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Surveying on Optimization of Routing and Channel Assignment in Multichannel Mobile Ad-Hoc Networks

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ABSTRACT

By assigning orthogonal channels to neighboring nodes, one can minimize both types of interferences and allow concurrent transmissions within the neighborhood, thus improving the throughput and delay performance of the ad hoc network the capacity of mobile ad hoc networks is constrained by the intra-flow interference introduced by adjacent nodes on the same path, and inter-flow interference generated by nodes from neighboring paths three novel distributed channel assignment protocols for multi-channel mobile ad hoc networks protocols combine channel assignment with distributed on-demand routing, and only assign channels to active nodes proposed protocols can effectively increase throughput and reduce delay, as compared to several existing schemes, thus providing an effective solution to the low capacity problem in multi-hop wireless networks.

INTRODUCTION

Despite recent advances in wireless local area network (WLAN) technologies, today's WLANs still cannot offer the same data rates as their wired counterparts. The throughput problem is further aggravated in multi-hop wireless environments due to intra-flow interference introduced by adjacent nodes on the same path and inter-flow interference generated by nodes from neighboring paths. the maximum capacity that the IEEE 802.11 medium access control (MAC) protocol can achieve for a chained network is just one seventh of the available bandwidth.[1]

All current IEEE 802.11 physical (PHY) standards divide the available frequency into several orthogonal channels, which can be used simultaneously within a neighborhood. Therefore, increasing capacity by exploiting multiple channels becomes particularly appealing. In fact, such bandwidth aggregation has been widely used in infrastructure-based WLANs, where high-end access points have multiple interfaces that operate on different channels simultaneously In infrastructure-based WLANs, non-overlapping channels are distributed among different access points at the network planning stage. However, IEEE 802.11 WLANs that operate in ad hoc mode rarely use multiple channels simultaneously. Since they do not take into consideration the case when there are not enough channels, convergence, i.e. reaching a desired stable result, may become a problem.[1][3]

Furthermore, most of distributed channel assignment protocols only consider secondary collisions, since they are mainly designed to solve the hidden terminal" problem. Nevertheless, primary collisions and interference are also important factors that adversely affect channel utilization and network capacity. Primary collisions occur when two neighboring nodes transmit to each other at the same time, whereas secondary collisions occur when transmitters outside of radio range of each other, also called \hidden terminals," transmit to the same receiver .Primary collisions can be avoided or reduced by using random access protocols, such as ALOHA or CSMA ,while secondary collisions can be avoided by multi-channel medium access schemes or handshake mechanisms, such as request-to-send/clear-to-send (RTS/CTS) [1] signaling .However, interference generated by nodes that are two or more hops away cannot be avoided by random access schemes or handshake mechanisms and, thus, such interference is potentially more harmful. Failing to take primary collisions and interference into consideration, existing channel assignment algorithms may suffer performance degradation, especially in a multi-hop environment.[4]

Three principles for efficient distributed channel assignment design.

First, to reduce the complexity of the channel assignment algorithm, channel assignment and routing are combined together. This cross-layer" design principle is motivated by the fact that both the channel assignment algorithm and the ad hoc routing algorithm must be invoked when there is a change in the network topology. Utilizing this design principle can greatly reduce the complexity of channel assignment algorithms.[1]

Secondly, channels should be assigned only to \active" nodes. This on-demand" channel assignment principle is motivated by the fact that only active nodes need valid channels Existing channel assignment schemes assign channels to all nodes in the network regardless of whether they are active or not. However, if this on-demand assignment principle is implemented, fewer channels may be required in the network.[1]

Finally, both primary and secondary collisions and interference should be taken into consideration. To mitigate interference as well as to resolve collisions, distinct channels should be assigned in a way that collisions and interference can be avoided as much as possible.[1]

RELATED WORK

I begin the discussion of background by reviewing some relevant details of contention- based medium access schemes, including the IEEE 802.11 MAC Distributed Coordination Function (DCF) protocol. Since contention-based medium access schemes perform poorly in a multi-hop environment, distributed channel assignment was proposed to solve the "hidden terminal" problem. Next, the "hidden terminal" and "exposed terminal" problems are in- troduced. In addition, I describe a "fairness" problem that contention-based medium access protocols commonly suffer from in a wireless environment. [3]

