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A New Dynamic Scheme for Efficient RTS Threshold Handling in Wireless Networks

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Abstract

Wireless network is an essential and integral part of the ubiquitous environment. For efficient access control, two different transmission schemes are used: The Basic Carrier Sensing Multiple Access with Collision Avoidance (CSMA/CA) and Request-To-Send/ Clear-To-Send (RTS/CTS) handshaking. The RTS/CTS handshaking addresses the hidden terminal problem as well as reduces the chance of collision in case of higher node density and traffic. However, in networks with low density, basic scheme would lead to higher throughput due to its less overhead. Efficient switching between these two schemes is imperative to maximize the throughput. We have first investigated to find a meaningful threshold value according to the network situation. The proposed algorithm then dynamically adjusts RTS Threshold according to the packet delivery ratio, which is an indicator of network traffic and shows a significant improvement over existing CSMA/CA and RTS/CTS schemes. Our adaptive scheme performed even better when data rates increases. We verify our proposed scheme with extensive network simulation using ns-2.

1. Introduction

In recent years, mobile and wireless communication has become more popular due to its convenience and lower price. However, the communication over wireless medium can support much lower bandwidth, together with high delay and error. The performance of mobile ad hoc networks depends on efficient channel sharing of wireless network. Among these, IEEE802.11 MAC is clearly the most accepted and widely used one at present. The sharing of channel is controlled by the Medium Access Control (MAC) protocol [1]. In order to control contentions, carrier sense based random-access multiple access algorithms are used. IEEE 802.11 uses the standard transmission scheme of Carrier Sensing Multiple Access with Collision Avoidance (CSMA/CA), which can operate efficiently. Depending on the geographical positioning of the nodes, hidden and exposed terminal problem can occur. Because in wireless networks, interference is location based. Resolving hidden terminal problem becomes one of the major design considerations MAC protocol used in both wireless LANs and mobile ad hoc networks (MANETs). To resolve the hidden terminal problem, a four way handshaking scheme (RTS/CTS) of channel reservation was introduced as an option in IEEE 802.11 MAC protocol. Here, an RTS Threshold (RT) acts as a switch between the two schemes. Data packets with size lower than RT are sent directly with the basic scheme. RT is not specified by IEEE 802.11 standard and has to be managed separately by each node.

In [2] [3] studies have been carried out on the performance evaluations of both the above mentioned schemes. The authors in [2] and [3] first conducted simulations to study the performance of RTS/CTS mechanism in IEEE 802.11 WLANs. In particular, [4] and [5] pointed out that the RTS/CTS handshake does not work as well as it is expected in dealing with the hidden station problem and reducing interference, even though it was mainly employed for that purpose. [6] also revealed other shortcomings of RTS/CTS handshake that did not exist in the basic scheme. Bianchi in [7] proved the superiority of RTS/CTS in highly loaded networks by calculating a theoretical upper limit for the throughput, based on a simplified chain model without

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taking into account packet retry limits. The authors in [8] have performed a simulation study, opted for maximum collision avoidance and suggested that the RTS/CTS mechanism must be employed at all times. On the other hand, [9] illustrated that the RTS/CTS mechanism provides very limited advantages with respect to the basic access scheme, when no hidden stations are present, especially at high data rates (5.5 Mbps and 11 Mbps), knowing that the control packets (RTS, CTS and ACK) are always transmitted at either (1 Mbps) or (2 Mbps). [10] and [11] worked on developing an RT expression that relies on calculating the average overheads of both schemes assuming ideal conditions (ignoring hidden stations or transmission errors), which are redundant and unobtainable in the real world. Other work [13] involves optimization of RT based on a power management scheme to improve the average energy consumption by packet.

