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Game Theory in Wireless Ad- hoc Opportunistic Radios

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1. Introduction

In this chapter we explain how we use game theory application in wireless communication ad-hoc network. The application of mathematical analysis to the study of wireless communication ad hoc networks has met with limited success due to the complexity of mobility, traffic models and the dynamic topology. A scenario based UMTS TDD opportunistic cellular system with an ad hoc behaviour that operates over UMTS FDD licensed cellular network is considered. We describe how ad hoc opportunistic radio can be modeled as a game and how we apply game theory based Power Control in ad-hoc opportunistic radio

2. Game theory

Game theory is a field of applied mathematics that describes and analyzes interactive decision situations. It provides analytical tools to predict the outcome of complex interactions among rational entities, where rationality demands strict adherence to a strategy based on perceived or measured results. The main areas of application of game theory are economics, political science, biology and sociology. From the early 1990s, engineering and computer science have been added to this list. We limit our discussion to non-cooperative models that address the interaction among individual rational decision makers. Such models are called "games" and the rational decision makers are referred to as "players." In the most straightforward approach, players select a single action from a set of feasible actions. Interaction between the players is represented by the influence that each player has on the resulting outcome after all players have selected their actions. Each player evaluates the resulting outcome through a payoff or "utility" function representing her objectives.

There are two ways of representing different components (players, actions and payoffs) of a game: normal or strategic form, and extensive form. Here we will focus on the normal form representation.

Formally, a normal form of a game G is given by

$$G = \{ N, A, \{u_i\}\} \tag{1}$$

where N={1,2,...,n} is the set of players (decision makers), A_i is the action set for player i, $A = A_1 \times A_2 \times,...,\times A_n$ is the Cartesian product of the sets of actions available to each player, and

$\{u_i\}=\{u_1,\dots,u_n\}$ is the set of utility functions that each player i ,wishes to maximize, where $u_i : A\rightarrow \mathbf{R}$. For every player i, the utility function is a function of the action chosen by player i, a_i and the actions chosen by all the players in the game other than player i, denoted as $\mathbf{a}_{-i}$. Together, a_i and $\mathbf{a}_{-i}$ make up the action tuple $\mathbf{a}$. An action tuple is a unique choice of actions by each player. From this model, steady-state conditions known as *Nash equilibria* can be identified. Before describing the Nash equilibrium we define the best response of a player as an action that maximizes her utility function for a given action tuple of the other players. Mathematically, $\bar{a}$ is a best response by player i to $\mathbf{a}_{-i}$ if

$$\bar{a} \in \{\arg\ \max u_i\ (a_i, \mathrm{a}_{-i})\} \tag{2}$$

Nash equilibrium (NE) is an action tuple that corresponds to the mutual best response: for each player i, the action selected is a best response to the actions of all others. Equivalently, a NE is an action tuple where no individual player can benefit from unilateral deviation. Formally, the action tuple

$\mathbf{a}^* = (a_1^*, a_2^*, a_3^*, \dots, a_n^*)$ is a NE if $u_i(a_1^*, \mathbf{a}_{-i}^*) \geq (a_1^*, \mathbf{a}_{-i}^*)$ for all $\forall a_i \in A_{\mathrm{i}}$ and for all $\forall i \in N$. (3)

The action tuples corresponding to the Nash equilibria are a consistent prediction of the outcome of the game, in the sense that if all players predict that Nash equilibrium will occur then no player has any incentive to choose a different strategy. There are issues with using the Nash equilibrium as a prediction of likely outcomes (for instance, what happens when multiple such equilibria exist?). There are also refinements to the concept of Nash equilibrium tailored to certain classes of games. A detailed discussion of these is outside the scope of this deliverable. There is no guarantee that a Nash equilibrium, when one exists, will correspond to an efficient or desirable outcome for a game (indeed, sometimes the opposite is true). Pareto optimality is often used as a measure of the efficiency of an outcome. An outcome is Pareto optimal if there is no other outcome that makes every player at least as well off while making at least one player better off.

Mathematically, we can say that an action tuple

$\mathbf{a} = (a_1, a_2, a_3,\dots, a_n)$ is Pareto optimal if and only if there exists no other action tuple

$\mathbf{b} = (b_1, b_2, b_3,\dots, b_n)$ such that $u_i(\mathbf{b}) \geq (\mathbf{a})$ for $\forall i \in N$, and

for some $k \in N$ $u_k(\mathbf{b}) \geq u_k(\mathbf{a})$.

3. Game theory in wireless communication

There is a significant amount of work in wired and wireless networking that make use of game theory. The strategic situations in wireless networking the players have to agree on sharing or providing a common resource in a distributed way, our approach focuses on the theory of *non-cooperative games*.

Cooperative games require additional signalization or agreements between the decision makers and hence a solution based on them might be more difficult to realize. In a non-cooperative game, there exist a number of decision makers, called *players*, who have potentially conflicting interests. In the wireless networking context, the players are the *users* or *network operators* controlling their devices. In compliance with the practice of game theory, we assume that the players are *rational*, which means that they try to maximize their *payoffs* (or utilities). This assumption of rationality is often questionable, given, for example, the altruistic behaviour of some animals. Herbert A. Simon was the first one was to question this assumption and introduced the notion of *bounded rationality* . But, we believe that in computer networks, most of the interactions can be captured using the concept of rationality, with the appropriate adjustment of the payoff function. In order to maximize their payoff, the players act according to their *strategies*. The strategy of a player can be a single *move* or a set of moves during the game.

We take an intuitive top-down approach in the protocol stack to select the examples in wireless networking as follows. Let us first assume that the time is split into *time steps* and each device can make one move in each time step.

