CS525M Course Project Report An Extension of Rate-Adaptive MAC Protocol for NS2 Simulator

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Abstract— **The IEEE 802.11 wireless media access standard supports multiple data rates at the physical layer. Moreover, various auto rate adaptation mechanisms at the medium access layer have been proposed to utilize this multi-rate capability by automatically adapting the transmission rate to best match the channel conditions. However, there is little available simulation implementation available for the multi-rate adaptation research purpose. In this project, an extension of rate-adaptive MAC protocol based on the Receiver-Based Auto-Rate (RBAR) was developed to enable the multi-rate simulation in NS2 simulator. Related simulation results and performance evaluation such as rate adaptation, throughput, delay and etc. are also presented to validate the simulation module.**

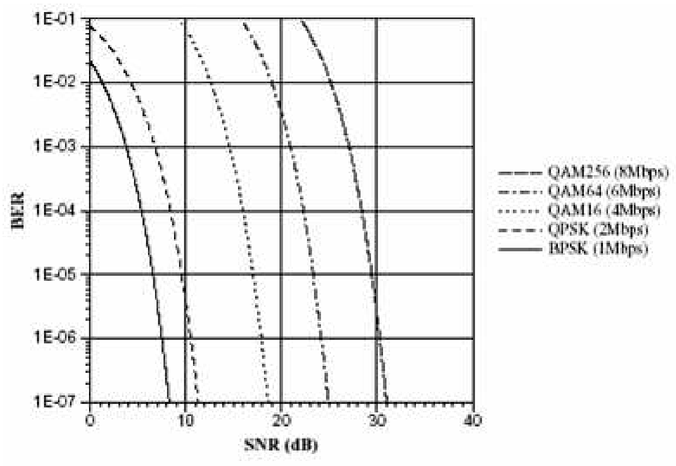

Fig. 1. BER and as a function of different SNR

I. Introduction

The IEEE 802.11 media access protocols provide supports of multi-rate physical-layer modulations. Related researches [1], [2] [3], [4] and [5] show that multi-rate adaption in IEEE 802.11 can improve the performance of WLAN significantly. Figure 1 [1] shows the relation between the bit error rate (BER) and signal-to-noise (SNR) for a several modulation schemes and data rate. For a given SNR, the modulation scheme with higher data rate has a higher BER. Therefore, by adapting the date rate with different modulation, we can achieve a low BER leading to a better performance.

The Auto Rate Fallback (ARF) protocol [5] was the first commercial implementation of a MAC that utilizes this feature. With ARF, senders attempt to use higher transmission rates after consecutive transmission successes (which indicate high channel quality) and revert to lower rates after failures. Under most channel conditions, ARF provides a performance gain over pure single rate IEEE 802.11.

In [1], a protocol termed Receiver Based Auto Rate (RBAR) is proposed. The core idea of RBAR is for receivers to measure the channel quality using physical-layer analysis of the request-to-send (RTS) message. Receivers then set the transmission rate for each packet according to the highest feasible value allowed by the channel conditions. As the RTS message is sent shortly before data transmission, the estimation of the channel condition is quite accurate, so that RBAR yields significant throughput gains as compared to ARF (as well as compared to single-rate IEEE 802.11). Moreover, as request- and clear-to-send messages are necessarily sent at the base rate so that all nodes can overhear them, overhearing nodes are informed of the modified data transmission times so that they can set their backoff timers accordingly.

The Opportunistic Auto Rate (OAR) protocol [3] was presented to better exploit durations of high-quality channels conditions. The key mechanism of the OAR protocol is to opportunistically send multiple back-to-back data packets whenever the channel quality is good. As channel coherence times typically exceed multiple packet transmission times for both mobile and non-mobile users, OAR achieves significant throughput gains as compared to state-of-the-art auto rate adaptation mechanisms.

