

Game Theory Based Protocols for Cooperative Transmission in Wireless Ad-hoc Networks

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Introduction

The natural similarity between the problem of resource management in a communication system and that of resource management in a complex social system suggests to adapt the methods, exploited for a long time by economists to tackle the latter problem, to solve the former one. One of the most relevant theoretical methods in this area is probably the so called *game theory*, which represents a powerful tool to model and solve the above mentioned problems.

Overview of Game Theory Methods

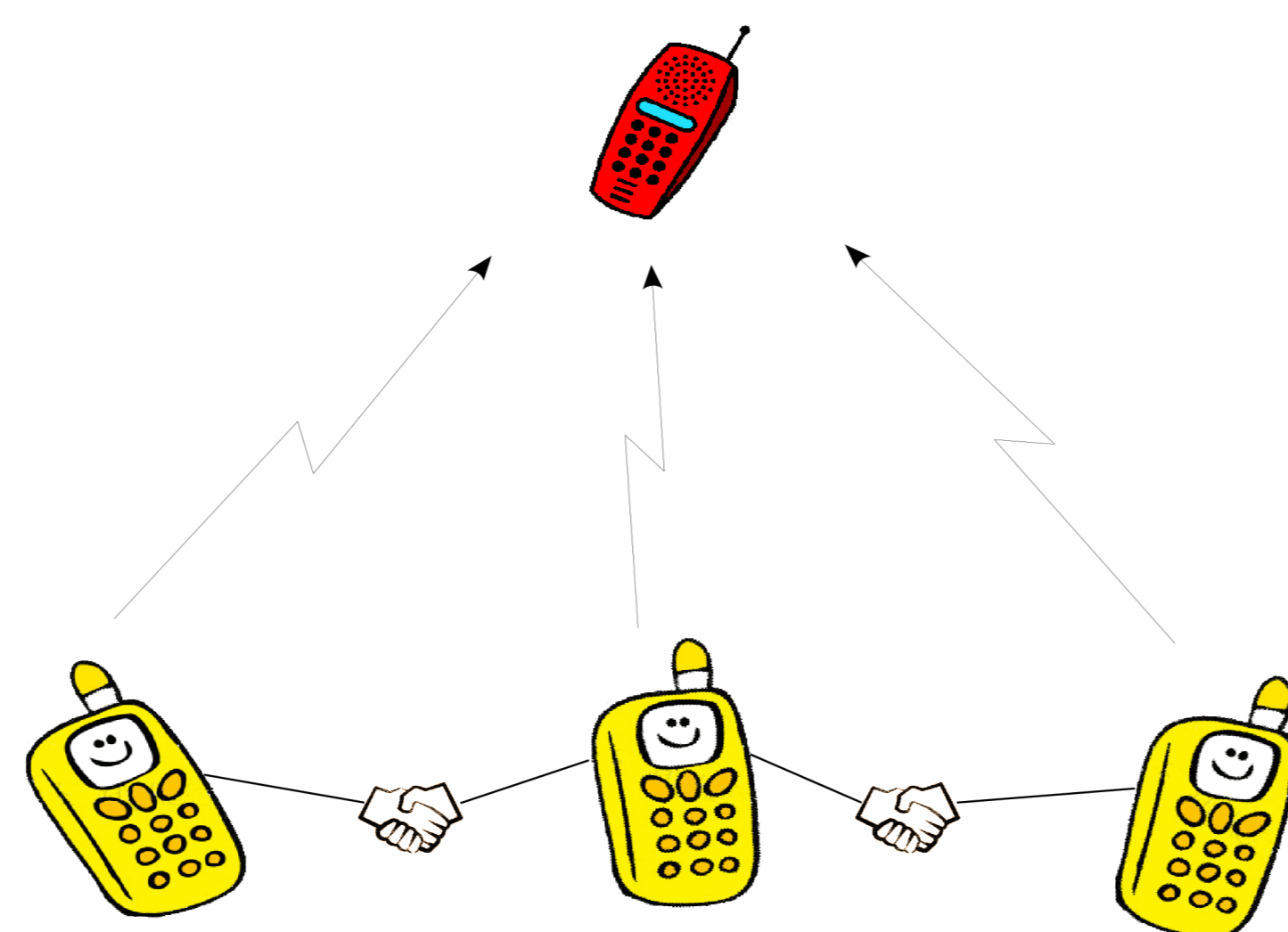
Game theory offers new interesting opportunities for the study and the modelling of complicated communication problems. The definition of a game encompasses a set of simple theoretical concepts: 1) the *set of players* taking part to the game; 2) the *actions* available to those players; 3) the *payoff* associated with all the possible game outcomes. In the study of a game, each player is always expected to be perfectly rational, so that it is able to understand (and pursue) its own interest absolutely and in every moment (player individualism). The players choose their actions on the basis of a specific *strategy*. This is defined as the rationale according to which any player decides to select a specific action from its possible action set, given the current conditions of the game or, more generally speaking, of the external environment, and of the player itself. Another fundamental feature of a game theoretical model is the assumption of player independence; this entails that, generally speaking, the choice made by each player is independent of the action selected by its opponents, even though the goals of the players usually make such choices correlated. As far as the last element in the definition of a game is concerned, it is important to point out that the payoff earnable by each player depends not only on its own moves, but also on the moves made by its opponents. If a problem can be described in the above mentioned terms, then a model exploiting the tools offered by game theory can be adopted. It is interesting to note that:

