Energy and throughput efficient transmission strategy with Cooperative Transmission in ad-hoc Networks

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Abstract— **In this paper, a new Medium Access Control (MAC) protocol combining Transmit Power Control (TPC), Rate Adaptation (RA) and Cooperative Transmission (CT) is proposed, in the context of multi-rate ad hoc networks. The protocol aims to achieve energy efficiency of data transmission while increasing the overall network throughput. The key idea of the protocol is to allow each wireless node to create a table with the optimal power-rate combinations based only on the network interface card specifications. In the presence of low data-rate nodes the network throughput is greatly degraded. To mitigate this well-known "rate anomaly" problem we use CT to replace the direct low-rate links by relayed high-rate links. By exchanging control frames and looking up the power-rate table, the wireless node chooses the most suitable transmission strategy (which consists of selecting the most optimal power-rate combination) for each data-frame as well as the transmission scheme (direct or relayed). Results reveal an important improvement in the overall network throughput as well as in the energy consumption with the new protocol compared to the scheme without TPC and without cooperation. Furthermore, simulation results show that our scheme deliver more data per unit of energy consumption than the IEEE 802.11 scheme.**

Keywords-component; power control; rate adaptation; cooperation; energy efficiency; throughput.

I. INTRODUCTION

Reducing the energy consumption is a key issue in wireless ad-hoc networks since widespread wireless devices, such as tablets and laptops, suffer from limited battery capacity. An effective approach to save energy is to reduce the transmit power level whenever possible; a wireless node is allowed to transmit at the minimum power level that can sustain successful transmissions. The energy consumption depends also on the physical layer (PHY) data-rate: Obviously, as the PHY data-rate increases, the frame transmission time is reduced, thus resulting in lower energy consumption in both transmission and reception. Hence, to reduce energy consumption we can either reduce the transmit power level or transmit at higher PHY rates. However, in multi-rate wireless networks, there exist an intertwined relationship among transmit power level and PHY data-rate. Increasing the transmit power level may increase the (error-free) PHY data-rate of a wireless link, but more energy is consumed. At the opposite, reducing the transmit power level may causes a reduced transmission rate (the bit error rate (BER) has to be below a given threshold). Thus, TPC and RA need to be jointly considered to achieve energy efficiency of data transmission. On the other hand, adjusting both the transmit power and the PHY data-rate have an impact on the overall throughput of the wireless network [1].

Current network interface cards (NICs) can support variable transmit power level and multiple PHY data-rates. The IEEE 802.11g, for example, has different PHY data-rates up to 54Mbps. Selecting the transmit power level and the PHY data-rate and/or data packet size is known as the transmission strategy. Different transmission-strategies could be used between two communicating nodes. This variety of choices is called the transmission-strategy diversity. However, It has been demonstrated in [2] that it is more appropriate to adapt the rate than adapting the packet size. Thus, in this paper we don't consider the packet size adaptation in the transmission strategy.

Several works have addressed the rate adaptation issue. Automatic Rate Fallback (ARF) [3] is one of the first rate adaptation scheme. ARF is a frame loss based RA mechanism. The rate in ARF is increased after consecutive successful transmissions and decreased after transmission failure. However, ARF cannot adapt efficiently when channel conditions change very quickly. In [4], the Adaptive Auto Rate Fallback (AARF) aims to improve the performance of ARF in slow-fading channels. In [5], the Receiver Based Auto Rate (RBAR) uses the RTS/CTS (Request To Send/Clear To Send) frames to estimate the channel quality and to adapt the rate. Other RA mechanisms have been proposed in [6] [7] [8]. The aforementioned schemes, aim to improve the network throughput or to enhance both throughput and delay using the rate adaptation. The energy efficiency was not addressed in these studies.

The transmit power control has been proposed in [9] [10] [11] [12] to reduce energy consumption. For instance, a TPC mechanism has been integrated in the RTS/CTS handshaking in [9]. This scheme allows the receiver node to help the sender node to choose a suitable transmit power level that guarantees a given SNR level. In [10], a similar scheme is presented where the RTS/CTS frames are transmitted at the highest possible power level and the DATA/ACK frames are transmitted at the lower power levels that can sustain successful transmissions. The authors in [11] suggest a simple enhancement to the scheme in [9] to overcome the deficiencies that may cause collisions and hence reduce the overall throughput. The work in [12] is similar to [10] but each node has to maintain a table of minimum power level required to communicate with n

eighbor nodes. In [13] the authors proposed a scheme to save energy for the Multiple-Input-Multiple-Output (MIMO)-capable wireless networks.