In the first game called the *Forwarder's Dilemma*, we assume that there exist two devices as players, p_1 and p_2. Each of them wants to send a packet to his destination, dst_1 and dst_2 respectively, in each time step using the other player as a forwarder. We assume that the communication between a player and his receiver is possible only if the other player forwards the packet. We show the Forwarder's Dilemma scenario in Figure 1. If player p_1 forwards the packet of p_2, it costs player p_1 a fixed *cost* $0 < C << 1$, which represents the energy and computation spent for the forwarding action. By doing so, he enables the communication between p_2 and dst_2, which gives p_2 a *benefit* of 1. The payoff is the difference of the benefit and the cost. We assume that the game is symmetric and the same reasoning applies to the forwarding move of player p_2. The dilemma is the following: Each player is tempted to drop the packet he should forward, as this would save some of his resources; but if the other player reasons in the same way, then the packet that the first player wanted to send will also be dropped. They could, however, do better by mutually forwarding each other's packet. Hence the dilemma.

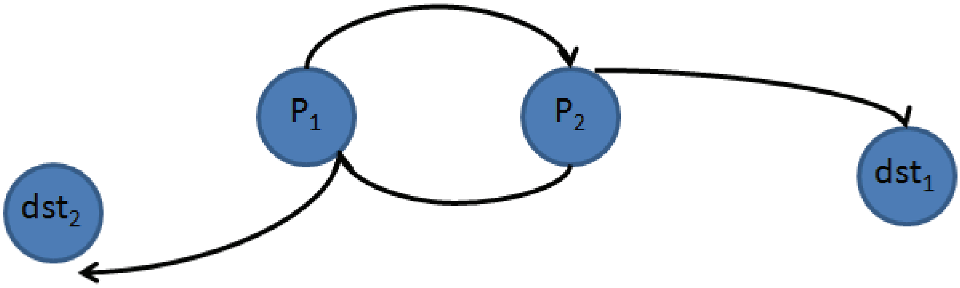

Fig. 1. The network scenario in the Forwarder's Dilemma game.

In the second example, called *Joint Packet Forwarding Game*, we present a scenario, in which a source *src* wants to send a packet to his destination *dst* in each time step. To this end, he needs *both devices* p_1 and p_2 to forward for him. Similarly to the previous example, there is a forwarding cost $0 < C << 1$ if a player forwards the packet of the sender. If both players forward, then they each receive a benefit of 1 (e.g., from the sender or the receiver). We show this packet forwarding scenario in Figure 2.

The third example, called *Multiple Access Game*, introduces the problem of medium access. Suppose that there are two players p_1 and p_2 who want to access a shared communication channel to send some packets to their receivers re_1 and re_2. We assume that each player has one packet to send in each time step and he can decide to access the channel to transmit it or to wait. Furthermore, let us assume that p_1, p_2, re_1 and re_2 are in the power range of each

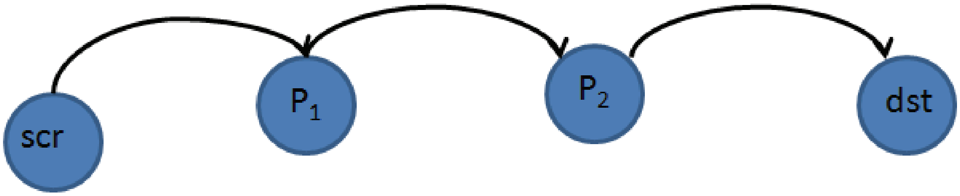

Fig. 2. The Joint Packet Forwarding Game.

other, hence their transmissions mutually interfere. If player p_1 transmits his packet, it incurs a sending cost of $0 < C << 1$. The packet is successfully transmitted if p_2 waits in that given time step (i.e., he does not transmit), otherwise there is a collision. If there is no collision, player p_1 gets a benefit of 1 from the successful packet transmission. The framework presented by Cagalj *et al.* in is a generalized version of the Multiple Access Game.

In the last example, called the *Jamming Game*, we assume that player p_1 wants to send a packet in each time step to a receiver re_1. In this example, we assume that the wireless medium is split into two channels x and y according to the Frequency Division Multiple Access (FDMA) principle. The objective of the *malicious* player p_2 is to prevent player p_1 from a successful transmission by transmitting on the same channel in the given time step. In wireless communication, this is called *jamming*. Clearly, the objective of p_1 is to succeed in spite of the presence of p_2. Accordingly, he receives a payoff of 1 if the attacker cannot jam his transmission and he receives a payoff of -1 if the attacker jams his packet. The payoffs for the attacker p_2 are the opposite of those of player p_1. We assume that p_1 and re_1 are synchronized, which means that re_1 can always receive the packet, unless it is destroyed by the malicious player p_2. Note that we neglect the transmission cost C, since it applies to each payoff (i.e., the payoffs would be $1\text{-}C$ and $-1\text{-}C$) and does not change the conclusions drawn from this game.

The Jamming Game models the simplified version of a game-theoretic problem presented by Zander .We deliberately chose these examples to represent a wide range of problems over different protocol layers (as shown in Figure 3). There are indeed fundamental differences between these games as follows. The Forwarder's Dilemma is a symmetric *nonzero-sum game*, because the players can mutually increase their payoffs by cooperating (i.e., from zero to $1\text{-}C$). The conflict of interest is that they have to provide the packet forwarding service for each other. Similarly, the players have to establish the packet forwarding service in the Joint Packet Forwarding Game, but they are not in a symmetric situation anymore. The Multiple Access Game is also a nonzero-sum game, but the players have to share a common resource, the wireless medium, instead of providing it. Finally, the Jamming Game is a *zero-sum game* because the gain of one player represents the loss of the other player. These properties lead to different games and hence to different strategic analyses.

3.1 Cognitive radio

In information times, the increase of wireless equipments makes the spectrum to be the most essential and important resources. Now the wireless networks are regulated by a fixed spectrum assignment policy. However, according to Federal Communications Commission (FCC), a large portion of the assigned spectrum is used sporadically and geographically, so the serious problem is the inefficiency usage. This restriction of the tradition spectrum policy necessitates a new technology to exploit the spectrum available opportunities which is called—cognitive radio.

