Fairness Enhancement for 802.11 MAC

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Abstract. Location dependency and its associated exposed receiver problem create the most severe unfairness scenario of the CSMA/CA protocol. An analytical model is built up to study the success probabilities of RTS reception and RTS/CTS handshake of the typical disadvantaged link under the exposed receiver scenario. Derived from the analytical insights, we propose a receiver assistance feature (RcvAssist) for the CSMA/CA protocol which not only significantly enhances the fairness of disadvantaged links suffering from exposed receiver problem, but also increases the overall throughput without introducing other side effects, such as aggregating the hidden terminal problem.

Keywords: Fairness; CSMA/CA; Receiver assistance; Exposed receiver.

1 Introduction

The CSMA/CA (Carrier Sensing Multiple Access with Collision Avoidance) MAC protocol, adopted by the IEEE 802.11 standard, has been widely deployed in both wireless LANs and mobile ad hoc networks. It is well known that CSMA/CA's user treatment is location dependent: some links are treated more favorably than others, depending on their spatial locations. This property leads to unfair channel sharing among different links in media access. There are other elements in CSMA/CA that also contribute to its unfair behavior, like the binary exponential back-off scheme that always favors the latest channel contention winner succeeding user in channel contentions and EIFS (Extended Inter-Frame Space) that could make one sender defer much longer than another contender before counting down the residual back-off time. But the severity of these problems is much less than that created by the location dependent property of CAMA/CA.

Location dependency of CSMA/CA leads to the hidden and the exposed terminal problems and both have some intrinsic fairness issues. Recently new schemes have been proposed that can eliminate to a large extent the hidden terminal problem [28]. The focus of this paper is on the improvement of the fairness issue caused by the exposed terminal problem in CSMA/CA networks. There are two types of exposed terminal problems: exposed senders and exposed receivers. The former prohibits concurrent transmissions, while the latter leads to unfair channel access. An illustration of the two types is given in Fig. 1 that contains the two independent transmission links and each can correspond to a wireless LAN or an ad hoc wireless link. The 4-way RTS/CTS/DATA/ACK handshake [11] and the IEEE 802.11 DCF [22] are assumed in these networks.

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- Exposed senders

  S3 and S4 in Fig. 1a are called exposed senders. Both are within their mutual carrier sensing range. Suppose S4 is transmitting. When S3 attempts to access the channel, it detects the channel busy and will defter its transmission. Although simultaneous transmissions from S3 and S4 will not interfere each other at their corresponding destinations, the protocol does not allow it. When S4 finishes its transmission, both S3 and S4 will compete for the channel in a fair manner. Thus fairness in the exposed sender case is not an issue. The main issue is throughput [8][9][12][13][14][15][16].

- Exposed receivers

  R1 is the exposed receiver in Fig. 1b, where S2 and S1 are out of their carrier sensing range, S2 and R1 are within each other's carrier sensing range, but S2 is out of interference range of R1 (if S2 falls into R1's interference range, this would be the case of hidden terminal problem). Suppose there is an on-going transmission between S2 and R2 when S1 tries to initiate a transmission to R1. Because R1 is within the sensing range of S2, CSMA/CA protocol prevents R1 from replying to S1 even if it can receive RTS packets from S1. Thus R1 is called an *exposed receiver*. The lack of reply from R1 will force S1 into the back off mode. The problem is further aggravated by the MAC's binary exponential back-off algorithm, which always favors the latest winner in channel contentions. As a result, the chances of R1's acquiring the channel will be less and less over time.

The impact of unfairness at the MAC layer will get amplified in higher layer protocols. If node S1 fails several more times (the total number of retrial is limited to 7 in the IEEE 802.11 standard), the MAC protocol would treat the link between S1 and R1 as broken and reports a link failure to the routing layer. This triggers route failure recovery at the network layer and all packets routed through S1 with R1 as the next hop destination will be dropped. Thus no packets can reach the destination until a new route is established by the routing protocol. To complicate the issue further, TCP will treat the packet loss as network congestion and halve its congestion window size accordingly, leading to low efficiency in channel utilization [1][3].

In this paper, we tackle the fairness problem caused by exposed receiver problem as described in Fig. 1b. We will show, with both analysis and simulation, that often there is a good chance for R1 to receive RTS packets correctly from S1. By exploiting this property, we propose a simple **receiver assistance (not initiated)** feature added to CSMA/CA that can significantly improve the fairness of the protocol. Our main contributions are the following.

