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Game Theoretic Analysis of Cooperation Relay Nodes in Cognitive Radio Ad Hoc Networks

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Abstract: Emerging as a new communication paradigm, cooperative communication is attracting lot of attention among the researchers. In Cognitive Radio Ad Hoc Networks (CRAHN's), the relay selection with user cooperation could be advantageous to both primary and secondary transmissions. This study deals with cooperative relay nodes that are very good in performance. In cooperative games, players collaborate with each other to jointly maximize the total utility of the game. In non-cooperative game, each player selfishly maximizes its own stationary utility function to reach the best response with Nash equilibrium strategies. The results reveal that the summation of node utilities in cooperation nodes is always greater than non-cooperative relay nodes and the relay node should be selected and configured according to the system requirements in order to improve the performance of cooperative cognitive radio ad hoc networks.

Key words: Cognitive radio ad hoc networks, Game theory, Nash equilibrium, Markovian processes, performance

INTRODUCTION

The evolution of communication technologies, especially in the wireless domain, developed a paradigm shift from static to mobile access, centralized to distributed infrastructure and passive to active networking. Low utilization and more demand for the radio resources suggests the notion of secondary use which allows licensed but unused parts to become available temporarily. Cognitive radios are adaptive radios that are aware of their capabilities, aware of their environment, aware of their intended use and able to learn from experience new waveforms, new models and new operational scenarios. Cognitive Radio (CR) technology enables secondary users to sense, identify and intelligently access the unoccupied spectrum. A notable difference of a cognitive radio network from traditional wireless networks is that, users need to be aware of the dynamic environment and adaptively adjust their operating parameters based on interactions with the environment and with other users in the network, there is no statistically allocated spectrum. All traditional wireless devices work on certain fixed spectrum block while each device in cognitive radio networks dynamically senses its Spectrum Opportunity (SOP), a set of frequency bands currently unoccupied and available for use. The current wireless communication system can be categorized into infrastructure and non-infrastructure networks. In infrastructure networks (such as cellular networks), the communication mode is multiple to one or one to multiple (multiple users to base station or base station to multiple users). Also, the central node of the network manages and dominates the network which helps to perform reasonable allocation of resources and the implementation of a central algorithm. In non-infrastructure networks (such as ad hoc networks), multiple source and destination node pair exist and there is no central node managing the network. In cognitive radio, adhoc relay node plays a vital role.

RELAY NODE

In most of the ad hoc systems, relaying methods are widely used to extend the range of the communication link, save transmit power at nodes and reduce interference. In basic relay enabled ad hoc networks, each node should transmit its own packets and should cooperate with other nodes as well to transmit their packets to the destination.

A relay node is one which is allowed to send a packet to its destination node and not allowed to send the packet to another relay node. The purpose of multiple relay is to reduce the flooding of broadcast packets in the network by minimizing the duplicate retransmissions locally. Zhao *et al.* (2006, 2008) discussed that relay management is necessary for bringing relay-assisted cooperative network into full play.

The attributes of relay nodes are different in different networks. Relay nodes can be fixed or mobile, active or inactive. Some nodes are equipped with a single antenna and others are equipped with multiple antennas.

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In cell network, mobile or fixed relay nodes are supported by energy. In most of the relay nodes, multiple antennas can be equipped to perform powerful processing and transmission capabilities. Multiple relays can use the same time slots and frequency simultaneously which saves radio resources. Therefore, more data can be transmitted to the relay node to lower the complexity and energy consumption of mobile terminals and at the same time, better QoS can be provided. In self-organized networks, the attributes of all nodes are basically same and most of them operate on battery power hence the processing capability is limited. As a result, the energy issue should be taken into consideration in the design of Cooperative Node Selection algorithm. The lifetime of the network can be expanded on the precondition that the service is guaranteed. Felegyhazi and Hubaux (2006) discussed that the behaviour of a given wireless device may affect the communication capabilities of a neighbouring device, notably because the radio communication channel is usually shared in wireless networks.

