A Comparative Study of Rate Matching and IG-MAC Schemes In Multi-Rate Ad Hoc Networks

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***Abstract*—Ad hoc networks face certain challenges such as mobility, scalability, time varying topology, hidden and exposed terminal problem, etc. This paper addresses the issue of hidden terminal problem. This problem occurs in MANETs due to its multi-hop nature. The transmitting nodes which are out of transmission range of each other but within the transmission range of common receiver act as hidden nodes. The problem is alleviated by IEEE 802.11 protocol, which uses RTS/CTS control signals. Further studies of hidden terminal problem showed that the nodes which are lying in the interference range of the receiver also act as hidden nodes. This hidden terminal problem cannot be solved by RTS/CTS control signals. Two mechanisms namely IG-MAC and Rate Matching can solve the above mentioned hidden terminal problem. In this paper, a comparative study of IG-MAC and Rate Matching is done in different scenarios of ad hoc networks.**

Keywords-multi-rate ad hoc network; hidden terminals; transmission range; interference range

I. INTRODUCTION

The ability to communicate with anyone from anywhere on the planet has been mankind's dream for a long time. Wireless is the only medium that can enable untethered communication. However, with the recent technological advances, coupled with the demand for feasibility and mobility of wireless systems, the development of an emerging "anyone, anywhere, anytime" paradigm of mobile ad hoc networks (MANETs) have the potential to serve as the basic building blocks of the future "ubiquitous communication and computing" systems capable of interconnecting thousands of heterogeneous devices [1].

The IEEE 802.11 protocol is designed for MANETs. With the advancement in the technology, the modified versions like IEEE 802.11 a/b/g come up in the market. These protocols support multiple data rates of transmission, thus providing multi-rate capability to ad hoc networks [2]. For example, the IEEE 802.11b supports the data rates of 1, 2, 5.5 and 11 Mbps. Depending on channel conditions automatic rate adaptation is done by MANETs.

Ad hoc networks are multi-hop wireless networks. A broadcast communication is performed in this network by using a single shared channel. In these networks, the signal propagation is Omni directional and the strength of the signal decreases in proportion to the square of the distance from the sender [3]. This makes the wireless networks unpredictable in nature and does not exhibit uniform characteristics throughout the signal transmission path. The unpredictable nature of wireless medium results into different kinds of coverage like transmission range, carrier sensing range and interference range. The presence of such different transmission coverage results into hidden terminal problem in wireless networks [4]. Hidden terminal problem adversely affects the transmission of wireless networks in the following ways:

(1) It increases collision due to hidden nodes which results in reduced throughput of the wireless networks.

(2) It increases access delay of the wireless network due to retransmissions.

The IEEE 802.11 standard has adopted Multiple Access with Collision Avoidance (MACA) protocol for medium access control in infrastructure based wireless networks. The MACA protocol effectively addresses the hidden terminal problem due to the provision of Request-to-Send (RTS) and Clear-to-Send (CTS) control messages before transmission of data packets between the nodes in wireless LANs.

In wireless networks the interference is location based, resulting in problem of hidden terminal frequently. While addressing the issue of hidden terminal, it has an underlying assumption that all hidden nodes are within the transmission range of the receiver. Such an assumption may not hold well in MANETs. In MANETs, some of the nodes which are out of the transmission range of both transmitter and the receiver may still interfere with the receiver. Such a situation occurs rarely in a wireless LAN environment since most of the nodes are in the transmission range of either the transmitter or the receiver. Thus, in MANETs, in addition to the existence of the conventional hidden terminal problem which is termed as type-1 hidden terminal problem, there exists another kind of hidden terminal problem caused due to the interference noise generated at receiver node which is termed as type-2 hidden terminal problem. In MANETs, type-2 hidden terminal problem is caused by the node lying in the interference range of the receiver. This node when transmits the data to some other node, which is in its transmission range, generates noise, causes into the interference at the receiver [5].

The MACA protocol is also adopted in MANETs for solving the hidden terminal problem. However, it does not solve completely the hidden terminal problem in such due to the existence of type-2 hidden terminals. The RTS/CTS packets transmit only up to the transmission range of the transmitter and the receiver respectively. The type-2 hidden nodes exist in the interference range which is not covered by RTS/CTS signals. Two methods namely Rate Matching and IG-MAC are suggested by researchers which solve the type-2 hidden terminal problem. In Rate Matching scheme, RTS/CTS signals and data are transmitted with different transmission rate which solves the type-2 hidden terminal problem [6]. In IG-MAC scheme, interference graph mechanism is used to solve type-2 hidden terminal problem [7].

