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Data Rate Control Algorithm for MAC Protocol in 802.11 Multi Hop Ad Hoc Networks.

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Abstract - Medium access control (MAC) protocol plays an important role in providing fair and efficient allocation of limited bandwidth in wireless LANs. In IEEE 802.11 standard protocol, data rate selection is not specified. 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. The two major components of rate control process are Channel estimation and rate selection. Although rate control has been studied extensively for wired networks, these results cannot be directly applied to multihop wireless networks. In this paper, we propose to develop A Data Rate Control Algorithm (DRCA) which is based on the channel state conditions. We also follow a two level channel estimation one at the receiver end and another at each intermediate node along the path. By simulation results we show that our proposed DRCA.

Index Terms - Ad hoc Network, Data Rate, Multihop routing, Routing Authentication, Routing Protocols, Security Service, Throughput, wireless, Wireless Network.

1. INTRODUCTION

1. 1. Multi Hop Ad Hoc Networks

A multi hop wireless ad hoc network is a self-configuring infrastructure less network of mobile devices connected by wireless links. ad hoc is Latin and means "for this purpose". Each of these nodes is a wireless transceiver that transmits and receives at a single frequency band which is common to all the nodes. These nodes can communicate with each other however they are limited by their transmitting and receiving capabilities. Therefore, they cannot directly reach all of the nodes in the network as most of the nodes are outside of direct range. In such a scenario, one of the possibilities for the information transmission between two nodes that are not in position to have a direct communication is to use other nodes in the network. To be precise, the source device transmits its information to one of the devices which is within transmission range of the source device. In order to overcome this, the network operates in a multihop fashion. Nodes route traffic for each other. Therefore, in a connected ad hoc network, a packet can travel from any source to its destination either directly, or through some set of intermediate packet forwarding nodes [1]. In multi-hop ad hoc networks, high packet loss rate, re-routing instability and unfairness problems may be caused as the stations may pump more traffic into the networks than can be supported. In case of a traffic flow from a source node to a destination node in a multi-hop network, when the traffic flow is forwarded, the nodes in the middle of the path have to deal with additional nodes. When lighter contention is experienced, the source node may inject more traffic into the path than what the later nodes can forward. Excessive packet losses and re-routing instability may be caused as an outcome. In the presence of multiple flows, when some flows experience higher contention than other flows, inequality may arise as well [2].

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1. 2. IEEE 802.11 Standards

IEEE 802.11 is likely to play an important role in the next generation of wireless and mobile communication systems. Originally, IEEE 802.11 DSSS (Direct Sequence Spread Spectrum) offered only two physical data rates. All transmission was done at either the 1Mbps or the 2Mbps rate. In 1999, the IEEE defined two high rate extensions

- 802.11b based on DSSS technology, with data rates up to 11Mbps in the 2.4GHz band
- 802.11a based on OFDM (Orthogonal Frequency Division Multiplexing) technology, with data rates up to 54 Mbps in the 5GHz band.

In 2003, the 802.11g standard that extends the 802.11b PHY layer to support data rates up to 54 Mbps in the 2.4 GHz band was finalized [method3].

1. 3. Rate Control in Ad Hoc Networks

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.

Channel quality estimation involves measuring the time varying state of the wireless channel for the purpose of generating predictions of future quality. Issues include: which metrics should be used as indicators of channel quality (e.g., signal-to-noise ratio, signal strength, symbol error rate, bit error rate), which predictors should be used, whether predictions should be short-term or long-term, etc. Hence following two issues are essential in the channel estimation process

- Identifying metrics to be used as indicators of channel quality. For instance SNR, signal strength, symbol error rate, BER.
- Algorithms to be used for channel prediction.

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. Modulation is the process of translating an outgoing data stream into a form suitable for transmission on the channel. It involves transforming the data stream into a sequence of symbols. Each symbol may encode a number of bits depending on the modulation scheme used. The symbol sequence is then transmitted at a certain rate, the symbol rate, such that the data rate is determined by the number of encoded bits per symbol for a given symbol [journal, mobicom].

Although rate control has been studied extensively for wired networks, these results cannot be directly applied to multihop wireless networks. In wired networks, the capacity of each link is fixed. In wireless networks, however, the capacity of each link is a function of the underlying schedule used at each time. Past works on rate control in wireless networks either consider only single-hop flows or impose simplified assumptions on a restrictive set of scheduling policies. Hence, these works have not fully exploited the benefit of multihop communication and joint multi-layer control [2822].

