COOPERATIVE RATE ADAPTION SCHEME FOR WIRELESS NETWORKS WITH IMPROVED FAIRNESS, DELAY AND TRANSMISSION RELIABILITY

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ABSTRACT

We propose a Cooperative Rate Adaptation (CRA) MAC protocol based on the standard CSMA/CA protocol used in IEEE 802.11 wireless networks. The proposal provides cooperative error recovery, namely cooperative packet retransmission, while using rate adaptation. The transmission rate is selected based on the transmission rate history of the neighbours. The cooperating partner is selected based on a fuzzy logic selection algorithm. Three inputs are considered in the fuzzy system: the average transmission rate of a neighbour, the erroneous packet ratio and the acknowledged packet ratio of a neighbour. The output of the fuzzy system is the partnership probability of a neighbour. In this paper, the protocol is compared to the non-cooperative rate adaptation scheme RBAR (Receiver Based Auto Rate) and to the cooperative rate adaptation scheme CRBAR (Cooperative Relay Based Auto Rate). The simulation results show that the proposed protocol improves the delay and packet delivery ratio while contributing to the transmission opportunity fairness among the terminals, regardless of their channel conditions.

KEYWORDS

Cooperation, Rate Adaptation, Wireless Networks, Fuzzy Logic

1. INTRODUCTION

Nowadays, there are more and more electronic devices connected to a wireless network. The most common standard used in wireless networks is the IEEE 802.11 standard [1]. This standard defines a Distributed Coordination Function (DCF) for accessing the medium based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol at the Media Access Control layer (MAC). In this protocol, when a station has a packet to transmit, it has to sense the channel idle for a DIFS (DCF Interframe Space) period and then decreases a backoff counter. However, terminals experiencing a transmission error have to double their contention window, which reduces their transmission probability. Consequently, the network is mostly used by terminals with low transmission error probability. Given that most transmission errors are the result of dire channel conditions, one can conclude that the current protocol treats unfairly terminals on the basis of their channel conditions.

In order to reduce transmission error probability in terminals with low Signal-To-Noise ratio (SNR), rate adaptive solutions have been investigated [3], [4]. Despite the signal's robustness

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offered by rate adaptation, low data rate transmissions of terminals in bad channel conditions take a long time, thus affecting the network's performances. As an alternative solution, cooperation between terminals has been proposed. Basically, several copies of the same data are transmitted from different stations to achieve spatial diversity [5]-[10]. Recently the merging of rate adaptation with cooperation has been investigated [14]-[16]. The results are higher transmission rates and a diversity gain but the problem of wasteful duplicate transmissions is not addressed while signaling to find the right partner adds overhead. The proposal in [18] alleviates this issue by triggering cooperation in absence of an ACK. However the waiting for the absence of an ACK and the contention among the relay candidates increase the network latency and induce a collision probability. The authors in [19] present a Cooperative Relay Based Auto Rate (CRBAR) MAC protocol based on RBAR [4].

Focusing on the relay selection issue and on error recovery, we previously proposed a Partnership-based cooperative protocol with a fix random partner assignment [11]. In [12], we presented a low complexity dynamic partner selection scheme based on the SNR. More recently we proposed a CSMA/CA-based cooperative MAC protocol employing a fuzzy logic partner selection scheme. However, the fuzzification is determined based upon a 54 Mbps transmission rate. Therefore, this protocol does not consider rate adaptive networks and the consensus-based partner selection scheme increases the overhead [13].

In this paper, we propose a Cooperative Rate Adaptation (CRA) MAC protocol for an 802.11 WLAN based on the CSMA/CA protocol. CRA provides cooperative error recovery while using rate adaptation. It avoids the wasteful duplicate transmissions when the first transmission is successful. It aims to alleviate the latency and collision issues existing in previous works on cooperative networks and rate adaptation by eliminating contention among neighbour terminals. Through error recovery, it tackles the fairness issue of CSMA/CA towards the terminals with dire channel conditions. The error recovery allows a terminal with bad channel conditions to keep a minimum contention window size if the cooperative retransmission succeeds. Besides, it implements a robust partner selection scheme by considering not only the transmission rate but also the link quality between neighbour terminals, the source and the destination. Cooperation is triggered by the destination only if the packet transmission has failed and the partner is selected by the source. Finally, the packets used in the proposal conform to the standard format.