Protocols that perform both Transmit Power and Rate Control (TPRC) have been proposed in [14] [15] [2]. Choi and al. in [14] presented a scheme called MiSer that minimizes the energy consumption by combining TPC with PHY RA. In MiSer each node maintains a power-rate table. However, MiSer requires acquiring precisely many parameters concerning the network topology, radio propagation and traffic pattern. These information, such as, the number of contending stations, the RTS collision probability, data transmission error, data payload length, path loss are necessary to create and to maintain the power-rate table. In addition, in order to obtain some parameters, such as, the path loss value, the stations should exchange extra frames. This exchange consumes energy and affects the network throughput. The scheme in [2] adapts either the transmit power level or the PHY rate based on the link conditions. In [15] a power/rate mechanism is also performed, the purpose here is to eliminate collisions from hidden terminal and to enhance the spatial reuse by diminishing the effect of exposed terminals.

However, in the IEEE 802.11 multi-rate wireless networks, nodes affected by wireless channel impairments, such as interference and signal loss due to fading and/or distance have to transmit with the minimum PHY data-rate and at the maximum transmit power level in order to ensure successful transmissions. These low data-rate nodes affect the overall network throughput causing the rate-anomaly problem [16]. Against this problem, solutions based on both TPC and/or RA schemes are limited. An effective way to deal with this problem is to use cooperative transmission. In a relayed transmission scheme, the transmitter-receiver pairs that experience bad link quality are assisted by a relay station selected in the vicinity of both nodes so that the low data-rate direct link is replaced by a two-hop path with a higher data-rate. In [17] the authors used a cooperative scheme combined with a RA mechanism similar to the scheme in [5] but the power control was not considered. In contrast, in [18] the cooperative scheme is combined with a TPC mechanism and the authors did not consider the RA. The point here is that both TPC and RA should be considered in conjunction due to the inherent tradeoff between both transmit power and rate control.

In this paper, we aim to reduce the energy consumption while increasing the network throughput. In our previous work [19], we proposed a protocol that combines a RA mechanism and a cooperative scheme in order to enhance the overall throughput. In contrast in this work, we propose a novel MAC protocol combining TPC, PHY RA and CT. The protocol is called PRACT (Power and Rate Adaptation with Cooperative Transmission). The basic idea is to adjust both the Transmit Power Level (TPL) and the PHY data-rate for each data frame transmission. When necessary a relayed transmission is initiated between the source and the destination nodes in order to enhance the direct links quality. The improvements of our protocol over other schemes are as follows: in typical TPC (RA) mechanisms only one parameter is adjusted in the transmission strategy. In contrast, our scheme adjusts both parameters power and rate. Another key contribution is that we combine our TPRC mechanism with a cooperative scheme. So, when the quality of the direct link is poor and typical TPRC mechanisms cannot help more, cooperation is used. Furthermore, the choice of the transmission strategy and transmission scheme (direct or relayed) is based upon real-time link measurements and using only available local information. Hence, the choice is more accurate and reactive to link conditions and no extra information is required. Moreover, only the RTS/CTS handshaking is used and no extra signaling is performed.

The rest of the paper is organized as follows. The proposed protocol is described in Section II. Results are provided in Section III. The conclusions are drawn in Section IV.

TABLE I: POWER RATE TABLE

N°	i	j	Power P_i dBm	Rate R_j Mbps	Req.SINR$_{th}$(P_i,R_j) dB	Pow.Cons. ratio
1	0	0	15	6	3,162	1,000
2	1	0	13	6	4,742	0,778
3	0	1	15	12	6,309	0,505
4	1	1	13	12	9,462	0,393
5	2	0	7	6	18,967	0,611
6	0	2	15	24	31,622	0,257
7	2	2	7	12	37,844	0,309
8	1	2	13	24	44,261	0,200
9	3	0	0	6	91,680	0,548
..	..	..	..	..	..	..
16	3	3	0	54	9484,185	0,073

II. PROPOSED PROTOCOL

A. Protocol Description

In order to achieve energy efficiency of data transmission while increasing the overall network throughput, PRACT uses a TPRC mechanism combined with a CT scheme. The protocol has two key features. The first one is the transmission strategy which consists of selecting the power level and the PHY data-rate from the power-rate table. The second key feature is the transmission scheme that can be either direct or relayed scheme, depending on the link quality.

