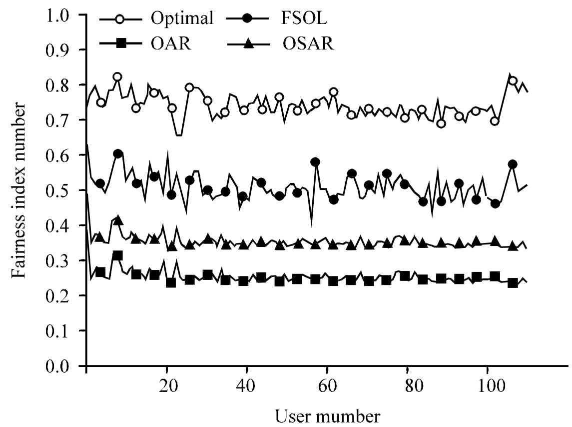

Fig. 7: Fairness index number

Fairness comparison: Here, we take the system fairness index number as the criterion to simulate, the simulate parameters are the same the difference is: compare with this paper's FSOL algorithm, the OAR (Consider the rate adaptive protocol of IEEE802.11b) algorithm is added in and the optimal link scheduling algorithm is added. Link transmission rate can be set according to IEEE802.11b. The final simulation result is shown in Fig. 7.

From Fig. 7, we can see that the algorithms comparison on system fairness performance. depending on the proportional fair algorithm, we can get the system normalized throughput, i.e.,: R_i/R^*_i, where R^*_i is the link bandwidth, R_i is the node's using bandwidth in system. Then the system fairness proportional factor can be defined as:

$$\text{fairness} = \frac{1}{N}\sum_{i=1}^{N} R_i / R_i^* \quad (15)$$

According to this equation, we can get the fairness index number comparison of each algorithm. Because the backoff algorithm is imported, if the values of α β are suitable selected, the nodes will be allocated appropriate bandwidth when they take part in the channel competition, so this study has greatly improved in the node's fairness of accessing channel and it is mostly close to the optimal algorithm, however, this algorithm will sacrifice some link rate. Compare with the other two algorithms because they are take the rate self-adaption (OAR) and link bandwidth (OSAR) as the main criterion, therefore, the OAR and OSAR algorithms are not as good as this studies in the system fairness and the performance of these two algorithms have little difference.

CONCLUSION

Aim at the channel access problem of multi-hop network, present study establishes the model on priority link scheduling and fairness, then a maximum solution space can be obtained through solving this model, based on this theory analysis, we get an optimal link scheduling model. After that, based on the graph theory, the Fair Scheduling for the Optimal Link (FSOL) algorithm is present which is suitable for the wireless multi-hop network environment. Compare with some existing link scheduling programs, this studies algorithm has improved the system throughput further and has a higher fairness.

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