2.1) Contention-based Medium Access Schemes

A wireless ad hoc network is a purely distributed network and is often set up "on the fly". Because the coordination of mobile nodes in a highly dynamic environment is difficult, mobile ad hoc networks (MANETs) seldom use centralized medium access control (MAC) protocols to assign dedicated resources to individual nodes. Instead, contention-based protocols, such as ALOHA [3] and carrier sense multiple access (CSMA) [4], are commonly employed. These two protocols and CSMA with collision avoidance (CSMA/CA) are described below.[4]

2.2) ALOHA Protocol

The basic operation of ALOHA is simple, yet elegant - stations can transmit whenever they have a packet that needs to be sent. If a collision occurs, the data packet is corrupted. The receiver can acknowledge successful receipt of the data packet. If the sender does not receive an acknowledgment within a certain timeout period, the sender assumes that there was a collision. The sender then waits a random amount of time and sends the packet again in another frame. While simple, ALOHA fails to effectively utilize channel resources. ALOHA also suffers from stability problems that can occur when a large number of stations have backlogged frames that need to be transmitted [1]. In effect, the performance of ALOHA degrades sharply when the traffic load is heavy. This performance degradation occurs mainly because all nodes transmit at will without considering transmissions at other nodes.[1][4]

PROGRAMMER'S DESIGN

Two performance metrics, the average number of nodes in a k-hop neighborhood sharing the same channel and the average accumulated interference at active receivers, fCA and RCA respectively, are defined.

MATHEMATICAL MODEL

First, the k-hop neighbors of a node v are defined as members of the set $N_k(v) = \{w \in V | l(v,w) \leq k\}$ Nk (v) ={ w €V \ l(v;w) <=k}, where l(v; w) is the hop distance from v to w, i.e. the minimum length of any path from v to w. Note that N1(v) is the set of directlyconnected neighbors of node v. C is defined to be a set of all available channels in thenetwork. Given a fixed number of channels, denoted by |C|, the first performance metric for channel assignment algorithms is the average number of nodes sharing the same channel with the designated node among this node's k-hop neighbors:

$$f_{CA} = \frac{1}{|V|} \sum_{v \in V} n_k(v).| \quad 3.1$$

Here, nk(v) is the number of nodes in Nk(v) that share the same channel with node v.If /C/ is large enough and k is set to an appropriate value, both primary and secondary collisions can be largely avoided and harmful interference can be mitigated. Therefore, the channel assignment problem can be formulated in such a way that the goal is, given a /C/, to minimize the average accumulated interference at each receiver. Because the transmitter- based and receiver-based channel assignments are essentially the same problem, I assume that the channel assignment scheme is transmitter based, i.e., channels are assigned to transmitters and receivers must \tune" to the channel assigned.

Vt ½ V is defined to be the set of active transmitters and Vr Ω V is defined to be the set of active receivers. Note that a node cannot be both a transmitter and a receiver at a given time, so membership in Vt and Vr is mutually exclusive, i.e. Vt \ Vr = ;. Let vr;i € Vr be a particular receiver and vt; j € Vt be a particular transmitter. If vt;j is transmitting on the same channel on which vr;i is receiving, but vt;j is not the intended transmitter to vr;i, then transmitter vt;j will interfere with receiver vr;i. The power associated with the interference, P(vt;j ; vr;i), is the received power at node vr;i, which is a function of the effective transmitter power of node vt;j and the distance between nodes vt;j and vr;i, and is determined by the path loss model. The average interference at active receivers is determined as follows.

$$R_{CA} = \frac{1}{|V_r|} \sum_{v_{r,i} \in V_r} \sum_{v_{t,j} \in V_t \setminus v_{t,T(i)}} [P(v_{t,j}, v_{r,i}) \cdot S(v_{t,j}, v_{r,i})] . \quad -3.2$$

Node vt;T (i) is the intended transmitter for receiver vr;i and is excluded from the inner summation of interference sources. The term S(vt;j ; vr;i) indicates the relation between the channels used by transmitter vt;j and receiver vr;i. Function S(vt;j ; vr;i) = 0 if vt;j and vr;I are using different (strictly orthogonal) channels and S(vt;j ; vr;i) = 1 if vt;j and vr;i are using the same channel. In code-division multiple access (CDMA) systems, different channels with non-orthogonal codes may be used, in which case 0 < S(vt;j ; vr;i) < 1.

Based on the performance metrics introduced above, the design objective is presented. The primary design goal of distributed channel assignment is to minimize the maximum number of nodes sharing the same channel with any designated node vt;j € Vt among this node's k-hop neighbors.

