On Channel-Adaptive Routing in an IEEE 802.11b Based Ad Hoc Wireless Network

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Abstract— **Ad hoc routing is important for mobile devices, when they are out of each other's transmission range, to communicate in an IEEE 802.11b based wireless LAN using the distributed coordination function. While traditional table-based or on-demand routing protocols can be used, it is much more efficient to use a routing protocol that is channel-adaptive—judiciously selecting links that can transmit at higher data rates to form a route. However, devising channel-adaptive routing protocols is still largely unexplored. In this paper, we propose a reactive ad hoc routing algorithm, called RICA (receiver-initiated channel-adaptive) protocol, to intelligently utilize the multi-rate services (based on different modulation schemes) provided by the IEEE 802.11b standard. Our NS-2 simulation results show that the RICA protocol is highly effective.**

Keywords: channel-adaptive, ad hoc networks, routing, proactive, receiver-initiated, IEEE 802.11b, wireless LANs, NS-2.

I. INTRODUCTION

There are two critical issues in the design of ad hoc routing protocols for a peer-to-peer wireless network. First, due to the mobility of the mobile devices in the network, their geographical locations may have changed when a data transfer is required, rendering a previously set up route useless. The second reason, which, we believe, is a more important one, is that the quality of the channels among the mobile devices is inevitably time-varying (due to shadowing and fast fading [11]), and thus, the links in a route may no longer be usable even if the geographical locations do not change much. In our study, we mainly consider on-demand routing algorithms for ad hoc networks but we also examine the effectiveness of one table based protocol. In particular, we are interested in studying the behavior and performance of routing protocols when the time-varying nature of wireless channels is taken into account. Indeed, because the IEEE 802.11b standard [3] also provides multi-rate services with different rates supported by different modulation schemes, it is useful to dynamically change routes by selecting links that can use higher bandwidth modulation schemes. In this paper, we propose a new ad hoc routing algorithm for an IEEE 802.11b based wireless LAN operating in the ad hoc mode (i.e., using the distributed coordination function without any centralized access point). Our algorithm, called RICA (receiver-initiated channel-adaptive) routing, works by proactively changing routes through judicious selection of links that can support higher data rates.

II. RECEIVER INITIATED CHANNEL-ADAPTIVE (RICA) ROUTING

The major feature of RICA is to make use of the time-varying property of the wireless channel in that the routing between the source and destination devices is adaptive to the change in *channel state information* (CSI), which corresponds to the SNR (signal-to-noise ratio) of the received signal. Specifically, in the RICA algorithm, it is possible that the entire route is changed in response to a change in CSI.

A. Channel Model

To exploit the time-varying nature of the wireless channel, typically a variable-throughput channel-adaptive physical layer is incorporated in the transceiver of a mobile device in that variable amount of data Redundancy is incorporated to the information packet for error protection, according to different channel conditions. Indeed, in view of the need to support higher data rate wireless transmission, in 1998 the IEEE 802.11b working group adopted complementary code keying (CCK) [2] as the basis for the high rate physical layer extension to transmit data rates up to 11 Mbps [3]. Specifically, through the adoption of the concept of adaptive modulation [7], an IEEE 802.11b wireless channel can provide multi-rate direct sequence spread spectrum (DSSS) [5] transmission at 1, 2, 5.5, and 11 Mbps, corresponding to differential binary phase shift keying (DBPSK), differential quaternary phase shift keying (DQPSK) (for both 2 and 5.5 Mbps), and CCK, respectively. Thus, each mobile device transmits data at an appropriate data rate using a particular modulation mode based on the perceived signal-to-noise ratio (SNR) of the immediately previous frame in the frame exchange process. For details about the IEEE 802.11b standard, the reader is referred to [3], [9]

We define a CSI based "hop" in the following manner. Based on the CSI (can be detected from the SNR of the received signal), we can classify the channel quality into four classes: A, B, C, and D, corresponding to data rates of 11 Mbps, 5.5 Mbps, 2 Mbps, and 1 Mbps, respectively, as specified in the IEEE 802.11b standard. Thus, if a link between two mobile devices with channel quality of class A (i.e., able to support the data rate of 11 Mbps), then the distance between these two devices is defined as ONE hop. We then use this "distance" as a baseline as follows. If a link between two mobile devices has a channel quality of class B (with a data rate of 5.5 Mbps), the distance between two devices is two hops because now the transmission delay is two times that of a class A link. In summary, the distance between two devices, with a link having class A (11 Mbps), class B (5.5 Mbps), class C (2 Mbps), or class D (1 Mbps), is 1, 2, 5.5, and 11 hops, respectively.