1) Transmission Strategy

In PRACT each wireless node creates a table with the optimal power-rate combinations allowed by the NIC. In MiSer, the power-rate table is created by estimating many parameters. In contrast, our power-rate table is created based only on the network interface card specifications. Let's assume that the NIC allows *m* TPL P_0, …, P_{m-1} ($P_0 > P_1 > \ldots > P_{m-1}$) (dBm) and *n* PHY data-rates R_0, …, R_{n-1} ($R_0 < R_1 < \ldots < R_{n-1}$) (Mbps) With P_0 is the maximum available power level and R_0 is the minimum data-rate. The pair (P_0, R_0) is the basic pair power rate and it is considered as the reference pair. The control frames are transmitted with the basic pair (P_0, R_0). We define the Required Signal To Noise and Interference Ratio threshold (Req.SINR$_{th}$(P_i, R_j)) as the minimum required SINR to receive a data at the P_i power level and with the R_j bit rate. In the table I we show an example with four power levels (P_0=15, P_1=13, P_2=7 P_3=0dBm) and four data-rates (R_0= 6, R_1= 12, R_2= 24 and R_3= 54Mbps). We have sixteen possible power-rate combinations. If we take the power-rate pair n°6 (P_0=15dBm and R_0= 24Mbps), the required SINR$_{th}$ necessary for a successful transmission is 37,844 and the energy consumption is 0.039 time as that of base power and rate.

When a source node *S* receives the CTS frame, it measures the frame signal strength and calculates the SINR value. Then, *S*

TABLE II: THE DIFFERENT CLASSES OF POTENTIAL RELAYS(MODES)

Class A_j	A1	A2	A3	A4	A5	A6
Rate R_{SRi}-R_{RiD} Mbps	54-54	54-24	24-24	54-12	24-12	12-12

chooses one of the power-rate combinations satisfying Req.$SINR_{th}(P_i,R_j)$ < SINR, from the power-rate table. For example, a measured SINR = 92 dB, among all combinations satisfying the condition Req.$SINR_{th}(P_i,R_j)$ < 92 dB, we choose a combination with the minimum energy consumption. We can notice that the selected combination corresponds to the optimal pair with the maximum data-rate. In the case of the previous example, the optimal transmission strategy is to select the pair n°8 (13dBm, 24Mbps). The energy consumption ratio of this combination is 0.2, which is the lowest energy consumption among all the possible combinations.

The selection is based upon SINR measurements made on the received control frames signal. The estimation of the CSI and the power-rate selection are located on the sender. As known, each data rate corresponds to a target SINR threshold value ($SINR_{th}$) that guarantees a BER. When the measured SINR, by a node *B*, is equal or greater than a given $SINR_{th}$, node *B* can successfully receive the data frame at the rate that corresponds to this threshold. Since the channel is assumed to be symmetric, the attenuation between the transmitter *A* and the receiver *B* is the same in both directions; hence R_{AB} is equal to R_{BA}.

2) *Transmission Scheme*

When the destination *D* receives the RTS frame it chooses the transmission scheme (direct(1), relayed(2)) based on the SINR value measured from the RTS frame; *D* compares this SINR value with a predefined SINR threshold, denoted by $SINR_{coop}$. Note that the $SINR_{coop}$ threshold is set so that a relayed transmission is selected on the *S-R- D* link only when the direct link's data-rate is lower than 12 Mbps. So, when the SINR value is greater than $SINR_{coop}$, a direct transmission is implemented and our protocol just reduces to the TPRC mechanism. Otherwise, cooperation is triggered and node *D* sends a CCTS (Cooperative Clear-To-Send) frame toward node *S*. The CCTS indicates to *S* that the level of the SINR value is very low at the node *D* and the direct transmission does not allow a high rate. Note that the CCTS is identical to the CTS control frame; it differs only in the value of sub-type field in the Frame Control of the packet. This difference is essential because it distinguishes the two frames. Each node R_i located around *S* and *D* listens to the ongoing control traffic. Upon successful decoding of the RTS frame from *S*, node R_i measures the SINR of the frame and based on that measure it chooses from the power-rate table the achievable pair power-rate (P_{SR_i}, R_{SR_i}) between nodes *S* and R_i. When node R_i also successfully receives the CCTS frame from *D*, it calculates the achievable pair (P_{R_iD}, R_{R_iD}) between nodes D and R_i using the power-rate table. Nodes that have successfully decoded RTS/CTS frames are considered as being potential relays for the *S-D* pair. These nodes then enter a relay selection phase.

