A Multi-relay Cooperative Automatic Repeat Request Protocol in Wireless Networks

Xin He and Frank Y. Li
Dept. of Information and Communication Technology, University of Agder (UiA), N-4898 Grimstad, Norway
Email: {xin.he; frank.li}@uia.no

Abstract—**This paper proposes a Multi-relay Cooperative Automatic Repeat ReQuest protocol (MC-ARQ) for IEEE 802.11 based wireless networks. The proposed distributed relay selection scheme not only selects the best relays but also solves the collision problem among multiple contending relays, by sorting the relays in the network according to their instantaneous channel quality towards the destination node. No prior information or explicit signaling among relay nodes is required. Both analytical and simulation results show that significant benefits can be achieved using the MC-ARQ protocol, compared with both the recently proposed PRCSMA scheme and the original non-cooperative DCF scheme.**

I. Introduction

The theory of cooperative diversity has been studied in depth during the past few years [1]∼ [3], and as a new trend, cooperative Media Access Control (MAC) design began to emerge recently in the literature. However, most of the existing cooperative MAC protocols require additional support from physical layer techniques. For example, Code Division Multiple Access (CDMA) [4] or space-time coding [5] are frequently assumed in order to support simultaneous channel access of the source and relay nodes.

A few cooperative MAC protocols are proposed based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme. For instance, [6] [9] focus on cooperative schemes in multi-rate Distributed Coordination Function (DCF) based wireless networks. In those protocols, high data rate stations are utilized to forward the traffic of low data rate stations in order to achieve higher throughput. Apart from these, other publications, e.g., [7] [8], have studied cooperative retransmission implementation. However, none of these retransmission protocols adopt dynamic relay selection schemes, and their performance evaluations do not take the extra overhead of proactive relay selection schemes into consideration.

Persistent Relay Carrier Sensing Multiple Access (PRCSMA) [10] is claimed to be the first MAC protocol designed to apply distributed cooperative automatic retransmission request schemes in wireless networks. In PRCSMA, all stations are invited to become active relays as long as they meet certain relay selection criteria. Multiple relays contend for channel access in the cooperative phase according to the DCF protocol [11]. However, the resulted long defer time and random backoff time at each relay lead to low bandwidth efficiency.

In order to improve the efficiency of the multiple relay retransmission scheme, this paper proposes a Multi-relay Cooperative Automatic Repeat ReQuest protocol (MC-ARQ) MAC protocol based on the IEEE 802.11 DCF scheme. The main features of the proposed scheme are three-fold: 1) cooperation on demand: the cooperative retransmission is initiated only if the direct transmission fails. Unnecessary occupation of channel and waste of system resource is therefore avoided. 2) distributed relay selection scheme: no prior information such as topology information or explicit signaling among relay nodes is required. 3) multiple relay cooperation: multiple relay nodes automatically schedule their retransmissions sequentially according to their instantaneous relay channel quality to the destination; the collision problem among multiple contending relays is solved at the same time.

The rest of the paper is organized as follows. The system model is introduced in Sec. II. The proposed MC-ARQ protocol is described in details in Sec. III. A throughput and packet delivery ratio performance analysis of the MC-ARQ scheme in comparison with the PRCSMA scheme and DCF scheme is given in Sec. IV, and simulation results are presented in Sec. V. Finally a conclusion is drawn in Sec. VI.

II. System Model and Assumptions

The system model for illustrating the cooperative protocol procedure is shown in Fig. 1. It consists of a source station S, a destination station D, and several relay candidates R_1, R_2, ..., R_n.

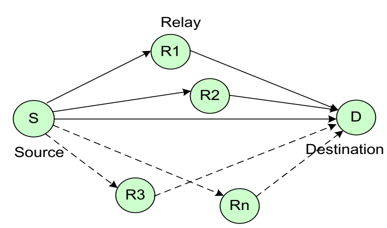


Fig. 1. System Model for Multi-relay Cooperative Retransmission.

In this network, all nodes can hear each other. Each packet transmission starts from S, with D as the intended destination. Other nodes in the network will capture the data packet from the direct link, and those which correctly decode the packet will become relay candidates. The qualified relay candidates will forward their received packets to D when necessary following the proposed MC-ARQ protocol.