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B. Route Discovery

The RICA protocol is a reactive and on-demand algorithm in that a source mobile device does not permanently keep a route to any destination. The source device will try to determine a route only when it has packets to send to a particular destination. When the source device has packets to transmit, it generates a *route request* (RREQ) packet which includes the following information: type of the packet, source address, destination address, hop count from the source (initialized to zero), hop distance based on CSI (initialized to zero), broadcast identifier (ID) of the RREQ, and a list of intermediate devices (initialized to an empty list). Whenever the source generates a RREQ, the broadcast ID is increased by one. Thus, the source and destination addresses together with the broadcast ID uniquely identify a RREQ. The source broadcasts the RREQ to all devices within the transmission range. These neighboring devices will relay the RREQ to other farther devices in a breadth-first fashion.

The destination device then generates a *route reply* (RREP) which includes the following information: type of the packet, source address, destination address, route reply ID (corresponding to the broadcast ID of the RREQ), hop distance (CSI-based) and hop count of the route, and the list of intermediate devices. The destination device unicasts the RREP along the selected route to the source device (note that each device knows its upstream neighbor to which for forwarding the RREP from the intermediate device list in the RREP).

C. Broadcast of CSI-Checking Packets

Because the channel quality between two devices is a time-varying function, the throughput of the route to the destination is also changing all the time. Thus, the prime goal of the RICA algorithm is to maintain a route between a communicating source-destination pair such that the highest throughput is achieved. Essentially, to attain this goal, a route will have to be updated, possibly frequently, according to the changing channel conditions. Our idea is to let the destination device broadcast a CSI-checking packet periodically (the period depends on the coherence time of the fading/shadowing conditions; typically three to four seconds is acceptable). The CSI-checking packet, acting as a probe, is used for measuring the CSI of every link it has traversed. Thus, an updated CSI-based hop distance can be obtained. During the life time of a communication session, the source could receive several CSI-checking packets periodically from the destination and thus, it can update the route accordingly.

D. Route Maintenance

In the RICA protocol, the updating of the routing table can be quite frequent and thus, an upstream device has to be sensitive to the status of the connection with its downstream device. The feedback information from the physical layer [6], [7] can be used to detect the connectivity of the link. When a device notifies that its downstream device has moved out of its transmission range, the device generates a *route error* (RERR) packet, which includes the following information: type of the packet, source address, destination address, last route update sequence number. The device then unicasts the RERR to the upstream device. The upstream device first checks whether the device unicasting the RERR is its downstream device or not, by looking up its routing table route entry and the related route update sequence number. If either one of these two fields does not match, the device ignores this RERR because such an RERR comes from a broken route which is out of date and is useless on the data transmission that is going on in the current route. On the other hand, if both fields match, the upstream device also unicasts the RRER to its upstream device. This process continues until the RERR reaches the source.

E. Route Updating

As described above, the updating of a route might be based on the CSI checking packets or RREP packets. However, these two updating mechanisms can lead to different results. If the route updating is based on RREP packet, the route update packet has the format of: type of the packet, source address, destination address, hop count, update sequence number, and list of intermediate devices. Because the route update could be based on CSI checking packet or RREP, routing loops [1] might be formed. To avoid the formation of loops and to differentiate the two cases of route updating based on RREP and on CSI checking packet, an update sequence number is also used. Each source and destination connection pair is related to an update sequence number, which is stamped by the source.

