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Channel Aware MAC Protocol with Rate Adaptation for MANET

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Abstract – **In Mobile Adhoc networks there will be a transient nature of channel conditions. Rate control is the process of switching data rates dynamically based on channel conditions. We propose a rate adaption algorithm. The channel condition information is given as the input to the Rate selection algorithm. Now with the channel condition information, each node uses the rate selection algorithm to calculate the most energy-efficient setting of PHY rates for all links in its maximum interference range.**

Keywords: **MAC Protocol, Rate Adaptation, MANET**

I. INTRODUCTION

Wireless ad-hoc network is a set of wireless mobile nodes dynamically self organizing a temporary network without any central administration or existing network infrastructure. The node in the wireless ad-hoc network can provide as routers and hosts. Hence they can forward packets for other nodes if they are on route from source to destination. In wireless communications, rate adaptation is a mechanism for the sender to determine an appropriate data transfer rate to use the channel to the maximum extent. A set of nodes that can communicate with each other devoid of well-known infrastructure or centralized control is termed as multihop mobile ad hoc networks. Due to the transient nature of channel conditions, such a mechanism must be responsive to the changes with a small overhead. Traditional working protocols cannot work well in wireless ad-hoc network because of the characteristics of the wireless ad-hoc networks. Since, mobile nodes have limited transmission capacity they mostly intercommunicate by multihop relay [1][2][5].

A. Rate Adaptation

Rate control is the process of switching data rates dynamically based on channel conditions, with the target of selecting the rate that will provide the maximum throughput feasible for a given channel condition. This mechanism has been shown to improve the performance of wireless networks, which suffer from fading and interference. Channel estimation and the rate selection can be considered as the two major components of the rate adaptation process. Rate selection involves using the channel quality predictions to select an appropriate rate. A common technique for rate selection is threshold selection, where the value of an indicator is compared against a list of threshold values representing boundaries between the data rates. In practice data transmission rates can be varied by different modulation schemes and/or coding techniques. The effectiveness of rate adaptation depends on the accuracy of the channel quality estimates [1].

B. Challenges and Issues in Rate Adaptation

The rate adaptation is not part of the IEEE 802.11 Specifications; the design of these mechanisms varies considerably. Depending on the scope of information that a sender uses to make the decision on rate selection, these mechanisms are usually divided into two categories, open loop and closed loop. In an open loop approach, the sender makes the decision solely based on its own perception, such as the outcome of a previous DATA transmission or the reception quality of an ACK. In a closed loop design, the sender explicitly solicits the receiver to estimate the channel condition and to feed this information back to the sender to select an appropriate data rate. Most previous work relies only on frame losses to infer channel quality, but performs poorly if frame losses are mainly caused by interference. Many existing algorithms make the rate selection decision based on the frame losses. But it is very difficult to distinguish losses due to collision from losses due to channel error. The joint design of power control and rate adaptation to achieve energy efficiency is especially challenging in an IEEE 802.11 multihop network. This is because the inequality of channel access in multihop networks can result in severe overall energy inefficiency [4][3][5].

II. Related Work

Jiansong Zhang *et al.,* in paper [3], they first conduct a systematic measurement-based study to confirm that in general SNR is a good prediction tool for channel quality, and identify two key challenges for this to be used in practice: (1) The SNR measures in hardware are often uncalibrated, and thus the SNR thresholds are hardware dependent. (2) The direct prediction from SNR to frame delivery ratio (FDR) is often over optimistic under interference conditions. Based on these observations, they present a novel practical SNRGuided Rate Adaptation (SGRA) scheme.

Kun Wang *et al.,* in paper [4], have studied the problem of using the rate adaptation technique to achieve energy efficiency in an IEEE 802.11-based multihop network. They formulate it as an optimization problem, i.e., minimizing the total transmission power over transmission data rates, subject to the traffic requirements of all the nodes in a multihop network. This problem is actually a well-known multiple choice knapsack problem, which is proven to be an NP-hard problem. Therefore, instead of finding an optimal solution, which is NP-hard, they seek a suboptimal solution. The key technique to attack this problem is distributed cooperative rate adaptation (CRA). Here, they promote node cooperation due to our observation that the inequality in noncooperative channel contention among nodes caused by hidden terminal phenomenon in a multihop network tends to result in energy inefficiency. Under this design philosophy, they propose a distributed CRA scheme and prove that it converges.