However, those solutions of multi-rate adaption modules are not always public available in the wildly used network simulator - NS2. One of the available version of multi-rate simulation of OAR and RBAR is provided by [3] in NS2 2.1b7, which can be downloaded from Rice Networks Group webpage. [1] Since there had been many major changes after the NS2 2.1b7 release, such as timer, transmitting control, routing algorithm and etc., that early OAR and RBAR implementation are not fully compatible with the latest NS2 release. Therefore, a up-to-date multi-rate IEEE 802.11 MAC protocol simulation is needed for the research issues such as routing protocol [6], capacity estimation, performance [7], power consumption, streaming multimedia and etc.

According to previous researches, both RBAR and OAR protocols perform better than the ARF, however, since the OAR was implemented via IEEE 802.11 fragmentation, which is not the focus of the project, the algorithm chosen to be implemented in this project are developed based on the RBAR algorithm presented in [1].

II. RBAR PROTOCOL [2]

The core idea of RBAR is to allow the receiver to select the appropriate rate for the data packet during the RTS/CTS packet exchange. In RBAR, instead of carrying the duration of the reservation, the packets carry the modulation rate and size of the data packet. This modification serves the dual purpose of providing a mechanism by which the receiver can communicate the chosen rate to the sender, while still providing neighboring nodes with enough information to calculate the duration of the requested reservation.

Referring to Figure 2 [2], the sender Src chooses a data rate based on some heuristic (such as the most recent rate that was successful for transmission to the destination Dst), and then stores the rate and the size of the data packet into the RTS. Node A, overhearing the RTS, calculates the duration of the requested reservation D_{RTS} using the rate and packet size carried in the RTS. This is possible because all of the information required to calculate D_{RTS} is known to A. A then updates its NAV to reflect the reservation. While receiving the RTS, the receiver Dst uses information available to it about the channel conditions to generate an estimate of the conditions for the impending data packet transmission. Dst then selects the appropriate rate based on that estimate, and transmits it and the packet size in the CTS back to the sender. Node

[1] http://www-ece.rice.edu/networks/

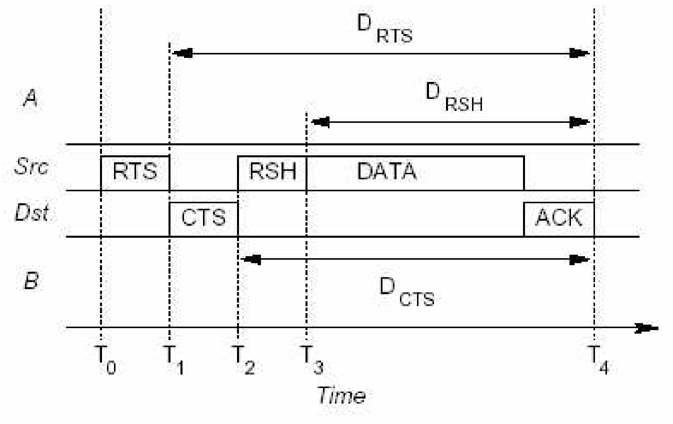

Fig. 2. Time line of RBAR Protocol

B, overhearing the CTS, calculates the duration of the reservation D_{CTS} similar to the procedure used by A, and then updates its NAV to reflect the reservation. Finally, Src responds to the receipt of the CTS by transmitting the data packet at the rate chosen by Dst.