The effectiveness of rate adaptation depends on the accuracy of the channel quality estimates. Furthermore, once good estimates are generated, it is important to use them before they become outdated. Therefore, it is also advantageous to minimize the delay between the time of the channel estimate and the time the packet is transmitted with the selected data rate [journal, mobicom].

1. 4. Rate control in Medium Access Control and its types

The multi rate features are provided by the physical layer of the protocol architecture. To exploit the full potential of multi rate transmissions, MAC layer of the protocol architecture should also be adapted to different transmission rates. A number of rate adaptive MAC layers suited to 802.11 multi rate physical layers have been proposed in the last decade [journal].

A. Auto Rate Fallback (ARF) - ARF was the first commercial 802.11 based MAC layer that supports the multiple transmission rates. It was designed to optimize the application throughput in devices, which implemented the 802.11 DSSS standard. In ARF, each sender attempts to use a higher transmission rate after a fixed number of successful transmissions at a given rate and switches back to a lower rate after one or two consecutive failures. Specifically, the original ARF algorithm decreases the current rate and starts a timer when two consecutive transmissions fail in a row. When either the timer expires or the number of successfully received per packet acknowledgments reaches 10, the transmission rate is increased to a higher data rate and the timer is reset. When the rate is increased, the first transmission after the rate increase must succeed or the rate is immediately decreased and the timer is restarted rather than trying the higher rate a second time. This scheme suffers from two problems

- If the channel conditions change very quickly, it cannot adapt effectively. For example, in an ad hoc network where the interference bursts are generated by other 802.11 packet transmissions, the optimum rate changes from one packet to the next. Because ARF requires 1 or 2 packet failures to decrease its rate and up to 10 successful packet transmissions to increase it, it will never be synchronized with the sub-packet channel condition changes.
- If the channel conditions do not change at all, or change very slowly, it will try to use a higher rate every 10 successfully transmitted packets. This results in increased retransmission attempts and thus decreases the application throughput.

B. RBAR - RBAR is the only other available rate adaptation algorithm whose goal is to optimize the application throughput. This algorithm requires incompatible changes to the IEEE 802.11 standard. The interpretation of some MAC control frames is changed and each data frame must include a new header field. The RBAR algorithm mandates the use of the RTS/CTS mechanism. A pair of Request called To Send and Clear To Send control frames are exchanged between the source and the destination nodes prior to the start of each data transmission. The receiver of the RTS frame calculates the transmission rate to be used by the upcoming data frame transmission based on the Signal to Noise Ratio (SNR) of the received RTS frame and on a set of SNR thresholds calculated with an a priori wireless channel model. The rate to use is then sent back to the source in the CTS packet. The RTS, CTS, and data frames are modified to contain information on the size and rate of the data transmission to allow all the nodes within the transmission range to correctly update their Network Allocation Vector (NAV). This protocol suffers from numerous flaws that are summarized below

- The threshold mechanism used in each receiver to pick the best possible rate requires a calculation of the SNR thresholds based on an a priori channel model.
- The algorithm assumes that the SNR of a given packet is available at the receiver, which is not generally true.
- The RTS/CTS protocol is required even though no hidden nodes are present.
- The interpretation of the RTS and CTS frames and the format of the data frames are not compatible with the 802.11 standard.

C. Opportunistic Auto Rate (OAR) - The key idea of OAR is to opportunistically exploit high quality channels when they occur through transmission of multiple back-to-back packets. In particular, when the multi rate MAC indicates that the channel quality allows transmission above the base rate, OAR grants channel access for multiple packet transmissions in proportion to the ratio of the achievable data rate over the base rate. Consequently, OAR nodes transmit more packets under high quality channels than under low quality channels. However, OAR cannot arbitrarily favor flows with the best channel quality, as access for flows with perhaps perpetually bad channels must also be ensured. OAR also ensures that all flows are granted the same temporal share of channel access under OAR as under single rate IEEE 802.11. OAR can provide flows with dramatically different throughputs as dictated by their channel conditions, but all flows will achieve approximately identical time shares. Some of its disadvantages are

- OAR requires a multi rate MAC protocol such as RBAR or ARF to access the medium at rates above the base rate. While OAR can be applied to both sender and receiver based protocols.
- OAR requires a mechanism to hold the channel for an extended number of packet transmissions when a high rate channel is provided by RBAR [[7]9960].

