A Game Theoretical Approach to the Management of Transmission Selection Scheme in Wireless Ad-Hoc Networks

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***Abstract*—In this paper, game theory is exploited to derive a novel solution to manage virtual antenna array based transmissions in an ad hoc wireless network consisting of *selfish nodes*. In the proposed strategy each node decides, in an autonomous fashion, whether and when transmitting data packets over a shared wireless channel. The resulting transmission scheme results to be functionally equivalent to a distributed transmission selection scheme, managed, however, in a fully distributed fashion. This approach offers an higher throughput level and an higher efficiency than other communication protocols implementing selection diversity in distributed multi-antenna systems.**

***Index Terms*—Game theory, transmission selection, selfish nodes, ad hoc networks, cooperative communication.**

I. INTRODUCTION

IN *wireless ad-hoc network* the connectivity between nodes can be achieved through multihop links [1]; in such links multiple nodes can cooperate to form a *cluster* acting as a single stage for data relaying. Recently, substantial attention has been paid to the problem of cooperation in ad hoc networks consisting of *selfish nodes*, i.e. of nodes that aim at maximizing their own interest only [4]; this problem has been tackled resorting to *game theory*. However, as far as we know, previous work in this area analyses only the problem of cooperation proneness of single nodes for data relaying. On the contrary, in this paper, we provide a novel solution to the problem of both cooperation and coordination in a relay stage. Our solution is represented by a cooperative transmission strategy, functionally equivalent to a *transmission selection scheme* [6], [7], [8], but managed in a fully distributed fashion. The proposed strategy is characterized by the following relevant features: a) it *maximizes the individual utility of network nodes*, so that each node can earn *credits* with the minimum use of its radio resources; b) it achieves high *efficiency* in the access to a shared medium; c) it outperforms standard cooperative strategies based on transmission selection [6], [7], [8], even in terms of mean achievable throughput on a source-to-destination link; d) it is characterized by autonomous observations and choices made by each node on the basis of its own profit, so that it works even in the presence of *selfish nodes*[1].

The remaining part of this paper is organized as follows. Our network model is described in Section 2. In Section 3 the relaying dilemma of network nodes is formulated as a *multiplayer game* and its solution is derived. The performance of this strategy is analysed in Section 4, where some numerical results are shown. Finally, Section 5 offers some conclusions.

II. NETWORK MODEL

To ease the derivation of our strategy for the management of node transmission and avoid diverting the attention from the main contribution of this work, a *double hop link*, i.e. a simple relay network, is analysed in the following. In this network a *source* (S) node needs to send a certain number of data packets to a *destination* (D) through a set of hierarchically equivalent and *rational* potential relay nodes, fully aware of their roles, each endowed with a *single antenna* and operating in a *decode and forward* fashion. In our model we also assume that: a) the source node does not reveal to the potential relays the total number of packets to be forwarded; b) each node is expected to behave in a selfish fashion, so that its intrinsic goal is to carry out its own data transmissions only, limiting its power consumption as much as possible. Despite the last assumption, each node can contribute to packet relaying, since, as it will become clearer later, this results in earning credits exploitable for future communications.

The solution developed below relies on a simple *economic model*[2]; this establishes that the provision of a service, i.e., of packet relaying in this case, is rewarded with an economic counterpart, represented by a certain amount of *credits* [3]. The introduction of this policy for stimulating node cooperation justifies the need of broadening the considered system model from a simple relay network to a more generic ad hoc wireless network. In fact, if each node can act as both a relay and a source of information, it is really interested in earning the credits needed for its future data communications, consuming, at the same time, as few radio resources as possible.

In the following, we focus on the data communication phase and, more specifically, on the S-to-D transmission of a single packet; this event consists of the following steps:

1) S sends a data packet to a potential relay set; such a packet, being broadcasted over the radio channel, is

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[1] Note that in transmission schemes relying on the exchange of channel state information among network nodes, like those proposed in [7] and [8], selfish nodes can cheat and provide false information to avoid cooperation and extend the lifetime of their batteries.

[2] This specific choice has been made to handle node interaction in a flexible fashion. Note, however, that other options could be considered and adapted to the approach proposed in this work.

received by a set of nodes with a non zero probability.