- Games can be analyzed under different perspectives. In fact, even if the goal of each player is always maximizing its own individual utility, this result can be achieved avoiding cooperation with its opponents or accepting it; the first case is that of a *noncooperative game*, the second one of a *cooperative* (also known as *bargaining*) game.



- In the classic game theory solving a game requires a perfect knowledge of all the involved payoffs. If this is the case, a game with *perfect information* is played. Generally speaking, the payoffs depend on the player point of view on the game and on the environment, and may not be retrievable by the opponents. When this occurs, the easiest way to solve the problem is assuming an information exchange among the players to restore the perfect knowledge of the game payoffs. When information sharing is not possible (or simply unwanted), a game with *incomplete information* is played; in this case finding its solution is not a trivial task. However, if the game is repeated, a solution can be still found cleverly exploiting the information acquired from the past turns of the game to infer the opponent strategy and to compute the best response of each player.

- Generally speaking, three different behaviors should be expected in a player set. The first behavior is that of a *cooperative node*, prone to interact with other nodes and to help them in order to maximize the effectiveness of the network it belongs to; the second one is that of a *selfish node*, which aims at maximizing its own interest even if its actions may damage or reduce the efficiency of the network; the last one is that of a *malicious node*, the only goal of which is to damage the network and its services.



A promising field for game theory: Transmit cooperation

When network nodes are endowed with a single antenna, cooperative transmission techniques can be used to set up virtual antenna arrays in order to achieve reliable data communications. In all the strategies based on this idea data communications consist of two distinct phases. In the first phase, a source node sends each data packet to a group of nodes, dubbed *relay set*, which are able to forward such a packet to other nodes; the antennas of a relay set, being collectively exploited, form a virtual array. In the second phase, a specific cooperative strategy based on the availability of such an array is adopted by the relay set to exploit spatial (and, possibly, frequency) diversity. One of the most interesting strategies is based on assigning randomly a codeword, selected from an orthogonal ST code.

Another important contribution to this class of cooperative relaying algorithms is provided by the so called opportunistic relaying. In practice, the relaying of a data packet is performed only by the node experiencing the best channel conditions to a given destination.

Class of possible solutions	
Centralized Space-Time based solutions (or Transmit Selection): transmission and code assignment are managed by a central authority.	<ul style="list-style-type: none"> ✓ - Synchronization is simplified and collision are not possible. ✗ - The overhead associated with CSI and codeword sharing can appreciably reduce network throughput. ✗ - In the presence of fast fading, delays in CSI exchange can make any dynamic resource allocation strategy ineffective or even damaging from an energy efficiency point of view.
Opportunistic TSD: transmission is actually accomplished only by one relay node at a time (the one experiencing the best channel realization towards the destination), the node selection is carried out indirectly by means of a delay timer proportional to the attenuation of the radio link.	<ul style="list-style-type: none"> ✓ - Zero overhead protocol. ✗ - Collisions may occur since node are not synchronized and the timer has a finite resolution. ✗ - The delay introduced lower the achievable throughput.
Distributed Randomic STBC: space time codewords are chosen randomly by the nodes from a sufficiently large code. All the nodes able to decode the information that has to be sent towards a destination actively cooperate to the transmission.	<ul style="list-style-type: none"> ✓ - Zero overhead protocol. ✗ - The number of nodes that participate may be too large or too small (in any case, this entail a waste of energy). ✗ - If multiple nodes choose the same codeword, the effectiveness of the link does not improve (the degree of diversity remain the same).
Plain symmetric contention protocol: the relay are aware of their number N and transmit with a fixed probability of $1/N$	<ul style="list-style-type: none"> ✓ - Zero overhead protocol. ✗ - Collisions may occur. ✗ - Data transmissions are not related to the channel status (energy inefficiency).
Game theory based protocols: based on a non cooperative game played among the relay nodes; each node autonomously decide its moves (when to transmit) in order to maximize its payoff	<ul style="list-style-type: none"> ✓ - The information needed to solve the game can be retrieved by means of the transmission overheard by the node, so without any explicit information exchange (zero overhead protocol). ✓ - No delay associated with data transmission (no throughput reduction). ✓ - The protocol is based on the individual choice made by each node (selfish nodes are allowed). ✓ - The nodes are continuously able to estimate their own channels and the opponent strategies to compute their best response (the protocol is naturally adaptive). ✓ - The node strategy can be easily related to other node parameters other than the experienced channel (resource efficiency).