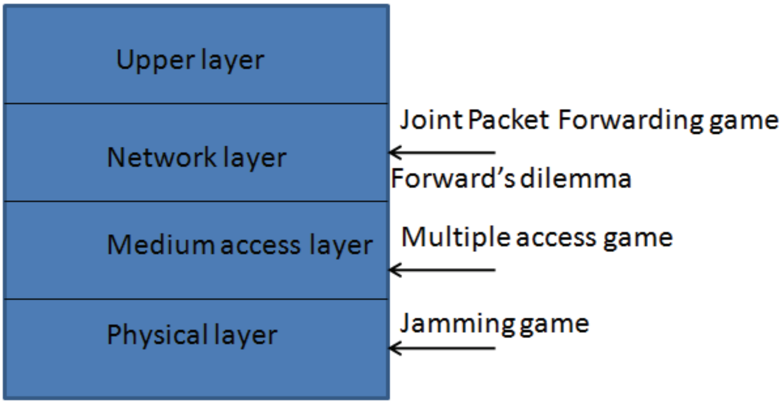

Fig. 3. The classification of the examples according to protocol layers.

A "cognitive radio" is a radio that can change its transmitter parameters base on interaction with the environment in which it operates . It is characterized by cognitive capability and reconfigurability. The cognitive capability refers to the capture and sense of the information from the radio environment by monitoring the power and capturing the temporal and spatial variations. The reconfigurability enables the radio to be dynamically programmed by the radio knowledge representation language (RKRL) to select the best spectrum and appropriate operating parameters. Therefore, the cognitive radio can enhance the flexibility through the cognitive cycle, which has three main steps: radio-scene analysis, channel state estimation and predictive modeling, transmit power control and spectrum management . The cognitive cycle is pictured in Figure 4.

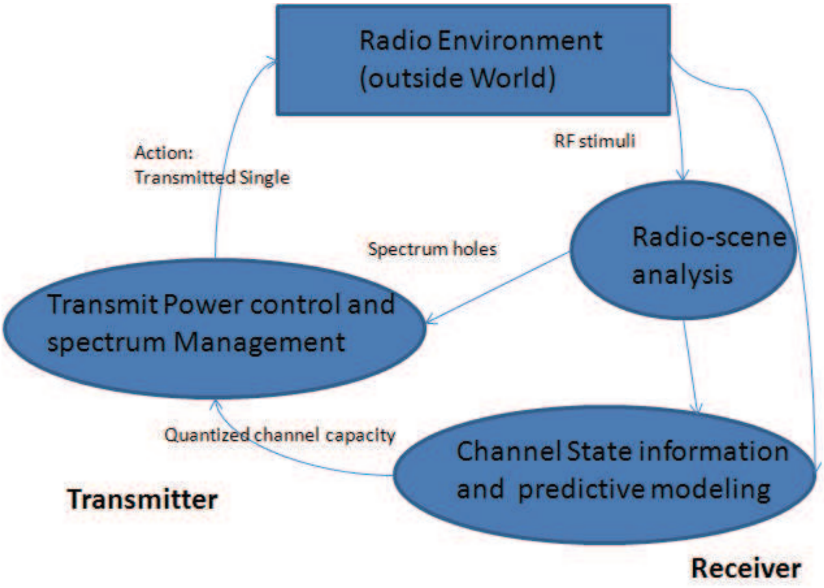

Fig. 4. Basic cognitive cycle

Transmit-power control is necessary for the cognitive radio system to broaden the scope of its applications and enhance the performance. It would have to operate under two limitations on network resources: the interference temperature limit imposed by regulatory agencies, and the availability of a limited number of spectrum holes depending on usage. In a multiuser cognitive radio environment, all the users operate in a decentralized manner; they are characterized by cooperation and competition. In such a case, information theory and game theory could be applied to exercise control over the transmit power.

4. Game theory in wireless ad- hoc opportunistic radios

Wireless communications play a very important role in military networks and networks for crisis management, which are characterised by their ad hoc heterogeneous structure. An example of a future network can be seen in Figure 5. This illustrates a range of future wireless ad hoc applications. In the heterogeneous ad hoc network, it is difficult to develop plans that will cope with every eventuality, particularly hostile threats, due to the temporary nature. Thus, dynamic management of such networks represents the ideal situation where the new emerging fields of cognitive networking and cognitive radio can play a part. Here we assume a cognitive radio ‘is a radio that can change its transmitter parameters based on interaction with the environment where it operates’, and additionally relevant here is the radio’s ability to look for, and intelligently assign spectrum ‘holes’ on a dynamic basis from within primarily assigned spectral allocations. The detecting of holes and the subsequent use of the unoccupied spectrum is referred to as opportunistic use of the spectrum. An Opportunistic Radio (OR) is the term used to describe a radio that is capable of such operation .We use the opportunistic radio system which was proposed that shares the spectrum with an UMTS cellular network. This is motivated by the fact that UMTS radio frequency spectrum has become, in a significant number of countries, a very expensive commodity, and therefore the opportunistic use of these bands could be one way for the owners of the licenses to make extra revenue.

The OR system exploits the UMTS UL bands, therefore, the victim device is the UMTS base station, likely far from the opportunistic radio, whose creates local opportunities. These potential opportunities in UMTS FDD UL bands are in line with the interference temperature metric proposed by the FCC s Spectrum Policy Task Force. The interference temperature model manages interference at the receiver through the interference temperature limit, which is represented by the amount of new interference that the receiver could tolerate. As long as OR users do not exceed this limit by their transmissions, they can use this spectrum band. However, handling interference is the main challenge in CDMA networks, therefore, the interference temperature concept should be applied in UMTS licensed bands in a very careful way.

The UMTS is a DS-CDMA system, thus all users transmit the information spreaded over 5 MHz bandwidth at the same time and therefore users interfere with one another. Figure 6 shows a typical UMTS FDD paired frequencies. The asymmetric load creates spectrum opportunities in UL bands since the interference temperature (amount of new interference that the UMTS BS can tolerate) is not reached.

In order to fully exploit the unused radio resources in UMTS, the OR network should be able to detect the vacant channelization codes using a classification technique. Thus the OR network could communicate using the remaining spreading codes which are orthogonal to the used by the UMTS network. However, classify and identify CDMA’s codes is a very computational intensive task for real time applications.