Yuanzhu Peter Chen *et al.,* in paper [5] have proposed a rate adaptation scheme that combines the advantages of the open-loop and the closed-loop approaches, called Differential Rate Adaptation (DRA). In particular, they use a single RTS/CTS exchange between a given sender-receiver pair to lead multiple DATA/ACK dialogs in the sequel. Each ACK contains in its header a bit to indicate the sender if the next higher data rate is recommended or not according to the reception of the previous DATA frame. Use of this feedback to the sender also provides a precision tolerance of the earlier channel quality estimation via RTS/CTS. Such a design follows a similar rationale of the Explicit Congestion Notification (ECN) as the TCP/IP architecture. The benefit of doing so is to avoid undesired outcomes before they happen rather than recovering from bad situations after they have occurred. In case of a lost DATA frame, the retransmit may be done at a lower rate.

Abhrajit Ghosh *et al.,* in paper [6] have described a communication middleware system: QoS-aware Adaptive Middleware (QAM) that shields distributed application developers from the complexities of tactical MANETs. QAM resolves the problem of bandwidth contention between multi-priority applications by providing an adaptive, priority aware, middleware layer that acts as an intermediary between an application and the network protocols it uses. QAM adapts to current network conditions by providing a reliable data transfer mechanism that is capable of adapting data transfer rates in response to changing network conditions. The adaptations performed by QAM attempt to limit the use of network bandwidth by applications when network bandwidth is diminished. Moreover, QAM limits network use more aggressively for lower priority applications than for higher priority applications, thus giving preferential treatment to the latter.

Ari Raptino H *et al.,* in paper [7] considers the secondary user (SU) multi-rate multi-hop impact under the temporal dynamic aspect of OSA. Firstly, we investigate the SU multi-rate transmission and number of hops impact under the temporal dynamic aspect of OSA. The observed metrics include both SU and PU performance. Numerical analysis and simulation results show the existence of multi-rate and multi-hop diversity. To obtain the optimal performance, the balance between high enough transmission rate and few enough number of hops is essential. Secondly, according to the multi-rate multi-hop investigation, they propose a rate adaption scheme with PU activity consideration, called Auto Rate Increase (ARI). ARI is based on the Auto Rate Fallback (ARF) scheme with the aims to select the best transmission rate under limited PU idle duration. ARI also adopts ARF simplicity, hence, there is no need for any prior nor additional knowledge of the networks environment.

III. Proposed Work

A. Overview

In our first work, we propose an interference reduction technique for MANET to improve the throughput using mathematical prediction filters. The technique used Hidden Markov Model (HMM) for predicting the interference of the nodes and then adjusting the transmission power values. In the second work, we propose a fairness mechanism in the MAC protocol which will increase the throughput further and achieve fair channel utilization. The proposed technique consists of estimating channel condition and queue level based on which the channel is fairly allocated to all the nodes. Based on the outcome of the above two works, we propose a rate adaptation mechanism as the third work. Here the rate selection is done on two parameters: Interference and channel condition. The channel condition information from our second work is given as input to the rate selection algorithm and node cooperation algorithm. Now with this information, each node uses the rate selection algorithm to calculate the most energy-efficient setting of PHY rates for all links in its maximum interference range. Then the power consumption is calculated using our first work.

B. System Design

1. Channel Condition

In this approach the end to end channel quality is represented in the form of path lifetimes. The channel state keeps changing continuously hence the end to end path will be valid for a temporary period of time. The term path lifetime is used to define the time interval for which the path associated for a flow is valid or exists. Suppose the lifetime of each and every link of path P from node i to node j is estimated as l1, l2, ... , ln, then the path lifetime is given by;

$$Pij = \min(l1, l2, \ldots, ln)$$

2. Rate Selection Algorithm

For each and every node the problem is decomposed into subproblems, a subproblem at each node is in essence still a multichoice knapsack problem, which is NP hard. The solution to this subproblem and the design of the rate selection algorithm is as given below.

Step 1: Set the PHY rate for each link in A's maximum interference range to the highest value as the initial setting.

Step 2: For each link within A's maximum interference range, select a PHY rate that has the largest $\Delta E/\Delta T$ where ΔE denotes energy reduction and ΔT denotes the channel time increase, as compared to the current setting. Then choose the link that has the largest $\Delta E/\Delta T$ among all the links within A's maximum interference range. Note that ΔE should be greater than 0, if we cannot find a setting that could result in $\Delta E>0$ the algorithm ends.

Step 3: Check whether the new PHY rate of the link is feasible by the below equation (1), if it is feasible select the new rate selection, otherwise reset to the previous setting.

$$\sum_{(x,y)\epsilon S} Channel\ Time_{(x,y)}(R(x,y)) \leq 1 \quad (1)$$

Where S ε {all max cliques in the conflict graph}

Step 4: Go to step 2

Here we assume node A uses the rate selection algorithm to calculate the most energy efficient setting of PHY rates for all the links in its maximum interference range.