In this paper, we proposed an algorithm to dynamically adjust the RT depending on the variations of network density and traffic based on short-term storage of packet delivery ratios. If the ratio drops below a certain threshold value, which is determined by investigation through simulation, RTS/CTS handshaking is used to avoid collision, else the packets is sent directly using basic scheme. The evaluation is done both analytically as well as by computer simulation using ns-2 and the results shows that they are corroborating each other. The main advantages of our approach is the simplicity, high accuracy rate. Besides, it relies only on success rate of packet delivery, irrespective of the network size. The adaptive adjusting of RT assures the balance between higher collision penalty and better channel utilization.

The remainder of this paper is organized as follows: In Section 2, we summarized the background of this work. The numerical comparison is given in Section 3. In Section 4 we introduce our proposed scheme. Both analytical and simulation based evaluation results are shown in Section 5. Finally we conclude the work and present future works in Section 6.

2. Background

To determine whether the medium is available for transmission, carrier sensing is used. MAC protocol used in DCF is CSMA/CA, which consists of two types of carrier sensing functions: (i) physical carrier sensing and (ii) virtual carrier sensing. For physical carrier sensing traditional CSMA/CA, as shown in Fig. 1 is used. It requires the mobile nodes to first sense the channel to check whether it is idle for a DCF Interframe Space (DIFS) interval, then attempts packet transmission.

On the other hand, for virtual carrier sensing, RTS/CTS handshake and NAV (network allocation vector) scheme is used as shown in Fig. 2. Here, if a node has a packet to send,

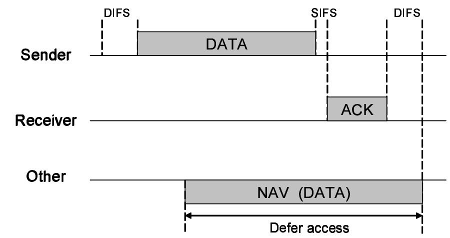

Figure 1. Basic CSMA/CA access mechanism

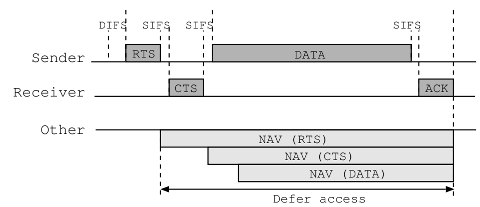

Figure 2. CSMA/CA with RTS/CTS mechanism

which is larger than the RT, it first tries to reserve the channel by sending an RTS frame. Here, if a node has a packet to send, which is larger than the RT, it first tries to reserve the channel by sending an RTS frame by following the backoff procedure as the basic mechanism. After that, instead of sending the data frame, it sends a special short control frame called RTS. This frame includes the information about the source, destination and duration required by the following transaction - CTS, DATA and ACK transmission. Upon receiving the RTS, the destination node responds with another control frame called CTS, which also contains the same information. The transmitting station allowed to send data if the CTS frame is received correctly. All other nodes overhearing either RTS or CTS frame adjust their Network Allocation Vector (NAV) to the duration specified in RTS/CTS frame.

The NAV contains period of time in which the channel will be unavailable and is used as virtual Carrier sensing. Stations defer transmissions if either the physical or virtual Carrier sensing finds the channel being busy. Thus RTS/CTS mechanism has the ability of early detection of collision. But [12] suggested that RTS/CTS can also induce congestion, due to medium access control, which is different from the congestion that arises in the familiar TCP context. So, a process to switching between traditional carrier sensing and RTS/CTS is essential for efficient data transfer.

3. Numerical Comparison

The maximum throughput for an ad hoc network in saturation mode is calculated as in [7] and it is as follows:

$$S = \frac{P_{tr} P_s Data}{(1 - P_{tr})\sigma + P_{tr} P_s P_s + P_{tr}(1 - P_s)T_c} \quad (1)$$

Where, P_{tr} is the probability of at least one transmission, P_s is the conditional probability of success of an occurring transmission, T_s is the average duration of a successful transmission, T_c is the average duration of a collision, σ is the duration of a single slot time. P_{tr} and P_s are functions of the network size, n is the probability of a packet transmission at slot time τ, which depends only on the initial backoff window size and its stage limit m.

$$P_{tr} = 1 - (1 - \tau)^n, \;\; P_s = n\tau(1 - \tau)^{n-1}/P_{tr} \quad (2)$$

Where,

$$\tau = \frac{2(1 - 2p)}{(1 - 2p)(W + 1) + pW(1 - (2p)^m)}$$

$$p = 1 - (1 - \tau)^{n-1}$$

T_s and T_c depend on the transmission scheme.