Minimize:

$$\max n_k(v_{t,j}), \qquad \forall\ v_{t,j} \in V_t$$

subject to:

$$\frac{P(v_{t,T(i)}, v_{r,i})}{\sum_{v_{t,j} \in V_t \setminus v_{t,T(i)}} [P(v_{t,j}, v_{r,i}) \cdot S(v_{t,j}, v_{r,i})] + N_0} \geq \beta, \qquad \forall\ v_{r,i} \in V_r.$$

Here, N0 is the assumed additive white Gaussian noise (AWGN) noise and β is the minimum SINR required for a successful packet reception. In Equation, note that node vt;T (i) is the intended transmitter for receiver vr;i and is excluded from the summation of interference sources.

we present three principles for designing efficient distributed channel assignment schemes. First, to reduce the complexity of the channel assignment algorithm, channel assignment and routing should be jointly designed. This ‘‘cross-layer” design approach is motivated by the fact that both the channel assignment algorithm and the ad-hoc routing algorithm are invoked when there is a change in the network topology. Exploring this design principle can potentially reduce the complexity of channel assignment algorithms. Second, channels should be assigned only to active nodes. This ‘‘on-demand” channel assignment principle is motivated by the fact that only nodes on active routes need valid channels. Some existing channel assignment schemes assign channels to all nodes in the network, regardless of whether they are active or not, thus requiring a large number of orthogonal channels. If this on-demand assignment principle is implemented, fewer channels (i.e. fewer resources) may be required in the network to achieve a comparable performance.

Third, the capacity of mobile ad hoc networks can be adversely affected by both ‘‘hidden terminals” and ‘‘exposed terminals.” The hidden terminal problem occurs when transmitters outside of radio range of each other transmit at the same time, causing a collision at the receivers. The exposed terminal problem occurs when a node is prevented from sending packets to other nodes due to a neighboring transmitter, even though this transmission will not cause interference. In addition, cumulative interference generated by nodes two or more hops away may also adversely affect channel utilization and network capacity. Thus, to improve network performance, distinct channels should be assigned such that hidden terminals, exposed terminals, and cumulative interference can be avoided as much as possible.

We present a new channel assignment protocol, named Channel Assignment Ad hoc On-demand Distance Vector routing (CA-AODV), that implements these design principles. In CA-AODV, channel assignment is combined with the AODV routing protocol and is performed in a cross-layer and on-demand fashion. Specifically, channel assignments performed during the route discovery phase and channel information is piggybacked in the routing control messages. CA-AODV assigns different channels for neighboring nodes within a k-hop region along the same path, thus allowing concurrent transmission on neighboring links along the path and effectively reducing the intra-flow interference.

We also present two extensions to the CA-AODV protocol, namely, the Enhanced 2-hop CA-AODV (E2-CA-AODV) protocol and the Enhanced k-hop CA-AODV (Ek-CA-AODV) protocol. In addition to intra-flow interference, these two extensions also aim to minimize inter-flow interference by assigning orthogonal channels to active nodes within a k-hop neighborhood, where k >= 2. With such channel assignment, more concurrent transmissions are achieved for nodes along various routes within the k-hop neighborhood, thus effectively improving the throughput and delay performance. Simulation results in mobile ad hoc networks show that the performance of E2-CA-AODV approaches that of a multi-channel scheme with an unlimited number of channels (i.e., the ideal case with unlimited amount of resources). In addition, the proposed protocols exhibit lower complexity than many existing centralized and distributed approaches.

In addition to the distributed channel assignment protocols, we also develop a transmitter-based multi-channel MAC (MC-MAC) protocol that extends the benefit of channelization to multi-hop mobile ad hoc networks. Because multiple hop information or the whole network topology can be visible to the routing layer, MC-MAC can benefit from the combined routing and channel assignment scheme and offers improved network performance

Distributed channel assignment protocols

We first describe the three design principles on distributed channel assignment and then introduce three protocols that implement these design principles. It is assumed that channel assignment is transmitter-based, meaning that distinct channels are assigned to different transmitters. It has been shown that transmitter- and receiver-based channel assignment problems are essentially equivalent .Therefore, the proposed design principles apply to receiver-based protocols and the proposed protocols can be easily modified to assign channels based on receivers as well.

Design principles

The first and primary principle is ‘‘cross-layer” design, where channel assignment is jointly considered with routing. This is motivated by the fact that both channel assignment and routing will be invoked when there is a topology change. In addition, piggybacking channel information in routing control messages can greatly reduce the communication overhead of channel assignment protocols.