In this paper, a comparative study of Rate Matching scheme and IG-MAC scheme is done for different topologies of MANETs.

II. RELATED WORK

There are many proposals for tackling the hidden terminal problem. Reference [8] proposed MACA as an improvement of CSMA by using the RTS/CTS handshake. MACAW [9] introduced RTS/CTS/DATA/ACK four way handshakes to enhance MACA's performance. FAMA [10] added to MACAW carrier sensing before the transmissions of RTS packets. Recognizing that hidden terminal problem mainly affects the receiver, MACA-BI [11] proposed a receiver initiated scheme. BTMA [12] and DBTMA [13] tried to solve the hidden terminal problem by using multiple channels and busy tone. They are not effective for eliminating type-2 hidden terminal because they assumed that hidden nodes are always within the transmission range of sender or receiver. Reference [2, 3, 5] proposed to increase the carrier sensing range to eliminate type-2 hidden terminals. This may work if all potential interfering stations can sense the radio signal from the transmitter. But in practise, this assumption is not possible because walls and other transmission barriers are always present. A longer carrier sensing range will also aggravate the exposed terminal problem [4, 9].

One paper related to our work is reference [1]. Because the interference range varies with the received signal's power at the receiver, [1] suggested that a node should reply an RTS packet only when the received RTS's power exceeds a certain threshold. Equivalently, this means to artificially shorten the communication distances so that CTS packets can reach all potential type-2 hidden terminals. This obviously has a negative impact on network throughput. This also goes against the trend followed by most routing protocols such as DSR, AODV, which maximize the performance by using the farthest node to relay traffic [14, 15].

Xu et al [16] indicates that the interference range can be modelled as a function of the distances between the source and destination nodes, and the physical layer techniques. The interference range may result in more variable number of hidden terminals. They also investigated how effective is the RTS/CTS handshake in terms of reducing interference. Ye et al [17] indicates the area that should be reserved by the virtual carrier sensing depends on the distance between the transmitter and receiver. And they propose a distance-aware virtual carrier sensing protocol by incorporating distance information in the decision making process for the channel reservation which consequently increases the spatial reuse. But it cannot solve the hidden terminal problem as well.

Another element related to our study is multi-rate transmissions, which has already been supported by IEEE 802.11 standard. Till now, the discussion on the impact of multi rate in most papers focused on routing metrics [18] and rate adaptation [19], and not on the hidden terminal problem. One related example is reference [3]. Its goal is to maximize network throughput by determining optimal carrier sensing range and routing metrics under multi-rate scenario. References [1, 4-5] also assumed different rates for RTS/CTS and DATA packets. But they also assumed the same transmission range and the same SNR requirement for all transmissions. This is obvious but not true in a practical network. As a result, their models can only be considered as a single-rate model.

In our proposed work, we study the effect of hidden terminals which are not in the transmission range of either transmitter or receiver but in their interference range. We have found that this hidden terminal problem cannot be solved by conventional RTS/CTS method. Two methods namely Rate Matching and IG-MAC solved the type-2 hidden terminal problem. In this paper, a comparative study of these two mechanisms has been done for different scenarios of ad hoc networks.

III. TYPE-2 HIDDEN TERMINAL PROBLEM

Some notations and terminologies are introduced first for understanding type-2 hidden terminal problem.

A. Transmission Range (Tx_Range)

The nodes within the transmission range will be able to transmit data to each other successfully. In this range, the transmitted data can be interpreted correctly by the receiver. The value of this range is mainly determined by the transmission power, the receiver sensitivity threshold, the Signal-to-Noise Ratio (SNR) requirement and the radio propagation environment.

B. Carrier Sensing Range (CS_Range)

This is the range within which the node can detect the presence of the signal but will not be able to interpret the received signal. This is because the transmitted power is large enough to differentiate it from the background noise. However, the error rate is too high to establish communication. Such a range is determined by the power sensing threshold (CS_Thresh), the antenna sensitivity and the radio propagation properties.

C. Interference Range (I_Range)

A node cannot detect the presence of a signal transmitted by other node, which is within its interference range. But a node which is in its transmission range adds noise to the receiver node.

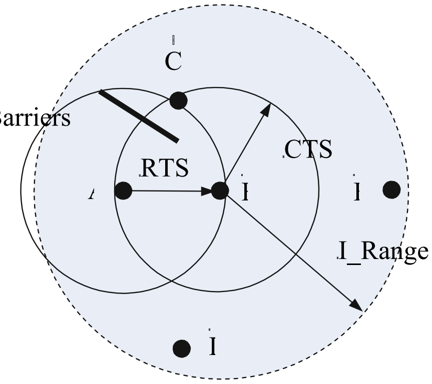

Figure 1: Hidden Terminal Problem.