The rest of this paper is organised as follows: We present the related work RBAR and CRBAR in Section 2. Section 3 offers the Cooperative Rate Adaptation protocol description. Section 4 describes the partner selection scheme. The proposal is evaluated and the results are discussed in Section 5. We conclude in Section 6.

The following notations will be used throughout this paper:
I-J: channel or link between the terminals I and J
R_{I-J}: data transmission rate used on the link I-J

2. RBAR AND CRBAR

2.1. Receiver Based Auto Rate (RBAR) [4]

In RBAR, the source begins the communication with an RTS conveying its predicted transmission rate and the packet size instead of the duration field. Upon reception of the RTS, the receiver estimates the SNR and selects the transmission rate accordingly. Then, the receiver conveys the selected transmission rate in the CTS. The source confirms the rate selection in a Reservation

SubHeader (RSH) of the data packet. Finally, the receiver ends the communication with an ACK. A threshold-based technique is used for the rate selection algorithm. The chosen rate is the highest transmission rate that allows a bit error rate (BER) lower than 10^{-05}. Let $M_1, \ldots, M_N$ be the modulation schemes corresponding to the available transmission rates. $\theta_1, \ldots, \theta_N$ are the SNR threshold at which $BER(Mi) = 10^{-05}$; $i = 1, \ldots, N$.

The selected modulation scheme is presented in equation (1).

$$\begin{cases} M_1 & \text{if SNR} < \theta_1 \\ M_i & \text{if } \theta_i < SNR < \theta_{i+1} \\ M_N & \text{otherwise} \end{cases} \quad (1)$$

2.2. Cooperative Relay Based Auto Rate (CRBAR) [19]

In CRBAR, communication begins with a RTS containing the packet length from the source. The destination replies with a CTS. The neighbors estimate the SNR of the RTS and the CTS. They use this information to determine the source-neighbor transmission rate and the neighbor-destination transmission rate. The transmission rates are determined in the same way as in [4] described in (1). The neighbors use the packet length and the selected transmission rates to calculate the time needed for a transmission without relay (direct transmission time) and the time needed for a transmission with a relay (cooperative transmission time). If the cooperative transmission time is shorter than the direct transmission time, the neighbour will contend to send a Ready to Relay (RTR). However, short transmission duration does not ensure a successful communication and contention among the relay candidates increases the delay and may induce collisions.

3. COOPERATIVE RATE ADAPTATION MAC PROTOCOL

3.1. Potential Partner Table

Each station holds a Potential Partner Table (PPT). The PPT contains the information about the neighboring terminals. Every station listens to the ongoing communications in order to fill up the PPT. A neighbor N's entry in the station S's PPT comprises an Error Ratio (ER) field, an Acked Ratio (AR) field, an Average Rate (AvgR) field and a Partnership Probability (PP) field. The determination of ER, AR, AvgR and PP is described later in the paper. There is also a SNR field that contains the SNR estimate of the last packet received from N. Finally there is the transmission rate R_{S-N} for a transmission from S to N based on SNR and the last transmission rate R_{N-AP} used by N to transmit to the access point (AP). The PPT is updated every time a data packet or an ACK is overheard. The neighbors are sorted from the highest to the lowest PP. If two terminals have the same PP, the one with the highest AvgR comes first in the PPT. Therefore, the first neighbor listed in the PPT is the one with the most reliable S-N and N-AP links and the highest transmission rate on those links. Fig.1 depicts an example of partner selection.

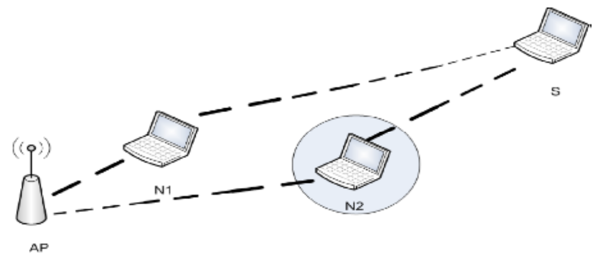

Figure 1. Example of partner selection

3.2. Protocol Description

The proposed MAC protocol is based on the CSMA/CA protocol used in the IEEE 802.11 standard. A station S initiates communication by sending a RTS frame to the access point (AP) after sensing the channel idle for a DIFS period. It includes the address of the first neighbour listed in its PPT in an unused address field as the selected partner in case of error. The AP replies with a CTS frame followed by the data packet transmitted by S. Before the data transmission, S selects the direct transmission rate R_{S-AP} based on the CTS's SNR. S calculates the direct transmission time T_{dir} when it transmits with R_{S-AP}. S also calculates the cooperative transmission time T_{coop} when it transmits a packet with R_{S-N} and the partner retransmits with R_{N-AP}. R_{S-N} and R_{N-AP} are found in the PPT. If $T_{dir} < T_{coop}$, S transmits with R_{S-AP}, otherwise it transmits with R_{S-N}. The calculation of T_{dir} and T_{coop} is given in equations (2) and (3) respectively.