In the instance that the rates chosen by the sender and receiver are different, then the reservation D_{RTS} calculated by A will no longer be valid. Thus, we refer to D_{RTS} as a tentative reservation. A tentative reservation serves only to inform neighboring nodes that a reservation has been requested but that the duration of the final reservation may differ. Any node that receives a tentative reservation with regard to treat it the same as a final reservation with regard to later transmission requests; that is, if a node overhears a tentative reservation it must update its NAV so that any later requests it receives that would conflict with the tentative reservation must be denied. Final reservation are confirmed by the presence or absence of a special subheader, called $ReservationSubHeader$ (RSH), in the MAC header of the data packet. The fields in the reservation subheader consist of a subset of the header field that are already present in the 802.11 data packet frame, plus a check sequence that serves to protect the subheader. The fields in the reservation subheader consist of only those fields needed to update the NAV, and essentially amount to the same fields present in an RTS. Furthermore, the fields (minus the check sequence) still retain the same functionality that they have in a standard 802.11 header. In the instance that the tentative reservation D_{RTS} is incorrect, Src will send the data packet with the special MAC header containing the RSH subheader. A, overhearing the RSH, will immediately calculate the final reservation D_{RSH}, and then update its NAV to account for the different between D_{RTS} and D_{RSH}. Note that, for A to update its NAV correctly, it must know what contribution D_{RTS} has made to its NAV. One way this can be done, is to maintain a list of the end times of each tentative reservation, indexed according to the $sender$ and $receiver$ pair. Thus, when an update is required, a node can use the list to determine if the NAV need to be changed.

III. NS2 Extension

As discussed in Section I, there was a earlier implementation [3] of RBAR in NS2 version 2.1b7. However, the latest NS2 release is version 2.27 and there are some related changes that may effects the compatibility of old implementation with the new release. The major 802.11 protocol related change was performed in version 2.25. [2] Those changes include:

- The new IEEE MAC-802.11 1999 standard defines a separate PLCP (Physical Layer Convergence Protocol) layer and PLCP header is requested to be transmitted at a fixed rate of 1 Mbps. The older version lack of the support for PLCP.
- The new standard also states that all nodes in a network must use a data rate from a set of what is called the basic data set, for transmitting their control packets (CTS, RTS and ACK). However, they may choose a different data rate for transmitting data packets. The old version didn't support the basic rate set.
- There are some other bug fixes. one is the length of time the MAC needs to wait before transmitting a data packet, which depends on whether CTS/RTS reservation is used or not.
- Packet header now have an additional field that have the transmission time for that packet.

Those changes make the behavior of 802.11 MAC different from the previous version, and become one of the major motivation of this project. Therefore, The new implementation in this project will be performed using the up-to-date release version of NS2.

A. Protocol Implementation

The algorithm of RBAR can be simplified as following pseudo code: [1]

$$\begin{array}{ll} M_1 & if SNR < \theta_1 \\ M_i & if \theta_i \leq SNR < \theta_{i+1}, \;\; i = 1, ..., N-1 \\ M_N & otherwise \end{array}$$

where M_i,...,M_N present the set of modulation schemes in increasing order of their data rate, and θ_i,...,θ_N present the SNR thresholds at which $BER(M_i) = 1E-5$.

Since the relationship of BER and SNR are not clearly defined in NS-2 simulation, the receiving power (Pr) and Pr thresholds are used instead of SNR and SNR thresholds in our implementation, while the Pr threshold (modulation sensitivity) are usually provide by the hardware vender in product specification documents.

[2] http://www.isi.edu/nsnam/ns/CHANGES.html

Parameter	Description
Frequency range	2400MHz to 2484MHz
Transmitter Power	15 dbm ± 2db
11 Mbps (CCK) Sensitivity	-82 dbm (6.310e-12 mw)
5.5 Mbps (CCK) Sensitivity	-87 dbm (1.995e-12 mw)
2 Mbps (DQPSK) Sensitivity	-91 dbm (7.943e-13 mw)
1 Mbps (DBPSK) Sensitivity	-94 dbm (3.981e-13 mw)
Carrier Sense Threshold	-108 dbm (1.585e-14 mw)
Capture Threshold	10
System Loss	0 dbm

TABLE I
Wireless card interface parameters

Therefore, the RBAR algorithm are implemented as following steps in NS-2 simulation. First, the simulated receiver will choose the data rate based on the Pr of receiving RTS packet and Pr threshold. Second, the receiver send that data rate to the sender in CTS packet. Finally, the sender will check the data rate field in CTS packets to decide the data rate of transmitting $DATA$ packet.

Since the latest version of NS-2 separates the basic rate and data rate and provides method to compute NAV time using data rate, our new version of RBAR doesn't need to consider the update for the NAV timer, which make the implementation easier than in previous version.