Fig. 1 explains type-2 hidden terminal problem. As shown in fig. 1, node A is sending data to node B, and node C is within the transmission range of node B. When node C receives a CTS packet, it defers to access the channel according to the time indicated in the CTS packet to allow node A and node B to finish the DATA/ACK transmission cycle. These types of hidden nodes that can be reached by sender or receiver are called type-1 hidden terminals in the paper. The collision problem associated with type-1 hidden nodes can be solved with the RTS/CTS scheme. However, there exist some terminals, like node E in fig. 1, which is out of the transmission range but is still within the interference range of node B. When the node E transmits data to some other node which is in its transmission range, adds noise at the receiver node, thus corrupt its transmission. This node acts as another kind of hidden terminal. They are called type-2 hidden terminals in the paper. Type-2 hidden terminals cannot be eliminated with the RTS/CTS scheme.

IV. ANALYSIS OF TYPE-2 HIDDEN TERMINAL PROBLEM

Homogeneous radios, fixed transmitter power, and one common channel for all nodes are assumed in the analysis. In real networks, Tx_Range, affected by the shadowing and fading effects, is a random variable. But in analysis, we often ignore the shadowing and the fading effect and use a deterministic model where Tx_Range can be computed from the following widely used two-ray ground reflection path loss model [20],

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^{\alpha}} \qquad (1)$$

Where P_r is the received signal's power, P_t the transmitting power, d the distance between transmitter and receiver, α, the path loss exponent (normally $3 \leq \alpha \leq 4$), based on the ITU (International Telecommunications Union) recommendation, G_t and G_r the antenna gains of transmitter and receiver respectively, h_t and h_r the height of both antennas.

To correctly decode a received packet, two conditions must be met. First, the received signal's power must be larger than a threshold, called receiver sensitivity in the paper and is denoted by *Rcv_Thresh*. Given *Rcv_Thresh*, we can use (1) to determine the maximum d i.e. Tx_Range. Second, the SNR at the receiver must be above a certain threshold, denoted by *SNR_Thresh*. Given *SNR_Thresh*, we can calculate how much interference a transmission pair can tolerate.

When interference P_i is present, the SNR for an ongoing reception is given as SNR = $P_r / (P_i + P_n)$, where P_n is the noise power. Under most conditions, P_n (100 dBm) is much weaker than P_i at the receiver and SNR can be reduced to P_r / P_i. Because carrier sensing is also used in the network, the chance of multiple interferes transmitting simultaneously is usually small and one interfere is normally assumed in analyses [3]. For simplicity, the same assumption is also used in the paper. But our analysis can be easily extended to the cases with multiple interferers. Let d_r be the distance between interferer and receiver. Then the SNR at receiver side is given as follows:

$$\text{SNR} = P_r / P_i = (d_i / d_r)^{\alpha} \qquad (2)$$

Even when a receiver is located at the fringe of the transmission range (i.e. d_r = Tx_Range) of a terminal, the received signal still needs to meet the SNR requirement (*SNR_Thresh*) is represented in decibel (dB). To ensure the correct reception, interferer's distance (d_i) should be as follows:

$$d_i \geq (10^{\text{SNR\_Thresh}/10})^{1/\alpha} \cdot \text{Tx\_Range}.$$

This leads to

$$\text{I\_Range} = (10^{\text{SNR\_Thresh}/10})^{1/\alpha} \cdot \text{Tx\_Range} \qquad (3)$$

Once Tx_Range and I_Range are determined, the area within which type-2 hidden terminals may exist can also be determined.

A. SNR_Thresh, Transmission Rate and Tx_Range

As indicated by (3), *SNR_Thresh* is the key factor to determine the value of *I_Range*. Prior analyses often assumed that *SNR_Thresh* is fixed. But in fact, it varies with the transmission rate. By Shannon's theorem, we have

$$R = W \log(1 + \textit{SNR\_Thrseh}) \qquad (4)$$

Where, R = {transmission bit rate} and W = {channel bandwidth}. The equation can be expressed as

$$\textit{SNR\_Thresh} = 2^{R/W} - 1 \qquad (5)$$

Equation (5) shows that *SNR_Thresh* is rate dependent and is a monotonic increment function of R (W is fixed in a bandwidth-limited system). This result is independent of the modulation schemes used in a network.