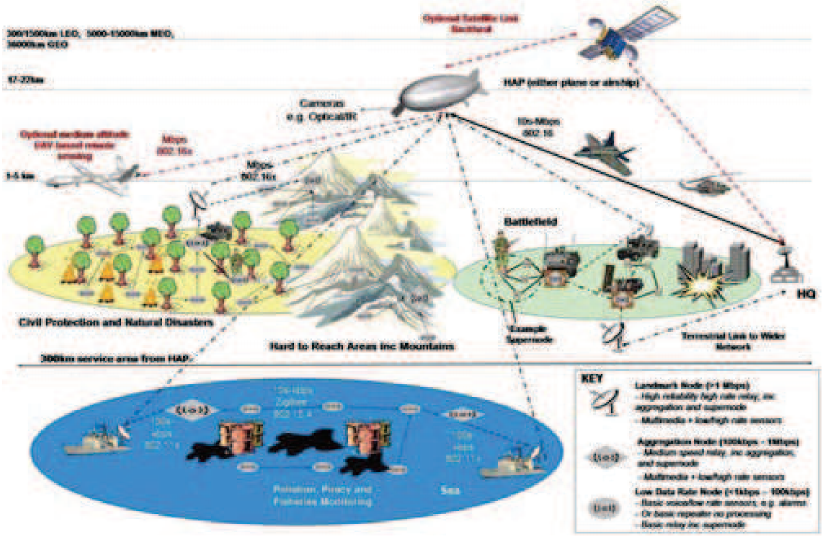

Fig. 5. Ad-hoc future network

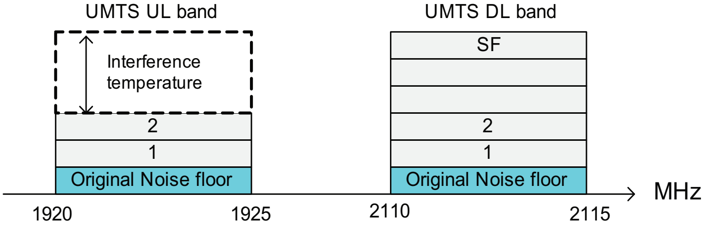

Fig. 6. UMTS FDD spectrum bands with asymmetric load

Moreover, synchronization between UMTS UL signals and the OR signals to keep the ortogonality between codes will be a difficult problem. Our approach is to fill part of the available interference temperature raising the noise level above the original noise floor. This rise is caused by the OR network activity, which aggregated signal is considered AWGN (e.g CDMA, MC-CDMA, OFDM).We consider a scenario where the regulator allows a secondary cellular system over primary cellular networks. Therefore we consider opportunistic radios entities as secondary users. The secondary opportunistic radio system can use the licensed spectrum provided they do not cause harmful interference to the owners of the licensed bands i.e., the cellular operators.Specifically we consider as a primary cellular network an UMTS system and as secondary networks an ad hoc network with extra sensing features and able to switch its carrier frequency to UMTS FDD frequencies. Figure 7 illustrates the scenario where an opportunistic radio network operates within an UMTS cellular system.

We consider an ah hoc OR network of M nodes operating overlapped to the UMTS FDD cell. The OR network acts as a secondary system that exploit opportunities in UMTS UL bands. The OR network has an opportunity management entity which computes the maximum allowable transmit power for each OR node in order to not disturb the UMTS BS.

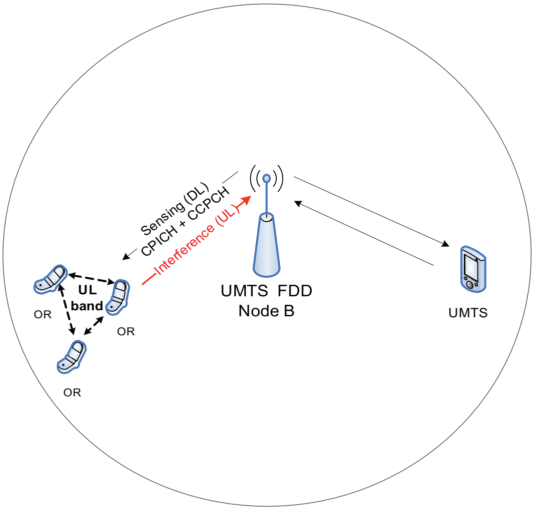

Fig. 7. Ad hoc ORs networks operating in a licensed UMTS UL band

4.1 The opportunities network with ad-hoc topology

The opportunistic network, showed in Figure 8, will interface with the link level simulator through LUTs.

