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A Distributed Channel Allocation Algorithm for Multi-channel Wireless Networks

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Abstract: Multi-channel can increase the network throughput but require new algorithm to allocate channels. This study proposed a new distributed channel allocation algorithm which utilizes multi-channel to improve network performances, such as network throughput, end to end delay. The algorithm is based on contention graph and adopts contention factor to evaluate conflicts in a channel. In a local contention graph, the link with maximal degree is assigned to channel with minimal contention factor. Simulation results show that the proposed algorithm improves the network throughput and end to end delay. Especially, with the increase of network load, the improvement increases significantly.

Key words: Channel allocation, multi-channel, wireless networks, contention graph, contention factor

INTRODUCTION

In recent years, with the vast growth in wireless applications, how to increase network capacity for higher data rate becomes an important problem. Multi-channel wireless networks have been identified as an effective way to enhance network capacity (Raniwala and Chiueh, 2005; Mo *et al*., 2008).

Currently, most of commercial wireless networks work with a single-channel but the protocols of physical layer provides multi-channel capability. The IEEE 802.11b protocol (IEEE Working Group, 1999) for Wireless Local Area Networks (WLAN) has 14 channels available in 2.4 GHz band and three of them can be used simultaneously without overlapping. The IEEE 802.15.4 protocol (IEEE Working Group, 2003) for low-power Wireless Personal Area Networks (WPAN) allows 16 non-overlapping channels in 2.4 GHz band. Although, these physical layer protocols provide multiple channels to use but in reality the suggested MAC protocols are designed for single channel without considering how to allocate multiple channels to a node.

In the existing literatures, there are many researches about channel allocation for wireless networks (Hoi-Sheung *et al*., 2007; Jha *et al*., 2011; Jiang *et al*., 2009; Merlin *et al*., 2008; Zhang *et al*., 2011). The current multi-channel allocation algorithms can be classified into two categories according to the number of wireless Network Interface Card (NIC). One is single-radio multi-channel algorithms; the other is multi-radio multi-channel algorithms. The single-radio multi-channel algorithms assume that each node only has one NIC and therefore the hardware of node is simple but the design of algorithms is complex. One example is the distributed game based channel allocation algorithm (GBCA) (Chen *et al*., 2011). With this algorithm, each node is only equipped with one half-duplex radio transceiver. The algorithm is comprised by an interfering parent discovery phase and a channel negotiation phase. In the first phase, all nodes broadcast to obtain the information used to calculate the payoff. In the second phase, each node selects channel by iteration calculation. In these two phases the communications use designated channel. GBCA needs time synchronization which is still hard for multi-hop networks. Multi-radio multi-channel algorithms assume that each node has several NICs. Generally, one NIC works on a designated control channel and the others work on data channel. One example is joint channel assignment and routing protocol (J-CAR) (Chiu *et al*., 2009). With J-CAR, the data channels are allocated by selecting the least interfered channel according to the channel interference index.

In this study, a distributed channel allocation algorithm is proposed to avoid conflicts between nodes. The nodes can work with single-radio or multi-radio. With this algorithm, the central control nodes are not needed and the nodes exchange information locally.

SYSTEM MODEL

Consider a multi-channel wireless network with n nodes. Each node is provided with m (m = 1) half duplex NICs. Assume there are C channels available. At any time, each NIC can work on one of C channels. A graph G = (V, E) is used to describe the wireless network, where V represents the set of nodes and E represents the set of

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directed links. Each link is directional and bidirectional links can be represented by two directional links. Assume the rate of every link is same. With protocol model presented by Gupta and Kumar (2000), a packet can be received successfully when:

- The distance between transmitter and receiver of this packet is not exceed the transmission range R
- The receiver is located outside (1+Δ)R of any other transmitters transmitting simultaneously over the same channel. Δ is the guard zone defined by PHY protocol to avoid excessive interference from any other transmitting node. (1+Δ)R is the interference range

These two conditions can be written as:

$$\begin{aligned} &|R_i - T_i| \le R \\ &|R_i - T_j| \ge (1+\Delta)R \end{aligned} \quad (1)$$

where, T_i and R_i is the transmitter-receiver pair and T_j denotes the other transmitters nodes transmitting simultaneously on the same channel.