The exact relationship between *SNR_Thresh* and transmission rate depends on the BER (bit error rate) requirement of the modulation scheme used by the network [21, 22]. The BER is determined by E_b/N_o (E_b is the energy per bit and N_o the average power spectral density of the noise). The relationship between E_b/N_o and SNR is the following,

$$SNR = \frac{P_r}{P_i + P_n} = \frac{R}{W}\frac{E_b}{N_0} \quad (6)$$

Where $P_r = R \cdot E_b$, $P_n + P_i = WN_0$. Given the BER requirement, E_b/N_0 will be fixed and the SNR requirement will change with rate. Replacing P_r by *Rcv_Thresh* in (1), we have

$$Tx\_Range = \left(\frac{P_T G_t G_r h_t^2 h_r^2}{Rcv\_Thresh}\right)^{1/\alpha} \quad (7)$$

Equation (7) shows that different values of *Rcv_Thresh* lead to different *Tx_Ranges*. As *Rcv_Thresh* is rate dependent, so is *Tx_Ranges* from (7).

V. A New Look At The Hidden Terminal Problem

In single-rate networks, all packets are sent with the same rate. The transmission range (Tx_Range) is fixed for data packets as well as for RTS/CTS control packets. Let's rewrite (3) as,

$$\frac{I\_Range}{Tx\_Range} = (10^{SNR\_Thresh/10})^{1/\alpha} \quad (8)$$

We have the following cases:

- Case i: I_Range/Tx_Range >1 if SNR_Thresh > 0 dB.

Under this condition, the interference area is larger than transmission area. Type-2 hidden terminals cannot be eliminated by the RTS/CTS scheme. Type-2 hidden terminal problem increases with the SNR requirement.

- Case ii: I_Range/Tx_Range<1 if SNR_Thresh < 0 dB.

Under this condition, I_Range is even smaller than Tx_Range. Hidden terminals can be eliminated by the RTS/CTS scheme. Although terminals located between the two circles of radius I_Range and of Tx_Range cannot corrupt an on-going transmission, they will not transmit because they receive the RTS/CTS packets correctly. This is a case of the so called exposed terminal problem [8].

- Case iii: I_Range/Tx_Range=1 if SNR_Thresh=0 dB.

This represents the best condition. Under this condition (i.e. I_Range = Tx_Range) neither type-2 hidden terminals nor exposed terminals can exist.

V. MAC Scheme For Solving Type-2 Hidden Terminal Problem

Two MAC schemes, Rate Matching and IG-MAC which solve, type-2 hidden terminal problem are explained as follows:

A. Rate Matching Mechanism

The idea of Rate Matching is that for a given data rate, RTS/CTS packets are transmitted at lower rate such that the transmission range of the lower rate can cover the interference range of the higher rate. How the data rate for sending RTS/CTS packets is selected, will be illustrated by two-rate example. In this example, the two rates are denoted by $DataRate_1$ and $DataRate_2$. $DataRate_1$ is used for transmitting RTS/CTS packets and $DataRate_2$ is used for transmitting data packets. $DataRate_1$ is assumed to be smaller than $DataRate_2$. For given $DataRate_2$, the analysis is done for finding out the value for $DataRate_1$, such that the interference range (I_Range_2) of $DataRate_2$ is covered by transmission range (Tx_Range_1) of $DataRate_1$. When this condition is met, all potential type-2 hidden terminals of $DataRate_2$ can receive the RTS/CTS messages. This alleviates the type-2 hidden terminal problem. Table 2 lists the corresponding parameters of the two-rate example.

Table I: Parameters corresponding to the two rate example.

Bit Rate (Mbps)	Rcv_Thresh (dBm)	SNR_Thresh (dB)	Tx_Range (m)
$DataRate_1$	Rcv_Thresh_1	SNR_Thresh_1	Tx_Range_1
$DataRate_2$	Rcv_Thresh_2	SNR_Thresh_2	Tx_Range_2

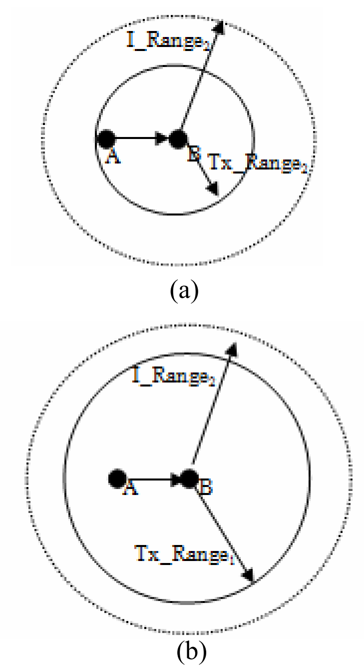

Figure 2: The case study of coverage comparison between $DataRate_1$ and $DataRate_2$. (a) Node A is using $DataRate_2$ to send RTS/CTS; (b) Node A is using $DataRate_1$ to send RTS/CTS.