B. Physical Interface Parameters

As we descripted in section I, the NS2 default physical layer parameter are out of date, which was from old release of Lucent Wavelan card working at 900 MHz. To get more realistic simulation result, we want the most recent physical interface parameters. As the parameters used in [7], our physical layer parameters are from the hard specification of Lucent OriNOCO wireless PC card [3], which also listed in Table I.

Due to the 0 dbm system loss in the simulation's Two Ray Ground prorogation model, the transmission ranges obtained from simulation using those parameters are greater than the ranges listed in vender's data-sheet. However, those results confirm with the results in [7]. The transmission range for different modulations are listed in Table II. While as shown in Table III, the throughput from the simulation are lower than the throughput listed in vender's data-sheet. This maybe due to the detail imple-

[3] http://www.agere.com/client/wlan.html

Modulation	Vender's data	Simulation
11 Mbps (CCK)	160 m	399 m
5.5 Mbps (CCK)	270 m	532 m
2 Mbps (DQPSK)	400 m	670 m
1 Mbps (DBPSK)	550 m	796 m

TABLE II
TYPICAL RANGE IN OPEN ENVIRONMENT

Modulation	Vender's data	Simulation
11 Mbps (CCK)	5.04 Mbps	3.56 Mbps
5.5 Mbps (CCK)	3.44 Mbps	2.66 Mbps
2 Mbps (DQPSK)	1.59 Mbps	1.42 Mbps
1 Mbps (DBPSK)	0.82 Mbps	0.82 Mbps

TABLE III
TYPICAL THROUGHPUT IN OPEN ENVIRONMENT

mentation and/or optimization are different from the what implemented in NS2, and there have been many discussions about the latest version NS2's low throughput problems in NS mailing list [4].

IV. VALIDATION

In order to validate our RBAR implementation, we performed two set of validations for both fading and mobility effects and compared the RBAR performance with the single rate MAC protocols. However, since the physical layer parameters and the NS-2 version are different from the old implementation, we didn't compare the absolute value of of the result.

A. Fading Simulation

The fading model used in our simulation are Ricean Fading described in paper [8]. The implementation in NS2 can be download from CMU's website [5].

The distance between two fixed nodes is set to 390 meters, which was selected to be able to setup connections for all single rate MAC protocols. Since the receiving power sensitivity gets higher as the capacity of the modulation increases, we pick a distance smaller and close to the shortest sensitivity range as the simulated distance, which is from 11 Mbps single rate protocol.

The receiving power oscillation caused by the Ricean Fading model is shown in Figure 3. As the receiving power changed, each RTS/CTS exchange will cause a channel capacity re-negotiation. The result of capacity in channel is shown in Figure 4.

[4]http://www.isi.edu/nsnam/ns/ns-lists.html
[5]http://www.ece.cmu.edu/wireless/downloads.html