- We build up an analytical model to study the success probabilities of RTS receptions and RTS/CTS handshakes of the disadvantaged link under the exposed receiver scenario in Fig. 1b. The insights derived from the analysis lay the foundation for our proposed fairness enhancement feature.
- We propose a receiver assistance feature for CSMA/CA protocol. The proposed feature not only enhances significantly the fairness of disadvantaged links (like link S1-R1 in Fig. 1b) in the exposed receiver scenario, but also increases the

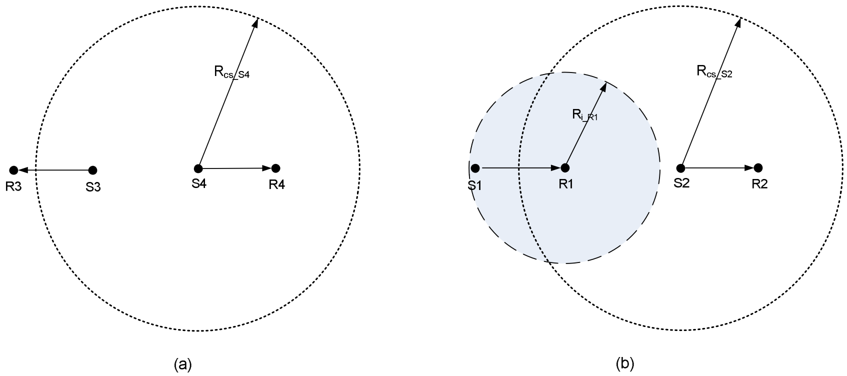


Fig. 1. Two typical cases of exposed terminal problem; (a) exposed sender S3 and S4 in R3-S3-S4-R4 scenario; (b) exposed receiver R1 in S1-R1-S2-R2 scenario; the dot circle represents the carrier sensing range; the dash circle denotes interference range. Although we use circle to represent the transmission, carrier sensing and interference ranges, the protocol does not assume circles for carrier sensing/interference areas and it works for any irregular shapes as well.

overall throughput without introducing other side effects, such as aggregating the hidden terminal problem. The resulting protocol retains the advantages of both sender-initiated and receiver- initiated MACs.

The rest of the paper is organized as follows. Section 2 presents the related work. Section 3 analyzes the success probabilities of RTS receptions and RTS/CTS handshakes of the disadvantaged link. Based on the results derived from Section 3, Section 4 presents the fairness enhancement feature. It also studies and compares performance of the protocol and 802.11 in terms of fairness and throughput via NS2-based simulations. Section 5 concludes our discussions.

2 Related Work

Both exposed and hidden terminal problems have severe negative impact on network performance and there exist many proposals addressing these problems. One issue is related to the relative frequency of the two events. Although major attention is given to the reduction of hidden terminals [2][4][7][8][9][11], Reference [17] has shown that the exposed terminal problem is actually much more severe than the hidden terminal problem. In their CMU campus-wide Wifi network measurement they studied, there were as many as 11438 exposed pairs, while there were only 406 hidden pairs. The focus of the paper will be on the exposed terminal problem. Another issue is the trade-off between the exposed and hidden terminal problems. The reduction of hidden terminal problems often comes at the cost of an increase of exposed terminal problems [2][7][8][9]. This, however, is not the case with the proposed scheme in this paper.

Several literatures have tried to address the exposed terminal problem. But most of them are focusing on increasing the concurrent transmissions [8][12][13][14][15], rather than solving the fairness issue in the presence of exposed terminals. Reference [8] studies the optimal carrier sensing threshold that can lead to maximum spatial reuse. MACA-P [12] introduces a control gap between the RTS/CTS exchange and the subsequent DATA/ACK exchange to facilitate other pairs to conduct potential concurrent transmission. References [13][14] exploit more concurrent transmission opportunities for exposed terminals via overhearing. DBTMA [15] proposes to use two busy tones to indentify and protect packet transmissions and receptions so that an exposed sender can launch concurrent transmissions if it does not hear reception busy tone.

In terms of the fairness, there exists a large amount of work on fairness improvement of the binary back-off scheme [1][23][24][25][26][27]. For example, Reference [1] presents a back-off copy scheme to manage the contention window size so as not to favor the terminal that has just won the contention in the subsequent transmission. References [23][24] suggest that by overhearing packets sent on the medium, each terminal can measure the rates of contending links and determine if its access rate is above or below its neighbors. [25][26] try to serialize transmissions among contending links based on their scheduling tags. Reference [27] proposes a general analytical model and MAC protocol to approach proportional fairness among the links. This type of research is independent of the work done in this paper, which focuses on solving the fairness issue caused by exposed terminal problem via improving the underlying MAC protocol.

As far as the latter is concerned, there is also some related work. MACA-BI [4] is a receiver initiated MAC protocol, while 802.11 DCF [22] a sender initiated MAC protocol. References [5][6] are hybrid protocols. A pure receiver initiated protocol, as exampled by [4], needs to have an effective polling scheme so that the receiver can predict the sending patterns of various potential senders. This is obviously difficult to achieve. References [5][6] propose to switch between sender-initiated and receiver-initiated mode. But this does not solve the fairness issue caused by exposed terminals, as receiver-initiated mode also suffers from exposed terminal problem. The proposed receiver assistance (not initiated) protocol keeps the simplicity of sender initiated MAC in packet delivery, and avoids its unfairness pitfall through a receiver assistance feature. As mentioned in [5][10], fairness enhancement schemes usually exhibit some form of tradeoff between throughput and fairness. This, however, is not the case with the proposed scheme. The results given later will show that the fairness improvement of the proposed scheme does not come at the cost of throughput.