From the path loss propagation model given in equation (1), following equation for transmission range is obtained.

$$Tx\_Range = \left(\frac{P_T G_t G_r h_t^2 h_r^2}{Rcv\_Thresh}\right)^{1/\alpha} \quad (9)$$

$$\frac{Tx\_Range_2}{Tx\_Range_1} = \left(10^{\frac{Rcv\_Thresh_1 - Rcv\_Thresh_2}{10}}\right)^{\frac{1}{\alpha}} \quad (10)$$

$$I\_Range_2 = \left(10^{\frac{SNR\_Thresh_2}{10}}\right)^{\frac{1}{\alpha}} .Tx\_Range_2 \quad (11)$$

On combining equations (10) and (11), the following equation is obtained.

$$\frac{I\_Range_2}{I\_Range_1} = \left(10^{\frac{-(Rcv\_Thresh_2 - Rcv\_Thresh_1 - SNR\_Thresh_2)}{10}}\right)^{\frac{1}{\alpha}} \quad (12)$$

If $Tx\_Range_1 \geq I\_Range_2$, then the RTS/CTS messages will be received by all terminals within I_Range_2 , which will eliminate type-2 hidden terminals. Therefore, the following condition should hold:

$$\frac{I\_Range_2}{Tx\_Range_1} \leq 1 \quad (13)$$

By combining equation (12) and equation (13) and assuming the value of $\alpha \geq 2$, the following condition is obtained.

$$Rcv\_Thresh_2 - Rcv\_Thresh_1 - SNR\_Thresh_2 \geq 0 \quad (14)$$

- The optimal condition occurs when the "=" sign holds in equation (14). Under this condition, the interference range of the higher data rate used for transmitting the data packets are equal to the transmission range of the lower data rate used for transmitting the RTS/CTS packets.
- For ">" case the data is transmitted at a data rate lower than RTS/CTS packets. Thus the interference range (I_Range_2) of data is smaller than transmission range (Tx_Range_1) of RTS/CTS packets. This leads to exposed terminal problem instead of type-2 hidden terminal problem.
- Even when both conditions ("=" and ">") cannot be met and the RTS/CTS messages cannot cover the entire I_Range_2, sending RTS/CTS with a lower data rate can lessen the type-2 hidden terminal problem because $Tx\_Range_1 > Tx\_Range_2$.
- Equation (14) indicates that whether Tx_Rage_1 can cover the I_Range_2 does not depend on the path loss coefficient α. But $|I\_Range_2 - Tx\_Range_1|$ does depend on α. As α decrease, it is more difficult to use Tx_Range_1 to cover the I_Range_2.

The best condition, in terms of eliminating hidden terminals, occur when $Tx\_Range_1 = I\_Range_2$. Under this condition, RTS/CTS packets will not reserve more area than needed. If this is not possible, selected rate for RTS/CTS packets is such that, which can minimize the parameter $|I\_Range_2 - Tx\_Range_1|$.

Table II. Tx_Range and I_Range of IEEE 802.11b with path loss coefficient (α) = 4.

Mbps	Tx_Range	$\left(10^{SNR\_Thresh/10}\right)^{1/\alpha}$	I_Range
11	0.5012	1.4954	0.7495
5.5	0.6683	1.4109	0.9430
2	0.8414	1.0958	0.9220
1	1	0.8453	0.8453

It is clear from the Table II that a higher data rate does not necessarily mean a larger *I_Range*.

B. Interference Graph Medium Access Control Protocol

In this section, Interference Graph based MAC protocol (IG-MAC) is explained.

(i) Interfernce Graph

Before we give the definition of the Interference Graph, we first define the Interference Set which is the basic element of Interference Graph.

Interference Set: for node m, if node k and node j can communicate (within each other's communication range) and their communication can be interfered by node m's transmission (in the other words, node m is within node k or node j's interference range), then we call this node pair (node k and j) a node m's Interference Link (IL). We define N_m, N_n as node m and n respectively IL (N_k, N_j) as a node m's Interference Link that composed by node k and j, S_m as node m's Interference Set. We use the following equation to describe the Interference Set:

$$S_m = S\ (IL\ (N_k, N_j)) \quad (15)$$

Interference Graph: The Interference Graph is defined as a set of all nodes in the network and their Interference Set. We can also consider the Interference Graph as a set of tuple (N_m, S_m). We use the following equation to describe the Interference Graph:

$$G = S\ (N_m, S_m) \quad (16)$$

We define R_t as the node transmission range, R_c as the node carrier sensing range and D (a, b) as the distance between node a and node b. As illustrated in the previous section, the interference range is depending on the data rate. It varies with the data rate. Then we can generate the Interference Graph using following scheme.