The channel between S and D and the channels between each relay candidate and D, referred to as *direct channel* and *relay channels* respectively in the rest of the paper, are assumed to be independent of each other. Moreover, we assume that consecutive packets on the same channel are subject to the same channel fading condition and identical packet error rate. The above assumptions are validated in experiments carried out with 802.11g systems in typical office environments [12].

III. MC-ARQ MAC Protocol Design

In this section, the proposed MC-ARQ protocol is described in details, starting from its multi-relay selection scheme.

A. Multi-relay Selection Scheme

Inspired by the idea of using different backoff time before transmission to choose the optimal relay [13], we propose a multi-optimal-relay selection scheme for MC-ARQ.

In our scheme, only nodes that have decoded the packets sent by S correctly become relay candidates, and some of these candidates will be selected to forward their received packets to the destination when necessary. Based on this, the relay channel quality is taken as the only criterion for the selection of suitable relays in cooperative retransmission. That is, only the channel quality between each relay candidate and the destination needs to be measured and the candidate with the best link quality will be selected to retransmit first.

According to the reciprocity of the physical channel, the relay channel quality in our scheme is represented by the measured Signal-to-Noise Ratio (SNR) of the Claim For Cooperation (CFC) packet received from the destination node. The CFC packet is specially designed in MC-ARQ to enable the relay nodes to measure their relay channel quality. How this procedure proceeds will be explained in the following subsection .

After the initiation of the cooperative phase, each relay candidate starts its timer with the initial value of:

$$T_i = \left\lfloor \frac{SNR_{low}}{SNR_i}(\text{DIFS} - \text{SIFS}) \right\rfloor, i = 1, 2, \cdots, n, \quad (1)$$

where T_i is defined as an integer number of microseconds; SNR_i is the SNR value in dB of the received packet from D measured at R_i and SNR_{low} is the threshold of SNR_i for relay candidates to participate in cooperative retransmission. If SNR_i is lower than SNR_{low}, the relay channel quality is regarded to be too poor to forward the packet. The value of SNR_{low} can be determined according to the specified available Modulation and Coding Schemes (MCSs) at the physical layer. DIFS and SIFS are DCF InterFrame Space and Short InterFrame Space in the DCF scheme respectively [11] and expressed as integer values in units of microsecond.

The granularity of T_i could in principle be configured flexibly. The smaller the granularity is, the lower the theoretical probability of collisions among relays will be. However, for convenience and with regard to practical implementation aspects, a microsecond granularity has been adopted here.

According to Eq. (1), the relay node R_b, which has the highest received signal strength SNR_b, will get the shortest backoff time T_b, and then naturally become the first one to forward the data packet to the destination node.

$$SNR_b = max\{SNR_i\} \Rightarrow T_b = min\{T_i\}, i = 1, 2, \cdots, n. \quad (2)$$

Similarly, all the relay candidates in the network will be sorted in this way according to their instantaneous relay channel quality. They will retransmit their received packets one after another when necessary, following our MC-ARQ protocol described in the following subsection.

Furthermore, the upper bound of the backoff time for relay candidates in Eq. (1) is DIFS-SIFS. This ensures privileged channel access for cooperative retransmissions by preventing other contending nodes from getting access to the channel before the relay nodes. If none of the relay timers expires within DIFS-SIFS duration, i.e., no qualified relay node is available in the network, the source node will try to retransmit the data packet again according to the original DCF scheme.

If two or more relay candidates have the same value of T_i, they will transmit simultaneously to the channel. In this case, a collision occurs and this cooperative retransmission attempt fails. Fortunately, simulation results in Sec. V will show that the collision probability is reasonably low in our relay selection scheme.