In this phase the potential relays use a contention resolution mechanism in order to allow the best relay to access the medium first. The contention resolution mechanism classifies the potential relays into six classes based on their rates R_{SR_i} and R_{R_iD}. The classes are presented in the Table II ordered by increasing transmission duration of the relayed link S-R_i-D (source-relay-destination). Each class corresponds to a relayed transmission mode. The classification order is obtained based on the computed transmission time for different relayed modes. Note that we take into account the overhead introduced by the relays. The potential relays that belong to the A_6 class, don't improve the transmission delay of the direct link. Hence, they are never used in a relayed transmission.

Direct transmission duration:

$$T_{DirectTX} = 3 * SIFS + RTS + CTS + DATA_{SD} + ACK \quad (1)$$

Relayed transmission duration:

$$T_{RelayedTX} = 4 * SIFS + RTS + CTS + CFC + DATA_{SR_i} + DATA_{R_iD} + ACK \quad (2)$$

For each relay R_i, the quality of the relayed path S-R_i-D is described by the SINR measurement. The use of a function involving the link quality of the two jumps is essential because it expresses the end-to-end performance. We have implemented a function that calculates the harmonic mean of the two hops [20]. This function balances between the quality of the two links.

$$h_i = 2 * \left(\frac{SINR_{SRi} * SINR_{RiD}}{SINR_{SRi} + SINR_{RiD}}\right) \quad (3)$$

After classification, each potential relay R_i calculates a timer δ_i that is inversely proportional to the value of *hi* according to:

$$\delta_i = \frac{k_{A_j}}{hi} \quad (4)$$

$\delta_i \in [\delta_{min}, \delta_{max}]$, where δ_{min} is the minimum value of δ_i that a potential relay could have. The constant k_{A_j} is chosen for each class so that the maximum value of δ_i denoted by δ_{max} is equal to 8µs.

Subsequently each potential relay calculates a duration β_j:

$$\beta_j = (j-1) * (\delta_{max} + \varepsilon) \quad (5)$$

where *j* is the index of the relay's class and ε represents the maximal propagation time. The duration β_j represents the delay that every potential relay should wait before triggering its timer δ_i. Note that β_j has a constant value for each class.

So the final timer that each potential relay in each class triggers is:

$$\begin{cases} Ti = \beta_j + \delta_i \\ Ti = (j-1) * (\delta_{max} + \varepsilon) + \frac{k_{A_j}}{hi} \end{cases} \quad (6)$$

According to (6), the potential relays of the first class triggers there timer δ_i immediately since β_0 is equal to zero. The potential relays of the second class should wait for duration β_1 equal to $(\delta_{max} + \varepsilon)$ before triggering the timer δ_i. So nodes of each class A_j are favored over the nodes of the class A_{j+1} by adding in each time a duration β_j to the timer δ_i of nodes in the class A_{j+1}. This approach allows us to avoid collisions between potential relays from different classes. From (4) and

(7) we can notice that, the timer δ_{R_b} of the best relay R_b will be the first to expire.

$$h_{R_b} = \max\{hi\} \Leftrightarrow \delta_{R_b} = \min\{\delta i\} \quad i = [1, \ldots, M-2] \quad (7)$$

where h_{R_b} is the value of h_i for the best relay R_b and M is the number of nodes in the network.

The best relay R_b sends a Clear For Cooperation frame (CFC) to indicate its willingness to participate in data transmission from S to D. The rest of the relays stop the relay selection phase once they realize that the channel state becomes busy. Then they update their Networks Allocation Vector (NAV) upon receiving the CFC frame from R_b. Canceling the relay selection phase as soon as the channel state changes from idle to the busy state instead of waiting until the end of the CFC frame can reduce the probability of collision between the relays. When the source S successfully decodes the CFC frame, a relayed transmission is initiated after a SIFS duration. S sends data to the best relay R_b at the rate R_{SR_b} and the relay will forward this packet immediately to the destination D at the rate R_{R_bD}. After successfully decoding the data frame by D, an ACK frame will be sent directly to the source S. In the case of a collision between relays of the same class or absence of potential relays, the source will send the data directly to the destination without cooperation after a SIFS duration at the rate R_{SD}. Several approaches have been proposed in order to reduce the probability of a collision. In [21], two optimal metric-to-timer mappings have been proposed. The first one minimizes the probability of a collision between several best relays and the second one minimizes the duration of the selection. The implementation of these optimal schemes is left for future work.