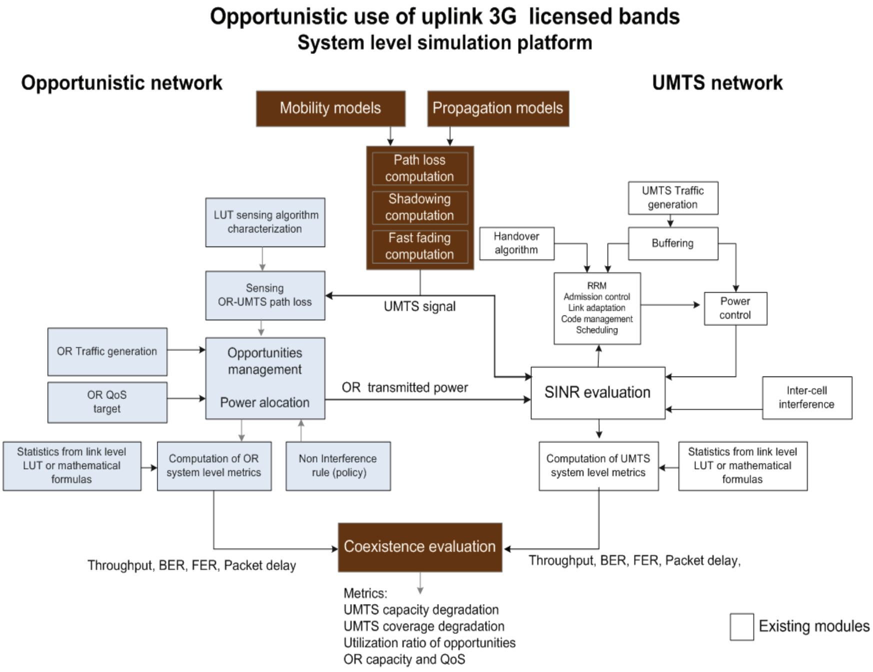

Fig. 8. Block diagram of the system level platform

The propagation models developed for the UMTS FDD network will be reused, and the entire channel losses (slow and fast fading) computed. The outputs will be the parameters that usually characterize packet transmissions: Throughput, BLER and Packet Delay. The LUT sensing algorithm characterization block contains the cyclostationary detector's performance, i.e. the output detection statistic, *d*, as a function of the SNR measured at the sensing antenna for different observation times [6].The sensing OR-UMTS path loss block estimates the path loss between UMTS BS and the OR location through the difference between the transmitted power and the estimated power given by cyclostationary detector (LUT sensing algorithm characterization block output). The OR traffic generation block contains real and non-real time service traffic models. OR QoS block defines the minimum data rate, the maximum bit error rate and the maximum transmission delay for each service class. The non-interference rule block compute the maximum allowable transmit power without disturbing the UMTS BS applying a simple non-interference rule (according to policy requirements).In the following, we briefly explain the opportunistic network blocks that was designed and implemented, using a C++ design methodology approach.

First of all, we assume that the OR knows a priori the UMTS carrier frequencies and bandwidths, which has been isolated and brought to the baseband. In order to get the maximum allowable power for OR communications the OR nodes need to estimate the path loss from its location to the UMTS BS, i.e., the victim device. The opportunistic user is interested in predefined services which should be available every time. This motivates the proposal of defining a set of usable radio front end parameters in order to support the demanded services classes under different channel conditions. Basically, at the beginning of each time step the opportunistic radio requires certain QoS guarantees including certain rate, delay and minimum interference to the primary user (non interference rule policy).

The opportunistic network has an opportunity management entity which computes the maximum allowable transmit power for each opportunistic node in order the aggregated interference do not disturb the UMTS BS. The aggregated transmit power allowed to the opportunistic network can be computed using a simple non-interference rule

$$10\log\left(\sum_{k=1}^{K}10^{\frac{P_{OR}(k)+G_{OR}+G_{BS}-\hat{L}p(k)}{10}}\right)\leq 10\log\left(10^{\frac{Nth+\mu}{10}}-10^{\frac{Nth}{10}}\right)-\Gamma \qquad (4)$$

Where G_{OR} is the OR antenna gain, G_{BS} is the UMTS BS antenna gain, *Lp* is the estimated path loss between the OR node and the UMTS BS, *K* is the Number of ORs, performed by a sensing algorithm, and *Nth* is the thermal noise floor. μ is a margin of tolerable extra interference that, by a policy decision, the UMTS BS can bear. Finally, Γ is a safety factor to compensate shadow fading and sensing s impairments. Notice if the margin of tolerable interference μ=0 the OR must be silent. Γ is a safety factor margin (e.g. 6-10 dB) to compensate the mismatch between the downlink and uplink shadow fading and others sensing's impairments. The margin of tolerable interference is defined according to policy requirements.

Employing scheduling algorithms, we can provide a good tradeoff between maximizing capacity, satisfying delay constraint, achieving fairness and mitigating interference to the primary user. In order to satisfy the individual QoS constraints of the opportunistic radios, scheduling algorithms that allow the best user to access the channel based on the individual priorities of the opportunistic radios, including interference mitigation, have to be considered. The objective of the scheduling rules is to achieve the following goals:

- Maximize the capacity;
- Satisfy the time delay guarantees;
- Achieve fairness;
- Minimize the interference caused by the opportunistic radios to the primary user.

A power control solution is required to maximize the energy efficiency of the opportunistic radio network, which operates simultaneously in the same frequency band with an UMTS UL system. Power control is only applied to address the non-intrusion to the services of the primary users, but not the QoS of the opportunistic users.

A distributed power control implementation which only uses local information to make a control decision is of our particular interest. Note that each opportunistic user only needs to know its own received SINR at its designated receiver to update its transmission power. The fundamental concept of the interference temperature model is to avoid raising the average interference power for some frequency range over some limit. However, if either the current interference environment or the transmitted underlay signal is particularly non uniform, the maximum interference power could be particularly high.

Following we are going to explain why we consider Ad-hoc topology for the opportunistic radio system in cellular scenario.Mobile ad-hoc network is an autonomous system of mobile nodes connected by wireless links; each node operates as an end system and a router for all other nodes in the network. Mobile ad-hoc network fits for opportunistic radio because the following features:

Infrastructure

MANET can operate in the absence of any fixed infrastructure. They offer quick and easy network deployment in situations where it is not possible. Nodes in mobile ad-hoc network are free to move and organize themselves in an arbitrary fashion. This scenario is fit in the Opportunities in UMTS bands which are local and may change with OR nodes movement and UMTS terminals activity.

Dynamic Topologies

Ad hoc networks have a limited wireless transmission range. The network topology which is typically multi-hop may change randomly and rapidly at unpredictable times, and may consist of both bidirectional and unidirectional links which fits the typical short range opportunities which operate on different links in UMTS UL bands.

Energy-constrained operation

Some or all of the nodes in a MANET may rely on batteries or other exhaustible means for their energy. For these nodes, the most important system design criteria for optimization of energy conservation. This power control mechanisms for energy conversion (power battery) also helps to avoid harmful interference with the UMTS BS.

Reconfiguration

Mobile ad-hoc networks can turn the dream of getting connected "anywhere and at any time" into reality. Typical application examples include a disaster recovery or a military operation. As an example, we can imagine a group of peoples with laptops, in a business meeting at a place where no network services is present. They can easily network their machines by forming an ad-hoc network. In our scenario OR network reconfigure itself, as the interference coming from licensed users (PUs) causes some links being dropped. Ad hoc multi hop transmission allows decreases the amount of the OR’s transmitted power and simultaneously decreases the interference with the UMTS BS.