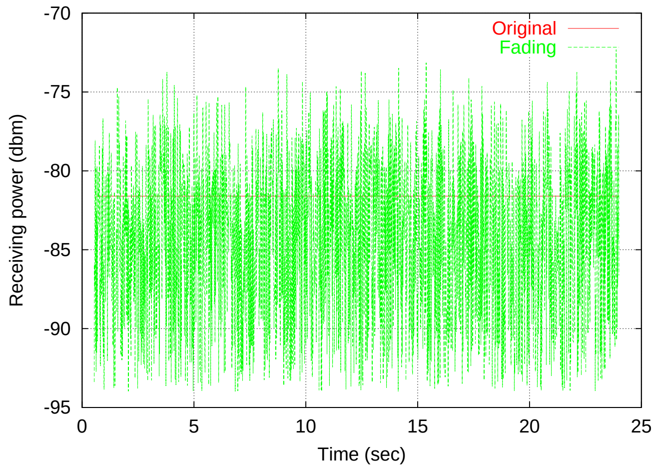

Fig. 3. Simulated fading effects in wireless channel

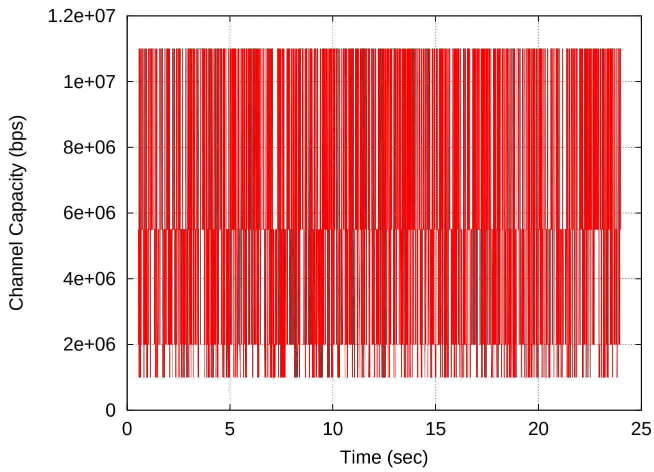

Fig. 4. Multirate adaptation in fading channel

Figure 5 compares the CBR throughput of BRAR with single rate MAC protocols, which are 1 Mbps, 2 Mbps, 5.5 Mbps and 11 Mbps. The throughput is the average CBR throughput in 1 second time period. As we expected, the RBAR get the highest throughput in a fading channel. However, the 11 Mbps MAC protocol performs poorly than we expected. It could be caused by the distance of 390 meters, which is close to the max sensitivity range of the 11 Mbps MAC protocol and fading may cause greater effects than in other cases. However, this is correct in practice because the high data rate modulation schemes usually request higher SNR value than the lower data rate modulation. Therefore, fading may cause greater impact on the modulations with higher data rate than those with a lower data rate.