If there are P available PHY rates, and we index them from 0 to P − 1 in the descending order, i.e., rate 0 corresponds to the highest rate while rate P − 1 corresponds to the lowest rate. If link l switches its rate from x to y, we define the benefit (power consumption reduced over channel time increased) of such switching as "benefit ratio" of replacing rate x with y on link l, which is defined by

$$benefit_{ratio(l,x,y)} = \begin{cases} \dfrac{power_{consumption(l,x)} - power_{consumption(l,y)}}{channe_{time(l,y)} - channel_{time(l,x)}}, & x \neq y \\ 0, & x = y \end{cases} \quad --(2)$$

The channel time needed for satisfying the traffic requirements on l under rate x is given by channel_time (l, x). the channel_time can be calculated by the equation (3).

2.1 Relationship between Channel Time and PHY Rate:

Now the desired channel (access) time is characterized for satisfying the traffic requirements as a function of the PHY rate. The channel time means that the fraction of a second used by a successful RTS/CTS/DATA/ACK exchange between a source and a destination. According to IEEE 802.11 standard, the channel time used by link (s, d) can be derived as follows:

$$channel\ time_{(i,j)}\left(R(i,j)\right) = \frac{\lambda(i,j)}{packet_{size}}.T \qquad (3)$$

Where

$$T = \left(t_{DIFS} + t_{RTS} + 2t_{SIFS} + t_{SIFS} + t_{CTS} + t_{DATA}\left(R(i,j)\right) + t_{ACK}\right) \qquad (4)$$

Where,

The minimum traffic requirement on link (s, d) is represented by λ(s, d), and current PHY rate on link (s, d) is represented by R(s, d) .

The power consumption on l under rate x is represented as power_consumption (l,x) and is calculated by the equation (5);

$$En_{(i,j)}\left(R(i,j)\right) = \frac{\lambda(i,j)}{packet_{size}}.B \qquad (5)$$

where

$$B = \left[K_t(basic_{rate}).(t_{RTS} + t_{CTS} + t_{ACK}) + K_t\left(R(i,j)\right).t_{DATA}\left(R(i,j)\right)\right] \qquad (6)$$

Using the aforementioned signal attenuation model, the transmission power of a source to the PHY rate is related as follows:

$$K_t\left(R(i,j)\right) = \frac{K_Y\left(R(i,j)\right).dist(i,j)^p}{c} \qquad (7)$$

2.2 Signal Attenuation Model

The signal attenuation model defines the mapping from the transmission power K_T of source to the receiving power K_Y of destination.

$$K_Y = c.\frac{K_t}{d^p} \qquad (8)$$

Where d is the geographical distance between source and destination, and both c and p are constants, which are determined by environments.

The channel time and power consumption of each PHY rate on link l corresponds to a point on the plane in the fig (1). benefit_ratio (l, x, y) is the absolute value of the slope of the line between the point for rate x and the point for rate y. It is the ratio of the power consumption reduction to the increased channel time when replacing rate x with rate y on link l.

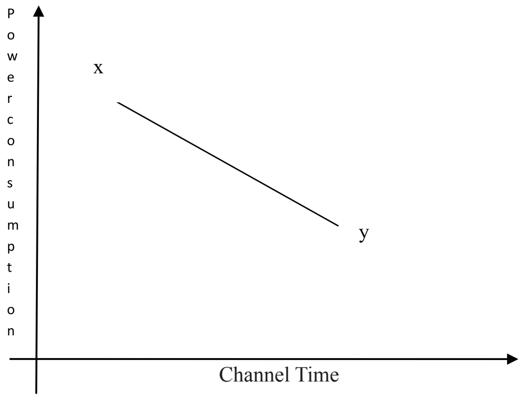

Fig.1 The channel time and power consumption

2.3 Estimation of Received Signal Power

From our previous paper the Received signal power of a node can be calculated as, [18]

$$r_p = t_p \times d^{-4} \times G^2 \times h^2 \times 10^{\tau/10} \qquad (9)$$

Whereas, r_p is the received power,

t_p is the transmitted power,

d represents distance between any two nodes,

G denotes node's omnidirectional antenna gain,

h is the height of the antenna,

τ indicates shadowing component of Gaussian random variable with zero mean and standard deviation of σ db.

2.4 Advantages

- Based on the interference and the channel condition the Rate adaptation is carried out.
- Due to the rate adaptation the power consumption is reduced.