Scheme: Generate Interference Graph

1. For each node m in the network
2. For each node k that D (m, k)<=R_c
3. For each node j that D (k, j) <=R_t
4. If D (m, k) <=D (k, j) or D (m, j)<= D(k, j)
   Then
5. IL (k, j) is an Interference Link of node m,
6. Add it to the node m's Interference Set.

After generating Interference Graph, each node knows which communication (every IL in that node's Interference Set) will be corrupted by its transmission. So, when these interfering communications exist, that node should postpone its transmission for a certain period of time.

(ii) Use Busy tone to Notify the Interfering Node

One important factor in designing our protocol is that we must notify the nodes which are outside of the current sender or receiver's transmission range but its transmission will interfere the ongoing communication.

According to signal theory, we know that the pure sine wave's transmission range is equal to its carrier sensing range. So we can send a pure sine wave as busy tone to inform the interfering nodes. For a channel in our protocol, the bandwidth is split into two parts: a large data channel and a narrow control channel. Data Channel transmits the RTS, CTS, DATA and ACK packets. The busy tone is sent through the control channel.

If a potentially interfering transmitter knows the current communication's transmitter and receiver node ID, it can decide whether it should start a new communication using Interference Graph (check whether the current communication's node pair is in the potential transmitter's Interference Set). We code the current transmitter node ID in frequency of the busy tone and receiver node ID in the busy tone's transmission time duration. We assume the current communication's transmitter node ID is x, receiver node ID is y, the total node number is z and the node ID is from 1 to z, then we set the busy tone's frequency and time duration as follows:

$$F_b = F_{min} + (F_{max} - F_{min}) * (x/z) \quad (17)$$

$$T_b = T_{min} + (T_{max} - T_{min}) * (y/z) \quad (18)$$

Where:
F_b = the frequency of the busy tone sending by the transmitter and receiver.
T_b = the time duration of the busy tone sending by the transmitter and receiver.
F_{max} = maximal frequency used by the busy tone.
F_{min} = minimal frequency used by the busy tone.
T_{max} = maximal time duration that the busy tone is sent.
T_{min} = minimal time duration that the busy tone is sent.

So, when a potential transmitter wants to start a new communication, it first sense the busy tone signal and get busy tone's frequency and time duration. In this way, the potential transmitter can know the current communication's transmitter and receiver's node IDs as follows:

$$x = \frac{F_b - F_{\min}}{F_{\max} - F_{\min}} * Z \quad (19)$$

$$y = \frac{T_b - T_{\min}}{T_{\max} - T_{\min}} * Z \quad (20)$$

When the potential transmitter knows the current transmitter and receiver's node IDs, it can use the Interference Graph to decide whether it should start the new communication.

IV. SIMULATION

We have used the NCTUns-5.0 simulator for implementing both the schemes. Since we are comparing these schemes for multi-rate ad hoc networks, we have used the IEEE 802.11b standard. The communication scenario and the parameters used for simulation purposes are discussed.

Fig. 3 depicts the communication scenario consisting of two node pairs. Thus, there are two simultaneous transmissions one from A to B and other from C to D. The distance between nodes A and B and between C and D are same and equal to *Tx_Range*.

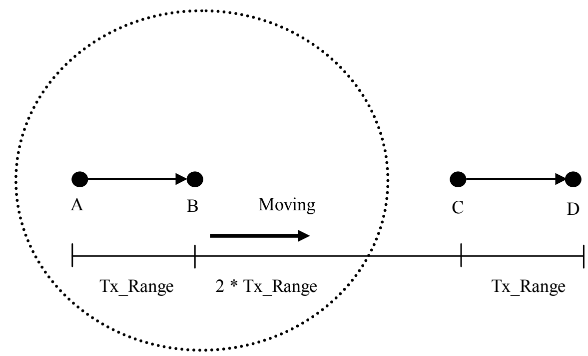

Figure 3: A communication scenario for the simulation of rate matching and IG-MAC.