2) Each node able to properly decode the packet represents a potential relay towards D within a virtual MISO link. It is assumed that the packets sent by S contain a known preamble which can be exploited by all the potential relays to achieve a rough synchronization only for their transmission. Then, considering the general case of unsynchronized and uncoded transmission, one of the following events occurs: a) a single relay node forwards the packet to D. In this case, this node spends a fraction of its energy but, at the same time, earns a given amount of credits; b) Multiple nodes transmit the same packet to D; this results in a collision and, consequently, in a waste of energy; c) no node forwards the packet to D, so that such a packet is queued and transmitted later.
3) D announces the outcome of the last transmission attempt broadcasting a single bit ACK/NAK feedback[3]. This feedback is supposed to be always correctly received by all the potential relay nodes which exploit it to estimate the quality of their channels towards D.

Note that the cooperative transmission scheme resulting from the interaction of cluster nodes can be interpreted as a form of transmit selection diversity [6], [7], [8]. Finally, it is worth mentioning that the following technical issues are not addressed in the following: a) how credits are stored in each node; b) how a consistent view of the credits in the ad-hoc network is kept; c) how credit transactions are managed in a distributed fashion. Note, however, that these problems are common to most of the available solutions exploiting both virtual currency or reputation based techniques for stimulating node cooperation; for this reason, a distributed control scheme (e.g., see [2]) can be adopted.

III. A NOVEL RELAY STRATEGY BASED ON GAME THEORY

A. Rules and description of the game

To ease the derivation of our strategy, the time axis is divided in slots (the slot length is equal to the duration of a data packet transmitted by a network node) and we focus now on a time instant[4] in which the n-th relay node of the network needs to decide whether forwarding a data packet or not. This transmission dilemma can be modeled as a *multiplayer game* in which, in principle, the set of players consists of the nodes belonging to the given relay cluster and the action set of each player is made of two distinct options (i.e., transmitting or remaining silent). Actually, in this game each player is interested only in adopting the strategy which can minimize the probability of collision for its transmissions, independently of the identity and of the number of the other nodes which can produce them. For this reason, the transmission dilemma can be interpreted as a "challenge" between the considered node and the remaining nodes of its relay cluster, so that the original multiplayer game can be simplified, in the eyes of each node, into a *fictitious two players game* [10]. In this model, the considered node plays against a *single fictitious opponent*; in practice, the action of the opponent sums up the actions of the other nodes of the cluster, i.e. the opponent transmits when at least one node of the cluster decides to transmit, otherwise it remains silent. It is worth nothing that, since each node is able to acquire information about the behavior of its opponents only from a generic ACK/NAK feedback sent by the destination node, this model is in agreement with the scenario seen by the node itself.

The payoffs earnable by the n-th node are evaluated as follows: a) if the n-th node decides to avoid the transmission of a data packet (i.e., it selects the no_TX action), the associated payoff is always equal to 0; b) instead, if the n-th node decides to transmit the packet (i.e., it selects the TX action), then the acquired payoff depends on the behavior of its *opponent*. In this case, if a packet transmission is accomplished properly, the payoff is equal to a_n, whereas, if a collision with any other node of the cluster occurs, a payoff c_n, denoting a lack of profit, is assigned. Specific procedures for the evaluation of the payoffs a_n and c_n are illustrated in Paragraphs III-B1 and III-B2, respectively. However, before tackling the problem of their computation, it is reasonable to assume that: a) $a_n > c_n$, since the n-th node is expected to deem a correct transmission of data packet more relevant than a collision; b) $c_n < 0$, since no reward is expected in the case of packet collision. The payoffs associated with the (fictitious) opponent playing against the n-th node (denoted $a_{fo,n}$ and $c_{fo,n}$ in the following) follows the same rationale, so that our game can be interpreted as a *chicken game* [11], in which the playing (transmitting) node wins when all the other nodes give up (stay silent). Note that both the payoffs $a_{fo,n}$ and $c_{fo,n}$ are unknown to the n-th node, since distinct nodes never share information. Therefore the game we are analysing belongs to the class of *games of incomplete information* [5].