Bandwidth-constrained, variable capacity links

Wireless links will continue to have significantly lower capacity. In addition, the realized throughput of wireless communications after accounting for the effects of multiple access, fading, noise, and interference conditions, etc. is often much less than a radio's maximum transmission rate This constrained also fit in our scenario where maximum transmission rate of ORs is less than the UMTS base station after the effects of multiple access, fading, noise and interference conditions.

Security

Mobile wireless networks are generally more prone to physical security threats than are fixed cable nets. The increased possibility of eavesdropping, spoofing, and denial-of-service attacks should be carefully considered. Existing link security techniques are often applied within wireless networks to reduce security threats. As a benefit, the decentralized nature of network control in MANETs provides additional robustness against the single points of failure of more centralized approaches. By using this property of MANETs, we avoid single point failure in ORs.

4.2 Co-existence analysis of single opportunities Radio link

We consider the simplest case where a single OR link operates within a UMTS FDD cell. Simulations were carried out to compute the coexistence analysis between the OR link and the UMTS network. The main parameters used for the simulations are summarized in Table 1. We consider an omnidirectional cell with a radius of 2000 meters. Each available frequency, in a maximum of 12, contains 64 primary user terminals. Each of these primary users receives the same power from the UMTS base station (perfect power control). We assume the primary users data rate equal to 12.2 kbps (voice call); the E_b/N_o target for 12.2 kbps is 9 dB. Thus, and since the UMTS receiver bandwidth is 3840 kHz, the signal to interference ratio required for the primary users is sensibly -16 dB. There is (minimum one) opportunistic radio in the cell coverage area, which has a transmitted power range from -44 to 10 dBm. The opportunistic radio duration call is equal to 90 seconds. We furthermore consider load characteristics.

Simulation results for a single UMTS frequency

In order to calculate Cumulative Distribution Function (CDF) for the interference at UMTS BS we consider 64 UMTS licensed UMTS terminals in each cell (with radius equal to R= 2000 m), as shown in the following Figure 9. The OR receiver gets interference from the PUs located in the central UMTS cell and in 6 adjacent cells. The ORs are within an ad-hoc network service area (with radius equal to R= 100 m); the OR receiver is 10 m away from the OR transmitter. The OR transmitter is constrained by the non-interference rule.

Based on the capacity's Shannon formula, the OR's link capacity that can be achieved between two OR nodes is given by:

$$C_{Mbps} = B\log_2\left(1+\frac{L_2 P_{OR\_Tx}}{Nth + I_{UMTS}}\right) \qquad \begin{array}{l} B = 5\text{ MHz} \\ Nth = -107\text{ dBm} \end{array} \tag{4}$$

Where B=5 MHz, L_2 is the path loss between the OR_Tx and the OR_Rx, Nth is the average thermal noise power and I_{UMTS} is the amount of interference that the UMTS terminals cause on the OR_Rx. On the other hand, the total interference at the UMTS BS caused by the OR activity can not be higher than the UMTS BS interference limit, -116 dBm.

Parameter Name	Value
UMTS system	
Time transmission interval (T_{ti})	2 ms
Cell type	Omni
Cell radius	2000 m
Radio Resource Management	
Nominal bandwidth (W)	5 MHz
Maximum number of available frequencies ($N_{[max]}$)	12
Data rate (R_b)	12.2 kbps
E_b/N_o target	9 dB
SIR target (γ)	-16 dB
Spreading factor	16
Spectral noise density (N_o)	-174 dBm/Hz
Step size PC	Perf. power ctrl
Channel Model	Urban
Carrier frequency	2 GHz
Shadowing standard deviation (σ)	8 dB
Decorrelation length (D)	50 m
Channel model	ITU vehicular A
Mobile terminals velocity	30 km/h
Primary User (PU)	
Number of primary user(s) terminals per cell/frequency (K)	64
Sensibility/Power received	-117 dBm
UMTS BS antenna gain	16 dBi
Noise figure	9 dB
Orthogonally factor	0
Opportunistic Radio (OR)	
Number of opportunistic radio(s) in the cell coverage area	2
Maximum/Minimum power transmitted ($P_{o\,[max/min]}$)	10/-44 dBm
Antenna gain	0 dBi
Duration call	90 s

Table 1. Main parameters used for the simulations

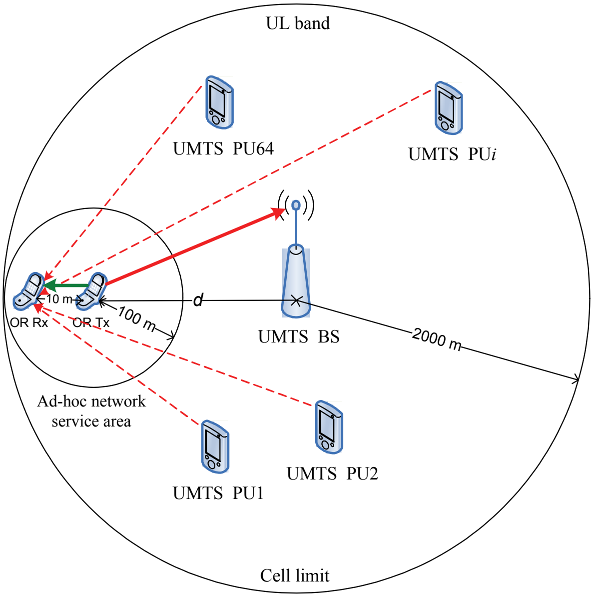

Fig. 9. Ad-hoc Single Link scenario

The following Figure 10 shows the CDF of the interference computed at the UMTS BS due the OR network activity. The results show that an 8 Mbps OR's link capacity is guaranteed for approximately 98% of the time without exceeding the UMTS BS interference limit (-116 dBm). However, this percentage decreases to 60% when an OR link with 32 Mbps is established identical in every UMTS cellular system and the frequencies are close enough so that the same statistical models apply.