T_s and T_c depend on the transmission scheme. From Fig. 1 we have:

$$\begin{cases} T_s^{Basic} = DIFS + T_{header} + \frac{Data}{R} + SIFS + T_{ACK} + 2\delta \\ T_c^{Basic} = DIFS + T_{header} + \frac{Data}{R} + \delta \end{cases} \quad (3)$$

And from Fig. 2:

$$\begin{cases} T_s^{RTS} = DIFS + 3SIFS + T_{RTS} + T_{CTS} + T_{header} + \\ \qquad \frac{Data}{R} + SIFS + T_{ACK} + 4\delta \\ T_c^{Basic} = DIFS + T_{RTS} + \delta \end{cases} \quad (4)$$

Here δ is the propagation delay and R is the data rate.

A numerical comparison between the maximum throughput of each scheme can be obtained by substituting in expression (1) the parameters shown in the Table 1.

As shown in Fig. 3, extra overhead introduced by RTS and CTS packets causes the handshake scheme to have lower throughput than the basic scheme in case of small network size, but performs much better in case of large number of contending nodes.

Node density and traffic can be constantly changing in mobile ad hoc networks. Consequently, nodes have to adapt their transmission schemes according to those changes, and it is imperative to find a way to dynamically switch between the two schemes and adjust RT irrespective of the number of surrounding nodes. In the following section we will introduce our dynamically adjusting scheme for adaptive transmission control.

Table 1. Numerical comparison parameters

Slot time	$20\mu s$
Propagation delay σ	$1\mu s$
SIFS	$10\mu s$
DIFS	$50\mu s$
Packet Payload	8184 bits
MAC header	272 bits
PHY header	128 bits
ACK	112 + phy hdr
RTS	160 + phy hdr
CTS	112 + phy hdr
Date rate R	2 Mb/s
Backoff Window size W	64
Backoff stage limit m	6

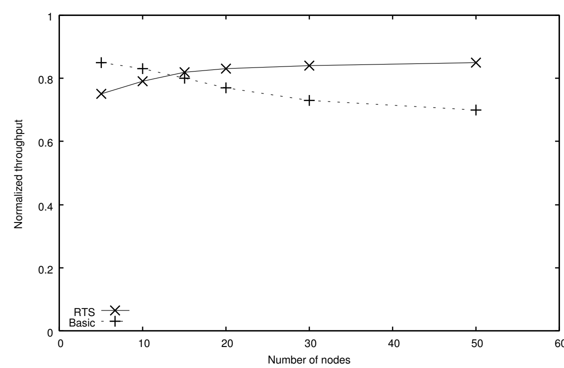

Figure 3. Numerical comparison of maximum throughput between CSMA and RTS/CTS

4. Proposal

4.1. Adaptive Transmission Control Scheme

If there is a small number of contending nodes and a low collision risk, in other words the packet delivery ratio is high, then the packets should be sent directly using the basic scheme. If that ratio drops below a certain threshold, RTS/CTS handshaking should be used. Hence, periodical adjustment of RT to the packet delivery ratio in necessary for optimal throughput.

Collision probability increases with the increase in the size of data packets and as a consequence the packet delivery ratio drops. Therefore, this threshold has to be accordant with the packet size. Each bucket ($B[i]$) contains the successful ($S[i]$) and unsuccessful ($C[i]$) packet index and the indexing is done by $B[i = PS/100]$, as shown in Fig. 4.