B. Evaluation of the payoffs

1) Payoff a_n: In this Paragraph the problem of evaluating the payoff a_n (expressing the additional benefit acquired by the n-th node when a packet is correctly transmitted) is tackled. The proposed solution is general and rational since it expresses the payoff a_n as a function of the consumed resource[5] and of the amount of earnable credits. In practice, in our model the amount of credits earned by the n-th node in a given end-to-end communication is proportional to the overall number of packets that have been correctly forwarded by that node. However, in order to allow S to define a priori the overall amount of credits to be assigned to the complete relay stage, the number of packet transmissions accomplished by the n-th node is normalised with respect to the number of packet transmissions carried out by the cluster it belongs to. Therefore, at the end of the t-th time slot the number of credits earned by the n-th cooperating node in its transmission

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[3] The learning strategy proposed in Section III can be easily extended to the case of cumulative ACK.

[4] It is important to keep in mind, however, that in practice the strategy played by each node needs to be *continuously* updated (in order to follow the variations of the payoffs defined in Paragraph III-B) during the relaying of subsequent packets.

[5] Note that, in this work, for the sake of simplicity, we have considered the cost of a single resource in data transmission, i.e. that of the energy; however, the same line of reasoning holds if other limited resources (e.g., the transmission bandwidth) need to be accounted for.

over a specific link is equal to

$$P(n,t) = B\frac{N_{tx}\left(n,t\right)}{\sum_{i\in C_n} N_{tx}\left(i,t\right)}, \tag{1}$$

where B is the overall amount of credits made available by S to reward the potential relay set for its efforts spent on the whole S to D link, $N_{tx}\left(n,t\right)$ is the number of packets that have been properly forwarded by the n-th cooperating node until the t-th slot and $\sum_{i\in C_n} N_{tx}\left(i,t\right)$ is the overall number of packets sent by the whole rely set C_n, which the n-th node belongs to, over the same time interval. It is worth noting that the rule expressed by (1) allows the potential relays to assess in any slot their current contribution to the link and, consequently, the additional benefit coming from a packet transmission in the next slot. In addition, it decouples the credits spent by S from, on the one hand, the number of packets that have to be transmitted and, on the other hand, the transmission scheme adopted by the relay set[6].

The energy consumed by the n-th node until the t-th slot is given by

$$E(n,t) = \sum_{k=0}^{t-1} E_k\left(n\right), \tag{2}$$

where $E_k\left(n\right)$ is the energy spent by this node over the k-th slot. Given the quantities $P(n,t)$ (1) and $E(n,t)$ (2), the benefit deriving from the transmissions made until the current slot is evaluated as $f\left(P(n,t)\right) - g\left(E(n,t)\right)$; here $f(\cdot)$ and $g(\cdot)$ are monotonic increasing functions having the specific purpose of making the contributions coming from these two quantities *homogeneous* and characterized by similar ranges (so that they play comparable roles in the evaluation of payoffs). If one more packet will be successfully forwarded by the n-th node, both $N_{tx}\left(i\right)$ and $\sum_i N_{tx}\left(i\right)$ increases by one, so that the amount of earnable credits becomes $P(n,t+1) = \left(N_{tx}\left(n,t\right)+1\right)/\left[\sum_{i\in C_n} N_{tx}\left(i,t\right)+1\right]$; moreover the energy spent $\sum_k E_k\left(n\right)$ increases by $E_{t+1}\left(n\right)$, representing an estimate of the energy needed for the next transmission and evaluated from the knowledge of the channel attenuation in the previous slot. Then, a_n can be defined as

$$\begin{aligned} a_n \triangleq & \left[f\left(P(n,t+1)\right) - g\left(E(n,t)+E_{t+1}\left(n\right)\right)\right] \\ & - \left[f\left(P(n,t)\right) - g\left(E(n,t)\right)\right], \end{aligned} \tag{3}$$

expressing the additional benefit acquired by the n-th relay node for the transmission of a new packet.