B. MC-ARQ Protocol Description

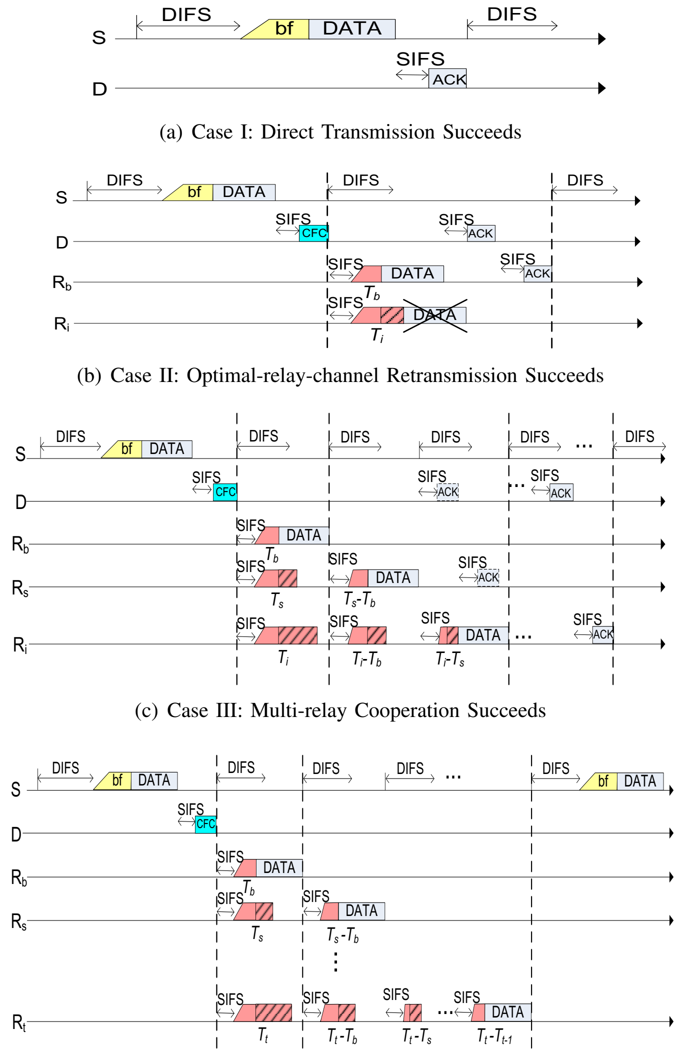
The proposed MC-ARQ protocol is based on the DCF basic access scheme. Fig. 2 illustrates its message sequences in different cases: I) direct transmission succeeds; II) optimal retransmission succeeds; III) multi-relay retransmission succeeds; and IV) the whole cooperative retransmission fails.

Case I: As the first step, S sends out a data packet to its destination D following the original DCF basic access scheme. As shown in Fig. 2(a), S listens to the channel for a DIFS interval and then executes the backoff (bf) process for a random time before transmission. If the transmission succeeds, an acknowledgment (ACK) frame will be returned to S after a SIFS interval.

Case II: If and only if the data packet is received erroneously at D, the cooperative phase will be initiated. The error-check can be performed by means of a cyclic redundancy check. As shown in Fig. 2(b), D will broadcast the CFC packet to invite other nodes in the network to be relay nodes in the cooperative retransmission.

The CFC packet provides relay nodes with the opportunity of measuring their respective relay channel quality. The CFC frame has a similar format as the ACK frame but with a broadcast address in its address field. It is transmitted at the basic data rate in order to invite as many relay nodes as possible. Each candidate will measure the signal strength of its received CFC packet and start its timer according to Eq. (1) if the SNR exceeds SNR_{low}.

The optimal relay node $\mathrm{R_b}$, which observes the strongest received signal and thus has the shortest backoff time T_b, will first get access to the channel and forward its received packet to the destination. When the other relay candidates hear the



(a) Case I: Direct Transmission Succeeds

(b) Case II: Optimal-relay-channel Retransmission Succeeds

(c) Case III: Multi-relay Cooperation Succeeds

(d) Case VI: Cooperative Retransmission Fails

Fig. 2. MC-ARQ Basic Access Scheme

packet from the channel, they will freeze their timer and keep on listening to the channel. If D decodes the packet correctly after the optimal-relay-channel retransmission, D will return an ACK packet, which is relayed afterwards by R_b to S in order to guarantee a reliable ACK transmission. All the relay nodes will reset their timer and discard the packets they have received after they detect the ACK packet from the channel. Thus, the cooperative retransmission phase is completed.

Meanwhile, S keeps listening to the channel for the next data transmission. If there are no relay nodes in the network that satisfy the relay selection criterion, S will obtain the channel access after DIFS and a random backoff time.