- Number of successfully transmitted packets $S[i]$.
- Number of collisions $C[i]$.
- Packet delivery ratio $PD[i] = \frac{S[i]}{S[i]+C[i]}$.
- Constant packet delivery ratio threshold $PDT[i]$ to determine whether $PD[i]$ is satisfactory or not.

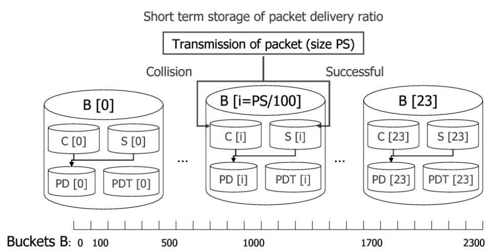

Figure 4. Short term storage of success ratio

PDT characteristic is obtained through simulation determining a satisfactory delivery ratio for each bucket using the basic scheme.

4.2. Investigation of PDT

Most widely recognized network simulator, ns-2 is used to evaluate the effectiveness of transmission schemes. The network model is a multi-hop wireless topology using AODV as routing protocol. The link layer is a shared media radio with nominal channel bit rates of 2, 5.5 and 11 Mbps. We run the simulation on the 1000 x 1000 m^2 field for 300 seconds. Nodes are moving according to the Random Waypoint model [14], with parameters: maximum speed=20 m/sec, minimum speed=0, pause time= 30 secs. Every plots in these graphs is the average of at least 10 simulations. There are 24 pairs of source-destination exchanging random size CBR packet between themselves, which is considered as background traffic. Only one static pair A and B are exchanging constant size packet and they are in one hop distance, which is the observed pair in our experiment. One hop distance is considered as it produces maximum packet delivery, which we required for determining the packet deliver thresholds.

For both schemes, we calculate for each bucket the throughput and the end-to-end delivery ratio between two static nodes A and B, as the offered load gradually increases. The offered load is varying with the number of pairs increasing from 0 to 25 or number of nodes increasing from 0 to 50. For instance, the results for bucket B[10] (packet size = 1000, data rate = 2Mbps) are presented in Fig. 5 and Fig. 6.

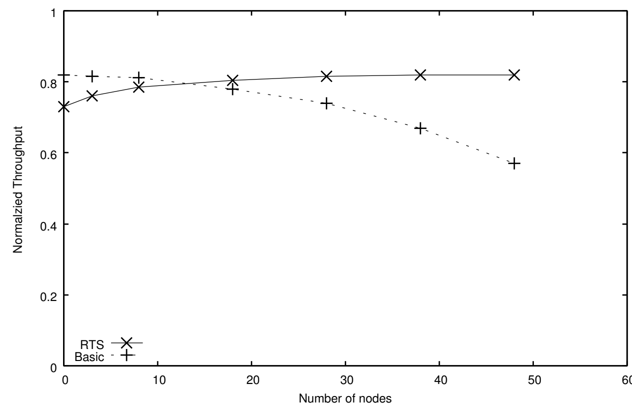

Figure 5. Throughput between node A and B (packet size = 1000, data rate = 2Mbps)

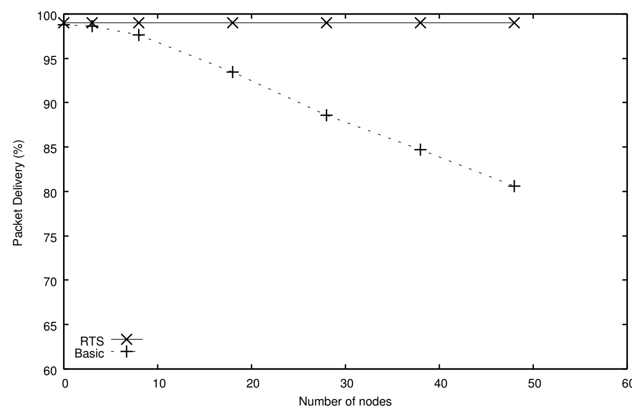

Figure 6. Packet Delivery Ratio between A and B (packet size = 1000, data rate = 2Mbps)