2) Payoff c_n: The payoff c_n assigned to the n-th node in case of packet collision can be evaluated resorting to the approach described in the previous Paragraph for a_n. If a collision occurs, the amount of packets which have been usefully forwarded by the n-th node and by all the other nodes of its cluster (i.e., the quantities $N_{tx}\left(n,t\right)$ and $\sum_{i\in C_n} N_{tx}\left(i,t\right)$, respectively) remains unchanged. Therefore, the payoff c_n can be expressed as (see (3))

$$c_n \triangleq g\left(E(n,t)\right) - g\left(E(n,t)+E_{t+1}\left(n\right)\right). \tag{4}$$

3) Risk affinity: The payoffs defined above do not take into account the willingness of the n-th node to spend its residual resources for data transmission. To account for this, the expressions of the payoffs a_n and c_n can be modified as

$$\begin{aligned} \hat{a}_n \triangleq & \begin{bmatrix} w_{tx}\left(n\right)\cdot f\left(P(n,t+d)\right) \\ -\, w_{en}\left(n\right)\cdot g\left(E(n,t)+E_{t+d}\left(n\right)\right) \end{bmatrix} \\ & - \left[w_{tx}\left(n\right)\cdot f\left(P(n,t)\right) - w_{en}\left(n\right)\cdot g\left(E(n,t)\right)\right] \end{aligned} \tag{5}$$

and

$$\hat{c}_n \triangleq w_{en}\left(n\right)\cdot\left[g\left(E(n,t)\right) - g\left(E(n,t)+E_{t+d}\left(n\right)\right)\right]. \tag{6}$$

respectively, where the weight $w_{tx}\left(n\right)$ ($w_{en}\left(n\right)$) measures the willingness of the n-th node to cooperate (to save its energy). Note that, since the functions $f(\cdot)$ and $g(\cdot)$ are generic, the real influence of these weights on the payoffs depends on their ratio, i.e. on the parameter

$$K_n \triangleq \frac{w_{tx}\left(n\right)}{w_{en}\left(n\right)}, \tag{7}$$

which can be interpreted as the *risk affinity* for the n-th node. A large risk affinity pushes the n-th node to cooperate with the aim of earning as many credits as possible, in order to be able to support heavy traffic in the near future. A small risk affinity, instead, can be interpreted as an appreciable energy avidity, which pushes the terminal to cooperate scarcely.

In the following we will always refer to the modified payoffs $\hat{a}_n$ (5) and $\hat{c}_n$ (6), which will be denoted a_n and c_n, respectively, to simplify the notation.

C. Opponent strategy

In our model the payoffs $a_{fo,n}$ and $c_{fo,n}$, that can be acquired by the fictitious opponent, are unknown to the n-th node. However, this lack of information can be made up for exploiting the repetitiveness of the game [10]. In particular, the transmission probability of the *fictitious opponent* $\Pr\left\{TX_{fo}\right\}$ can be estimated as the ratio of the number $N(TX_{fo})$ of transmission attempts (regardless if they have been successful or have produced a collision) carried out by the opponent relay cluster to the total number of transmission attempts, i.e.

$$\Pr\left\{TX_{fo}\right\} = \frac{N(TX_{fo})}{N(TX_{fo}) + N(no\_TX_{fo})}. \tag{8}$$

Note that the knowledge of the slot period allows each node to count both the number of transmission attempts and the number $N(no\_TX_{fo})$ of slots during which the relay cluster has remained silent.

In the derivation of the strategy played by the n-th node it is important to keep in mind that the considered communication scenario cannot be deemed static if the wireless channel is affected by *time selectivity*. To overcome this problem, the probability $\Pr\left\{TX_{fo}\right\}$ can be estimated considering only the last N_{moves} (and not the entire history of the link). This means that, in the k-th slot,

$$N(TX_{fo})|_k \triangleq \sum_{l=1}^{N_{moves}} w\left(l\right)\delta_{TX}\left(k-l\right) \tag{9}$$

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[6] In principle, if a distributed space-time coded communication is considered, multiple relays can cooperate within the same transmission; in this case, it is reasonable to assume that the reward is divided among the active nodes.

is used in place of $N(TX_{fo})$ in (8). Here the sequence $\delta_{TX}(l)$ is equal to unity if a packet transmission occurred in the l-th slot and to zero otherwise, and

$$w(l) \triangleq \frac{N_{moves} - l + 1}{N_{moves}} \tag{10}$$

is a weight assigned to the move carried out l slots earlier.