Case III: The cooperative retransmission failure can be caused either by collisions among at least two relay nodes with the same backoff time T_b or by data corruption on the transmission channel. In this case, no ACK packet is detected from the channel, and the other relay nodes will reactivate their timers simultaneously after the ACK timeout, as shown in Fig. 2(c).

Following the same procedure as the optimal-relay-channel retransmission, the timer of the relay node with the second-optimal-relay-channel R_s will expire first this time and R_s will forward the packet before others. An ACK packet will be returned if the second retransmission succeeds. Other relay nodes will freeze their timers during the second retransmission and reactivate them after ACK timeout. The reason for using R_s for the second retransmission instead of using R_b again is that the channel is assumed to be highly temporally correlated, which means if a frame transmission is failed on a channel, the probability that the next transmission on the same channel is successful is very low.

As shown in Fig. 2(c), the relay nodes will participate in data retransmission consecutively until D decodes the packet successfully and responds with an ACK packet. Whenever the ACK packet is detected from the channel, the remaining relay candidates will reset their timers and discard their received packets, and the cooperative transmission is thus completed.

Case IV: If the cooperation of all relay nodes still does not lead to a successful data reception at D, or if the number of retransmission attempt reaches the retry limit, the cooperative transmission fails. As shown in Fig. 2(d), the source node will obtain channel access again for another round of packet transmission after the retransmission via the last relay node R_t fails.

IV. Performance Analysis

In this section, we analyze the performance of the three concerned protocols in this study, i.e., DCF, MC-ARQ and PRCSMA, in terms of saturation throughput and Packet Delivery Ratio (PDR).

The normalized system saturation throughput, denoted by S, is defined as the successfully transmitted payload bits per time unit. According to [14], S can be calculated as follows:

$$S = \frac{E[G]}{E[D]}, \tag{3}$$

where $E[G]$ is the number of payload information bits successfully transmitted in a virtual time slot, and $E[D]$ is the expected length of the virtual time slot. More specifically, $E[G]$ and $E[D]$ can be expressed as:

$$E[G] = (1 - \prod_{i=1}^{m} p_{e,i})L; \tag{4}$$

$$E[D] = \begin{cases} E[D_1]; & m{=}1 \\ (1-p_{e,1})E[D_1] + p_{e,1}E[D_2]; & m{=}2 \\ (1-p_{e,1})E[D_1] + \prod_{i=1}^{m-1} p_{e,i}E[D_m] & \\ + \sum_{i=2}^{m-1} \prod_{j=1}^{i-1} p_{e,j}(1-p_{e,i})E[D_i] & m{\geq}3. \end{cases} \tag{5}$$

In the above expressions, m is the maximal number of possible transmission attempts, including the initial transmission from S; $p_{e,i}$ is the error probability of data packets at the ith transmission attempt, which can be obtained through the physical layer abstraction algorithm [15]; L is the packet length in bits and D_i is the virtual time slot duration in the case when i transmission attempts are executed.

The PDR is the ratio between the number of the successfully transmitted packets at the MAC layer and the number of all the packets delivered from its upper layer.

$$PDR = 1 - \prod_{i=1}^{m} p_{e,i}. \quad (6)$$

A. Non-cooperative DCF scheme

For the purpose of comparison, the throughput of the original DCF protocol is calculated first. In this case, $p_{e,i}$ with $i = 1, 2, ..., m$ is the packet error rate for the *i*th transmission attempt *on the same direct channel from S to D*, where m is the retry limit defined in the 802.11 standard [11] plus 1, since the first transmission attempt should be included. According to our assumptions in Sec. III, consecutive packets on the channel are subject to the same signal strength attenuation and therefore with identical packet error rates p_e.

Denote D_i as D_i^b for this basic, non-cooperative access scheme. It is expressed as:

$$D_i^b = \sum_{j=1}^{i} \delta_j + i(T_{DATA} + T_{ACK} + SIFS + DIFS), \quad (7)$$

where T_{DATA} and T_{ACK} represent the time used for transmitting the DATA and ACK frames respectively, and δ_j is the average backoff time of the *j*th transmission. Since there are no other contending nodes in the network, δ_j can be calculated as follows.

$$\delta_j = (2^{j-2}(CW_{min} + 1) - \frac{1}{2})T_{slot}, j = 1, 2, \ldots, m - 1, \quad (8)$$

where CW_{min} is the size of the minimal contention window and T_{slot} is the duration of a slot time.