B. *Medium Reservation and Cancellation*

To deal with hidden nodes problem and enhance the spatial reuse, we implemented a new NAV mechanism. In the IEEE 802.11 RTS/CTS mechanism a *duration* field that contains the time value, in microseconds, required to reserve the wireless medium for the current communication is defined. The RTS/CTS *duration* fields contain the corresponding time value, respectively:

$$Duration_{RTS} = 3 * SIFS + T_{CTS} + T_{DATA} + T_{ACK} \quad (8)$$

$$Duration_{CTS} = 2 * SIFS + T_{DATA} + T_{ACK} \quad (9)$$

where T_{DATA}, T_{CTS}, T_{ACK} denote the times required to transmit the DATA, CTS and ACK frames, respectively. In our mechanism, the time values of the $Duration_{RTS}$ and $Duration_{CTS}$ are as follows. Since the source node S does not know if cooperation is required before transmitting the RTS, it uses a T_{DATA} computed considering the basic rate of 6 Mbps. This maximizes the duration over which the channel is referred to as being in a busy state, but this has no impact on the protocol performance since this value is updated in the CTS or CFC frames depending on either cooperation is needed or not. When cooperation is not needed, destination node D updates the value of T_{DATA} in $Duration_{CTS}$ based on R_{SD} and sends a CTS frame accordingly. In contrast, when cooperation is needed, node D sends a CCTS frame with the time value

TABLE III: SIMULATION PARAMETERS

RTS	160 bits
CTS/ACK/CFC	112 bits
SIFS	10 us
Node mobility	none
Traffic	CBR
Routing protocol	none
Power consumption in TX at 15, 13, 7, 0 dBm	2.25, 1.75, 1.375, 1.235 Watt
Power consumption in RX	1.35 W
Radio-propagation model	Two-Ray-Ground

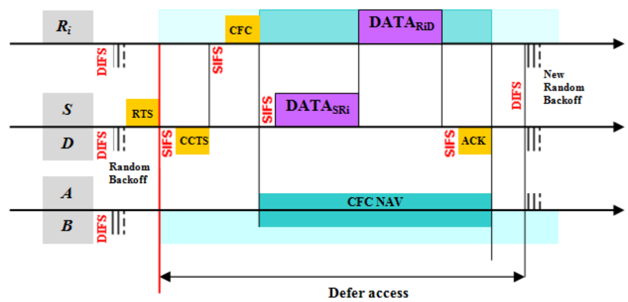

Fig. 1 : The new NAV mechanism

$Duration_{CTS}$ calculated in (9) with duration T_{DATA} computed according to the basic data rate of 6 Mbps. After receiving the CCTS frame, potential relay nodes enter the selection process. When a best relay node is selected, it sends a CFC frame with an updated *duration field* $Duration_{CFC}$:

$$Duration_{CFC} = SIFS + T_{DATA_b} + T_{ACK} \quad (10)$$

where T_{DATA_b} results from the sum of the transmission time of the two hops: one hop from S to R_b and second hop from R_b to D. After successfully receiving the relayed-data frame by D, it sends an ACK to notify neighbor nodes that the medium becomes free. To avoid unnecessary channel reservation made by the conservative reservation of the RTS or CCTS, each node updates its NAV each time it receives a control frame. Thus, no NAV problem arises. The problem of hidden terminal can be avoided, since (i) control frames are transmitted with the basic power-rate pair i.e. at the basic rate and with the highest transmission power; hence have a long transmission range, (ii) current wireless cards have higher power sensibility which leads to a carrier sensing range much larger than transmission range. Fig. 1 explains the new NAV mechanism.