D. Solution of the game

The game we are analysing is characterized by 3 Nash equilibria. Two of them are pure equilibria and are trivially identified by the strategies $(TX,\ no\_TX)$ and $(no\_TX,\ TX)$[7]. Obviously, these two equilibria are useless for our application since do not result in a practically exploitable policy for the network nodes. The third equilibrium point, corresponding to a *mixed strategy*, can be derived as explained below (see [5, p. 34], [11, p. 9]). If $P_{fo}(TX)$ and $P_{fo}(no\_TX)$ denote the actual probabilities with which fictitious opponent of the n-th node transmits and remains silent, respectively, the average payoff for the n-th node is given by

$$\begin{aligned} E_n(TX) &= c_n P_{fo}(TX) + a_n P_{fo}(no\_TX) \\ &= c_n P_{fo}(TX) + a_n(1 - P_{fo}(TX)) \end{aligned} \tag{11}$$

if it decides to transmit, and by $E_n(no\_TX) = 0$ in the opposite case. The mixed equilibrium point can be derived equalling the average payoffs $E_n(TX)$ (11) and $E_n(NO\_TX)$; from this it is easily inferred that the probability with which the opponent relay cluster transmits at the mixed equilibrium point is

$$\hat{P}_{fo}(TX) = \frac{a_n}{a_n - c_n}. \tag{12}$$

The *best response* (BR) of the n-th node to the fictitious opponent actions is transmitting if $\Pr\{TX_{fo}\} \le \hat{P}_{fo}(TX)$ or remaining silent if $\Pr\{TX_{fo}\} > \hat{P}_{fo}(TX)$. Note that the probabilities appearing in the last formula are evaluated by the n-th node on the basis of its information only, so that an estimate of $\Pr\{TX_{fo}\}$ is used. In order to avoid a discontinuous behavior of the players, the adoption of a stochastic version of the considered fictitious game is recommended; this explains why the *smoothed best response* (SR) curve is introduced in our transmission strategy. Such a curve is defined by

$$P_{pl}^{SR}(TX) = \begin{cases} 1 + \dfrac{(-\exp(\gamma \cdot \Pr\{TX_{fo}\}))}{2\exp\left(\gamma \cdot \hat{P}_{fo}(TX)\right)}, \\ \qquad \text{if } \Pr\{TX_{fo}\} \le \hat{P}_{fo}(TX) \\ \dfrac{\exp(-\gamma \cdot \Pr\{TX_{fo}\})}{2\exp\left(-\gamma \cdot \hat{P}_{fo}(TX)\right)}, \\ \qquad \text{if } \Pr\{TX_{fo}\} > \hat{P}_{fo}(TX) \end{cases} \tag{13}$$

and consists of two exponential pieces connecting at the *indifference point* $\hat{P}_{fo}(TX)$ [10]. Note that: 1) the factors $(2\exp(\gamma \cdot \hat{P}_{fo}(TX)))^{-1}$ and $(2\exp(-\gamma \cdot \hat{P}_{fo}(TX)))^{-1}$ in (13) normalize the smoothed curve; 2) the parameter $\gamma \in \Re^+$ provides a degree of freedom for a proper adjustment of the approximation of the smoothed best response curve to the discontinuous BR.

E. Convergence of the solution

In a smooth fictitious game characterized by two pure equilibria and by one mixed equilibrium, the player strategy converges to one of the strategies associated with the pure equilibria with unitary probability (the final strategy depends, however, on the initial conditions of the game) [11]. The mixed strategy proposed in Paragraph III-D is not associated with a stable equilibrium but, despite this, it can be deemed an acceptable solution, since the game evolves over time. In fact, the scenario considered in this work is time-varying, in the sense that the channel gains experienced by network nodes (and, hence, their payoffs) change over time. Then, even if the behavior of each player evolves towards one of the strategies associated with a pure equilibrium, this attracting point is continuously changing. In this process the more profitable solution of the network is always followed even if, to allow a proper game update when the environmental conditions change, the adaptation proneness is reduced by a sufficiently large degree of smoothing.