3 Probabilities of Successful RTS Receptions and RTS/CTS Handshakes

Before proceeding with the new scheme proposal, an analytical model for studying the success probabilities of RTS receptions and RTS/CTS handshakes of the disadvantaged link S1-R1 under the exposed receiver scenario (see Fig. 1b) is given first. We will show that even under heavy traffic between S2 and R2, a large number of RTS packets that can still be received by R1. This fact is exploited later in Section 4.

In the analysis, both links are assumed to always have packets to send, and 802.11b standard parameter setting is used. The following summarize the notations appearing in the analysis:

$T_{backoff}$	The back-off time of S2
T_{4-way}	4-way handshake time of link S2-R2
T_{total}	The cycle time of link S2-R2 to finish a packet delivery process, which includes 4-way handshake T_{4-way}, the back off time $T_{backoff}$, and DIFS
T_{silent}	The silent time of S2 in T_{total}
T_{RTS}	The transmission time for RTS frame
T_{CTS}	The transmission time for CTS frame
T_{DATA}	The transmission time for DATA frame
T_{ACK}	The transmission time for ACK frame
CW_{S2}	The contention window size of S2
$\mathrm{CW}_{\min}$	The minimum contention window size (note that in 802.11b, $CW_{\mathrm{win}} = 31$).
BO	the back off number picked by S2 from its contention window
IFS	SIFS =10us, DIFS =50us, and EIFS =SIFS+ T_{ACK}+DIFS [22].

In Fig. 1b, the degree of cooperation imposed by the 802.11 MAC between the two links is determined by the interaction between R1 and S2. Senders S1 and S2 are out of their mutual carrier sensing range, but R1 and S2 are still within the carrier sensing range of each other. So link S1-R1 has to compete for the channel with link S2-R2 through R1. As link S2-R2 is continuously back-logged, the transmission by link S2-R2 consists of cycles. An important observation from the discussion of Section 1 is that when link S2-R2 has an on-going flow, there is little chance for link S1-R1 to interrupt the transmission. This means that although the cycle and cycle time is occasionally interrupted by link S1-R1, we can ignore link S1-R1's scattered interruption, without sacrificing the accuracy of the results much.

Once we ignore link S1-R1's interruption, link S2-R2's cycle would be the one shown in Fig. 2. The cycle time, denoted by T_{total} , becomes

$$T_{total} = T_{4-way} + T_{backoff} + DIFS$$

Where $T_{backoff} = 20us \times BO$, BO is the back-off number selected from [0, CW_{S2}]. The successful reception of an S1's RTS packet at R1 can only occur if S1 starts to

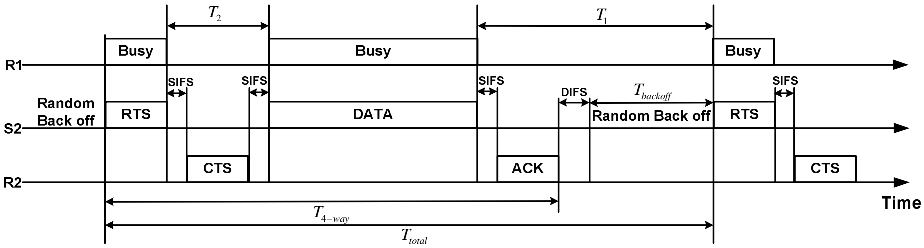


Fig. 2. Packet transmission cycles of the S2-R2 link

transmit the RTS packet when S2 is silent. If not, R1 is already locked to the signal from S2 and this prevents the correctly decoding the packet from S1 even if it is stronger than the signal with which R1 is already synchronized with [17][18][19][21]. The total length of S2's silent intervals, denoted by T_{silent}, is $T_1 + T_2$. Let A be the event that the RTS from S1 can be received correctly by R1. Since S1's attempt to access the channel can occur at any point within the cycle, we have the following conditional probability

$$P(A\ |BO = x) = \frac{T_{silent}}{T_{total}} = \frac{T_1 + T_2}{T_{total}} = \frac{3 \times SIFS + T_{CTS} + 20x + T_{ACK} + DIFS}{T_{4-way} + DIFS + 20x}$$