III. PERFORMANCE EVALUATION

We used the extended model 802.11Ext of the NS2 simulator to evaluate and to compare the performance of the protocol with the IEEE 802.11. We evaluate the overall throughput, the total energy consumption, the energy efficiency and the energy-per-bit. The total energy consumption is defined as the sum of the energy used by the NICs to transmit and to receive all frames of all network nodes. Note that we consider the overhead energy consumption. Energy efficiency is defined as the ratio of overall throughput to total energy consumption.

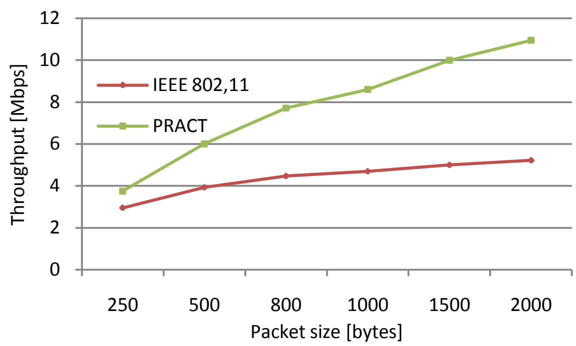

Fig. 2: Throughput vs. packet size

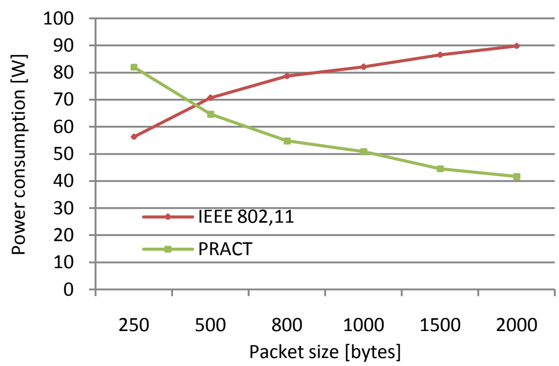

Fig. 3: Energy consumption vs. packet size

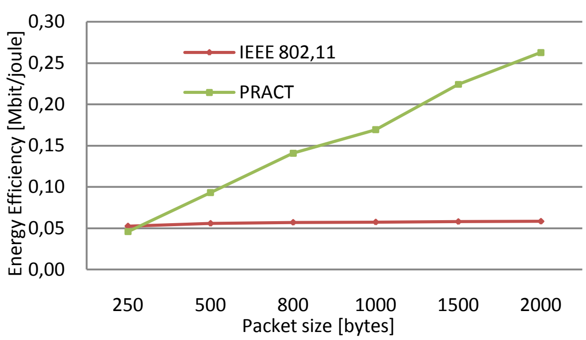

Fig. 4: Energy efficiency vs. packet size

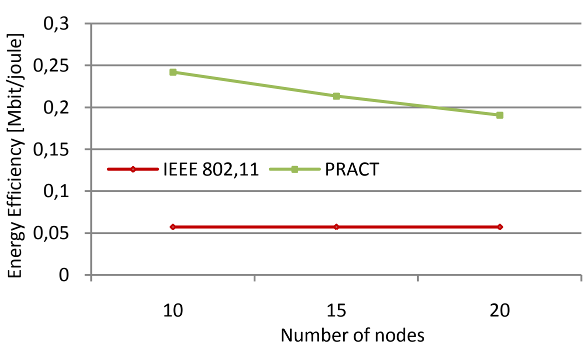

Fig. 5: Energy efficiency vs. nodes number

A. Simulation Setup

The IEEE 802.11g physical layer is used in this paper with the rates: 6, 12, 24 and 54 Mbps. The parameters used in the simulation are summarized in the Table III. We study the performance of our protocol in a single hop ad-hoc network with a grid topology. To investigate the effectiveness of the cooperative scheme combined with the TPRC mechanism, we put two sources on the top edge of the area and their destinations are set at the bottom edge. The potential relays are located in the middle of this area. The flows are saturated with CBR traffic. We repeated the simulations with a variable number of nodes, to see the impact on the network performance.