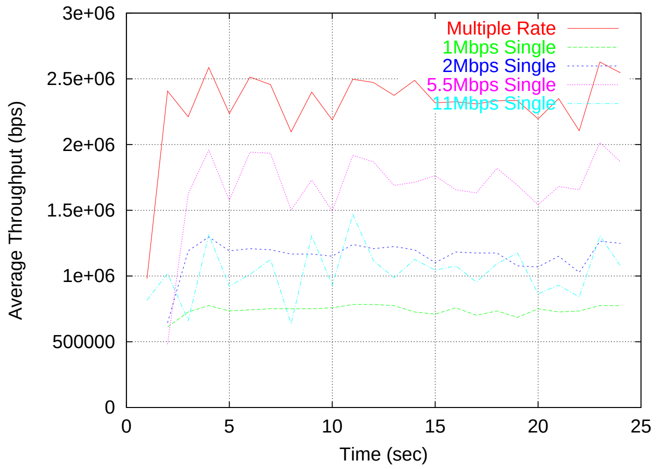

Fig. 5. Throughput comparison in fading channel

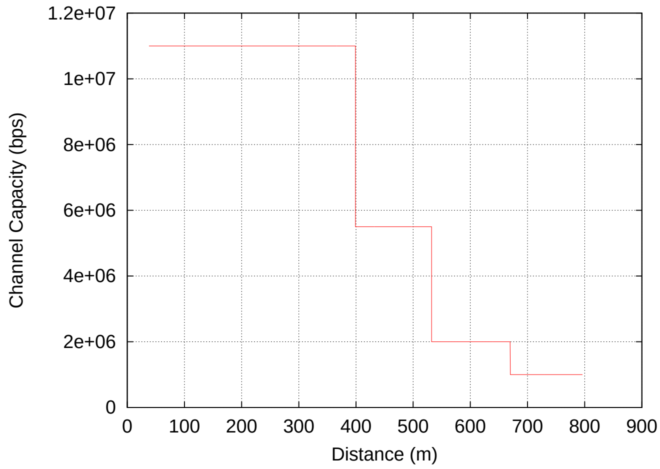

Fig. 7. Channel capacity reduced as distance increases

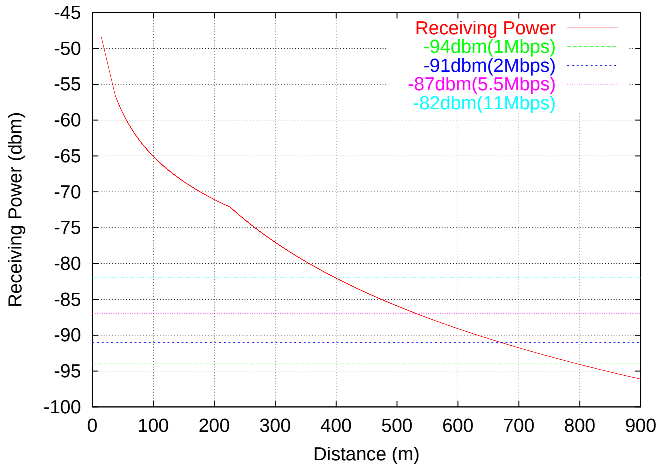

Fig. 6. Receiving power reduced as distance increases

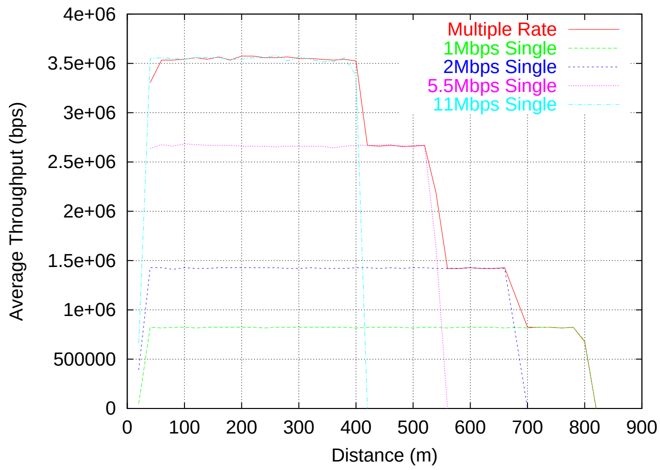

Fig. 8. Throughput comparison as distance increases

B. *Mobility Simulation*

In out mobility simulations, we set up a 1000 meter * 1000 meters flat topology with one node moving away from the other node. The distance between two nodes is from 0 meter up to 1000 meters. The moving speed is 20 m/s and the simulation time is 50 seconds.

Figure 6 depicts the receiving power changes as the distance between two nodes increases. The horizontal lines in the figure present the sensitivity thresholds for different modulation schemes. As the receiving power lower than one threshold, the RBAR will switch to another modulation scheme if possible, while the single rate protocol that has the particular threshold will loss the channel connection. Figure 7 present the modulation (capacity) switching of RBAR protocol in a mobility simulation.

Figure 8 compares the CBR throughput of BRAR with single rate MAC protocols, which are 1 Mbps, 2 Mbps, 5.5 Mbps and 11 Mbps. The throughput is the average CBR throughput in 1 second time period. RBAR protocol get the highest throughput in the mobility simulation. And after the receiving power lower than the 1M bps threshold, all MAC protocols lose the connections.

V. Summary

A multi-rate adaption IEEE 802.11 MAC protocol was implemented as an extension of NS2 simulator version 2.27. By comparing the state-of-art mechanisms in multi-rate adaption area, the receiver-based auto-rate (RBAR) was selected to be implemented as the multi-rate adaption simulation module. With the up-to-date physical layer parameters and implementation in latest version of NS2, the multi-rate adaption MAC protocol could be used as a reliable and flexible tool for future WLAN research.

Furthermore, fading and mobility simulation of RBAR project are used to validate the new module implementation.

The possible future work may include further validation in more complex simulation environment, such as complex topology, ad hoc routing and etc. Also, this implementation could be used as a platform to carry on other related research, such as routing optimization, performance improvement, etc.

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