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A novel channel assignment scheme for improving channel reuse efficiency in multi-channel ad hoc wireless networks

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Abstract

How to increase channel reuse efficiency is one of the most important issues in wireless cellular networks. Recently, many multi-channel MAC protocols have been proposed for ad hoc wireless networks. However the channel assignment schemes used in these protocols do not consider the issue of channel reuse. The channel assignment schemes only let a mobile host select a channel from the channels which are not currently being used by its one-hop neighbors. To form a channel reuse pattern, the mobile host should consider its two-hop channel usage and select a channel which is been used by its two-hop neighbors. In this paper, we propose a novel channel assignment scheme for improving the channel reuse efficiency. By overhearing control packets of one-hop neighbors, a host can easily know the channel condition within the range of two-hop hosts and then select a suitable transmitting/receiving data channel to form the better reuse pattern. To enhance the probability of forming channel reuse pattern, we propose a backoff counter adjustment scheme such that a host with more channel information can transmit control packets early than with less channel information. We verify the performance of our protocol via simulations and give some comments on the simulation results.

Keywords: Channel reuse; Channel management; Communication protocol; Medium access control (MAC); Ad hoc wireless networks; Wireless networks

1. Introduction

An ad hoc wireless network is formed by a group of mobile hosts each equipped with a wireless interface card and can be deployed quickly without any established infrastructure or centralized administration. Due to concerns such as radio power limitation and channel utilization, a mobile host may not be able to communicate directly with other hosts in a *single-hop* fashion. In this case, a *multi-hop* scenario occurs, where packets sent by a source host must be relayed by several intermediate hosts before reached its destination host. Applications of ad hoc wireless networks appear in areas where the deployment of network infrastructure is difficult or unavailable, such as the emergency, military, entertainment, and outdoor business environments. Issues of ad hoc wireless networks have been studied intensively [2,3,13,14,17,18,20–24,26–29].

IEEE 802.11 standard [1] is the widely accepted *single-channel* MAC protocol. However, the single-channel protocol has a serious problem that the aggregate throughput of a network will degrade quickly as the number of mobile hosts increases due to the rapidly enlarged contentions and collisions. One approach to mitigate this problem is to utilize multiple channels. Using multiple channels not only reduces the contention/collision problem but also increases the aggregate throughput. In addition, there is no extra cost to acquire extra spectra for using multiple channels because IEEE 802.11b standard [10] provides three non-overlapping frequency channels while IEEE 802.11a standard [11] provides 12 non-overlapping frequency channels. Thus, the aggregate throughput can be easy multiplied by using multiple channels concurrently in a wireless network.

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Typically, A *multi-channel* MAC protocol requires to address two issues: *channel assignment* and *medium access*. The former is to determine which channels can be used by which hosts, and the later is to resolve the contention/collision problem among communicating hosts in a particular channel. In this paper, we focus on the issue of channel assignment. We know that the performance of wireless networks is affected by the factor of *spatial channel reuse* significantly. Within a given area, a channel can be reused more efficient if more communication pairs can use the same channel at the same time without interference. Therefore, to improve the network performance, we should carefully assign a channel to a mobile host by taking spatial channel reuse into consideration. In wireless cellular networks, this factor can be easily covered because we can plan the best reuse pattern in advance by getting the location of every base station and the signal interference model of every cell [4]. Thus, the compact channel reuse pattern can be set up easily. But the issue is a hard problem in ad hoc wireless networks because the network topology is unpredictably changeable due to mobility.

There already exist many channel assignment algorithms [6,5,7–9] for a packet radio network. However these algorithms may not be appropriate for an ad hoc wireless network due to its changeable topology. Many multi-channel MAC protocols [12,27,28,18,14,16,23,2,3] have been proposed for ad hoc wireless networks and, based on their general principles of operation, can be classified into three types: *dedicated control channel*, *split phase*, and *channel hopping*. The type of dedicated control channel [27,28,18,14,16] usually has a dedicated control channel and several data channels. The purpose of the control channel is to resolve the potential contention on data channels and to assign data channels to mobile hosts. Data channels are used to transmit data packets and acknowledgements. The type of split phase, such as [23,15], divides time into two phases: appointed phase and data transmission phase. During the appointed phase, nodes exchange control packets in a common channel and reserve a specific data channel for transmission. During the data transmission phase, each node tunes its radio to the reserved data channel for sending or receiving data packets. As the type of channel hopping, all available channel are sorted in an order, call *hopping sequence*. In reference [25], all of mobile hosts switch channels from one to another by following the same hopping sequence, called *common hopping sequence*. When tune on a channel, they contend with each other for sending control packets to decide which communicating pair can obtain the right to transmit data packets on the channel. And then the other hosts, which fail to contend the transmission right, switch to the next channel indicated by the order in the common hopping sequence. In reference [12], each host has its unique hopping sequence. If a host wants to transmit a data packet to its receiver, it tunes on the current stayed channel of the receiver for transmitting data packets.

The channel assignment schemes proposed by above protocols do not take the issue of channel reuse as their primary concern. They only consider the channel status within one-hop neighbors, i.e., a mobile host selects a channel from free channels which are not currently used by its one-hop neighboring nodes. In other words, the selected channel is only based on the condition of one-hop channel usage. These MAC protocols are not to address the issue of spatial channel reuse in their channel assignment algorithms. Tseng et al. [26,24] propose a protocol, which is a similar idea like wireless cellular networks, that assign different channels to mobile hosts depended on its current locations. Although the works [26,24] take care the issue, extra hardware cost of position devices (e.g., GPS) will be needed and may be difficultly operated in indoor environment. Moreover, the reuse channel distance and grid size are not realistic because these values are determined by radio transmission range which is assumed the same of all mobile hosts in [26,24].

The need for spatial reuse of available channels motivates us to design an efficient channel assignment algorithm without any extra hardware cost for location information. By overhearing control channel packets which include the channel usage of two-hop neighbors, mobile hosts can easily select a suitable channel for transmission. The suitable channel means the best benefit to the channel reuse pattern for the current topology of the ad hoc network. The better channel reuse pattern, the more nodes are able to transmit concurrently. It will also increase the network capacity and lower the packet transmission delay too.

The rest of this paper is organized as follows. In Section 2, we introduce our motivation of the work. The proposed protocol is presented in Section 3. Section 4 presents the channel assignment scheme used in MAC protocols while Section 5 gives the backoff adjustment scheme for speeding up the channel reuse pattern. Simulation results are in Section 6 and conclusions are in Section 7.

2. Motivation and review DCA protocol

In this section, we first present our motivation and then review DCA protocol [27] briefly. We know that the channel utilization can be promoted by exploiting the better reuse pattern. As mentioned earlier, the channel assignment schemes presented in current multi-channel MAC protocols let a mobile host select a channel from free channels which are not currently used by its one-hop neighbors. This assignment may easily form a *blocking zone* and so break channel reuse pattern. An area is called a blocking zone if no free channel can be used by any node located within the area. As a result, the network performance will be significantly degraded because the nodes located at blocking zones will be prevented from any data transmission. We give an example to explain the phenomenon of blocking zone as shown in Fig. 1.

In Fig. 1(a), assuming the total number of data channels is three, node A and B firstly choose channel 1 for their