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, researchers 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 the 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 the 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, researchers avoid single point failure in Opportunistic Radio (OR).

COOPERATIVE COMMUNICATION

The main objective of the Cooperative System is to increase the network capacity, reduce power consumption and expand network coverage. The tradeoff is network capacity, power consumption and network coverage. But cooperation for relaying will also increase energy consumption and decrease throughput of relay nodes. In a cooperative communication system, each wireless user is assumed to transmit data as well as act as a cooperative agent for another user. The same thing explained in Fig. 1. Cooperation leads to interesting trade-offs in code rates and transmit power. In the case of power, one may argue on one hand that more power is needed because each user when in cooperative mode is transmitting for both

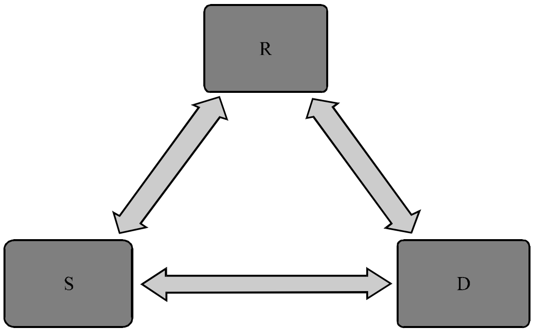

Fig. 1: Relay channel

users. On the other hand, the baseline transmits power for both users will be reduced because of diversity. In the face of this trade-off, one hopes for a net reduction of transmit power, given everything else being constant. Similar questions arise for the rate of the system. In cooperative communication each user transmits both its own bits as well as some information for its partner; one might think this causes loss of rate in the system. However, the spectral efficiency of each user improves because due to cooperation diversity the channel code rates can be increased. Again a trade-off is observed. Cooperation as a zero sum game in terms of power and bandwidth of the mobiles in the network. The premise of cooperation is that certain (admittedly unconventional) allocation strategies for the power and bandwidth of mobiles lead to significant gains in system performance. In the cooperative allocation of resources, each mobile transmits for multiple mobiles.

The cooperation assumes that a small bandwidth control channel is available to exchange the cooperation messages. A CR user either invites co operators for cooperation or listens to all co operators and just ignores the ones denoted as unreliable. In the first case, the invitation to cooperate is performed only once at the beginning of each application period and only if there has been a change in the set of used cooperators.

In case co operators are invited for cooperation, the CR user also needs to perform occasional check up of possibly new co operators. This can be done only when the current performance is not satisfactory for a long period or when a lot of co operators have disappeared. Note that the CR user can optionally set a maximum limit for the number of co operators in a suitability list. With this option it can also occasionally remove highly unreliable co-operators and replace them with the new ones.

LITERATURE REVIEW

The most relevant research to the work includes relay node assignment and selection. Michiardi and Molva (2002) showed that the simple game can be expanded to the m-dimensional game which can be adopted to represent the strategy to be chosen by the nodes of a mobile ad hoc network. Zhao *et al*. (2008) showed for a single source-destination pair, in presence of multiple relay nodes, it is sufficient to choose one best relay node instead of multiple nodes. Wang *et al*. (2007) showed how game theory can be used by a single session to select the best cooperative relay node. Mumtaz *et al*. (2009) described 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.

The selection of relay node is an important factor in Cooperative Node Selection algorithm. It should choose different optimization targets according to different system requirements. The essence of cooperative communication is to optimize the whole system from a network perspective. But it introduces more optimization elements which can cause increase in algorithm complexity. It is an important standard for evaluating the Cooperative Node Selection algorithm to control the algorithm complexity in order to achieve better system performance.

Srinivasan *et al*. (2003) have claimed that under specific conditions, cooperation may emerge without incentive techniques. However, they have assumed a random connection setup thus abstracting away the topology of the network.