When offered load is low, RTS/CTS handshaking has lower throughput due to the extra overhead. While at high offered loads, throughput of the basic drops because of high collision probability. Both schemes have equal throughput when number of pairs is less than 6, where the delivery ratio for the basic scheme is 95%. Given this, if the delivery ratio is kept above 95%, highest possible throughput can be maintained at any offered load. That means, when transmitting packets with size only between 1000 and 1100, using basic scheme will assure a satisfactory packet delivery yet a higher throughput. As the offered load increases, the delivery ratio is expected to drop. When it reaches below 95%, switching to RTS/CTS will maintain the high throughput. Thus, gathering these optimal packet delivery ratios corresponding to each bucket, we can obtain for each nominal channel bit rate the packet delivery thresholds shown in Fig. 7.

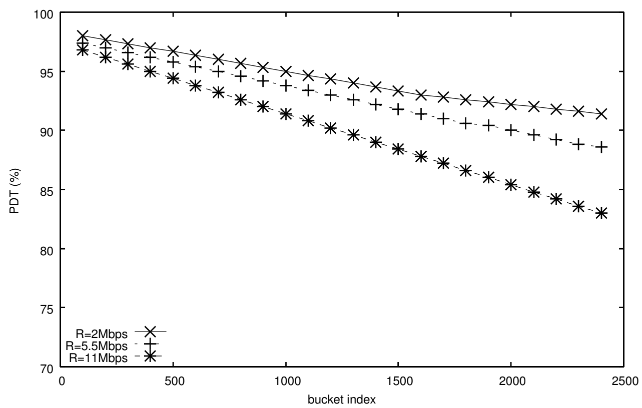

Figure 7. Characteristics of packet delivery ratio threshold

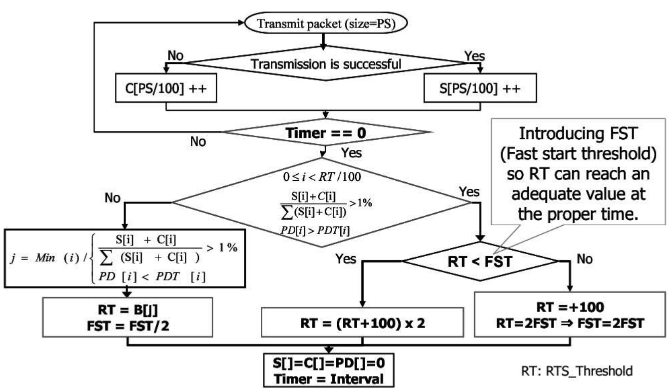

Figure 8. Algorithm flowchart

Based on this packet delivery threshold characteristics, the proposed algorithm will store success history of transmissions of each bucket, calculate their delivery ratios while ignoring those with low number of transmissions, compare them to their delivery ratio thresholds respectively, and adjust RT accordingly after every period of time equal to Interval. The RT updating Interval is chosen inversely relative to the data sending rate to make sure there will be enough history of transmissions to operate on.

In the real world, RT is set to a MTU=2400 and RTS/CTS is never used assuming low node density and traffic as the likely circumstances. Considering this as the initial value for RT and after a transmission course, if all bucket have satisfactory delivery ratio, RT will be increased. Otherwise, RT will be set to the lowest bucket with unsatisfactory delivery ratio. As shown in the flow chart of the algorithm (Fig. 8), the amount by which RT changes is controlled by a Fast Start Threshold (FST) parameter to help, it reaches an adequate value at the proper time. After RT is adjusted the counters are reset and the timer is set back to Interval.