Let B be the event that an RTS/CTS handshake of link S1-R1 can be completed successfully. Event B can occur if (a) an RTS packet is received correctly and (b) R1 sees a clear channel in the immediate SIFS interval right after the reception of RTS. That means that S2 needs to be silent for a $(T_{RTS} + SIFS)$ duration. Only time slot T_1 allows this to happen and the transmission time of S1 must occur during the first $(T_1 - T_{RTS} - SIFS)$ second of T_1. This means

$$\begin{aligned} P(B\ |BO = x) &= \max\left(\frac{T_1 - T_{RTS} - SIFS}{T_{total}}, 0\right) \\ &= \max\left(\frac{20x + T_{ACK} + DIFS - T_{RTS} - SIFS}{T_{4-way} + DIFS + 20x}, 0\right) \end{aligned}$$

It is rare that link S2-R2 experience collision, thus $CW_{S2} = CW_{min}$. The back off number BO is uniformly distributed within [0, $\mathrm{CW_{win}}$]. Therefore,

$$P(A) = \sum_{x=0}^{x=CW_{win}} P(A\ |BO = x)P(C = x) = \sum_{x=0}^{x=CW_{win}} P(A\ |BO = x)\frac{1}{CW_{win} + 1}$$

$$P(B) = \sum_{x=0}^{x=CW_{win}} P(B\ |BO = x)P(C = x) = \sum_{x=0}^{x=CW_{win}} P(B\ |BO = x)\frac{1}{CW_{win} + 1}$$

Fig. 4a shows the analytical results of the success probabilities of RTS receptions and of RTS/CTS handshakes of link S1-R1, while Fig. 4b and 4c are the corresponding simulation results. It is noted that under the condition that R1 and S2 are within their mutual carrier sensing range in Fig. 1b, R1 and S2 can be within or outside their mutual transmission range (see Fig. 3a and Fig. 3b). The difference is that if they are within the mutual transmission range, S2 can decode the packet transmitted by R1. If outside the transmission range, it can only sense the packet. The difference will lead to different lengths of T_{total} and T_{silent} when an S2-R2 transmission cycle is interrupted by an S1-R1 transmission, thus the simulation results for both sub-cases are provided. Results in Fig. 4 show that the accuracy of the simplified analysis is pretty good. Both analytical and simulation results indicate that a large number of RTS packets can still be received by R1. However, the number of successful RTS/CTS handshakes is much smaller— meaning that most successful RTS packets at R1 are wasted.

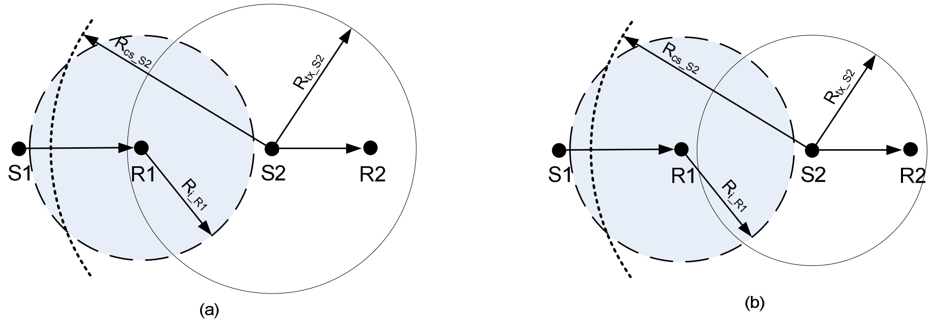


Fig. 3. (a) R1 and S2 are within the transmission range. (b) R1 and S2 are out of the transmission range. The dash circle is R1's interference range; the dot circle is S2's carrier sensing range.

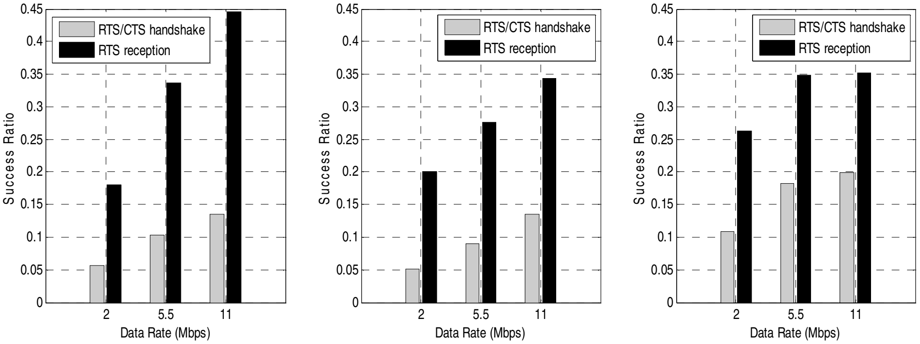


Fig. 4. The probabilities of successful RTS reception and RTS/CTS handshake of link S1-R1; From left to right: (a) Analytical results (b) Simulation results of Fig. 4a. (c) Simulation results of Fig. 4b. Packet lengths = 1000 bytes.