IV. NUMERICAL RESULTS

The performance of the proposed transmission strategy has been assessed for a double hop relay network containing 10 potential relay nodes. In our simulations, we have also assumed that: a) the time slot duration T_U is known (and common) to all the network nodes; b) the wireless link between any couple of nodes is affected by time-selective Rayleigh fading with Doppler bandwidth B_D (the well known Jakes' model has been used in our simulations) and the channels affecting distinct links are statistically independent; c) the values $N_{moves} = 10$ (see eq. (9)) and $\gamma = 10$ (see eq. (13)) has been selected empirically; d) the linear models $f(x) = x$ and $g(x) = kx$ have been adopted for the functions introduced in Paragraphs III-B1-III-B3. The value selected for the parameter k ensures that the two terms range over similar intervals and, consequently, influence the payoffs in a comparable fashion.

Our transmission strategy has been compared with the opportunistic transmission selection scheme of [6] and with a simple symmetric contention channel access protocol [9]. In the first scheme each potential relay initializes a timer with a value which is inversely proportional to the estimated channel gain any time a data unit is ready to be forwarded; consequently, the timer of the most suitable relay decreases to zero more quickly. In the adopted symmetric contention protocol any node is supposed to know the number N of potential relays and transmits with a fixed probability (equal to $1/N$) in each time slot.

Computer simulations have been run to assess: 1) the *average throughput*

$$th \triangleq \frac{N(TX)}{T} \tag{14}$$

of the considered transmission strategies, where $N(TX)$ is the number of packets correctly transmitted by the whole relay stage and T is the number of time units considered in the simulations; 2) the *energy efficiency*

$$eff \triangleq \underset{n \in CL}{\mathrm{E}} \left(\frac{N(TX_{all}(n))}{E_n} \right), \tag{15}$$

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[7] The notation $(A_1,\ A_2)$ specifies the action A_1 (A_2) of the player 1 (2) at the equilibrium point.

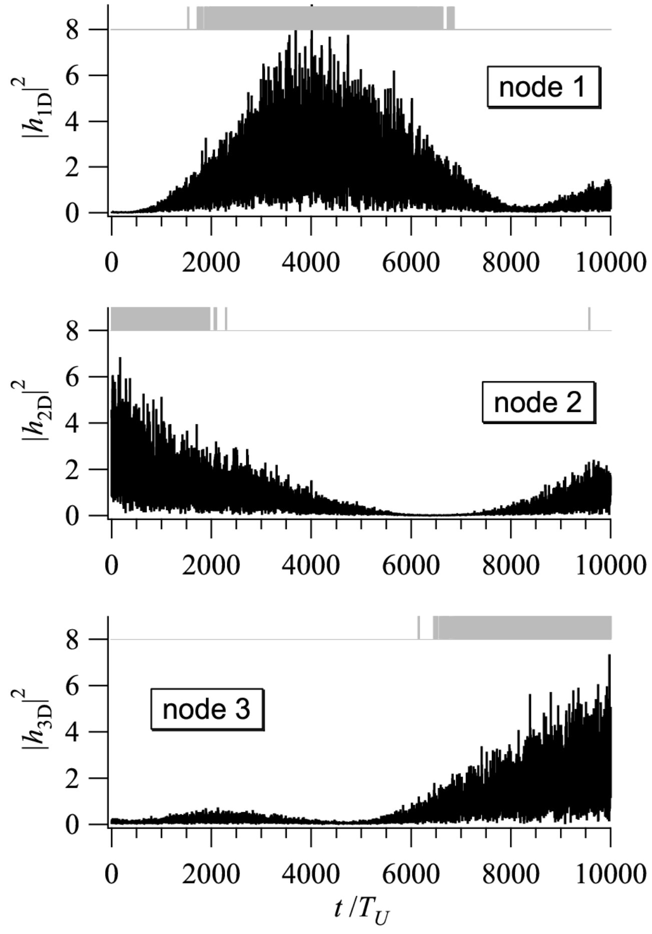

Fig. 1. Channel power gains experienced by 3 distinct nodes in a cluster and their transmission attempts.

of the transmission schemes. Here n is the index selecting the node in the cluster CL of potential relays, and $N(TX_{all}(n))$ and E_n are the number of transmission attempts of the n-th node and the overall energy spent by the same node, respectively. For a given n the parameter E_n is evaluated summing up the quantities $E_{n,\hat{t}} = 1/|h_{n,\hat{t}}|^2$, $\hat{t} = 1, 2, ...$, where $|h_{n,\hat{t}}|^2$ is the complex channel gain experienced by the node n over the $\hat{t}$-th time slot. It is worth noting that the energy efficiency allows to assess the ability of the transmission strategy in exploiting the best options within the pool of available channels at the potential relays.