1. 5. Metrics to be Analyzed

While evaluating an MAC protocol for a wireless mobile ad hoc network, the following performance measures should be considered

- ✓ **Throughput** - Throughput is generally measured as the percentage of successfully transmitted radio link level frames per unit time.
- ✓ **Transmission delay** - It is defined as the interval between the frame arrival time at the MAC layer of a transmitter and the time at which the transmitter realizes that the transmitted frame has been successfully received by the receiver.
- ✓ **Fairness** - Generally, fairness measures how fairly the channel allocation is among the flows in the different mobile nodes. The node mobility and the unreliability of radio channels are the two main factors that impact fairness.
- ✓ **Energy** efficiency - Generally, energy efficiency is measured as the fraction of the useful energy consumption (for successful frame transmission) to the total energy spent [8].
- ✓ **Packet Error Rate** - The packet error rate is generally calculated by the bit error rate (BER) and the packet length. The receiver estimates the SNR for the RTS packet and gets the BER with a transmission rate by the equations derived from an analytical model [[9]1933].

In our previous work we have proposed a cross layer based MAC protocol to completely utilize the channel bandwidth and increase the fairness of each flow without causing congestion. In our protocol, available bandwidth along each path of the source and destination pair was estimated based on a probing technique. The destination node would have sent probe packets to the source node so that the source node could estimate the available bandwidth and contention between them. Then the source would select the paths that have enough bandwidth and the least contention, using a multipath routing protocol. In addition to this, a centralized flow scheduler was designed to overcome the overheads and drawbacks of the IEEE 802.11. This scheduler schedules the flows instead of nodes. As an extension to our previous work, we propose a data rate control mechanism for MAC protocol in 802.11 multi-hop ad hoc networks.

2. Related Work

Masaki Bandai et al. [10vtc] have proposed a novel medium access control (MAC) protocol with transmission power and transmission rate control in multi rate ad hoc networks in order to realize high energy efficient data transmission. In their proposed protocol, each node prepared a table that included energy efficiency in all combinations of transmission power and rate. In their protocol they have used direct and relay transmission sequences randomly by exchanging control frames and looking up the transmission power and rate table. They have adopted the relay sequence instead of direct transmission, when relay transmission by intermediate node between sender and receiver was more effective in terms of power consumption.

Yuanzhu Peter Chen et al. [11DRA] have proposed a feedback mechanism called DRA (Differential Rate Adaptation), which was a rate adaptation scheme for IEEE 802.11 networks. Their DRA have used a single RTS/CTS exchange between a given sender-receiver pair to lead multiple DATA/ACK dialogs in the sequel. Each of their ACK contained in its header, a bit to indicate the sender if the next higher data rate was recommended or not according to the reception of the previous DATA frame. Their DRA have enabled a high network throughput by adaptively tuning the data transmission rate according to the channel conditions and was responsive to link quality changes.

Jiansong Zhang et al. [12ref-2] have conducted a regular measurement based study to confirm that SNR was a good prediction tool for channel quality and have identified two key challenges. They have found that the SNR measured in hardware were often uncalibrated and thus the SNR thresholds were hardware dependent. Also they have found that the direct prediction from SNR to frame delivery ratio (FDR) was often over optimistic under interference conditions. Based on these observations, they have presented a novel practical SNR Guided Rate Adaptation (SGRA) scheme. Their proposed SGRA have addressed all identified challenges and was fully compliant with 802.11 standards.

Kun Wang et al. [13ref-3] have studied the problem of using the rate adaptation technique to achieve energy efficiency in an IEEE 802.11 based multihop network. In particular they have formulated it as an optimization problem specifically minimizing the total transmission power over transmission data rates, subjected to the traffic requirements of all the nodes in a multihop network. They have followed distributed Cooperative Rate Adaptation (CRA) for promoting node cooperation and have observed that the inequality in non cooperative channel contention among nodes caused by hidden terminal phenomenon in a multihop network tend to result in energy inefficiency. Their CRA scheme consisted of three modules, namely information exchange algorithm, rate selection algorithm, and node cooperation algorithm.

Xia Zhou et al. [14ref-4] have proposed a novel scheme called Correlation based Rate Adaptation (CORA) to address the rate adjustment problem in which the transmission parameters were adjusted based on the correlation between adjustment action and results Their CORA would split the rate into more atomic components and adjusted them according to the correlation between rate adaptation actions and transmission results. They have used IEEE 802.11n as the context for their CORA design, where transmission mode has been expanded to spatial dimension in addition to the usual modulation and convolution coding mechanisms.