$$T_{dir} = T_{DATA}(R_{S-AP}) + T_{ACK} + SIFS \quad (2)$$

$$T_{coop} = T_{DATA}(R_{S-N}) + T_{RTC} + T_{DATA}(R_{N-AP}) + T_{ACK} + (3 \times SIFS) \quad (3)$$

with

$T_{DATA}(R_{I-J})$: data transmission duration with the rate R_{I-J}
T_{CTRL}: control packet transmission duration (ACK or RTC)
SIFS: Short Interframe Space

The rate selection is performed according to the estimated SNR in the same way as in [4] and [19] described in equation (1). The data transmission rate selection is depicted in Fig. 2. If the packet is not received correctly, AP triggers cooperation by sending a RTC (Request to Cooperate) packet. The RTC contains the basic mandatory fields of a MAC frame in the 802.11 standard. It comprises the address of the source of the packet S and the address of the chosen partner formally conveyed in the RTS frame. The partner selects the retransmission rate according to the estimated SNR of the RTC as in [4], [19]. The AP ends the session with an ACK packet. At the beginning of the transmission sequence, the NAV is set to the duration of a successful transmission and is updated in the RTC in case of error. This frame sequence is depicted in Fig.3.

Note that in contrast with the RBAR scheme in [4] and the CRBAR scheme in [19] where the frame formats have been modified, here, all the frame formats follow the standard general frame format[1]. The partner is selected by the source and conveyed in the RTS packet. Therefore, there is no risk of collision among the neighbours and there is no need to wait for an ACK-timeout period in order to know that an error occurred. The RTC avoids the wasteful cooperation attempts by hidden terminals who may not detect the ACK. In the standard CSMA/CA, when a packet is not received successfully, the source has to go through contention against all the terminals in the network with an increased contention window size, thus there is no guarantee of an immediate retransmission. With the cooperative MAC protocol, the retransmission is performed right after the error occurred. If cooperation succeeds, the contention window size of the source remains to the minimum. If the RTC is not received correctly by the partner or if the retransmission fails, the source reverts to the CSMA/CA for the subsequent retransmissions. The proposed protocol provides erroneous packet recovery therefore a successfully transmitted packet does not need retransmission.