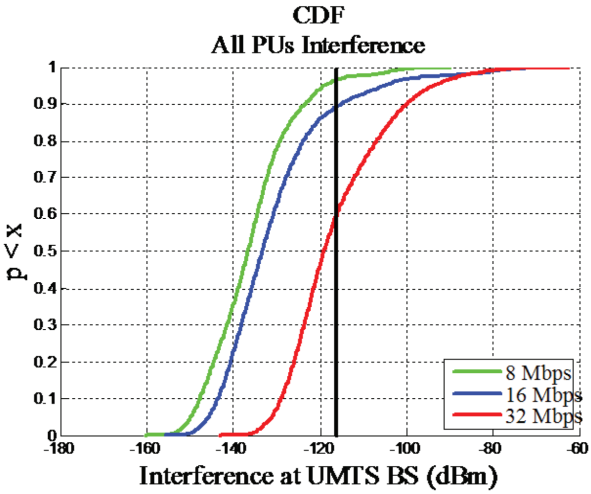

Fig. 10. Interference at UMTS BS

5. Game theory in opportunitics radio

A wireless ad hoc network is characterized by a distributed, dynamic, self-organizing architecture. Each node in the network is capable of independently adapting its operation based on the current environment according to predetermined algorithms and protocols. So, we are choosing analytical models to evaluate the performance of ad hoc networks with opportunists radio access have been scarce due to the distributed and dynamic nature of such networks. Game theory offers a suite of tools that may be used effectively in modeling the interaction among independent OR nodes in an ad hoc network. We are choosing analytical models to evaluate the performance of ad hoc networks with opportunists radio access have been scarce due to the distributed and dynamic nature of such networks. Game theory offers a suite of tools that may be used effectively in modeling the interaction among independent OR nodes in an ad hoc network.

For over a decade, game theory has been used as a tool to study different aspects of computer and telecommunication networks, primarily as applied to problems in traditional wired networks. In the past three to four years there has been renewed interest in developing networking games, this time to analyze the performance of wireless ad hoc networks (ORs). Since the game theoretic models developed for ad hoc networks focus on distributed systems, results and conclusions generalize well as the number of players (ORs) is increased. It is also of interest to investigate how selfish behavior by individual nodes (ORs) may affect the performance of the UMTS system as a whole.In a game, players (ORs) are independent decision makers whose payoffs depend on other players' (OR) actions. Nodes (OR) in an ad hoc network are characterized by the same feature. This similarity leads to a strong mapping between traditional game theory components and elements of an ad hoc network. Table 2 shows typical components of an ad hoc networking game. Game theory can be applied to the modeling of an ad hoc network at the physical layer (distributed power control), link layer (medium access control) and network layer (packet forwarding). Applications at the transport layer and above exist also, although less pervasive in the literature. A question of interest in all those cases is that of how to provide the appropriate incentives to discourage selfish behavior. Selfishness is generally detrimental to overall network performance; examples include a node's increasing its power without regard for interference it may cause on its neighbors (layer 1), a node's immediately retransmitting a frame in case of collisions without going through a backoff phase (layer 2), or a node's refusing to forward packets for its neighbours (layer 3).

Components of a game	**Elements of an ad hoc network**
Players	Nodes in the network
Strategy	Action related to the functionality Being studies(e.g. the decision to forward packets or not, the setting of power level, the selection of waveform/modulation scheme)
Utility function	Performance metrics(e.g. throughput, delay, target signal-to noise ratio)

Table 2. Typical mapping of ad hoc network components to a game

5.1 Using game theory as power control

Transmit-power control is necessary for the opportunistic radio system to broaden the scope of its applications and enhance the performance. It would have to operate under two limitations on network resources: the interference temperature limit imposed by regulatory agencies, and the availability of a limited number of spectrum holes depending on usage. In a multiuser opportunistic radio (ORs) environment, all the users operate in a decentralized manner; they are characterized by cooperation and competition. In such a case, game theory could be applied to exercise control over the transmit power. Distributed power control may be adopted by a node (OR). From a physical layer perspective, performance is generally a function of the effective signal-to-interference-plus-noise ratio (SINR) at the node(s) of interest. When the nodes in a network respond to changes in perceived SINR by adapting their signal, a physical layer interactive decision making process occurs. This signal adaptation can occur in the transmit power level and the signaling waveform (modulation, frequency, and bandwidth). The exact structure of this adaptation is also impacted by a variety of factors not directly controllable at the physical layer, including environmental path losses and the processing capabilities of the node(s) of interest. A game theoretic model for physical layer adaptations can be formed using the parameters listed in Table 3.
From Table 2 , the stage game for interactive physical layer adaptations can be modeled as

$$G = \{ N, \{ \mathbf{P}_j \times \boldsymbol{\Omega}_j \},\{u_j (\mathbf{P}, \boldsymbol{\omega}, H) \} \qquad (5)$$

Symbol	Meaning	Symbol	Meaning
N	The set of decision making nodes in the network;{1,2,…n}	**P**	The power space (R^n) formed from the Cartesian product of all $\mathbf{P}_j$ $\mathbf{P} = \mathbf{P}_1 \times \mathbf{P}_2 \times \ldots \times \mathbf{P}_n$
hij	The link gain from node i to j . Note this may be the function of waveform selected	**p**	A power profile vector) from **P** formed as $\mathbf{p} =(p_1, p_2, \ldots p_n)$
H	The network link gain matrix. $H = \begin{bmatrix} 1 & h_{12} & h_{13} & \cdots & h_{1n} \\ h_{21} & 1 & & & \vdots \\ h_{31} & & & & \vdots \\ \vdots & & & \ddots & \vdots \\ h_{n1} & h_{n2} & & & 1 \end{bmatrix}$	Ω_j	The set of waveform know by node j.
		ω_j	A waveform chosen by j from Ω_j
		Ω	The waveform space formed by the Cartesian product of all Ω_j . $\Omega = \times_{j \in N} \Omega_j$
$\mathbf{P}_j$	The set of power level available to node *j*. This is presumde to be a subset of real number line.	ω	A waveform profile (vector) from Ω formed as $\omega = \omega_1, \omega_2, \ldots \omega_n$
p_j	A power level chosen by j from $\mathbf{P}_j$.	$u_j(p, \omega, H)$	The utility derived by *j*.