4 Proposed Receiver Assistance MAC Protocol

The results of Section 3 indicate that there are many RTS packets that can arrive correctly at the R1 of the disadvantage link. To exploit this result, we propose a simple receiver assisted feature. The proposed protocol, called ***RcvAssist*** in the paper, can significantly improve the degree of fairness.

4.1 RcvAssist Protocol

RcvAssist is almost identical to 802.11, the only difference being a simple receiver assistance feature added to the sending and the receiving side of the MAC protocol. On the sending side, everything remains the same except that after a fixed number of failed RTS attempts (the value is determined later), the sender will turn on a "help" flag in subsequent RTS packets. This will activate the receiver assistance feature on the receiving side.

When the receiver receives an RTS packet and the channel is detected busy, the receiver will check if the "help" flag in RTS packet is set. If not, it simply drops the RTS packet, in the same way as defined in the 802.11 protocol. If yes, it will generate a CTS packet and contends the channel (for sending the CTS packet) once the channel is sensed idle. The channel contention follows the normal procedure defined in IEEE 802.11 MAC. But the receiver only makes one, not seven, attempt to acquire the channel. The receiver will get back to the normal mode once the attempt is done, regardless if it is a failure or success.

Note that in the four-way handshake RTS/CTS/DATA/ACK defined by 802.11, if the receiver assistance feature is turn on and the CTS reply is done through channel contention by the receiver, then there will be a gap between arrival of the RTS and the transmission time of the CTS packet by the receiver. This gap corresponds to the channel contention time. This gap is not included in the NAV (Network Allocation Vector) of sender's RTS. Thus the NAV setting in RTS might not be long enough to protect the ACK reception. This, however, is not a problem because on the sender side, in addition to RTS packets, all terminals still use carrier sensing and they thus still need to wait for a duration of an EIFS (EIFS = SIFS + ACK duration + DIFS) period before trying to access the channel again. This means that the ACK at sender side can be protected as before even if the NAV in the RTS packet is not accurate.

Another situation worth mentioning is that when receiver assistance MAC is activated, both the sender and the receiver will initiate packet transmissions to each other and their transmissions may collide. But the chance is slim as the probability that they transmit in the same time slot is no larger than $32\times(1/32)\times(1/64)= 0.0156$ (sender's contention window size has doubled because of no reply for its previous RTS transmission before. 31 is the minimum contend window size defined in 802.11b MAC). Even in 802.11a, of which the minimum contend window size =15, the probability is no larger than $16\times(1/16)\times(1/32) = 0.0313$.

Fig. 5 give an illustration of the proposed receiver assistance feature based on the scenario in Fig. 3a. As the number of failed RTS attempts exceeds the pre-set threshold, S1 turns on the help flag in its subsequent RTS transmissions to node R1. Once R1 can correctly receive a RTS packet with "help" flag on and channel becomes clear again, it will contend the channel for sending back the CTS packet. This contention between R1 and S2 does not favor S2, as in the traditional 802.11 protocol. So R1 will have an equal probability of seizing the channel.

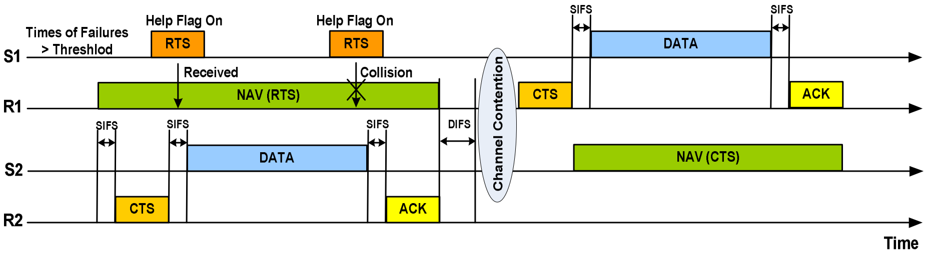


Fig. 5. A graphic illustration of receiver assistance MAC based on Fig. 3a

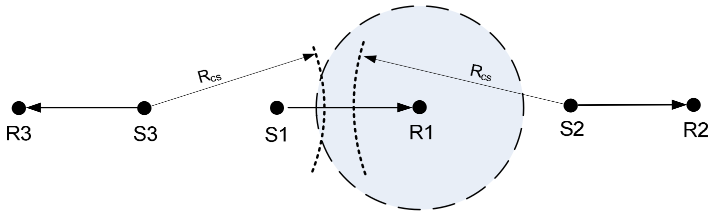
4.2 Performance of RcvAssist

NS2 (version 2.30) simulator [21] is used to evaluate and compare the performance of the proposed protocol and the IEEE 802.11 DCF. Performance evaluation is based on two metrics: network throughput at transport layer and fairness among different communication sender/receiver pairs. Network throughput measures the protocol's efficiency of channel utilization and fairness indicates how channel bandwidth is shared among different communication links. The degree of fairness is indicated by the instantaneous throughput of individual users versus the total channel capacity.