A contention graph is used to describe the contention relationship between the links (Kai and Liew, 2010; Kai and Liew, 2011). It is assumed that two links conflicted with each other when the receiver of one link is within interference range of the transmitter of the other link. In the contention graph, each vertex represents a link and an edge between two vertexes denotes there exists contention between two links. Two links with contention relationship cannot work on the same channel simultaneously which can only work simultaneously on different channels. The channel allocation algorithm should allocate channel to links to minimize contention. In a contention graph, the degree of a vertex is proportioned to the probability of the corresponding link conflicting with other links. As an example, considering a simple wireless network topology shown in Fig. 1, the corresponding contention graph is shown in Fig. 2. In Fig. 2, the degree of vertex 1 is 7 and the degree of vertex 10 is 5 which means with this topology, link 1 maybe conflicts with 7 links and link 10 maybe conflict with 5 links. Therefore, the probability of link 1 conflicting with other links is larger than that of link 10. The vertexes with maximal degree in Fig. 2 are denoted with dash line.

The object of our channel allocation algorithm is to reduce contention and increase the number of links working simultaneously. The contention factor cf_k is defined to evaluate the contention in channel k:

$$cf_k = \sum_{j=1}^{l}\sum_{i=1}^{l} a_{ij} \quad (1 \le k \le c) \quad (2)$$

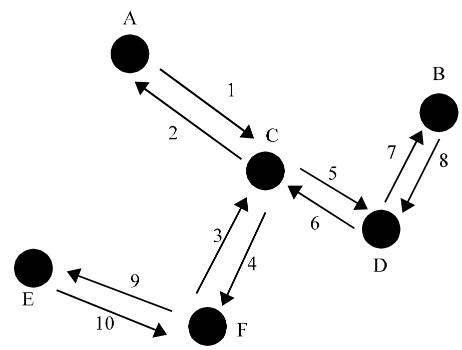

Fig. 1: Network topology, A-D: Nodes, 1-10: Links

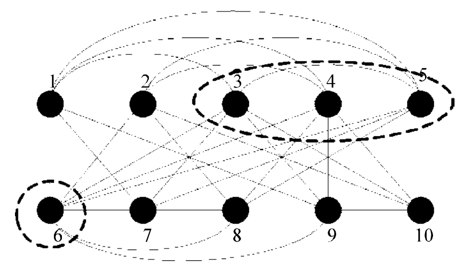

Fig. 2: Contention graph, 1-10: Links

where, l is the number of links working on channel k and a_{ij} is the connection relationship between vertex i and j in the contention graph. If there exists an edge between vertex i and j, then $a_{ij} = 1$, else, $a_{ij} = 0$.

Distributed channel allocation algorithm: In our proposed distributed channel allocation algorithm, each node needs to obtain information of network topology independently. The process of topology discovery will consume wireless resources. To reduce the cost, it is assumed that a node only collects the information of topology within two hops. Every node broadcasts a Hello message periodically in a dedicated channel. A neighbor table is piggyback with the Hello message. The neighbor table contains all neighbors of this node which is discovered by the Hello messages received in the previous round. By this way, every node in the multi-channel network can obtain the local topology within two hops.