Felegyhazi *et al*. (2006) discussed that to determine under which conditions such cooperation without incentives can exist while taking the network topology into account. In the cooperative system, more information should be transmitted and as a result, the communication overhead is increased which impacts the system negatively. Cooperation should be selected only when the cooperative gain is greater than the performance loss of extra overhead. Owing to the time-variation and node mobility, channel information and node state information cannot be obtained accurately. Hence, the Cooperative Node Selection algorithm should be robust and able to adjust the selection policy in an auto-adaptation mode and at the same time, it should be error-tolerant of the worst channel environment and there is no-response of the cooperative node.

Zhang *et al*. (2010) discussed that determining the number of relay nodes is a primary concern of the Relay Node Selection algorithm and whether to use a single or multiple nodes remains an open question. To use a single cooperative node, the hardware at the receiving end is simple and easy to implement and at the same time the diversity steps are not lost. Single relay node selection requires the information of each channel and the information need to be sorted before the optimum node is selected. The processing capability and supported power of a single node are limited. When the channel is in deep recession, a single relay node cannot implement the QoS requirements of the source node. Multiple relay nodes can increase the multiplexing gain of the system. Therefore, the Selection algorithm which can adjust the count of node selection according to the channel and relay node states is more reasonable.

Vucevic *et al.* (2012) discussed that cooperation is usually needed in these cases to ease the resources utilization. In such a case, a CR user collects information (the advices) from cooperators and makes a decision about its next actuation regarding opportunistic spectrum access. Different cooperation modes significantly impact the Selection algorithm of the cooperative node. In decode and forward cooperation mode, the properly decoded node can participate in cooperative transmission. In amplify and forward, the cooperative node does not process the source node signals and all cooperative nodes can transmit the information. It affects the alternative collection of the cooperative node selection algorithm. Therefore, different Cooperative Node Selection algorithms should be selected for different cooperative modes and researchers can integrate cooperation mode selection with cooperative node selection.

In the same system, different cooperation modes and Cooperative Node Selection algorithms in an adaptive mode can be used. For the cooperative system, the cooperative node is only one part of the system resources. Therefore, the current research takes cooperative node selection and other resource allocations such as power and bandwidth into consideration. System resources can improve the system performance through cross layer design. But owing to the introduction of more variables and optimization goals, system design is faced with a great challenge. In most cases, the system optimization problem becomes a Non-Polynomial (NP) problem.

How to find the appropriate joint optimization parameters and design executable progressive optimum algorithm is the key to cooperative node selection and other Resource Allocation algorithm. Game theory is a set of tools developed in economics for the purposes of analyzing the complexities of human interactions. Depending on the availability of nodes and the cooperative communication protocols, there are three different communication topologies: one to one, one to many and many to one as shown in Fig. 2.

