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Computer Communications 30 (2007) 3832–3840
computer communications
www.elsevier.com/locate/comcom

Dynamic frame length channel assignment in wireless multihop ad hoc networks

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Received 8 February 2007; received in revised form 19 September 2007; accepted 19 September 2007
Available online 29 September 2007

Abstract

A good channel assignment scheme in a multihop ad hoc network should not only guarantee successful data transmissions without collisions but also enhance the channel spatial reuse to maximize the system throughput. From the channel assignment schemes in time division multiple access (TDMA) slot assignment protocols developed in previous studies, we have found that these protocols do not have a convenient frame length shrink scheme after the expansion of the frame length. As the network size grows, the frame length expands quickly, particularly when we set the frame length as a power of two. A very long frame may result in poor channel utilization when it contains many unused slots. In this paper, we propose a dynamic frame length expansion and recovery method called dynamic frame length channel assignment (DFLCA). This strategy is designed to make better use of the available channels by taking advantage of the spatial reuse concept. In DFLCA, the increase in the spatial reuse is achieved by adding certain amount of control overhead. We show that the bandwidth saved due to the channel spatial reuse is larger than the additional bandwidth spent on the control overhead.

Keywords: DFLCA; TDMA; Ad hoc network

1. Introduction

In wireless networks, bandwidth is a scarce resource that can be shared either dynamically according to the amount of data required to be transferred to or from each node or deterministically by assigning a fixed number of channels to each cell, as in a cellular network. In the case of assigning a fixed number of channels, a portion of the bandwidth, called a channel is assigned to certain nodes or groups of nodes so that they have exclusive access to the assigned bandwidth. Thus, a QoS (bandwidth, delay) guarantee can be provided. However, traditional channel assignment is pre-planned, hence, it is less adaptive to traffic load variations and network topology changes.

In this paper, we consider the problem of providing a QoS guarantee to users and simultaneously maintaining the most efficient use of scarce bandwidth resources. For providing the QoS guarantee, we need to employ a certain channel assignment scheme, whereas for enabling the efficient use of the bandwidth, the channel assignment scheme needs to be dynamic according to the traffic demand variations at each node. A good channel assignment scheme should not only guarantee successful data transmissions without collisions but also enhance channel spatial reuse to maximize system throughput [1].

Most of the previous studies on channel assignment are based on cellular networks [2]. In the fixed channel assignment (FCA) approach, each cell is assigned a fixed set of nominal channels that cannot be used by other cells. This provides a QoS assurance and transmission guarantee; however, new calls are blocked when all the channels are assigned, even when some or all of those channels are unused. Due to the time-varying characteristics of traffic loads, the FCA approach results in low resource transmission efficiency. This type of channel assignment is also less adaptive to traffic load variations or network topology changes.

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0140-3664/$ - see front matter
doi:10.1016/j.comcom.2007.09.013

In the dynamic channel assignment (DCA) approach, the channels are not pre-allocated to any user. A channel is dynamically assigned to any user who requires data transfer. Channel reuse is also observed based on the spatial reuse concept. Thus, the DCA approach can automatically adapt to traffic variability in both space and time [2].

Most of the present studies do not consider the autonomous behaviors of new nodes. Conventional protocols that assign time slots for new nodes show low channel spatial reuse because they are required to provide a sufficient number of time slots for new nodes, thereby resulting in a large number of unassigned slots [3,4]. In [5], the authors have proposed a channel assignment method to resolve the hidden terminal problems in ad hoc networks. However, the FCA scheme is considered in their method.

In [6], the authors propose the unifying slot assignment protocol (USAP). This method considers the autonomous behaviors of new nodes and assigns a frame to each node. In this method, each frame has a fixed number of slots. In USAP, a sufficient number of frames and slots must be assigned to each node in the network. Consequently, when the network expands, the channel utilization becomes low due to a large number of unassigned slots. USAP multiple access (USAP-MA) [7] improves USAP by reducing the number of unassigned slots taking into consideration the number of nodes in the network topology. However, this method does not indicate when to change the frame length or how to select a slot to be assigned to a new node. Moreover, the use of this method wastes an excessive number of slots and results in lower channel utilization.

A dynamic slot channel assignment (DTSA) technique based on-USAP has been proposed [8]. This method takes into account more autonomous behaviors in a wireless multihop ad hoc network. However, this method is still a pre-planned channel assignment method, where a time slot is pre-assigned to each node. The pre-assigned slot is not released even when the node has no data transmission. Therefore, the channel spatial reuse results in lower utilization. This method cannot provide more slots when a node requires them to deal with burst traffic. Therefore, in wireless ad hoc networks, the use of this method results in lower channel spatial reuse.

Conventional channel assignment methods do not provide a solution to minimize or shorten the frame length. The performance is lowered when the amount of connections flowing through a node reduces after its frame length has been enlarged. The number of unused slots increases in certain cases, and a part of the channel bandwidth is wasted.

In this paper, a dynamic time division multiple access (TDMA) frame length control channel assignment method referred to as dynamic frame length channel assignment (DFLCA) has been proposed. This method efficiently utilizes the channel bandwidth by assigning unused slots to new nodes and enlarging the frame length when the number of slots in the frame is insufficient to support the nodes. This method also shrinks the frame length when the frame of a node is half empty.

We consider dividing a transmission frame into a time slot structure in the multihop ad hoc network. The bandwidth available for the ad hoc network is a set of channels created by the time slots through using the TDMA technique. Then, we propose that our dynamic channel assignment scheme, which provides both QoS guarantees and resource efficiency, be employed to optimize the channel spatial reuse and minimize the control overhead.

The rest of this paper is organized as follows. In Section 2, we explain why the TDMA structure is considered. In Section 3, we explain the protocol proposed in this paper, which is the environment where we perform the simulation. We present our simulation results in Section 4 and conclude this paper in Section 5.

2. Time division multiple access

Time division multiple access (TDMA) shares the available bandwidth in the time domain. Each frequency band is divided into several time slots (channels). A set of such periodically repeating time slots is known as the TDMA frame. Each node is assigned one or more time slots in each frame, and the node transmits only in those slots. For two-way communication, the uplink and down link time slots, used for transmitting and receiving data, respectively, can be on the same frequency band (TDMA frame) or on different frequency bands. The former is known as time division duplex-TDMA (TDD-TDMA), and the latter as frequency division duplex-TDMA (FDD-TDMA). Though TDMA is essentially a half-duplex mechanism, where only one of the two communicating nodes can transmit at a time, the small duration of time slots creates the illusion of a two-way simultaneous communication.

Perfect synchronization is required between the sender and the receiver. To prevent synchronization errors and inter-symbol interference due to signal propagation time differences, guard intervals are introduced between time slots. Since the sizes of slots are already small, the introduction of guard intervals results in a significant overhead for the system [9].

For multimedia transmission of voice or video stream, the connection-oriented approach is usually taken. Such connections do not permit interference or competitions from others in order to guarantee the delay and jitter. For such a high QoS guarantee, the multimedia transmission needs an independent channel with its exclusive bandwidth. Each connection can independently occupy one time slot until the end of the connection. A TDMA system is advantageous from the viewpoint that the number of radio transceivers can be decreased, and that system control functions, such as hand-off control, can be easily implemented. Monitoring for other channel before hand-off is performed at time slots that are not dedicated for the current communications.