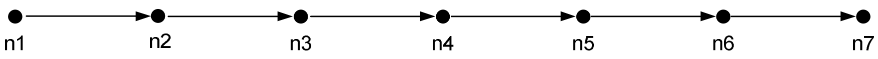
UDP flow is used in simulation. Data packets are generated by continuously-backlogged CBR (Constant Bit Rate) flows with a fixed packet size 1KB. Because the default setting of channel update in NS2 does not reflect the real situation when multiple packet transmissions occur simultaneously, one of our simulation efforts is to modify the current implementation and make it reflect the real channel conditions at each node.

Four cases are simulated. Two are the basic scenarios shown in Fig. 3, and the other two are shown in Fig. 6. IEEE 802.11b protocol parameters are adopted in the simulation. In addition, the following parameters, unless indicated otherwise, are chosen in the simulations:

(1) The number of failed RTS attempts for turning on the "help" feature in RcvAssist is set to 1.
(2) The transmission range and the carrier sensing range of each node are R_{tx}=250m and R_{cs}=550m respectively.
(3) The SINR threshold for capture requirement is 10dB.
(4) The propagation model is the two-ray ground reflection model.
(5) The default data rate is 11Mbps.
(6) Each simulation runs for 50 seconds.



Case 3



Case 4

Fig. 6. Case 3 and Case 4; The dash circle is interference range of R1, the dot circles are carrier sensing range in Case 3.

4.2.1 Case 1

This case refers to the scenario in Fig. 3a. There are two communication flows: S1→R1 and S2→R2. The distances between S1 and R1, R1 and S2, S2 and R2 are 210m, 250m and 210m respectively. The simulation environment in NS2 simulator provides no walls and obstacles. We need to set the carrier sensing range and capture SINR threshold smaller (R_{cs}=450m and SINR threshold = 2) to simulate scenario 1. This is the only situation where the default R_{cs} and the SINR threshold are changed. Flow S1→R1 starts first and begin its transmission at t = 0. At time = 4s, flow S2→R2 starts.

Fig. 7a and 7b describe the instantaneous throughputs of two links under 802.11 and RcvAssist respectively. The throughput of flow S1→R1 under 802.11 drops quickly once flow S2→R2 starts; in contrast, it can still maintain a fair level of throughput flow in RcvAssist. The degree of fairness is improved significantly in the RcvAssist protocol. The S1→R1 link of the RcvAssist can grab around 33% total channel capacity; in contrast, it only gets 10% of the channel capacity if 802.11 is used. Fig. 7c compares the total throughput. It shows that RcvAssist can achieve higher network throughput than 802.11. One reason is that RcvAssist has a better spatial reuse factor. For example, flow S1→R1 in RcvAssist may finish their RTS transmission during the transmission of S2→R2. If the receiver assisted feature is turn on, R2 may seize the channel during the inter-frame period of S1→R1. This means that R1 only needs to finish the remaining phases (CTS/DATA/ACK). The overlapping of RTS transmission of the S1-R1 link with the transmissions of the S2→R2 is not possible in conventional 802.11.

Fig. 8 plots the throughput of flow S1→R1 under different threshold values that will trigger the receiver assisted feature in RcvAssist. As can be seen, different thresholds lead to different degrees of channel sharing for flow S1→R1. A lower threshold allows flow S1→R1 to grab a higher portion of the capacity. If the threshold is set to 8, the throughput of S1→R1 in RcvAssist is reduced to that in the 802.11 MAC protocol.

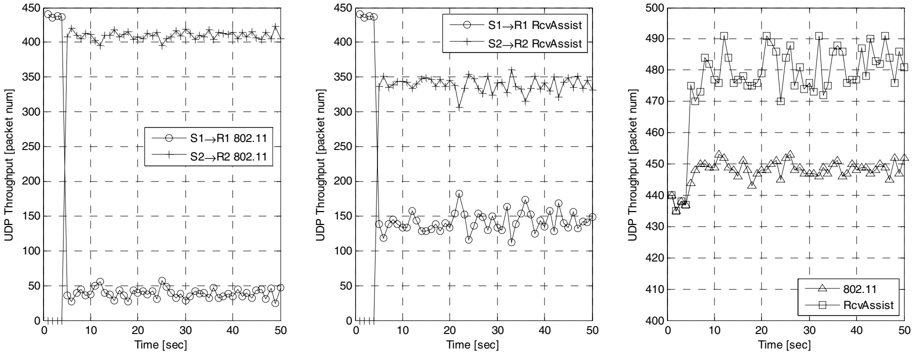


Fig. 7. Case 1 throughput performance; from left to right: (a) Throughput performance of two links in 802.11; (b) Throughput performance of two links in RcvAssist; (c) Network throughput comparison between 802.11 and RcvAssist