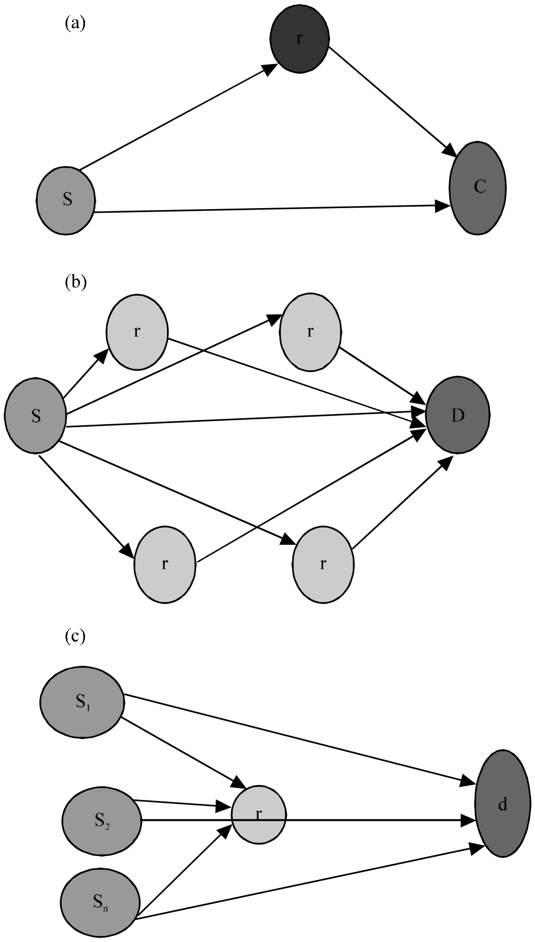

Fig. 2: Communication topoligies: a) cne to one; b) one to many; c) many to one

Take the simplest topology, one to one as an example to illustrate the basic idea of cooperative communication. In this example, s is the source node that transmits information, d is the destination node that receives information and r is the relay node that relays information to enhance the communication between the source and the destination. Let P_s and P_r denote the transmission power of s and r, respectively. Let W denote the bandwidth of the transmission channel. Modulation scheme, coding rate, protocol, flow control parameter, transmit power level or any other factor that is under the control of the node. When each player chooses an action, the resulting "action profile" determines the outcome of the game.

The research: In the research, a basic relay network consists of a source, relay node and a destination node. This system can be modelled as a two player game including source and relay nodes. The cooperation of relay nodes can be considered in Nash equilibrium and non cooperation of relay nodes can be considered as two way approach. One way is using Nash equilibrium and the other one is Markov chain process.

WHY GAME THEORY

Game theory is a discipline, aimed at modelling scenarios where individual decision-makers have to choose specific actions that have mutual or possibly conflict consequences. Neel *et al.* (2005) discussed that Game theory is a set of tools developed in economics for the purposes of analyzing the complexities of human interactions. It is a proper method to model the packet forwarding in ad-hoc networks and analyze the contrast between nodes interest to avoid forwarding others packet due to limited power and to provide relay service in order to increase throughput of the system on the other side. There is a significant amount of work in wired and wireless networking that makes use of Game theory.

The importance of studying cognitive radio networks in a game theoretic framework is multi fold. First, by modeling dynamic spectrum sharing among network users (primary and secondary users) as games, network users' behaviours and actions can be analyzed in a formalized game structure by which the theoretical achievements in game theory can be fully utilized. Second, Game theory equips us with various optimality criteria for the spectrum sharing problem. To be specific, the optimization of spectrum usage is generally a multi-objective optimization problem which is very difficult to analyze and solve.

Game theory provides us with well defined equilibrium criteria to measure game optimality under various game settings. Third, non-cooperative Game theory, one of the most important branches of game theory, enables us to derive efficient distributed approaches for dynamic spectrum sharing using only local information. Such approaches become highly desirable when centralized control is not available or flexible self-organized approaches are necessary. Menon *et al.* (2004, 2005) discussed that potential games are applied to the analysis of adaptive interference avoidance problems. DaSilva and Srivastava (2004) discussed that Game theory provides useful insight into incentive mechanisms that are needed to induce node participation. Michiardi and Molva (2002, 2005) discussed that the works of develop game theoretic models for analyzing selfishness in forwarding packets. Hicks *et al.* (2004) discussed that the analysis, potential games appear to be less susceptible to the introduction of noise and thus steady state stability is implied.

A game is made up of three basic components: a set of players, a set of actions and a set of preferences. The players are the decision makers in the modelled scenario. In a wireless system, the players are most often the nodes of the network. The actions are the alternatives available to each player. In dynamic or extensive form games, the set of actions might change over time. In a wireless system, actions may include the choice of a players. The decision makers are called players, denoted by a finite set N = f_1, f_2...,n_g. The players of the game are assumed to be rational and selfish which means each player is only interested in maximizing its own utility without respecting others' and the system's performance.