The throughput for the original basic access scheme can be obtained by merging Eq. (7) and Eq. (8) into Eq. (4) and Eq. (5) and then into Eq. (3). The PDR performance is obtained easily by substituting $p_{e,i}$ with p_e in Eq. (6).

B. MC-ARQ scheme

To calculate the throughput and PDR performance of the proposed MC-ARQ protocol, m is the minimal value between the retry limit and the number of relay candidates available in the network, plus 1 for the first direct transmission; $p_{e,1}$ is the packet error rate on the direct channel and $p_{e,i}, i = 2, 3, ..., m$ is the packet error rate on the (*i*-1)th relay channel sorted in descending order of relay channel quality. $p_{e,i}$ becomes 1 if a collision happens among multiple active relays at the *i*th transmission attempt. In our analysis, it is assumed that the MAC header is always decoded correctly at the destination.

The virtual time slot duration in the case when *i* cooperative transmission attempts are executed in the MC-ARQ scheme is denoted as D_i^c and expressed as follows.

$$D_i^c = \begin{cases} DIFS + \delta_1 + T_{DATA} + SIFS + T_{ACK} & \text{if } i\text{=1}, \\ DIFS + \delta_1 + (i+3)SIFS \\ +2T_{ACK} + iT_{DATA} + T_{CFC}^c + T_{i-1} & \text{otherwise.} \end{cases} \quad (9)$$

In Eq. (9), T_{CFC}^c represents the time used for transmitting the CFC frame in MC-ARQ, and T_i is the backoff time consumed at the ith retransmitting relay node.

The throughput and PDR performance for the MC-ARQ scheme can be obtained by substituting the above parameters into Eqs. (3)∼ (5) and Eq. (6) respectively.

C. PRCSMA scheme

The throughput of the PRCSMA scheme in [10] is calculated for comparison. According to the PRCSMA scheme, all active relays contend, based on DCF, with equal chance for channel access in order to retransmit the data packet, until the packet is decoded correctly at the destination.

When Eqs. (4)(5) are applied to the PRCSMA scheme, m is the specified retry limit plus 1, which is independent of the number of relay candidates available in the network because the relay nodes in PRCSMA can be used for retransmission of the same packet for several times[1]; $p_{e,1}$ is the packet error rate on the original channel and $p_{e,i}$ with $i = 2, 3, ..., m$ is the packet error rate on the relay channel used for the (*i-1*)th retransmission. The sequence of the retransmission channels is determined through contentions among all relays following the DCF protocol. $p_{e,i}$ becomes 1 if a collision among multiple active relays occurs at the *i*th transmission attempt. D_i in this case is expressed as D_i^p for the basic PRCSMA scheme:

$$D_i^p = \begin{cases} DIFS + \delta_1 + T_{DATA} + SIFS + T_{ACK} & \text{if } i\text{=1}, \\ iDIFS + \delta_1 + iT_{DATA} + 3T_{ACK} \\ +2SIFS + T_{CFC}^p + \sum_{j=1}^{i-1} \delta_j^p & \text{otherwise.} \end{cases} \quad (10)$$

In Eq. (10), T_{CFC}^p represents the time duration used for transmitting the CFC packet in PRCSMA, which is also used to call for relay when direct transmission fails. δ_i^p is the backoff time consumed by relay nodes before their transmissions when they are contending for the ith retransmission.

The throughput and PDR performance for PRCSMA can be obtained in the same way with MC-ARQ using the above given parameters.

V. Simulations and Numerical Results

In this section, we implement all these three protocols in Matlab and compare their performance.

The relay nodes are uniformly distributed in a square area of 50 m × 50 m. The source node and the destination node are placed symmetrically along the center line and 25 m apart from each other. The path loss coefficient, λ, is set to be 2 and the transmitting and receiving antenna gains are set to be 1. The channels between each transmission pair, i.e., from source to destination, source to relay and relay to destination, are independent Rayleigh fading channels.

For both MC-ARQ and PRCSMA, the threshold SNR value for relay nodes to cooperate is set to be 2.0 dB corresponding to a PER of 0.97 for 500-byte packet length and QPSK with convolutional code rate 1/2 scheme. The retry limit is set to

[1] In contrast in MC-ARQ, each relay node is only allowed to forward once.