Fengji Ye et al. [15ref-5] have investigated the performance of IEEE 802.11 in multi hop scenarios and have showed how its aggressive behavior could throttle the spatial reuse and reduce bandwidth efficiency. They have also proposed an adaptive, layer-2 distributed coordination scheme for 802.11 using explicit MAC feedback in order to speed the transmissions on adjacent nodes. In that way their scheme assisted the MAC protocol to operate around its saturation state while minimizing resource contention.

3. Channel State Estimation

In ad hoc networks, there is no base station to act as the central controller or dedicated control channel to feedback the channel state. Due to these characteristics, we estimate the channel state based on packet success rate, checked at two levels as follows

- ✓ At the receiver end
- ✓ At each intermediate node along the path

Only if the requirements at both the levels are satisfied, the channel is confirmed to be in good condition. The steps for the estimation of channel state are given under Algorithm - 1.

The state of a wireless link is estimated to be either good or bad. A packet sent on a good link has a much higher probability of success than that on a bad link. The link conditions are independent of each other. Unsuccessful transmissions are due to either channel errors or packet collisions. The transmitter has no means to know the cause of an unsuccessful transmission.

At the Receiver End

By exchanging the two short control packets between a sender and a receiver, all neighboring nodes recognize the transmission and back off during the transmission time advertised along with the RTS and CTS packets. In our channel state estimation, the CTS packets and ACK packets are checked at the receiver side. Based on the results of these packets, we classify the channels with three states namely GOOD1, BAD1 and AWAITING1. Thus, a flag (FL) is associated to indicate the corresponding channel state. The flag can take three values: GOOD1, BAD1 or AWAITING1.

- ✓ Check for the CTS packets, which informs the sender that the packets are confirmed to be sent
- ✓ Also check for the ACK packets, which is an acknowledgement of successful data transmission.

If both the above conditions are satisfied, then the channel is in GOOD state and will be checked for the subsequent conditions at the nodes. If any of the above condition is not satisfied then the channel is in BAD state and eventually the further transmissions are dropped out.

At Each Intermediate Node Along the Path

Packet success rate (PS) is defined as the fraction of the number of successful transmissions over the most recent transmissions. Furthermore at each node, the packet success rate (PS) is checked against a threshold value (Pth). If the value falls above the threshold value, the link is in good condition with its state marked as GOOD2 else the link is considered bad and marked as BAD2. Since the channel condition is checked at each and every node, the changes in channel are updated with the exact channel conditions.

Suppose if a path has many links with both GOOD2 and BAD2 states, then in such cases the path is valid only if it contains maximum number of links with state GOOD2 else the path is invalid (i.e.) not suitable for transmission and will be kept in the AWAITING2 state for a particular time period (tth). For instance if there are totally 5 links in a path with 3 of the links in state GOOD2, then the path is valid as the maximum links have GOOD2 states. Suppose if only 2 of the links are in GOOD2 state, then the path is invalid. Once the channel condition improves and if the maximum number of links in the path have state GOOD2, then the path is valid. Also once the tth value is exceeded, then also the path is invalid and is not suitable for transmission.

Algorithm - 1

1. At the receiver,

1. 1. If CTS && ACK = True, then
    1. 1. 1. The flag (FL) is set as GOOD1.
    1. 1. 2. Go to step -2
  Else
    1. 1. 3. The flag (FL) is set as BAD1.
    1. 1. 4. The Atimer is ON.
    1. 1. 5. If Atimer expires, then
        1. 1.5 .1. Flag is set to AWAITING1
        1. 1.5. 2. If CTS && ACK = True, then
            1. 1. 5.2.1. Set flag as GOOD1.
            1. 1. 5.2.2. Reset Atimer
        Else
            1. 1.5.2.3. Set flag as BAD1.
            1. 1.5.2.4. Double the Atimer
        End If.
    End if.
  End if.

2. At each node,

2. 1. If PS > Pth, then
    The flag (FL) is set as GOOD2.
  Else
    The flag (FL) is set as BAD2.
  End If.
  2. 2. If there are N links in a path P, then
    2. 2. 1. Nmax = (N/2) + 1.
  End If.
  2. 3. If no. of GOOD2 links > Nmax, then
    2. 3. 1. The path P is valid and can be used for transmission.
  Else
    2. 3. 2. The path P is invalid and marked as AWAITING2 state.
  End If.
2. 4. If time t in the AWAITING2 state exceeds, t > tth, then
    2. 4. 1. The path P is invalid.
  End If.