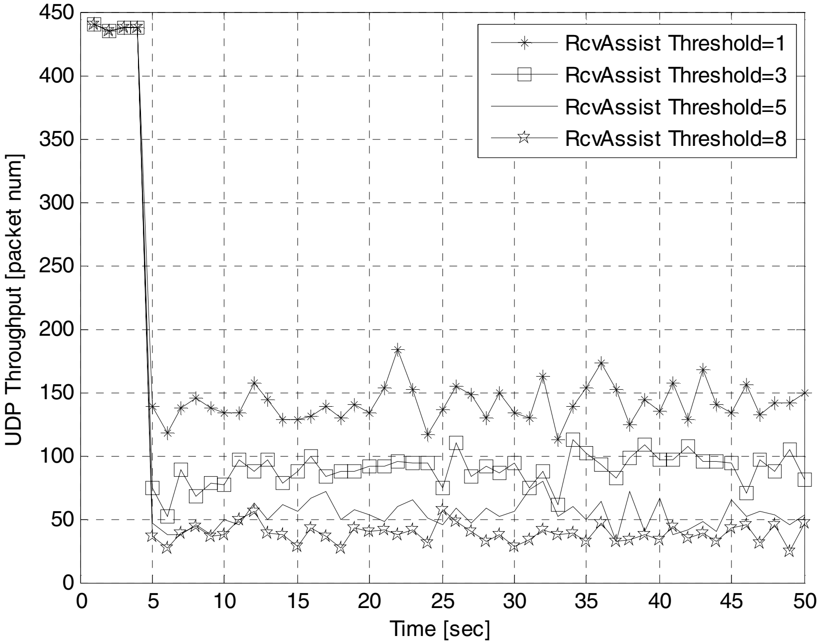


Fig. 8. RcvAssist throughput performance with different thresholds in Case 1

4.2.2 Case 2

This case refers to the scenario shown in Fig. 3b. The distances from S1 to R1, R1 to S2 and S2 to R2 are 220m, 400m and 220m respectively. Flow S1→R1 begins its transmission at t = 0. At time = 4s, flow S2→R2 starts. The performance of the two links and total network throughput are shown in Fig. 9. The interpretations for the

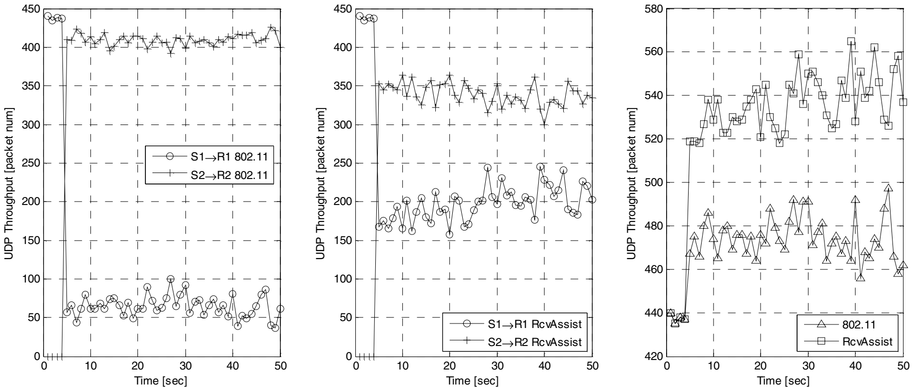


Fig. 9. Case 2 throughput performance; from left to right: (a) Throughput performance of two links in 802.11; (b) Throughput performance of two links in RcvAssist; (c) Network throughput comparison between 802.11 and RcvAssist

results are similar to that in Case 1. The main difference of Case 2 is that R1 and S2 are out of their mutual transmission range. Whenever R1 gets a chance of sending a packet, there is an additional EIFS (EIFS = SIFS+T_{ACK}+DIFS) back-off in S2's back-off period because S2 cannot decode CTS packets from R1. This leads to a better chance for flow S1-R1 to capture the channel. The performance for both protocols is better than Case 1. RcvAssist and 802.11 gets 11.3% and 3.4% more capacity in case 2.

4.2.3 Case 3

This case (Fig. 6) has three links and S1-R1 needs to compete with S2-R2 and S3-R3 simultaneously. In both contention cases, S1-R1 represents the disadvantageous link in an exposed receiver scenario. The distances from R3 to S3, S3 to S1, S1 to R1, R1 to S2, and S2 to R2 are set to be 220m, 350m, 220m, 400m, and 220m. Both flows S1→R1 and S2→R2 have continuously-backlogged packet to send. Flow S1→R1 begins its transmission at t = 0. At t= 4s, flow S2→R2 starts. At t = 15s, flow S3→R3 starts with rate = 0.4Mbps. It then increases the rate to 0.8Mbps at t = 30s, to 1.2Mbps at t= 45s, and to 1.6Mbps at t = 60s. The simulation ends at time =70s. Again, Fig. 10 shows that RcvAssist outperforms 802.11 MAC and flow S1→R1 can maintain a decent throughput level even under this double jeopardy condition.