The distance between node B and node C is originally set to twice of the *Tx_Range* so that both the transmissions occur without interfering each other. The node pair A-B moves towards the stationary node pair C-D with a constant speed equal to (*2 * Tx_Range*) / 50. This means the corresponding speeds for rates 1M, 2M, 5.5M, 11M will be 4, 3.36, 2.68, and 2m/s. After some time, node C will gradually become a type-2 hidden terminal for the node pair A-B, then a type-1 hidden terminal and finally a non-hidden terminal. Now node A and node C can hear each other and there will be no more collisions. The size of UDP packets is kept 1400 bytes. The value of *RTS_Threshold* is 500 bytes. The values for the *Tx_Range* and *I_Range* are set as depicted in the Table II.

Four data rates 11, 5.5, 2 and 1Mbps are used for simulating IEEE 802.11 ad hoc network topology.

V. COMPARISON OF RESULTS

With the setting given in Section IV, we run the topology for both the schemes. We make comparisons on the results obtained by the simulation to know the effectiveness of both the schemes in ad hoc networks. The receiver is the node which is affected most due to the presence of type-2 hidden terminals. Therefore, in this section we compare the results obtained by both the schemes at the receiver. We used throughput, number of collisions and number of packets drop as the metrics for this comparison.

Results obtained at the receiver for the three metrics are compared on multiple data rates supported by the IEEE 802.11b standard under the rate matching and the IG-MAC schemes using the scenario given in fig. 3. These results are shown in fig. 4, 5, and 6. For all the comparisons, we used the RTS rate of 11Mbps as there is no provision of varying the RTS rate in IG-MAC protocol.

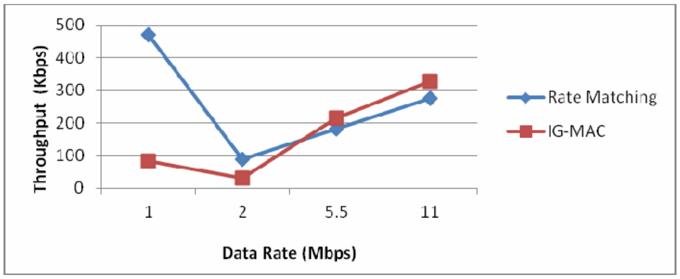

Figure 4: Graph between data rate and throughput.

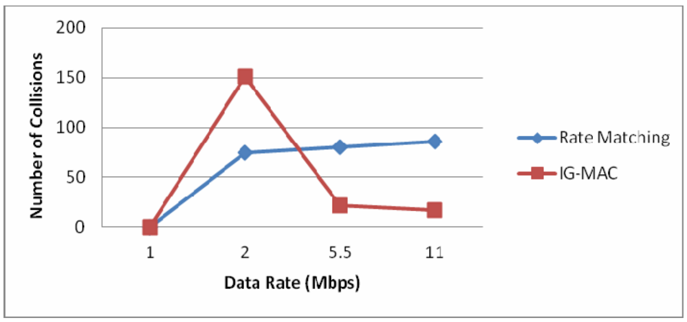

Figure 5: Graph between data rate and number of collisions.

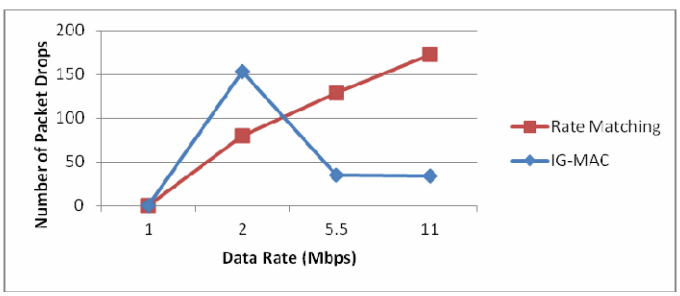

Figure 6: Graph between data rate and packet drop.

From the fig. 4, we observe that in terms of throughput, the behavior of both the schemes is unpredictable at all the data rates except 1Mbps. On an average, the rate matching scheme performs good at 2Mpbs while at the data rates of 5.5 and 11Mbps, IG-MAC performs well.

In the fig. 5, we can see that both the schemes maintained an average expected behavior as the numbers of collisions in IG-MAC are less at those data rates on which it has performed well in terms of throughput that is on the rates of 5.5 and 11Mbps.

Fig. 6 depicts that the same expected behavior is maintained by both the schemes in terms of packets lost at the receiver.

It is clear from the coverage comparison shown in fig. 2, that at 1Mbps, the interference range is covered by the transmission range. Therefore, no type-2 hidden terminals exist in this case but the problem of exposed terminals arises at this rate. Thus, because of this new problem, the behavior of both the schemes is independent of their functionality and can be seen in all the figures from fig. 4-6.