4. Data Rate Control Algorithm

A sender competes for the channel before exchanging RTS/CTS with the receiver. Then, a burst of DATA/ACK pairs will be transmitted between the sending and receiving parties. This burst of DATA/ACK frames is accountable for adapting to channel condition changes and for retransmitting corrupted packets.

In our Data Rate Control Algorithm (DRCA), the basic data rate is varied between two values namely, Rmin and Rmax, where Rmin is the minimum rate to which the rate can be reduced and Rmax is the maximum rate to which the rate can be increased. Suppose if the channel conditions at the two levels stated in the previous section are BAD1 and BAD2, then the current rate (Ri) is decreased by a step value (λ). Suppose if the channel conditions at the two levels are GOOD1 and GOOD2, then the current rate (Ri) is increased by a step value (λ). The steps in our rate adjustment algorithm are given under Algorithm - 2. This rate adjustment is done at the receiver and puts such a planned data rate in the CTS frame so that the sender can adopt this rate in the subsequent burst of DATA frames. Further, the estimation errors and the channel condition changes can be compensated by piggy-backing a single bit in the ACK from the receiver to indicate the optimal data rate feasible for the next DATA frame in the burst.

Algorithm - 2

1. If the channel conditions at the two levels are BAD1 && BAD2, then
   1. 1. If (Ri > Rmin) then : where Ri is the current rate value
      1. 1. 1. Ri = Ri – λ : where λ is the step value
   Else
      1. 1. 2. Maintain the same rate
   End If.
End If.
2. If the channel conditions at the two levels are GOOD1 && GOOD2, then
   2. 1. If (Ri < Rmax) then
      2. 1. 1. Ri = Ri + λ
   Else
      2. 1. 2. Maintain the same rate.
      End If.
End If.

5. Experimental Results

5. 1. Simulation Model and Parameters

We use NS2 [16] to simulate our proposed algorithm. In our simulation, the channel capacity of mobile hosts is set to the same value: 2 Mbps. In our simulation, 100 mobile nodes move in a 1500 meter x 300 meter rectangular region for 100 seconds simulation time. Initial locations and movements of the nodes are obtained using the random waypoint (RWP) model of NS2. We assume each node moves independently with the same average speed. In this mobility model, a node randomly selects a destination from the physical terrain. In our simulation, the speed is 10 m/s. and pause time is 10 seconds. The simulated traffics are Constant Bit Rate (CBR) and Variable Bit Rate (VBR) traffic. For each scenario, ten runs with different random seeds were conducted and the results were averaged.

Our simulation settings and parameters are summarized in table 1.

No. of Nodes	100
Area Size	1500 X 300
Mac	ORAA
Radio Range	250m
Simulation Time	50 sec
Traffic Source	CBR and Video
No. of Connections	6
Packet Size	512
Mobility Model	Random Way Point
Speed	5m/s
Pause time	5 sec
Rate	100kb,200kb,…..500Kb
Error Rate	0.01,0.02,….0.05

Table 1: Simulation Settings

5. 2. Performance Metrics

We compare the performance of our proposed Data Rate Control Algorithm (DRCA) with the ADCF scheme in [15]. We evaluate mainly the performance according to the following metrics.

Throughput: It is the number of packets received successfully.

Average End-to-End Delay: The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations

Average Packet Delivery Ratio: It is the ratio of the number .of packets received successfully and the total number of packets transmitted.

Bandwidth: It is the measure of received bandwidth for all traffic flows.

Fairness: For each flow, we measure the fairness index as the ratio of throughput of each flow and total no. of flows.

The performance results are presented graphically in the next section.

5. 3. Results

Based On Error Rate

In our initial experiment, the channel error rate is varied from 0.01 to 0.05, with traffic rate set as 100kb.