5. Evaluation

5.1. Analytical Evaluation

The throughput of the adaptive scheme is

$$S_{Adap} = \frac{P_{tr}P_sData}{(1-P_{tr})\sigma + P_{tr}P_sT_s{}^{Adap} + P_{tr}(1-P_s)T_c{}^{Adap}} \quad (5)$$

Where,

$$\begin{cases} T_s{}^{Adap} = P_{Basic}T_s{}^{Basic} + P_{RTS}T_s{}^{RTS} \\ T_c{}^{Adap} = P_{Basic}^2T_c{}^{Basic/Basic} + \\ \quad 2P_{Basic}P_{RTS}T_c{}^{Basic/RTS} + P_{RTS}{}^2T_c{}^{RTS/RTS} \end{cases}$$

Here, $P_{RTS} = 1 - P_{Basic}$ is the probability of using RTS/CTS.

$$\begin{cases} T_c^{RTS/RTS} = RTS + DIFS + \delta \\ T_c^{Basic/RTS} = T_{header} + DIFS + \delta + \\ \quad 1/R\int_0^{RT}\frac{F(Data)}{F(RT)}dData \\ T_c^{Basic/Basic} = T_{header} + DIFS + \delta + \\ \quad 1/R\int_0^{RT}\frac{F^2(Data)}{F^2(RT)}dData \end{cases}$$

$F(Data)$ is the distribution of the payload transmitted.

As the proposal deals with adapting the transmission scheme to the network topology and traffic, it is fair to assume a network model composed of two areas with different node densities for the evaluation.

For simplicity we consider that the data size is constant.

Nodes in the sparse area (n1), where the risk of collisions is less, will tend to raise their RTs in order to increase their channel utilization. The throughput of the adaptive scheme can be simplified this way:

$$n1: \begin{cases} P_{Basic} \cong 1 \\ T_s^{Adap} \cong T_s^{Basic} \\ T_c^{Adap} \cong T_c^{Basic/Basic} \cong T_c^{Basic} \end{cases}$$

$$S_{Adap}(n1) \cong S_{Basic} = MAX(S_{Basic}(n1) + S_{RTS}(n1)) \quad (6)$$

On the other hand, there will be higher collision risk in the desne area (n2). Therefore, nodes will decrease their RTs and use the RTS/CTS handshaking.

$$n2: \begin{cases} P_{Basic} \cong 0 \\ T_s^{Adap} \cong T_s^{RTS} \\ T_c^{Adap} \cong T_c^{RTS/RTS} \cong T_c^{RTS} \end{cases}$$

$$S_{Adap}(n2) \cong S_{RTS} = MAX(S_{Basic}(n2) + S_{RTS}(n2)) \quad (7)$$

Using the adaptive scheme will generate a throughput greater than that of RTS/CTS or the basic scheme, for both areas combined.

$$S_{Adap}(n) \cong S_{Adap}(n1) + S_{Adap}(n2) \succ \left\{ \begin{array}{l} S_{Basic}(n1) + S_{Basic}(n2) \\ S_{RTS}(n1) + S_{RTS}(n2) \end{array} \right. \quad (8)$$

5.2. Simulation based Evaluation

Adopting the same network topology used for the numerical evaluation, the network model is combined of two areas of different node densities, as illustrated in Fig. 9. We evaluated the proposed algorithm and compared it to the other schemes through simulation done in ns-2. Network traffic parameters are similar to the simulation environment used for the investigation of PDT. This time, the data size exchanged between the nodes is random. Performance metric in our observation is the throughput of the whole network.

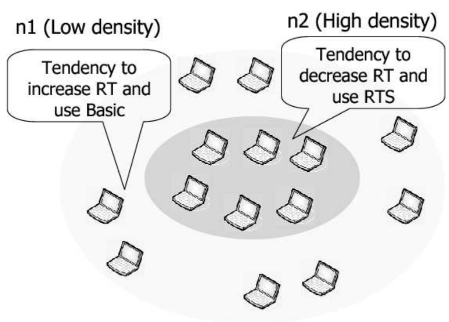

Figure 9. Network model: n1 with low traffic and n2 with high traffic load

As expected from the analytical evaluation, the graphs in Fig. 10 shows that our proposed scheme outperforms basic and RTS schemes. After the first Interval of time, nodes in different areas (n1 and n2) using our algorithm were able to calculate the success ratios and adjust their RTS Thresholds accordingly to an adequate value to sustain a good packet delivery ratio as well as to maintain the throughput to the highest possible level. The performance of the algorithm improves with time as we are accumulating the information regarding the success ratio and can more correctly calculate the threshold value.