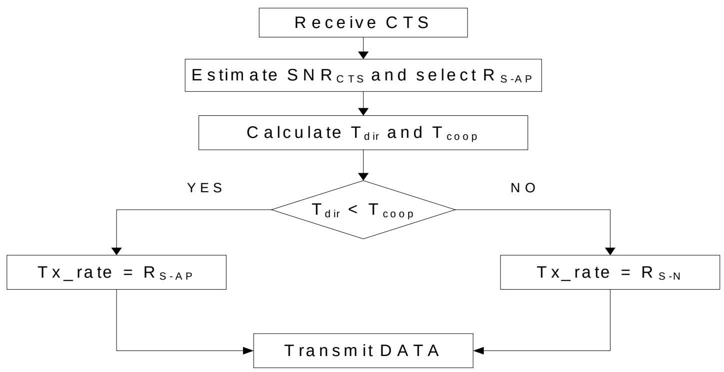

Figure 2. Transmission rate selection

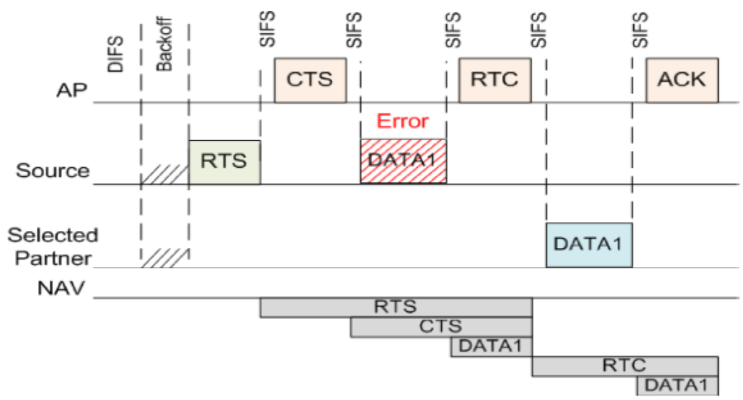

Figure 3. Frame sequence of the cooperative MAC protocol

4. FUZZY LOGIC PARTNER SELECTION SCHEME

4.1. Membership Functions

Fuzzy logic is an engineering technique used in neural networks or experts systems to name a few. As opposed to crisp logic or two-valued logic, fuzzy logic assumes a multivalued logic. A variable can be represented by several linguistic values. The variable has a membership degree to their membership functions [20][21]. Our fuzzy system considers three inputs: the erroneous packets ratio, the acked packets ratio and the average transmission rate used by a neighboring terminal. The output of the system is the partnership probability. These parameters are explained in detail in the following subsections. By using the erroneous packets ratio and the acked packets ratio a terminal can estimate the channel quality between itself and a neighbour and between that neighbour and the access point. The fuzzy system is depicted in Fig.4.

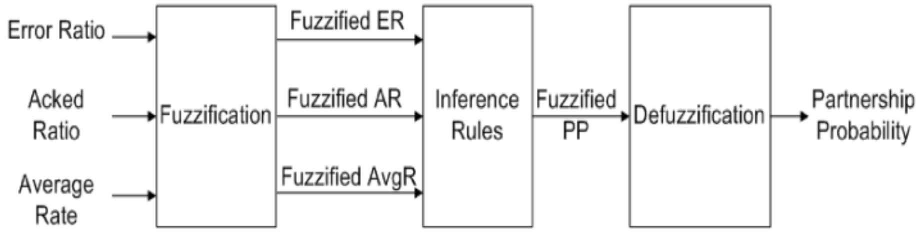

Figure 4. Fuzzy system

4.1.1. Erroneous Packets Ratio

In order for a neighbor N to be able to retransmit a packet from the source S, first of all it has to be able to receive the packet successfully. Therefore, the channel between S and N has to be reliable. To evaluate the S-N link quality we use the erroneous packets ratio or error ratio ER. It is the ratio of the number of the packets that have not been received correctly from a neighbor N to the total number of packets received from N. ER is given by (4):

$$ER = \frac{N_{Err}}{N_{Rx}} \tag{4}$$

with:
N_{Err}: the number of erroneous packets from N
N_{Rx}: the number of all the received packets from N

This information helps to determine the ability of the neighbor N to receive successfully a packet from S. The fuzzified ER has three linguistic values: FzER = {low, fair, high}. We use triangular fuzzy membership functions (MF) [20][21] to represent the linguistic values. Since ER is a ratio, it ranges in the interval [0, 1] and the threshold values used to build the MF of low, fair and high are 0, 0.5 and 1. The MF are given in (6), (7) and (8) respectively.

4.1.2. Acked Packet Ratio

For a successful cooperative packet retransmission from a neighbor N to the AP, the N-AP channel also has to be reliable. To estimate the quality of the N-AP link, the acked packets ratio or acked ratio AR is used. AR is the ratio of the number of ACK received after a packet transmission from a neighbor N out of the number of packets received from N as expressed in (5).

$$AR = \frac{N_{ACK}}{N_{Rx}} \tag{5}$$

with:
N_{ACK}: the number of acked packets of N
N_{Rx}: the number of all the received packets from N

In order to make the calculation of this metric possible and to maximize the successful ACK transmissions, all the ACKs are transmitted at the lowest rate (6 Mbps). AR informs about the average channel quality between N and the access point N-AP. As AR is also a ratio, its fuzzified form is defined as FzAR={low, fair, high} and its MF are defined in the same way as FzER as seen in (6), (7) and (8).