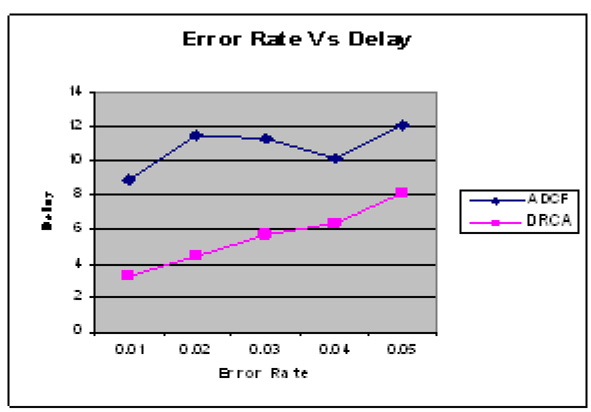

Figure - 1: Error rate Vs Delay

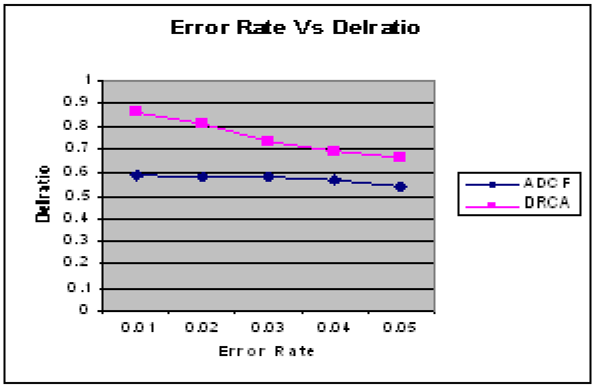

Figure - 2: Error rate Vs Delratio

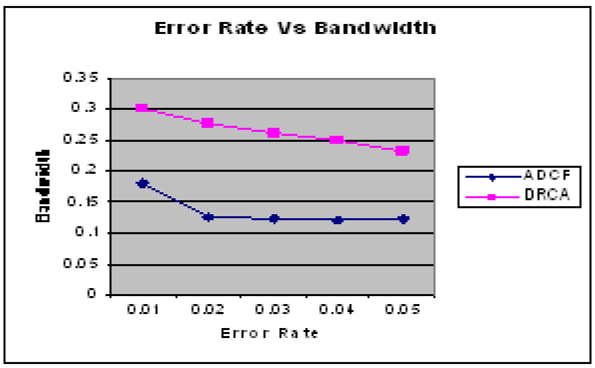

Figure - 3: Error rate Vs Bandwidth

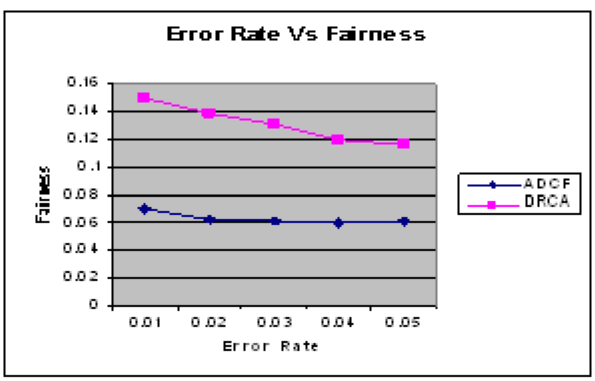

Figure - 4: Error rate Vs Fairness

Normally, when the channel error rate is increased, the received bandwidth of all the flows will tend to decrease. As it can be seen from the figures 3, the bandwidth of all the flows slightly decreases, when the error rate is increased.

Figure 1 shows the transmission delay of both the schemes. We can find that our proposed ORAA have less delay when compared with the ADCF scheme.

From Figure 2, it is evident that the delivery ratio of our proposed ORAA is more when compared with the ADCF scheme.

Figure 3 shows the bandwidth of both the schemes. It is clear that our proposed ORAA have more bandwidth when compared with the ADCF scheme.

Next, we measure the fairness index. Figure 4 shows that ORAA achieves high fairness than
ADCF scheme, when the error rate is increased.

6. Conclusion

In this paper we have developed A Data Rate Control Algorithm (DRCA) based on the channel state conditions. Our channel state estimation has two levels, one at the receiver end and another at each intermediate node along the path. At the receiver side, three states namely GOOD1, BAD1 and AWAITING1 are classified based on the Packet Success rate (PS). Similarly at each intermediate node along the path, three more states namely GOOD2, BAD2 and AWAITING2 are classified based on the CTS and ACK packets. In our ORAA the rate adjustments are done based on any of the above discussed channel states. Hence in adhoc networks, where the channel conditions are dynamic, our proposed ORAA provides the accurate data rate most suitable for the current changes in the network. Simulation results show that our proposed ORAA achieves high throughput and fairness, when compared with the standard IEEE 802.11 MAC protocol.

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