TABLE I
SIMULATION PARAMETERS.

MCS Scheme	QPSK with Convolutional Code 1/2
Payload length	500 bytes
MPDU header	24 bytes
PHY header	20 μs
Datarate	12 Mbps
Basic datarate	6 Mbps
RTS	20 bytes
CTS	14 bytes
CFR	14 bytes
DIFS	34 μs
SIFS	16 μs
Slottime	9 μs

be 7 for all schemes. Respectively, 5 and 50 potential relay nodes are randomly distributed in the network in order to investigate the influence of different relay densities on the protocol performance. Other simulation parameters are listed in Table I. E_t/N_0 is used to describe the channel qualities in our simulation environments, where E_t is the transmitted energy per bit at the transmitter and N_0 is the spectral power density of the Gaussian white noise at the receiver [2].

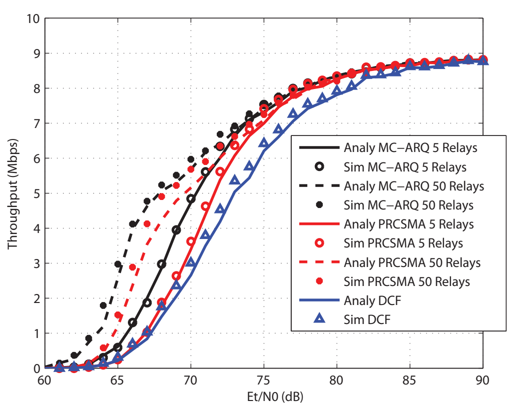


Fig. 3. Throughput Performance Comparison (λ=2).

Fig. 3 shows the throughput performance of the proposed MC-ARQ scheme compared with the PRCSMA scheme and the original DCF non-cooperative scheme under different channel qualities. The simulation results generally coincide with the theoretical analysis. It is obvious that the throughput is enhanced by cooperative schemes when the channel is in poor conditions (60$\sim$80 dB in the E_t/N_0 axis). The reason is cooperative retransmission is executed in that range and the selected relay channels generally have better quality compared with the direct link. When the network gets denser, due to the fact that the probability of finding a good retransmission channel gets higher, the benefit of using cooperative communication becomes more evident.

Moreover, when comparing MC-ARQ with PRCSMA, we observe that the MC-ARQ scheme outperforms the PRCSMA scheme generally over all ranges of the investigated channel

[2]Note that in our simulations, the transmitting power is fixed for all nodes. The transmitting node that is closer to the destination will provide higher received signal strength and hence a higher data transmission successful probability. Therefore, E_t/N_0 is a more sensible metric than E_b/N_0 to illustrate the performance of different schemes. That also explains why the range of the x-axis in the figures of this section seems unexpectedly high.

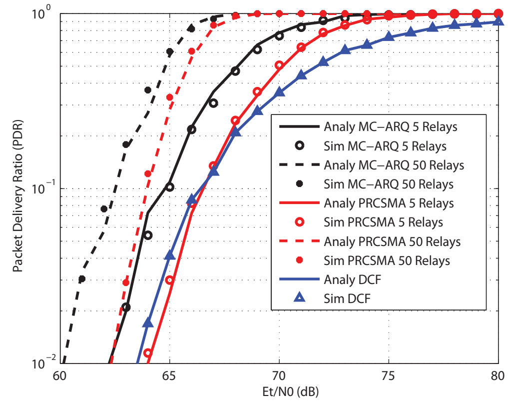


Fig. 4. Packet Delivery Ratio Comparison (λ=2).

conditions. The benefits come from not only the reduction of retransmission time in the protocol design in MC-ARQ but also its optimal relay selection scheme. The relay nodes in MC-ARQ do not need to defer for DIFS any more as they do in both PRCSMA and DCF, and the upper bound of the backoff time in MC-ARQ is DIFS. Therefore, considerate amount of time is saved for data retransmissions in MC-ARQ. Furthermore, MC-ARQ selects the relay node with the best relay channel quality to retransmit, while PRCSMA simply chooses a random node in the network following DCF, regardless of channel quality. That is why the cooperative retransmission in the MC-ARQ protocol is more efficient.