Also, as control frames, RTS,CTS and ACK, are always sent at 2 Mbps, big data packets can be sent without channel reservation since they appear to be relatively smaller at higher data rates. As a result to that, scheme shows better performance in Fig. 11 where the data rate (5.5, 11 Mbps) is considerably high compared to control frames rate (2 Mbps).

The proposed scheme provides better channel utilization in the low traffic area (n1) and higher collision penalty in the area with high traffic (n2).

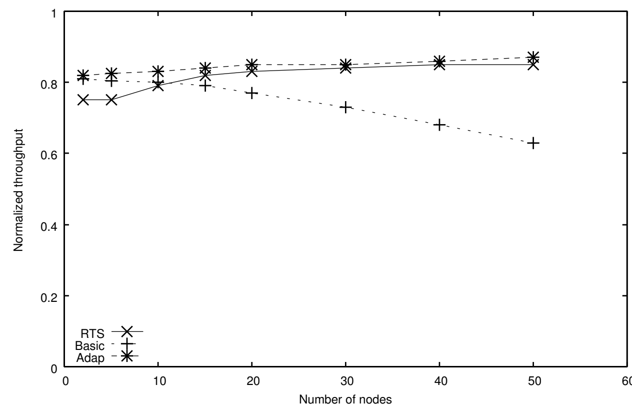

Figure 10. Comparison of Throughput between Adaptive, CSMA and RTS schemes

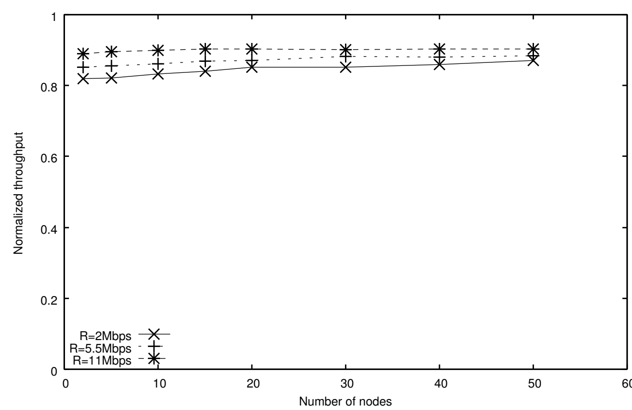

Figure 11. Adaptive Scheme Throughput with higher Data Rates

6. Conclusion

In this work we have studied the basic CSMA/CA and the optional RTS/CTS handshaking transmission schemes employed by the MAC protocol in IEEE802.11. We have also showed how the performance of both these schemes depend on the network topology and traffic load and how an adaptive RTS threshold, a key to the switching between the two schemes can adjust to the constantly changing network traffic.

We proposed a dynamic way to adjust the RTS threshold according to the packet delivery ratio, which is an indicator of the network situation. We demonstrated through simulation results how the proposed algorithm tunes up the transmission to an adequate value at a proper time irrespective of the number of contending nodes.

Evaluation results showed that the proposed adaptive transmission control scheme out-performs the basic and the RTS/CTS handshaking scheme. In this work, we have used an ns-2 based realistic model to evaluate our propose scheme. If the network mobility and traffic is static, then the effectiveness our algorithm is nominal compared to the existing schemes. But in real-world, network traffic is constantly changing as different kinds of applications are running and as a result the range of packet size also widely varies, and in such situation the effectiveness of our schemes will be more visible.

We further intend to experiment on MobiREAL simulator [15], which is a realistic network simulator for MANET. It provides a new methodology to model and simulate realistic mobility of nodes and enables to evaluate MANET applications in more actual environments.

Acknowledgement

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