III. PERFORMANCE RESULTS

In this section, we present the results obtained in our extensive simulations comparing the four protocols RICA, AODV [13], DSDV [12], and DSR [4] considered in this study. These four protocols have been implemented (only RICA is coded by ourselves; the other three already exist in NS-2) in the standard NS-2 environment [10], which is described below[1]

A. Simulation Environment

In our simulation environment, we use an indoor wireless channel model, which captures the fast fading and long-term shadowing factors. Specifically, we incorporate our channel model as described in Section II-A into the NS-2 platform. This additional channel model component provides a time-varying transmission environment to all four protocols simulated under the NS-2 system. The maximal transmission ranges for 4 modulation schemes are specified as: 70 meters for 1 Mbps, 60 meters for 2 Mbps, 45 meters for 5.5 Mbps, and 35 meters for 11 Mbps. To model an ad hoc network, we also use the distributed coordination function (DCF) in the simulated IEEE 802.11b wireless LAN. Using a collision avoidance scheme and handshaking with request-to-send/clear-to-send (RTS/CTS) exchanges between the sender and receiver, and acknowledgment (ACK) from the receiver, packets can be reliably unicast between any two neighbors within an appropriate range. Through the exchange of RTS/CTS/DATA/ACK, the MAC protocol can detect any data link disconnection with its neighbor and report this to the network layer. In all the simulations, the broadcast packets (e.g., RREQ) and control packets such as RTS/CTS and

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[1] Note that ABR and Link State protocols are not included in our comparison because the standard NS-2 platform does not include these two protocols.

ACK are transmitted at the basic data rate set, (i.e., 1 Mbps). Other simulation parameters we used are as follows:

- testing field: 200m × 200m; such a large field can model the environment in a shopping mall or an exhibition center;
- mobile speed: uniformly distributed between 0 and MAXSPEED (28.8 km/hr);
- mobility model: we use the random way-point model (as defined in the movement files in NS-2): when the device reaches its destination, it pauses for 3 seconds, then randomly chooses another destination point within the field, with a randomly selected constant velocity;
- traffic load: 10 source-destination pairs for the 50-device scenarios and 20 pairs for the 100-device scenarios; in the former test cases, the traffic load is varied as 10 and 15 packets/sec; in the latter test cases, the traffic loads are 5 and 8 packets/sec;
- simulation time: 600 seconds.

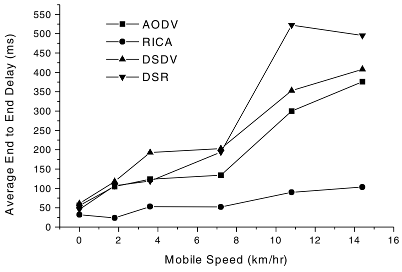
Furthermore, the data packet size is 512 bytes and the capacity of data buffer size is set to 50. The transmission of packets is a store-and-forward process. When a packet reaches an intermediate device, it waits in the queue for service in a first-come-first-served (FCFS) manner. Each packet is allowed to be kept in the buffer for no more than 30 seconds such that if it has not been transmitted during this period, it will be discarded. Such a relatively short time-out period is chosen because we would like to exert a high pressure on the routing protocols to test their responsiveness in dealing with congested routes (possibly due to poor channel qualities in some links). Finally, the generation of data packets in each source device is based on a constant bit rate (CBR) traffic source defined in the standard NS-2 simulator platform. Each simulation scenario is repeated 10 times with a different random seed and each data point is the average of these 10 trials. The results are shown in Figures 1 to 5. Due to space limitations, detailed descriptions of the results are omitted here but can be found from [8]. We just provide our interpretations of the results in the next section.

B. Critiques on the Four Protocols

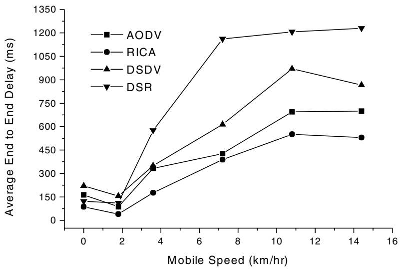
Four routing protocols have been studied in detail in our simulations. RICA is the best because it is devised for such CSI fluctuating environment, which, obviously, is better than the other three routing protocols. It is very effective in small or moderate scale network. But in larger networks (e.g., 1000 devices) with more source-destination pairs (e.g., 100 pairs) within a small area, it might not perform well because, in such a scenario, destination has to broadcast CSI checking packets periodically, which might be a waste of limited bandwidth and battery power.