After the contention graph is generated from the local topology graph, the node allocates channels to links whose transmitter is this node. The distributed channel allocation algorithm is proposed as follows:

Step 1: In initialization, set the contention graph CG = (V, E) $\forall i \in (1,c)$. Set $cf_j = 0 \forall i \in (1, l)$

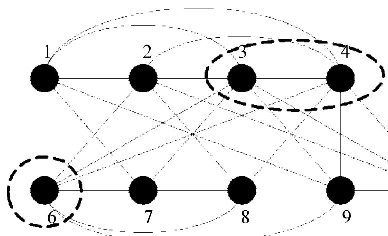

Fig. 3: Contention graph after first round, 1-10: Links

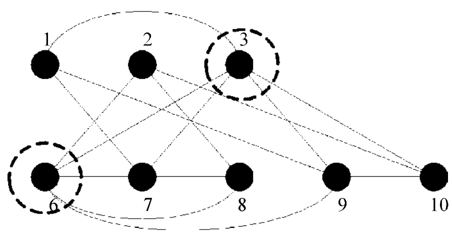

Fig. 4: Contention graph after second round, 1-10: Links

Step 2: From the current contention graph, select the vertex with maximal degree and denote it with v. Find the channel with minimal contention factor and denote with k. Allocate the vertex v to channel k. If there exist several vertexes with the same maximal degree, select one randomly. If there exist several channels with the same minimal contention factor, select one with minimal number of allocated vertexes

Step 3: Delete vertex v from the CG and refresh the contention factor of channel k

Step 4: If CG is null, the channel allocation process is end; else, go to step 2

For example, node C obtains the topology information within two hops from the neighbor nodes and generates the local contention graph which is the same as the contention graph in Fig. 2. Assume there are 3 orthogonal channels to be used. In the first round, vertexes 3, 4, 5 and 6 have the maximal degree. Assume vertex 5 is selected and channel 1 is assigned to vertex 5. Then refresh the contention factor of channel 1. Because there only one link assigned to channel 1, the contention factor of channel 1 is still zero. Delete the vertex 5 and attached edges from the contention graph, the new contention graph are shown in Fig. 3.

In the second round, in Fig. 3, vertexes 3, 4 and 6 have the maximal degree. Assume vertex 4 is selected. For every channel, the contention factor is zero. However, channel 1 have been allocated to vertex 5. Therefore, channel 2 or 3 can be chose for vertex 4. Assume channel 2 is chose for vertex 4 and refresh the contention factor of channel 4. The contention factor of channel 2 is still zero. Delete vertex 4 from the contention graph, the new contention graph is shown in Fig. 4. By this way, all the vertexes in the contention graph are assigned to channels until the current contention graph is null.

By this way, all vertexes in the contention graph are assigned to channels until the current contention graph is null.

After the channel allocation, every link is assigned to one channel. Node will select idle NICs for the links which prepare to transmit packets. If there not exits idle NIC, the packets to be transmitted will be queued to the queue with minimal packets.

SIMULATION RESULTS

In the simulation model, the size of static wireless network field is 1500×500 m. The transmission range for each node is 300 m and Δ is 0. There is a bidirectional logical link between two nodes if they are within the transmission range of each other. Assume there are three orthogonal frequency channels available and the bandwidth of each channel is set to 11 Mb sec^{-1}. Each node is equipped with two NICs. The packet size is 2048 bytes. The influence of routing protocol is not considered in the simulations. Packets can be transmitted between nodes within the transmission range of a single hop. For every packet, destination node is selected randomly from the neighbor nodes. The simulation model of a node with two NICs is shown in Fig. 5. The packets are generated from the source model. The sink model is used to accept packets from Media Access Control (MAC) model. The distributed channel allocation algorithm runs at the MAC model.

To evaluate the performance of multi-channel allocation method, metric used in the simulation is network throughput and the end to end delay. Network throughput is the average transmission rate of successful message delivered from the source to destination over the entire multi-channel wireless network. The end to end delay is the delay from the time a packet is generated at the source to the time it is received by the sink, including queuing delay at the MAC layer, link layer retransmission delay, transmission delay.