$$\begin{cases} \mu_{low}(x) = \frac{fair_{thr} - x}{fair_{thr} - low_{thr}} & \text{if } low_{thr} < x \le fair_{thr} \\ \mu_{low}(x) = 0 & \text{if } fair_{thr} < x \le high_{thr} \end{cases} \tag{6}$$

$$\begin{cases} \mu_{fair}(x) = \frac{x - low_{thr}}{fair_{thr} - low_{thr}} & \text{if } low_{thr} < x \leq fair_{thr} \\ \mu_{fair}(x) = \frac{high_{thr} - x}{high_{thr} - fair_{thr}} & \text{if } fair_{thr} < x \leq high_{thr} \end{cases} \quad (7)$$

$$\begin{cases} \mu_{high}(x) = 0 & \text{if } low_{thr} < x \leq fair_{thr} \\ \mu_{high}(x) = \frac{x - fair_{thr}}{high_{thr} - fair_{thr}} & \text{if } fair_{thr} < x \leq high_{thr} \end{cases} \quad (8)$$

where *x* represents the error ratio, the acked ratio or the partnership probability and low_{thr}, $fair_{thr}$ and $high_{thr}$ are the thresholds of *low, fair* and *high.*

4.1.3. Average Transmission Rate

The last input of the fuzzy system is the average transmission rate AvgR used to find the neighbor with highest transmission rate. The AvgR of a neighbor N is the ratio of the sum of the transmission rates used by N for each data transmission to the total number of packets received from N and is given by (9).

$$AvgR = \sum \frac{Tx\_rates}{N_{Rx}} \quad (9)$$

with:
Tx_rates: the transmission rates used by N
N_{Rx}: the number of all the received packets from N

The transmission rate used by N can be found in the PLCP header of a packet [1]. The fuzzified AvgR is FzAvgR = {low, high}. CRA uses the data rates available in the 802.11a PHY ranging between 6 and 54 Mbps. Therefore, the thresholds are 6 and 54 and the MF are given in (10) and (11). Note that we only define two membership functions for AvgR. This reduces the complexity of the system without affecting the partner selection since the main criteria to choose a partner are the Source-Neighbor S-N channel quality and the Neighbor-Access Point N-AP channel quality given by ER and AR respectively. Nevertheless, we consider the transmission rate in the system in order to find the neighbor with the most reliable S-N and N-AP channels and with the highest transmission rate possible.

$$\mu_{low}(x) = \frac{high\_rate_{thr} - x}{high\_rate_{thr} - low\_rate_{thr}} \quad \text{if } low\_rate_{thr} < x \leq high\_rate_{thr} \quad (10)$$

$$\mu_{high}(x) = \frac{x - low\_rate_{thr}}{high\_rate_{thr} - low\_rate_{thr}} \quad \text{if } low\_rate_{thr} < x \leq high\_rate_{thr} \quad (11)$$

where *x* represents the average transmission rate. low_rate_{thr} and $high\_rate_{thr}$ are the MF thresholds of *low* and *high*.

4.1.4. Partnership Probability

The Partnership Probability PP is the output of the fuzzy system. The fuzzified PP is FzPP = {low, fair, high}. Since PP is a probability, it ranges between 0 and 1. Note that ER, AR and PP range between the same interval [0, 1]. Besides they are represented by the same linguistic values low, fair and high. Therefore ER, AR and PP have the same membership functions given by (6), (7) and (8).

4.2 Inference Rules and Defuzzification

Once we have the fuzzified inputs, we fire the inference rules given in Table 1 to obtain the fuzzified PP. The conventional way to define the inference rules in a fuzzy logic system is using the Intersection Rule Configuration (IRC) method. In this method, if we have F fuzzy inputs with L linguistic values each, we have F^L rules. However, according to the data and the requirements of the system designer, the rules number can be reduced [21].

A neighbor N is a good partner if the S-N link and the N-AP link are both good since it is likely that N will be able to receive a packet from S and to forward it to AP successfully. If either of these links is in bad condition, the cooperation is likely to fail. This explains the rules R1 and R2. If both the links are fairly good, the partner is fairly good as well (R3). Note that the three first rules stand regardless of the average transmission rate. However, we use the average transmission rate to distinguish the good partners from the fairly good ones when one of the S-N and N-AP links is good and the other is fairly good (R4, R5). We use the Zadeh min-max method [20] for the AND (&&) and OR (||) operators in the inference rules. There are several defuzzification methods. The most commonly used method is the centroid method also called center-of-gravity method. After firing the rules, the fuzzified PP is deffuzified using the centroid method given in equation (12) [20][21].