DSDV is a table-driven protocol, which exchanges routing information among adjacent devices. Normally, this information is the whole routing table, which might be very bandwidth consuming. Another drawback of DSDV is that it lacks an effective mechanism to timely recover the broken routes which might lead to the drop of the data packets.

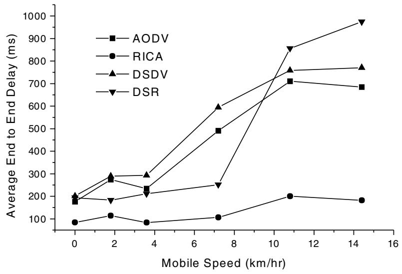
In contrast, DSR uses source routing to deliver packets to the destination. This routing mechanism lightens the burden of the intermediate devices. But it also has a severe drawback: DSR does not apply any aging mechanism to the cached routes which have expired. The aged routes can pollute the route caches of other devices because the intermediate devices may have stale



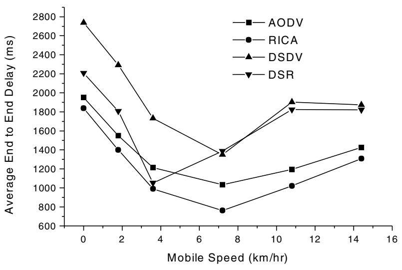
(a) 50 devices, 10 packets/sec



(b) 50 devices, 15 packets/sec

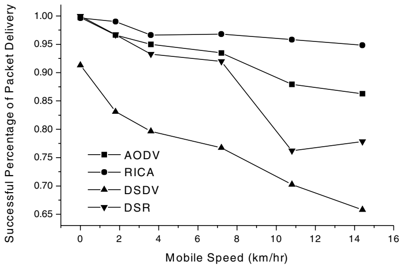


(c) 100 devices, 5 packets/sec

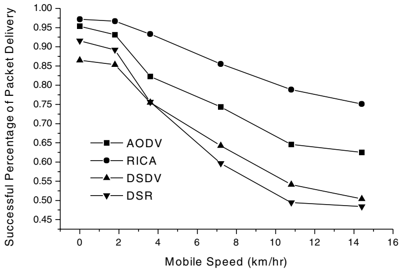


(d) 100 devices, 8 packets/sec

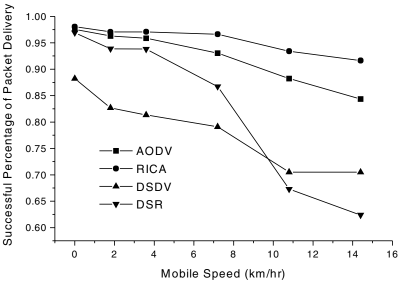
Fig. 1. Average end-to-end delays of all protocols.