We further investigate the packet delivery ratio performance of different schemes. In Fig. 4, both the analytical and simulation results show that the PDR performance is enhanced significantly by the proposed MC-ARQ scheme. More significant improvement is observed when the relay nodes are more densely distributed in the network. This is because when there are more potential relay nodes to choose from, the selected optimal relay channel will likely offer better channel quality, and hence the probability for successful cooperative retransmissions is higher. In contrast, PRCSMA, which does not prioritize relay channels with higher link quality, has inferior PDR performance to the MC-ARQ scheme. When the channel quality is poor and there are few available relays in the network (e.g., 63$\sim$67 dB in the E_t/N_0 axis with 5 relays), PRCSMA may perform even worse than the original DCF protocol due to the defect of its relay selection scheme.

Fig. 5 shows the average number of cooperative retransmissions (excluding the initial transmission from S) based on 1000 simulated cooperative data transmissions. It can be observed that cooperative retransmission happens mainly between 60 dB and 80 dB in the E_t/N_0 axis. The reason is that when the channel quality is too poor, there is no relay node in the network qualified to retransmit the data packet. On the other hand, when E_t/N_0 is higher than 80 dB, the direct channel itself is good enough and no retransmission is needed. It is shown in the figure that fewer cooperative retransmissions are executed in the C-ARQ scheme due to its higher probability of successful cooperative retransmissions. Besides, one may also notice that more retransmissions are executed when relay nodes are more densely distributed.

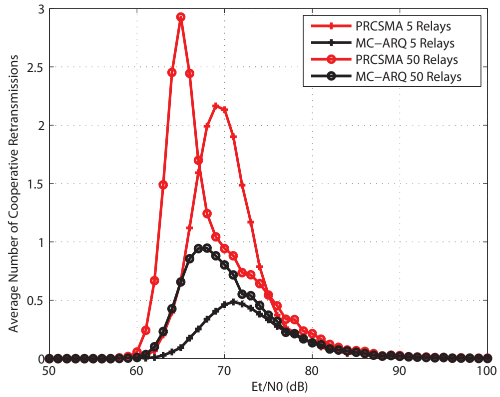


Fig. 5. Average Number of Cooperative Retransmissions Comparison

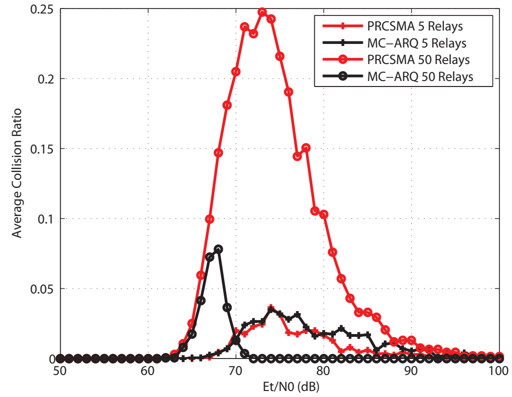


Fig. 6. Average Collision Ratio Comparison.

The reason is that the number of cooperative retransmissions is highly dependent on the number of the qualified relay nodes available in the network, especially when E_t/N_0 is low. When relay nodes are more densely distributed, the probability to have a qualified relay for cooperation is higher. Hence, the chance for cooperative retransmissions to take place is higher when they are needed.

Fig. 5 illustrates also that the MC-ARQ relay selection scheme is so efficient that the average number of retransmissions is no more than 1 in our simulation scenarios.

The average number of collisions averaged among all the simulated cooperative data transmissions is illustrated in Fig. 6. With this respect, we can observe that the collision problem, which is a big challenge in a relay selection scheme, is effectively solved in the MC-ARQ protocol. When the network is sparsely distributed, collision probability is low for both the PRCSMA scheme and the MC-ARQ scheme (below 0.03 when number of relay nodes is 5). As the network density increases, the number of collisions increases significantly in PRCSMA (the peak value reaches up to 0.25 with 50 relays), but still remains reasonably low (below 0.07) for MC-ARQ.

Additional simulations have been made to investigate the performance of the proposed MC-ARQ scheme with different payload length and different MCS schemes. These results, even though not presented in this paper, have illustrated that significant performance enhancement is obtained by MC-ARQ in all the investigated scenarios.