Fig. 1 shows some randomic channel realizations and the actions selected by each node in a simple experiment characterized by 3 potential relays. In this representation each node decides to transmit (to remain silent) when its boolean indicator is equal to 1 (0). This figure evidences the rationality of the proposed transmission strategy, since it shows that a) an order can emerge in the packet transmissions of the nodes even if there is not any explicit negotiation among them and b) the potential relay offering the best communication channel is always able to exploit it.

Fig. 2 illustrates the mean throughput achievable by a link exploiting the game-based transmission strategy versus the risk affinity factor K_n. These results show that an increase of K_n leads to a larger throughput, even if the growth rate becomes gradually smaller and then stabilizes because of a rise in the number of collisions. It is also worth pointing out that, as evidenced by Fig. 3, an excessive increase of K_n is damaging for the energy efficiency of the link because it leads to frequent collisions.

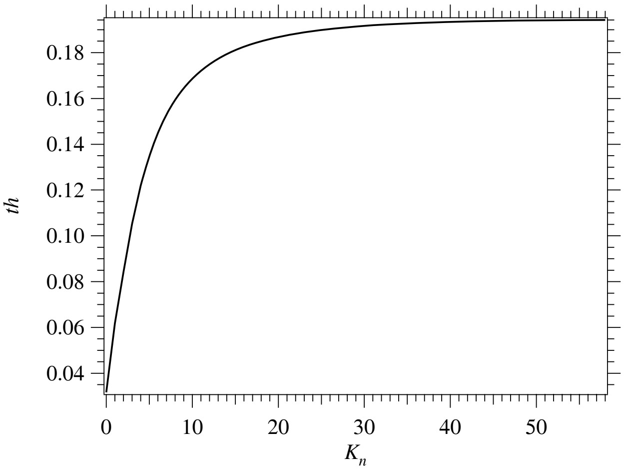

Fig. 2. Achievable throughput versus the mean risk affinity of the cluster nodes for the proposed transmission strategy.

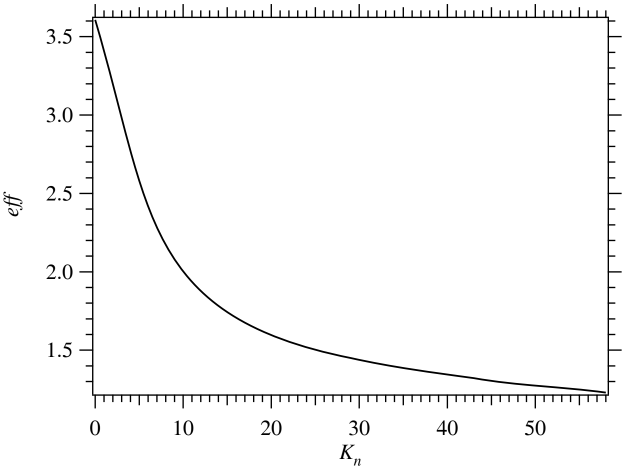

Fig. 3. Energy efficiency of the link versus the mean risk affinity of the cluster nodes for the proposed transmission strategy.

Figs. 4 and 5 compare the above mentioned three transmission schemes in terms of mean achievable throughput and energy efficiency, respectively, versus the normalized Doppler bandwidth $B_D T_U$ and for a fixed K_n. These results evidence that the proposed approach substantially outperforms the opportunistic strategy without increasing the number of collisions (their presence would reduce the energy efficiency of the link). This performance gap is due to the fact that the opportunistic solution is penalized by the variable delay characterizing the transmission of the node with the best channel. These results also show that the throughput offered by the symmetric contention protocol is lower than that of the approach we propose and is characterized by a larger number of collisions, resulting in a decrease of the energy efficiency. The throughput offered by the proposed solution approaches