IV. SIMULATION RESULTS

A. Simulation Parameters

We evaluate our Channel Aware Rate adaptation MAC protocol (CARAMAC) through NS-2 [7]. We use a bounded region of 1000 x 1000 sqm, in which we place nodes using a uniform distribution. The number of nodes is 100. We assign the power levels of the nodes such that the transmission range of the nodes is 250 meters. In our simulation, the channel capacity of mobile hosts is set to the same value: 2 Mbps. We use the distributed coordination function (DCF) of IEEE 802.11 for wireless LANs as the MAC layer protocol. The simulated traffic is Constant Bit Rate (CBR).

TABLE I SIMULATION PARAMETERS USED

No. of Nodes	100.
Area Size	1000 X 1000
Mac	802.11
Simulation Time	50 sec
Traffic Source	CBR
Packet Size	500
Transmit Power	0.660 w
Receiving Power	0.395 w
Idle Power	0.035 w
Initial Energy	10.3 J
Transmission Range	250m
Routing Protocol	AODV
Flows	2, 4, 6 and 8.
Rate	250,500,750 and 1000Kb

B. Performance Metrics

We compare the performance of our proposed CARAMAC with DRA technique [5]. We evaluate mainly the performance according to the following metrics:

Received Bandwidth: It is the number of bits transmitted to the destination through the channel.

Packet Lost: It is the number of packets dropped during the transmission.

Delay: It is the amount of time taken by the packets to reach the destination.

1. Based on Flows

In our experiment we vary the number of CBR traffic flows as 2, 4, 6 and 8.

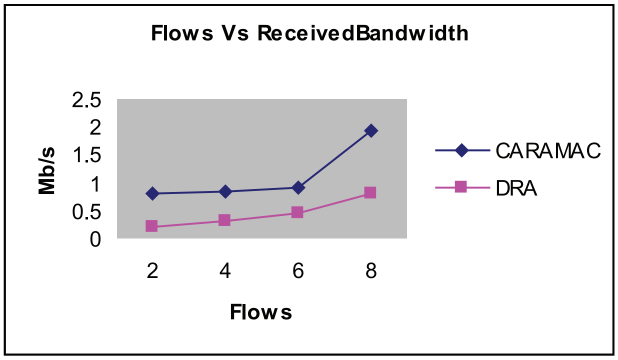

Fig.2 Flows Vs Received Bandwidth

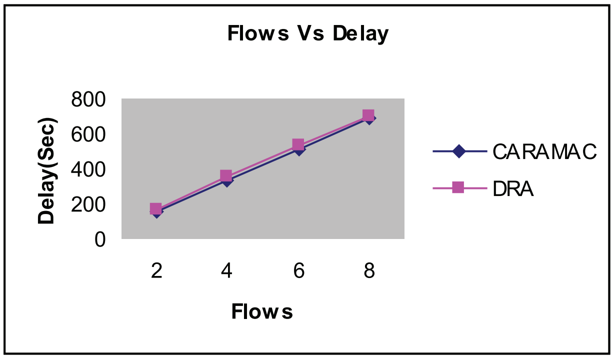

Fig.3 Flows Vs Delay

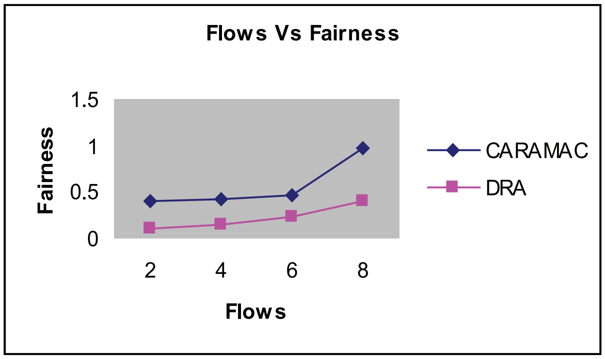

Fig.4 Flows Vs Fairness

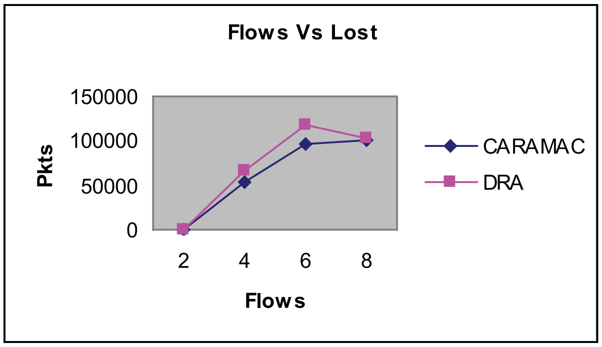

Fig.5 Flows Vs Lost

From figure 2, we can see that the received bandwidth of our proposed CARAMAC is higher than the existing DRA technique.