VI. CONCLUSION

In this paper, the comparative study has been done for rate matching and IG-MAC schemes. The comparison is done by measuring the parameters like throughput, collision and packets drop at the receiver. It is observed that as compared to the IG-MAC, Rate matching scheme performs good only at 2 Mbps in terms of all the parameters. However, IG-MAC performs well for the same parameters at the data rates of 5.5 and 11 Mbps. Therefore, IG-MAC is more effective to use at the data rates of 5.5 and 11 Mbps. It is observed that at 1 Mbps type-2 hidden terminal problem does not exist. It is concluded that two schemes does not exhibit the same performance at different data rates.

REFRENCES

1. Xu. K., Gerla, M., & Bae, S. (2002). How effective is the IEEE 802.11 RTS/CTS handshake in ad hoc networks? Proceeding of IEEE GlobeCom.
2. Yang, X., & Vaidya, N. On physical carrier sensing in wireless Ad Hoc networks. In Proceedings of the IEEE Infocom'05.
3. Zhai, H., & Fang, Y. Physical carrier sensing and spatial reuse in multirate and multihop wireless Ad Hoc networks. In Proceedings of the IEEE Infocom'06.
4. Xu, S., & Saadawi, T. (2001). Does the IEEE 802.11 MAC protocol work well in multihop wireless ad hoc networks? IEEE Commun. Mag. (pp. 130-137).
5. Zhu, J., Guo, X. Yang, L. L. & Conner, W.S. (2004). Lever aging spatial reuse in 802.11 mesh networks with enhanced physical carrier sensing, IEEE ICC.
6. Caishi Huang, Chin-Tau Lea, Albert Kai-Sun Wong, "Rate matching: a new approach to hidden terminal problem in ad hoc networks," Wireless networks, Springer, pp. 2139-2150, 2010.
7. W. Lin, C. Zhang, M. Li, M.Y. Wu, "An interference graph based MAC protocol for ad hoc wireless networks," Proceedings of the sixth IEEE international conference on computer and information technology, CIT, 2006.
8. Bhaghavan, V., Demers, A., Shenker, S., & Zhang, L., MACAW: A medium access protocol for wirelress LANs. SIGCOMM' 94.
9. Karn, P. (1990). MACA: A new channel access protocol for packet radio, APRL/CRRL Amateur radio 9th Comp. Net, Conference (pp 262-73).
10. Fullmer, C.L. & Garcia-Luna-Aceves, J.J., "Floor

Acquisition Multiple Access (FAMA) for Packet-Radio Networks," SIGCOMM'97 (pp. 262-73).
11. Talucci, F., Gerla, M., & Fi-atta L. (1997) "MACA-BI (MACA By Invitation): A receiver oriented access protocol for wireless multiple networks", PIMRC'97.
12. Tobagi, F. A., & Kleinrock, L. (1975), Packet switching in radio channels: Part II- the hidden terminal problem in carrier sense multiple-access and the busy-tone solution. IEEE Transactions Communications, 23 (12), 1417-1433.
13. Hass, Z. J. & Deng, J. (2002). Dual busy tone multiple access (DBTMA): A multiple access control scheme for Ad hoc networks. IEEE Transactions Communications, 50(6), 975-985.
14. Johnson, D. B., & Maltz, D. A. (1996). Dynamic source routing in ad hoc wireless networks. In Imielinski and Korth (Eds.) Mobile computing. Kluwer Academic Publishers, vol. 353.
15. Perkins, C.E. & Royer, E.M. (1999). Ad-hoc on-demand distance vector routing. In Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications (pp. 90-100). New Orleans, LA.
16. K. Xu, M. Gerla, and S. Bae. Effectiveness of RTS/CTS handshake in IEEE 802.11 based ad hoc networks. Journal of Ad Hoc Networks, pages 107-123, 2003.
17. F. Ye. S. Yi, and B. Sikdar, "Improving spatial reuse of IEEE 8002.11 based ad hoc networks," In Proc. GLOBECOM 2003, San Francisco, CA, December 2003.
18. Zhai, H. & Fang, Y., "Impact of Routing Metrics on Path Capacity in Multirate and Multihop Wireless Ad Hoc Networks", ICNP'06
19. Holland, G. & Vaidya, N. (2001). A rate adaptive MAC protocol for multi-hop wireless networks. In Proceedings ACM MOBICOM.
20. Rappaport, T.S. (1996). Wireless communications Principles and Practise, New Jersy: Prentice Hall.
21. Proakis, J.G. (2001) Digital Communications (4th ed.) McGraw Hill
22. Nguyen, G. Ephremides, A., & Wieselthier, J. On capture in random-access systems. ISIT'06.