As shown in Fig. 6, compared with IEEE 802.11b, the network throughput of distributed channel allocation algorithm is better. Especially with the increase of network load, the network throughput of the distributed channel allocation algorithm increases obviously. When the load is 10 Mb sec^{-1}, the IEEE 802.11b and the proposed algorithm have the average network throughput of 8.14 Mb sec^{-1} and 9.78 Mb sec^{-1}, respectively. The

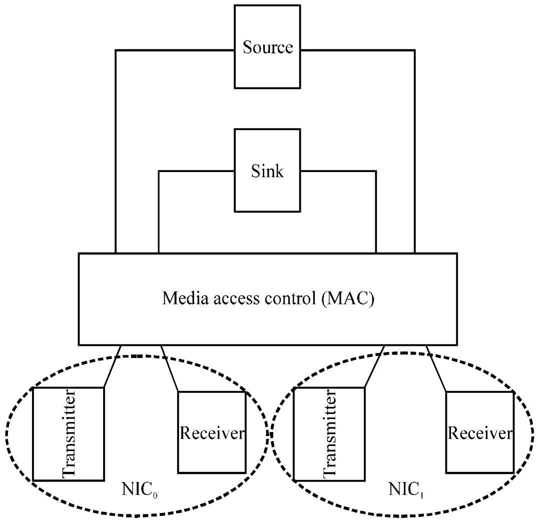

Fig. 5: Model of node with two NICs (network interface card)

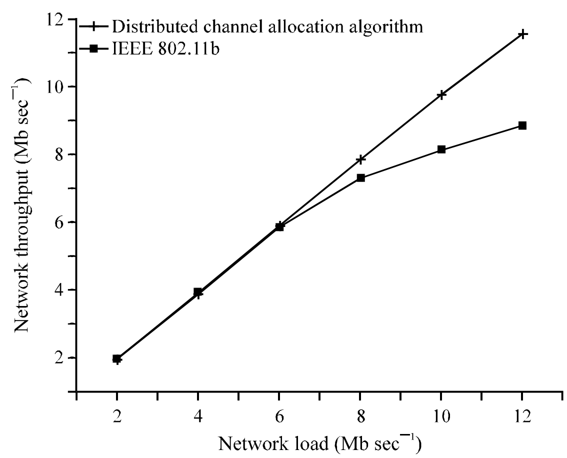

Fig. 6: Network throughput

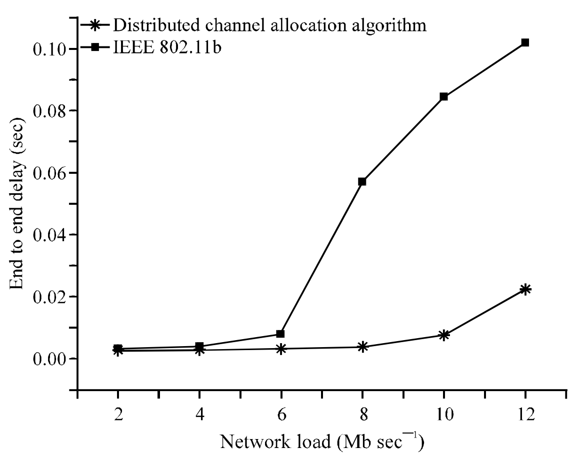

Fig. 7: End to end delay

reason is that the distributed channel allocation algorithm allocates links to channels with minimal contention factor which leads to decrease of conflicts between links.

Figure 7 gives the performance of end-to-end delay. It shows that the distributed channel allocation algorithm decreases the end to end delay significantly and the improvement becomes evident with increased network load. The reason is that when the network load is light, there exists few conflicts; when the network load is heavy, the proposed algorithm decreases conflicts and increases the number of links which can transmit simultaneously.

CONCLUSIONS

This study proposed a distribute channel allocation algorithm for multi-channel networks. Based on local topology information, the node allocates channels by contention graph to reduce contention between links. Simulation results show that when the network load is small, performance of the network throughput for the distributed channel allocation algorithm and IEEE 802.11b are similar. With the increase of network load, the distributed channel allocation algorithm increases the network throughput and decrease end to end delay obviously. Therefore, adopting the distributed channel allocation algorithm, the multi-channel wireless network can obtain better performance with higher network load.

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