B. Results

In Fig. 2 we present the throughput versus packet size. We can notice that PRACT outperform the standard IEEE 802.11 protocol. As the packet size increases the throughput improvement increases. In fact, when cooperation is performed, a direct low-rate link is replaced by a two-hop high-rate link, hence, the number of delivered packet per unit of time is increased which enhances the throughput. Another important conclusion from this figure is that the IEEE 802.11 rate-anomaly [16] caused by low-data rate nodes can be mitigated since now low data-rate nodes are assisted by intermediate nodes and the slow communications are accelerated via cooperative communications. Fig. 3 shows the total energy consumption versus packet size. Note that the energy consumption is calculated for transmitting the same amount of data. This figure shows that after a certain payload length value PRACT consume less energy than the standard mechanism and the consumption decreases significantly as the packet size increases. Indeed, for small packet size the overhead introduced by the cooperative transmissions affects the energy consumption, but for long packet sizes this overhead is not significant compared to the packet size. Furthermore, because the cooperation occurs only when the basic rate can be supported in the direct mode, the time to transmit and receive data packet in this mode is larger than in relayed mode, hence the gain of cooperation is significant and direct transmission consumes more energy than the cooperative transmission. So, we conclude from this figure that our scheme consumes less energy than the standard scheme to transmit the same amount of data.

Fig. 4 reveals the relation between the energy efficiency and the packet sizes. We can notice that there is a proportional relation between the energy efficiency of PRACT and the packet size; as the packet size increases the energy efficiency increases. For the IEEE 802.11, the energy efficiency increase is not significant. This is due to the fact that in PRACT both throughput and energy consumption are improved as the packet size increases, in contrast, for large packet size the IEEE 802.11 consumes more energy than PRACT. Hence, our scheme delivers more data per unit of energy consumption than the standard scheme.

The impact of the number of nodes is shown on the Figs. 5 and 6. Fig. 5 gives the energy efficiency comparison between PRACT and the IEEE 802.11, whereas Fig. 6 gives the energy consumption for the two schemes. The nodes number has no impact on either energy consumption or energy efficiency of the standard scheme. In contrast, for PRACT the energy efficiency decreases as the nodes number increases nevertheless it remains better than of the IEEE 802.11.

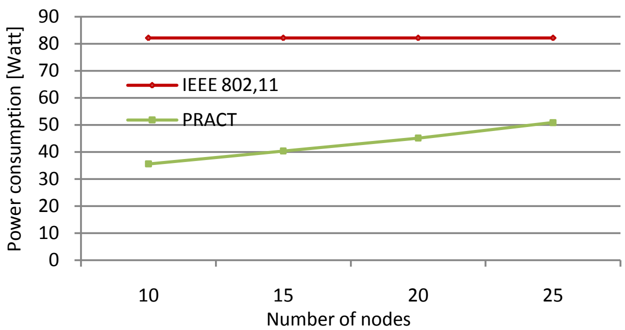

Fig. 6: Energy consumption vs. nodes number

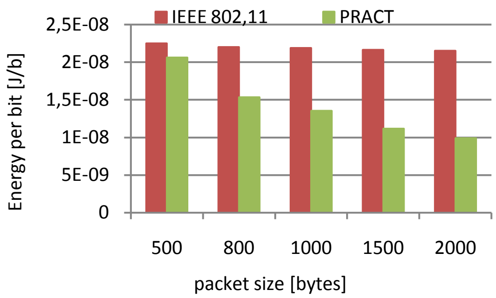

Fig. 7: Energy-per-bit vs. packet size

As regards the energy consumption, it increases in PRACT when the number of nodes increases but it still less than the energy consumption of the IEEE 802.11. The reason is that when the number of nodes increases the energy consumed due to the overhead also increases.

Fig. 7 gives the energy-per-bit of the two schemes for different payload sizes. Note that the the energy consumption is calculated for the same simulation time T for all schemes. We can notice that PRACT improves the energy-per-bit. Indeed, as the transmission time is reduced due to the RA and cooperation, the time spent by the NICs in both transmission and reception state is reduced, thus resulting in lower energy consumption. Moreover, the reduction of the transmission time allows delivering a higher number of frames during T. Therefore, the energy-per-bit is further improved.

IV. Conclusion

In this paper we introduced a new MAC protocol, called PRACT, that combines a TPRC mechanism with a cooperative scheme. Performing both power control and rate adaptation allows an important improvement in terms of global throughput and energy saving. Moreover, when we use cooperation in conjunction with the TPRC mechanism the network performance can be further more enhanced. Cooperation is used as a complementary scheme to direct communications and not as an alternative scheme. Note that our protocol with its TPC mechanism is a complementary scheme to the Power-Saving Mode (PSM) used in the IEEE 802.11 that allows a node to enter a doze state when deemed reasonable to save battery energy.

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