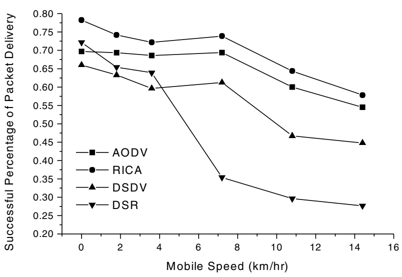
(a) 50 devices, 10 packets/sec



(b) 50 devices, 15 packets/sec

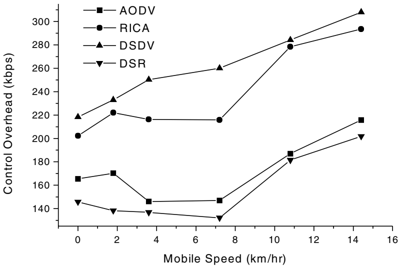


(c) 100 devices, 5 packets/sec

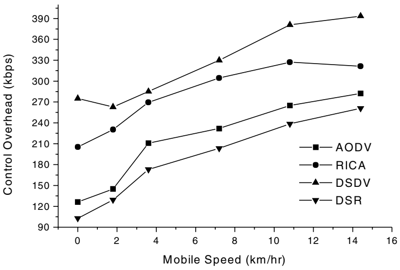


(d) 100 devices, 8 packets/sec

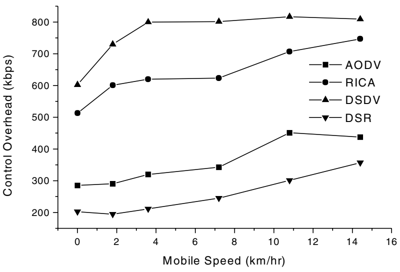
Fig. 2. Successful percentages of packet delivery of all protocols.



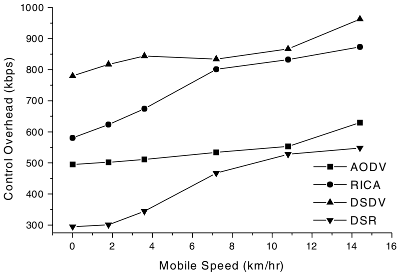
(a) 50 devices, 10 packets/sec



(b) 50 devices, 15 packets/sec

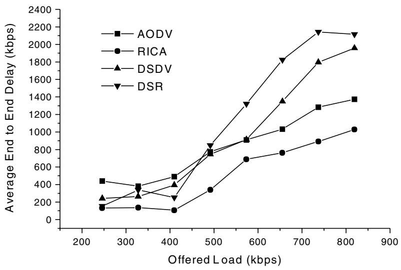


(c) 100 devices, 5 packets/sec

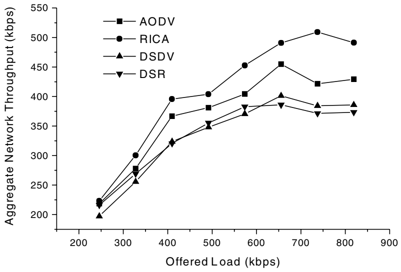


(d) 100 devices, 8 packets/sec

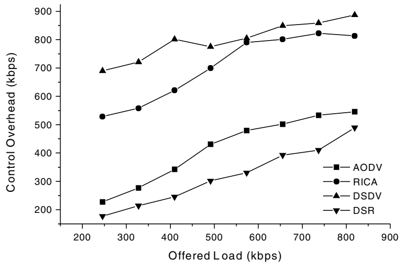
Fig. 3. Control overheads of all protocols.



(a) end-to-end delay



(b) throughput



(c) control overhead

Fig. 4. Scalability performance of all protocols under various levels of offered load for cases with 100 devices and 20 source-destination pairs.

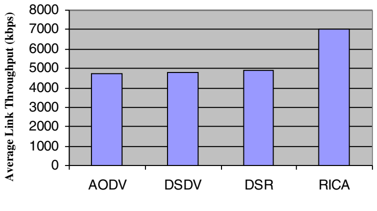


Fig. 5. Route quality.

routes stored in their roue caches and pass the information about these invalidated routes to the source. Using these invalidated routes by the source potentially leads to the drop of great amount of packet and more delay as source may need more time to reconstruct a valid route. This will be more obvious when the mobility and traffic load is high. In the worst case, DSR performs even poorer than DSDV. In terms of control overhead, DSR in fact is not so conservative. Note that we have not taken the source route in the header of each data packet into account. If we have considered these routing overheads, the amount of overheads by DSR might be comparable to that of AODV. Thus, which above analysis, DSR might not be so bandwidth-saving as it seems to be.

On the contrary, AODV has not so much access to the routing information as DSR, and thus, it has to resort to route recovery more often. AODV is a strong candidate protocol for ad hoc routing (to be standardized by IETF). However, there is still room for improvement. In AODV, the route selection is based on the smallest hop count. This may cause unfair burden on some intermediate devices, which might become the bottleneck of the network. Thus, load balancing cannot be achieved as in RICA.

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