$$PP = \sum_{i=1}^{L} \frac{x_{max}(FzVal_i) \times FzVal_i(\mu_x)}{\sum_{i=1}^{L} FzVal_i(\mu_x)} \quad (12)$$

with:
$x_{max}(FzVal_i)$: the crisp input corresponding to the maximum of the membership function of $FzVal_i$.
$FzVal_i(\mu_x)$: the membership degree to the fuzzy value $FzVal_i$
L: the number of linguistic values of the variable, here 3 (low, fair, high)

Table 1. Inference rules

R1: IF ((ER is high || AR is low) && (AvgR is low || AvgR is high)) THEN PP is low
R2: IF ((ER is low && AR is high) && (AvgR is low || AvgR is high)) THEN PP is high
R3: IF ((ER is fair && AR is fair) && (AvgR is low || AvgR is high)) THEN PP is fair
R4: IF (((ER is low && AR is fair) || (ER is fair && AR is high)) && (AvgR is high)) THEN PP is high
R5: IF (((ER is low && AR is fair) || (ER is fair && AR is high)) && (AvgR is low)) THEN PP is fair

5. EVALUATION

5.1 Simulation Setup

The proposed protocol is evaluated by simulation using the ns3 network simulator [23]. There are 8 transmission rates available: 6, 9, 12, 18, 24, 36, 4 and 54 Mbps as in 802.11a. The communications are performed between the terminals and the AP. The stations are randomly spread in a circular area. The AP is in the center of the simulation area. The control frames (RTS, CTS, ACK, RTC) are transmitted at the minimum rate (6Mbps). In our simulations, the signals suffer from the log-distance path loss and the path loss exponent is 3. All the terminals are mobile. They can move in every direction in the plane and the direction is updated every 5s. The stations generate packets of 1500 bytes based on an OnOffApplication available in ns3. The OnOffApplication allows the terminal to generate packets in flows and inter-flows [23]. The flow and inter-flow durations follow the exponential distribution. During the flows, the packets are generated at a constant rate 1Mbps. If the cooperative retransmission fails, the source of the packet reverts to the CSMA/CA protocol and retransmits the packet on its own. The packet is discarded if the SLRC (Station Long Retry Counter) reaches the long retry limit set to 7. We simulate different scenarios to evaluate the influence of different parameters such as the number of terminals, the area size and the terminals speed, on the network performances. The Cooperative Rate Adaptation (CRA) MAC protocol is compared to a non-cooperative and a cooperative rate adaptation schemes. Since we use the same rate selection method as in [4] and [19], we choose the proposed schemes therein: Receiver Based Auto Rate (RBAR) and Cooperative Relay Based Auto Rate (CRBAR) respectively.

5.2 Results and Discussion

In the first scenario, we have a circular area of 150m diameter. The stations move at a speed between 0 and 4m/s. We evaluate the influence of the density by varying the number of terminals. Since our protocol's main objective is to provide error recovery, the first metric we evaluate is the average packet delivery ratio (Avg PDR). The Avg PDR is the ratio of the packets successfully received at the destination out of the all the packets transmitted.

Fig.5 depicts the Avg PDR of the three protocols with respect to the number of terminals. Cooperative retransmissions noticeably reduce the number of lost packets. When the density is low, the number of potential partners is also low. However the retransmission rate selection based on the SNR of the RTC maximizes the chances for a successful error recovery. As the number of terminals increase, the number of potential partners increases too. This yields an Avg PDR around 99% when CRA is used, regardless of the density. In contrast, the Avg PDR of RBAR and CRBAR increase gradually with the density and reach a more or less stable Avg PDR around 74% and 80% respectively when there are more than 60 stations. Due to its cooperative feature, CRBAR offers a greater Avg PDR than RBAR.