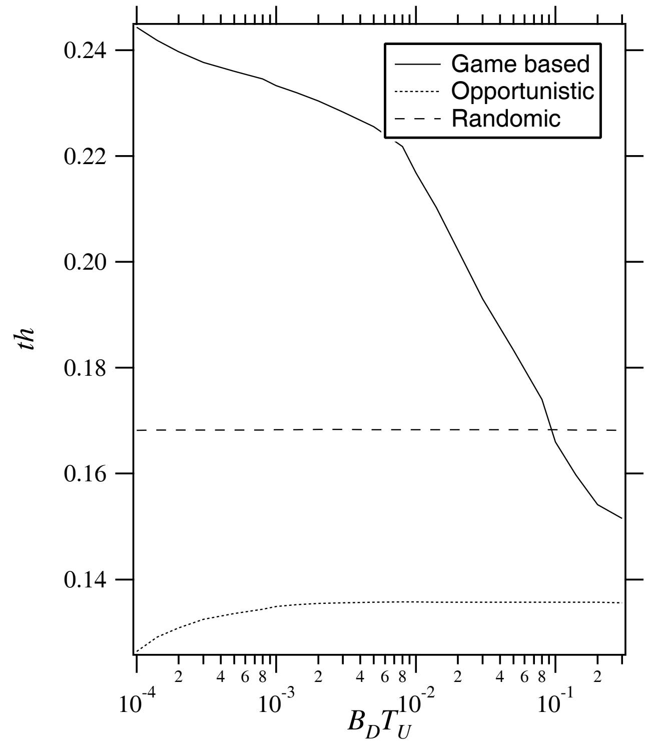

Fig. 4. Comparison among the achievable throughputs (versus the normalized Doppler bandwidth B_DT_U) offered by three different transmission strategies.

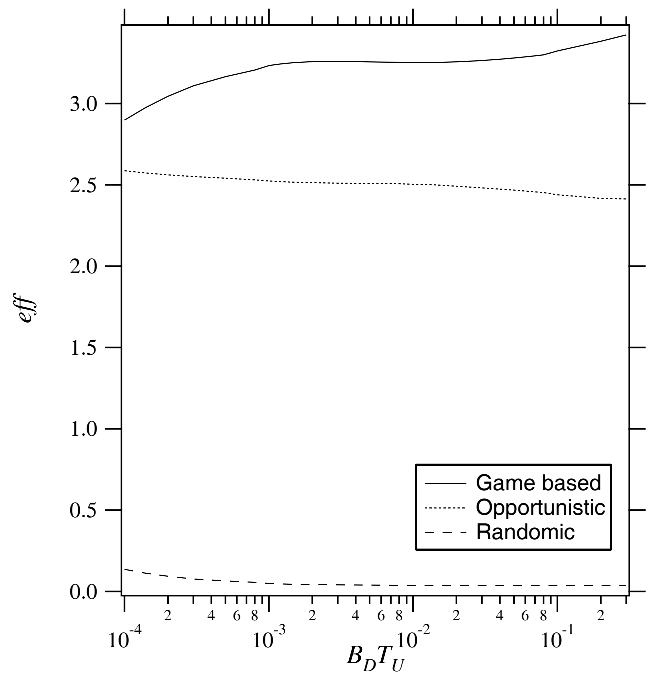

Fig. 5. Comparison among the energy efficiencies (versus the normalized Doppler bandwidth B_DT_U) offered by three different transmission strategies.

one half of the maximum achievable throughput on the link (which is is equal to 0.5 for a double hop link based on half duplex nodes) and decreases significantly only in the presence of very fast fading (say, when B_DT_U approaches 0.1), since the correlation between subsequent game turns reduces and so also the effectiveness of the learning strategy to face the moves selected by the opponent.

V. CONCLUSIONS

In this paper game theory has been applied to develop a novel cooperative transmission strategy for data communications in an ad-hoc wireless network; this strategy is functionally equivalent to a transmission selection scheme, which is managed, however, in a fully distributed fashion. The proposed strategy consists of an autonomous choice, made by each potential relay in a cluster of nodes, between two simple alternatives: transmitting an information data packet to a destination or remaining silent. This allows to coordinate the transmissions among the potential relays without any explicit information exchange between them. Thanks to this feature, the proposed solution offers a larger throughput and higher efficiency than other communication techniques exploiting distributed transmission selection.

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