Table 3. Game theoretic model for OR ad hoc networks

For a general game, each OR node, j, selects a power level, p_j, and a waveform, ω_j, based on its current observations and decision making process. Distributed power control systems permit each OR radio to select p_j, but restrict $\mathbf{\Omega}_j$ to a singleton set; distributed waveform adaptation systems (interference avoidance) restrict the choice of p_j, but allow ω_j to be chosen by the physical layer.

Power control, though closely associated with cellular networks and is implemented in OR ad hoc network that operated in the same bands that the primary user UMTS system We now model the power control algorithm suggested as a normal form game. Note that a similar approach can be followed to model the other distributed algorithms as games, with each game involving a different utility function. We adopt the notation in Table 3.For most game models, the game theoretic equivalent of a distributed algorithm's steady state is a *Nash equilibrium* (NE). An action vector (or alternative vector) a is said to be a NE if equation (1) is satisfied.

$$u_i(\mathbf{a}) \geq u_i(b_{i,}\, a_{-i}) \;\forall\, i \in N, b_i \in N \tag{6}$$

Consider a DS-CDMA system with a centralized receiver where all OR nodes other than the centralized receiver are adjusting their transmitted power levels in an attempt to maximize their signal-to interference- plus-noise ratio (SINR) as measured at the receiver. Here our set of players are the OR nodes (other than the centralized receiver); the action sets are the available power levels (presumably a finite number of power levels) all OR player's utility functions are given by equation (7)

$$u_i(\mathrm{p}) = h_i p_i \;/\; ((1/\mathrm{K}) \sum_{j \in N \setminus i} h_k p_k + \sigma) \tag{7}$$

where p_i is the transmitted power of node i, K is the statistical estimate of the spreading factor, h_i is the gain from a node to the receiver, and σ is the noise at the receiver.

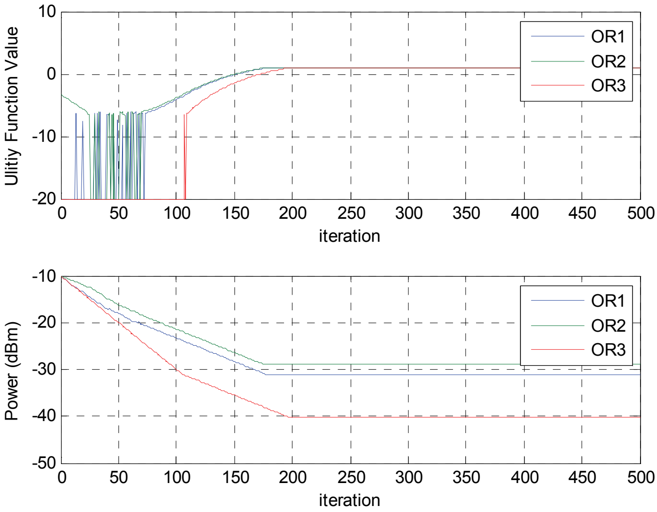

Fig. 11. 3 OR node closer to the UMTS system

As would be indicated by intuition, the unique Nash equilibrium for this game is the power vector where all OR nodes transmit at maximum power. This is an undesirable outcome as (6) capacity is greatly diminished due to near-far problems (unless the nodes are all at the same radius from the receiver as shown in the Figure 11 and Figure 12 where OR node are closer and far away from the UMTS system), equation (2) the resulting SINRs are unfairly distributed (the closest node will have a far superior SINR(as shown in the Figure 11) to the furthest node(as shown in the Figure 11 and (12) battery life would be greatly shortened. However, this outcome is Pareto optimal as any more equitable power allocation will reduce the utility of the closest node, and any less equitable allocation will reduce the utility of the disadvantaged nodes. In this scenario Pareto optimality actually misleads the analyst with respect to the desirability of the outcome.

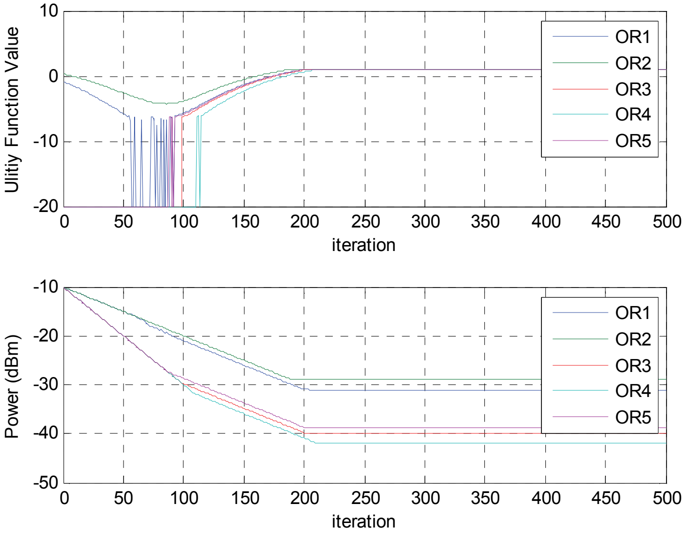

Fig. 12. 5 OR node far away to the UMTS system

6. Conclusion

Emerging research in game theory based power control applied to ad hoc opportunist networks shows much promise to help understand the complex interactions between OR nodes in this highly dynamic and distributed environment. Also, the employment of game theory in modeling dynamic situations for opportunist ad hoc networks where OR nodes have incomplete information has led to the application of largely unexplored games such as games of imperfect monitoring. Ad hoc security using game theory is the future area of research in ORs we have considered an ah hoc behavior in the opportunists radio (ORs) and suggested that by implementing ah hoc features in the ORs will improve the overall performance of system.

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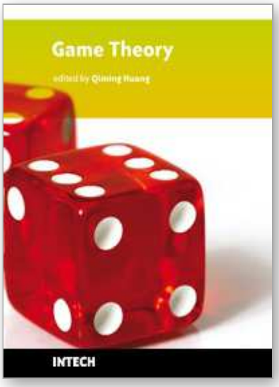

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Game theory provides a powerful mathematical framework that can accommodate the preferences and requirements of various stakeholders in a given process as regards the outcome of the process. The chapters' contents in this book will give an impetus to the application of game theory to the modeling and analysis of modern communication, biology engineering, transportation, etc...

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