From figure 3, we can see that the delay of our proposed CARAMAC is less than the existing DRA technique.

From figure 4, we can see that the fairness of our proposed CARAMAC is higher than the existing DRA technique.

From figure 5, we can see that the packet lost of our proposed CARAMAC is higher than the existing DRA technique.

2. Based on Rate

In our second experiment we vary the transmission rate as 250,500,750 and 1000Kb.

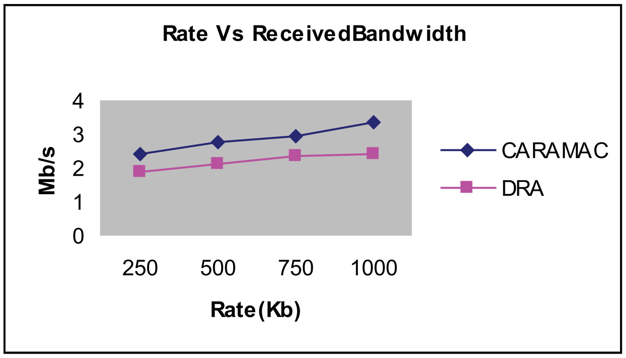

Fig.6 Rate Vs Received Bandwidth

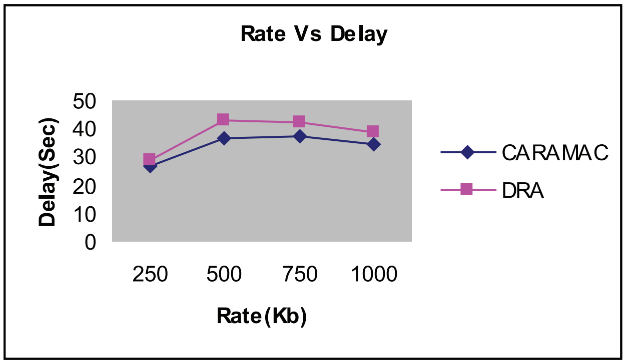

Fig.7 Rate Vs Delay

From figure 6, we can see that the received bandwidth of our proposed CARAMAC is higher than the existing DRA technique.

From figure 7, we can see that the delay of our proposed CARAMAC is less than the existing DRA technique.

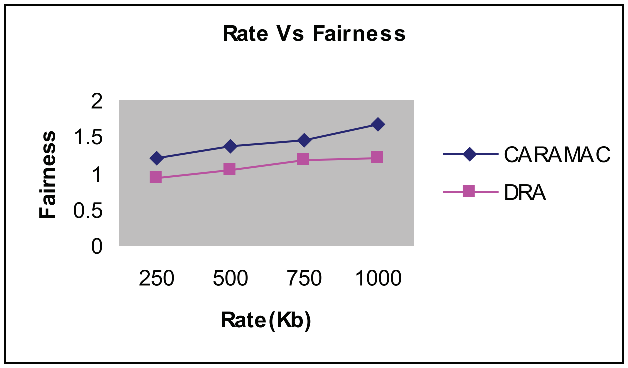

Fig.8 Rate Vs Fairness

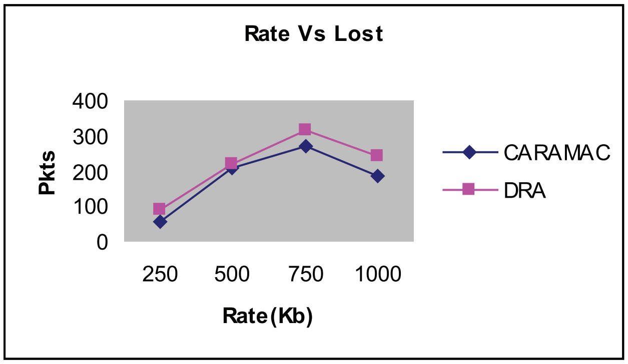

Fig.9 Rate Vs Lost

From figure 8, we can see that the fairness of our proposed CARAMAC is higher than the existing DRA technique.

From figure 9, we can see that the packet lost of our proposed CARAMAC is higher than the existing DRA technique.

V. CONCLUSION

In this paper we have proposed a rate selection algorithm. The channel condition information is given as the input to the Rate selection algorithm. Now with the channel condition information, each node uses the rate selection algorithm to calculate the most energy-efficient setting of PHY rates for all links in its maximum interference range. The advantages of this paper are that based on the interference and the channel condition the Rate adaptation is carried out. Due to the rate adaptation the power consumption is reduced.

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