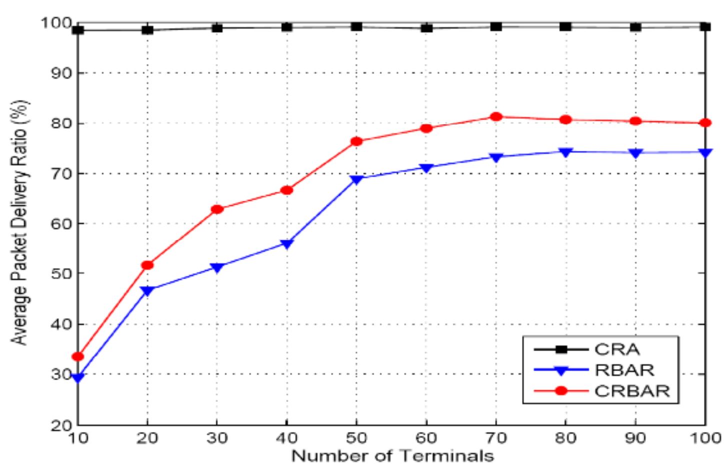

Figure 5. Average Packet Delivery Ratio vs Number of Terminals

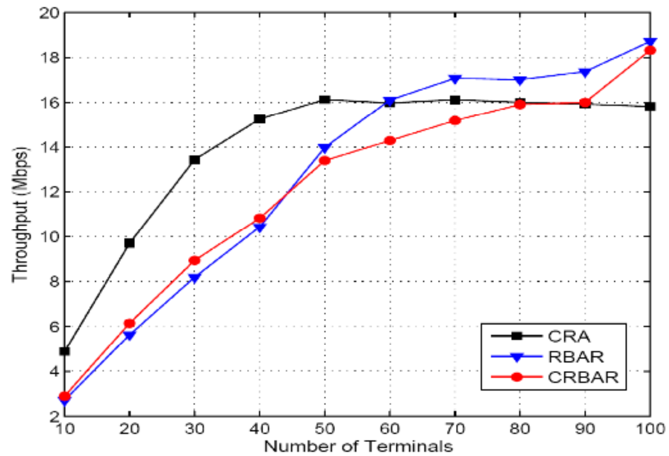

Figure 6. Throughput vs Number of Terminals

However the graph shows that a partner selection based only the transmission rate is not enough to provide successful cooperation since a high transmission rate does not ensure a successful co-operation. CRA takes into account the S-N and N-AP channel quality, which leads to a more robust partner selection and a higher Avg PDR than CRBAR. Fig.6 shows that the throughput increases with the density when RBAR and CRBAR are used. CRA's throughput increases until it reaches a relatively constant throughput around 16Mbps and is outperformed by RBAR and CRBAR. When the density increases, the transmissions from the good stations increasingly outnumber the transmissions from the bad stations yielding to the RBAR and CRBAR increasing throughput.

In the second scenario we evaluate the influence of the size of the area when there are 50 terminals moving at a speed between 0 and 4m/s. Fig.7 shows the average transmission delay and the throughput with respect to the area diameter. The transmission delay is the time elapsed between a RTS transmission and the reception of the corresponding ACK. As a result, the more errors and retransmissions, the longer this duration. As the area widens, the transmission delay increases and the throughput decreases for all protocols.

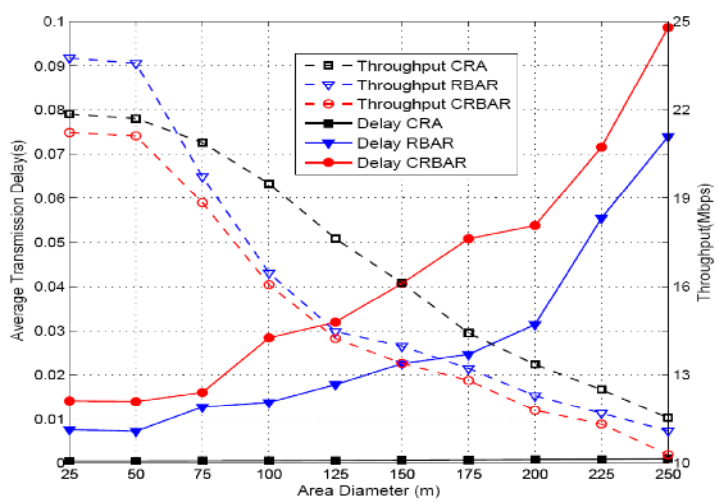

Figure 7. Average Transmission Delay and Throughput vs Plane Diameter

With CRA, when cooperation is successful this duration is equal to twice the transmission duration of the packet at the lowest rate (6Mbps) and the overhead (control packets and SIFS) at most. Consequently, CRA offers a transmission delay greatly shorter than RBAR and CRBAR. When RBAR and CRBAR are used, the terminals with dire channel conditions will experience a higher delay, therefore the average transmission delay becomes higher for these protocols. As a result, the low delay offered also shows the fairness provided by CRA. When the diameter is small, there are less errors, cooperation becomes useless and the overhead caused by CRA and CRBAR induce a lower throughput compared to RBAR. As the area widens, CRA experiences smoother throughput decay and outperforms the other protocols. As described in Sect.2.2, CRBAR provides a cooperative transmission at higher rates whenever it can be performed faster than the direct transmission. However, high transmission rates do not guarantee successful transmissions. As a result, multiple retransmissions due to errors affect the throughput and the transmission delay of CRBAR.