The second design principle states that channels should be assigned only to active nodes. Before a node acquires a valid route, it cannot transmit or receive data packets and, thus, does not need a channel. We call this type of node an ‘‘inactive” node, and a node in a valid route an ‘‘active” node. Most existing channel assignment schemes assign channels to all nodes in a wireless network, regardless whether they are active or in active. If not all nodes in a network are active at the same time, such schemes may require more wireless channels than necessary. By assigning channels on-demand to only active nodes, we can potentially reduce the number of channels required in a wireless network, since the number of required wireless channels is generally proportional to the number of active nodes rather than the total number of nodes in the entire network.

Finally, distinct channels should be assigned in such a way that hidden nodes, exposed nodes and interference can be avoided as much as possible. Many existing channel assignment schemes are designed to solve the hidden node problem. However, the exposed node problem can also reduce channel utilization. Interference can also corrupt data packets and reduce throughput. We propose to assign distinct channels to any nodes within a k-hop neighborhood, where k is a design parameter that provides a suitable tradeoff between the number of required channels and the achieved interference level, and between the system performance and control overhead. Therefore, concurrent transmissions in the k-hop neighborhood can be achieved to improve the network performance overhead. Therefore, concurrent transmissions in the k-hop neighborhood can be achieved to improve the network performance.

Distributed channel assignment protocols

The proposed design principles can be applied to both reactive routing algorithms, such as Ad hoc On Demand Distance Vector (AODV) protocol, and proactive routing protocols, such as the Optimal Link State Routing (OLSR) protocol . In the following, we will use AODV as an example to demonstrate the three design principles. AODV is a reactive routing protocol, which means nodes do not maintain up-to-date routes to all destinations at all times. Instead, a node initiates a route discovery procedure by broadcasting a Route Request (RREQ) message only when it has packets for the destination node and it has no valid route to the destination. Upon receiving the RREQ message, the destination node or an intermediate node that has a valid route to the destination will send back a Route Reply (RREP) message to the source node. The RREP sets up a path from the source to the destination as it is forwarded back to the source node.

We assume that each node is equipped with two transceivers: one for data transmissions and the other for control messages. Control messages, such as RREQ and RREP, are sent on the control channel that is shared by all the nodes in the network. Data packets may be sent on different data channels that have been assigned to active nodes in the network. we present a combined channel assignment and AODV scheme, namely, Channel Assignment AODV (CA-AODV), and its two extensions: Enhanced 2-hop CA-AODV (E2-CA-AODV) and Enhanced k-hop CA-AODV (Ek-CA-AODV).

Combined channel assignment and AODV

CA-AODV, like AODV, operates in two phases: route discovery and route reply. During the route discovery phase, channel information about a node's k-hop neighbors along the same route is carried by the broadcast RREQ message. Any node that receives the RREQ message updates its next hop table entries with respect to preceding nodes in the path back to the source. Each table entry consists of both the route and the indices of channels that have been taken, so far, by the node's k-hop neighbors on the same route. If the node has no channel assigned to it, it updates its available channel set, denoted by A € C, by marking the channels taken by the preceding k (or fewer if the route is not k hops long) nodes on the path as unavailable.

Then, it randomly picks a channel from the set of available channels A. Furthermore, this node will associate a timer with these updates. If this node does not receive an RREP before the timer expires, these updates will be restored to the original states, since this node will not be included in that path. During the route reply phase, channel information is carried in the unicast RREP message. Upon receiving the RREP packet, each node along the route updates its next-hop table entries, as well as the index of the channel to be used for this link.

After the route has been established, each node along the route should have a channel that is different from any of its k-hop neighbors on the same route. As in AODV, a route expires if it is not used or reactivated for a certain period of time. The entry that corresponds to this route will then be deleted from the routing table and the channels assigned to this route will become available for reassignment.

A flowchart that describes the operation of CA-AODV is shown in Fig. describe its four main procedures, i.e. sendRREQ(), recv RREQ(RREQ), sendRREP() and recvRREP(RREP).sendRREQ() and recvRREQ(RREQ) are invoked in the route discovery phase, while sendRREP() and recvRREP(RREP) are invoked in the route reply phase. In recvRREQ(RREQ) and recv(RREP), get-NeighborInfo() retrieves channel information from RREQ or RREP messages received from neighboring nodes, while randomChannel(A) returns a channel index that is uniformly chosen from the available channel.

Distributed channel assignment protocols

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