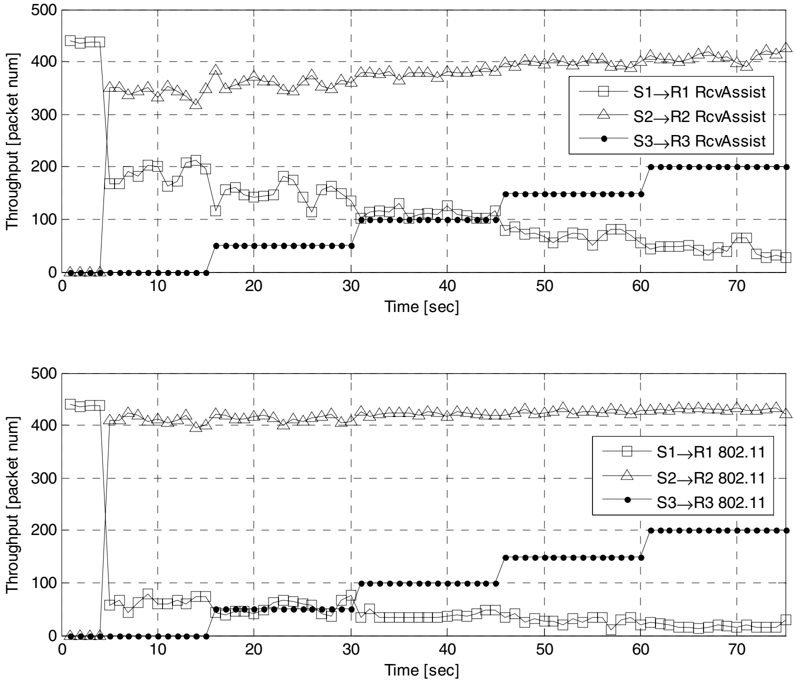


Fig. 10. Throughput performance comparison between RcvAssist and 802.11 MAC in Case 3

4.2.4 Case 4

This case refers to the multi-hop topology with 7 nodes shown in Fig. 6. Each node is 200m away from its immediate neighbors. Node 1 (n1) is the source node and the last node (n7) the sink. This is the same scenario used in [29] for studying ad hoc wireless networks. The packet generation rate at n1 is 1Mbps. Fig. 11 shows that the throughput of RcvAssist is 23.3% higher than that of 802.11.

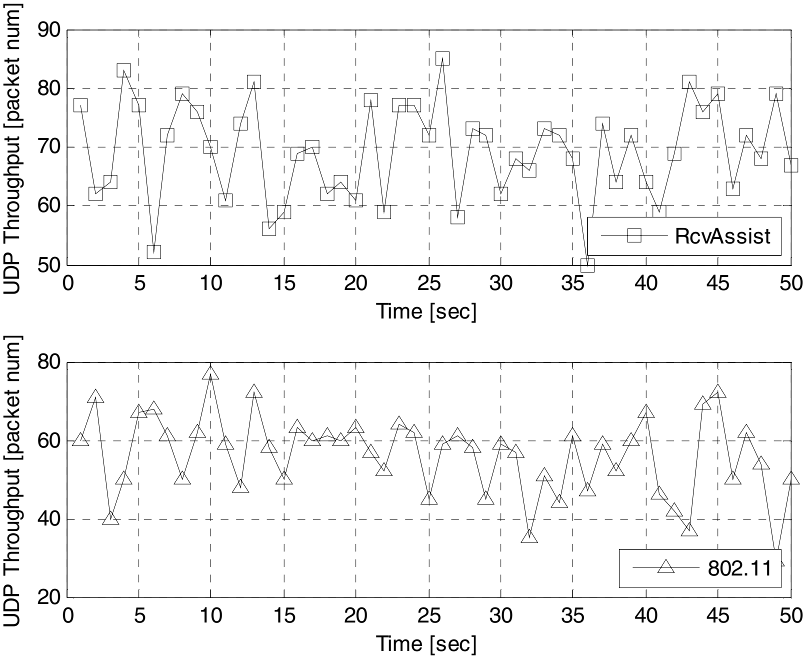


Fig. 11. Throughput performance comparison between RcvAssist and 802.11 MAC in Case 4 multihop environment (chain topology)

5 Conclusion

In this paper, we developed an analytical model to study the RTS reception and RTS/CTS handshake success rates of a typical disadvantaged link in the exposed receiver scenario. Derived from the analytical insights, we proposed a new protocol RcvAssist for fairness enhancement in CSMA/CA wireless networks. The simulation results of various scenarios indicate that the new protocol not only significantly improves the fairness of the CSMA/CA protocol, but also increases the overall throughput without introducing other side effects, such as aggregating the hidden terminal problem. The added feature is easy to implement and the concept is applicable to the design of future MAC protocols.

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