Finally, we evaluate the robustness of the protocol against the stations mobility. There are 50 terminals spread in a 150m diameter circular area and all the stations move at the same constant speed. Fig.8 illustrates the Avg PDR and the throughput with respect to the station speed. When the speed increases, the channel changes more frequently, the transmission rate selection becomes more difficult and the Avg PDR and the throughput decrease. At lower speed, the transmission rate selection becomes more accurate yielding more successful transmissions. As a result, the overhead induced by CRA yields a throughput lower than that of RBAR and CRBAR. However, the partner selection relies not only on the transmission rate but also on the overall links reliability. Consequently, with its robust partner selection, CRA's throughput outperforms that of RBAR and CRBAR when the speed increases. Besides, CRA also provides a smoother decay of the Avg PDR maintaining it to high level and the improvement compared to RBAR and CRBAR increases with the station speed. This is because RBAR and CRBAR select the transmission rates at the beginning of the transmission sequence and do not consider the channel variation throughout the packet exchanges. In contrast, the partner selects the retransmission rate upon reception of the RTC packet. The SIFS between a RTC and the retransmitted packet lasts 16µs, it is greatly smaller than the coherence time even when the terminals move at 4m/s, therefore the rate selection is more accurate and the retransmission has more chances to succeed.

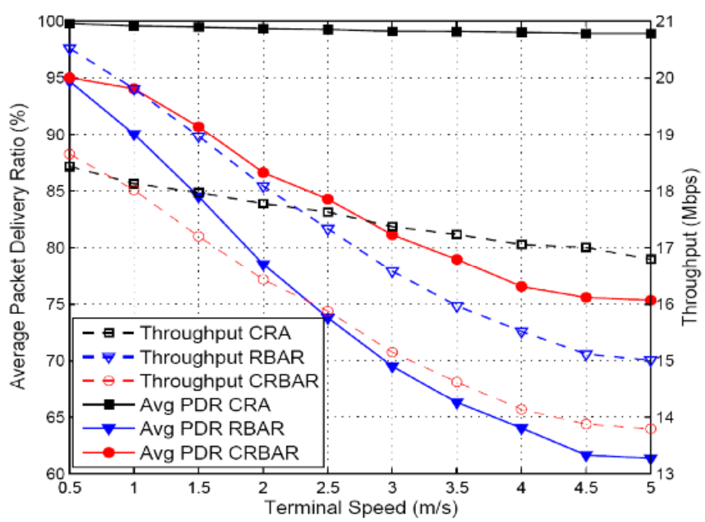

Figure 8. Average Packet Delivery Ratio and Throughput vs. Terminal Speed

6. CONCLUSION

We proposed a Cooperative Rate Adaptation (CRA) MAC protocol. The partner is selected considering the source-neighbor (S-N) and the neighbor-access point (N-AP) link reliability and considering the average transmission rate of the neighbor. These metrics are used in a fuzzy logic system and the output of the system is the Partnership Probability of a neighbor. Every station holds a Potential Partner Table and the chosen partner is the first neighbor listed in the table. The cooperative MAC protocol is based on the standard CSMA/CA used in IEEE 802.11 wireless networks and all the frame formats conform to the standard frame format. The protocol is compared to a non-cooperative and a cooperative rate adaptation schemes: the RBAR (Receiver Based Auto Rate) and the CRBAR (Cooperative Receiver Based Auto Rate) respectively. The cooperative retransmission of erroneous packets in CRA leads to a noticeable improvement in the average packet delivery and the average delay compared to CRBAR and RBAR. The comparison between the performances of CRA and CRBAR show that the transmission rate is not enough to select an efficient partner and our fuzzy logic selection scheme improves greatly the performances. By selecting the retransmission rate right before cooperation, CRA helps to maintain good performances when the terminals move faster. Despite a lower throughput under some conditions, the results show that CRA offers great improvement in the average packet delivery ratio, transmission delay while providing fairness with respect to the density, the area width and the stations mobility.

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