VI. Conclusions

In this paper, we have proposed a multi-relay cooperative retransmission MAC protocol, MC-ARQ, which is based on DCF protocol and provides an efficient distributed relay selection scheme.

The analytical and simulation results show that the MC-ARQ protocol outperforms both the PRCSMA and the original DCF protocol in terms of throughput and packet delivery ratio performance. The improvement becomes more evident when more potential relay nodes are distributed in the network. The relay selection scheme is so efficient that the average number of retransmission attempts needed for successful packet delivery is not more than 1 in our simulation scenarios. Collisions among multiple relay nodes, which are a big problem in PRCSMA and other multi-relay cooperative schemes, is effectively solved by sorting relay nodes according to their instantaneous relay channel quality. Even in a dense network with 50 potential relay nodes, the highest collision ratio is still below 0.07.

References

[1] J. N. Laneman, D. N. C. Tse and G. W. Wornell, "Cooperative diversity in wireless networks: efficient protocols and outage behavior", IEEE Trans. Inform. Theory, Vol.50, No.12, pp.3062-3080, Dec. 2004.

[2] A. Sendonaris, E. Erkip and B. Aazhang, "User cooperation diversity-Part I: system description", IEEE Trans. Comm., Vol. 51, No.11, pp.1927-1938, Nov. 2003.

[3] A. Sendonaris, E. Erkip and B. Aazhang, "User cooperation diversity-Part II: implementation aspects and performance analysis", IEEE Trans. Comm., Vol. 51, No.11, pp.1939-1948, Nov. 2003.

[4] A. Azgin, Y. Altunbasak and G. AlRegib, "Cooperative MAC and routing protocols for wireless ad hoc networks", in Proc. of IEEE GLOBECOM, Atlanta, GA, USA, Dec. 2005.

[5] S. Moh, C. Yu, S. Park and H. Kim, "CD-MAC: Cooperative diversity MAC for robust communication in wireless ad hoc networks", in Proc. of IEEE ICC, Glasgow, UK, June 2007.

[6] P. Liu, Z. Tao, S. Narayanan, T. Korakis and S. Panwar, "CoopMAC: A cooperative MAC for wireless LANs", IEEE JSAC, Vol.25, No.2, pp. 340-354, Feb. 2007.

[7] M. Dianati, X. Ling, K. Naik and X. Shen, "A node-cooperative ARQ scheme for wireless ad hoc networks", IEEE Trans. Comm., Vol. 55, No. 3, pp. 1032-1044, May 2006.

[8] G. Yu, Z. Zhang and P. Qiu, "Cooperative ARQ in wireless networks: protocols description and performance analysis", in Proc. of IEEE ICC, Istanbul, Turkey, June 2006.

[9] J. S. Pathmasuritharam, A. Das and A. K. Gupta,"Efficient multi-rate relaying (EMR) MAC protocol for Ad Hoc networks", in Proc. of IEEE ICC 2005 , Singapore, May 2005.

[10] J. Alonso-Zarate, E. Kartsakli, Ch. Verikoukis and L. Alonso "Persistent RCSMA: A MAC protocol for a distributed cooperative ARQ scheme in wireless networks", EURASIP Journal on Advances in Signal Processing, Vol. 2008, 2008, doi:10.1155/2008/817401.

[11] IEEE 802 WG, "Wireless LAN medium access control (MAC) and physical layer (PHY) specifications" IEEE 802.11, 1999.

[12] A. K. Sadek, W. Yu and K. J. R. Liu, "When does cooperation have better performance in sensor networks?", in Proc. of IEEE SECON, Reston, VA, USA, Sept. 2006.

[13] A. Bletsas, A. Khisti, D. P. Reed and A. Lippman, "A simple cooperative diversity method based on network path selection", IEEE JSAC, Vol.24, pp. 695-672, March 2006.

[14] G. Bianchi, "Performance analysis of the IEEE 802.11 distributed coordination function", IEEE JSAC, Vol. 18, No. 3, pp. 535-547, March 2000.

[15] X. He, F. Y. Li and J. Lin, "Link adaptation with combined optimal frame size and rate selection in error-prone 802.11n networks", in Proc. of IEEE ISWCS, Reykjavik, Iceland, Oct., 2008.