Neel *et al.* (2002) discussed that the application of mathematical analysis to wireless ad hoc networks has met with limited success due to the complexity of mobility and traffic models, coupled with the dynamic topology and the unpredictability of link quality that characterize such networks.

Various games Urpi *et al.* (2003) discussed the works of develop game theoretic models for analyzing selfishness in forwarding packets. In the Forwarder's Dilemma, the assumption is that there exist two devices as players, p1 and p2. Each of them wants to send a packet to its destination, D1 and D2, respectively, in each time step using the other player as a forwarder. The communication between a player and its receiver is possible only if the other player forwards the packet. The Forwarder's Dilemma scenario is shown in Fig. 1. If player p1 forwards the packet of p2, it costs player p1 a fixed cost $0<C<<1$ which represents the energy and computation spent for the forwarding action.

By doing so, the player1 enables the communication between p2 and D2 which gives p2 a benefit of 1. The payoff is the difference of the benefit and the cost. The game is symmetric and the same reasoning applies to the forwarding move of player p2. 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, it is called as the dilemma. It is shown in the Fig. 3.

MacKenzie and Wicker (2001) have shown that Game theory is an appropriate tool for analyzing a variety of problems encountered in the design and analysis of a communications network. In the next game, called joint packet forwarding to send a packet to its destination D in each time step. To this end, it needs both devices p1 and

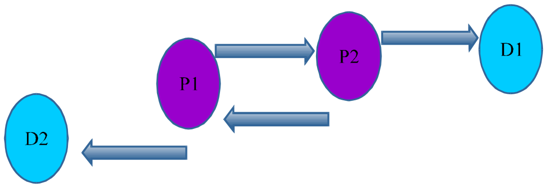

Fig. 3: Network scenarios in the Forwarder's Dilemma game

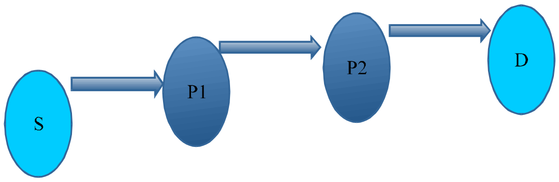

Fig. 4: Joint packet forwarding game

p2 to forward for other player. 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 (from the sender or the receiver). This packet forwarding scenario is shown in Fig. 4.

The third example, called multiple access game, introduces the problem of medium access. Suppose that there are two players' p1 and p2 who want to access a shared communication channel to send some packets to their receiver's re1 and re2. 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 the assumption is that p1, p2, re1 and re2 are in the power range of each other and hence its transmissions mutually interfere. If player p1 transmits its packet, it incurs a sending cost of 0<C<<1. The packet is successfully transmitted if p2 waits in that given time step, otherwise there is a collision. If there is no collision, player p1 gets a benefit of 1 from the successful packet transmission. The framework presented by Cagalj *et al*. (2005). It is a generalized version of the multiple access game.

In the last example, called the Jamming Game, the assumption is that player p1 wants to send a packet in each time step to a receiver re1. 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 p2 is to prevent player p1 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 p1 is to succeed in spite of the presence of p2. Accordingly, the player receives a payoff of 1 if the attacker cannot jam its transmission and it receives a payoff of 1 if the attacker jams its packet. The payoffs for the attacker p2 are the opposite of those of player p1. The second assumption is that p1 and re1 are synchronized which means that re1 can always receive the packet unless it is destroyed by the malicious player p2. Note that neglecting the transmission cost C, since it applies to each payoff (i.e., the payoffs would be 1-C and -1-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 (1991).

There are indeed fundamental differences between these games as follows. The Forwarder's Dilemma is a symmetric non-zero-sum game because the players can mutually increase their payoffs by cooperating (i.e., from zero to 1-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 non-zero-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.

Nash equilibrium: A strategy profile constitutes a Nash equilibrium if none of the players can improve its utility by unilaterally deviating from its current strategy. Two individuals are involved in a synergistic relationship. If both individuals devote more effort to the relationship, they are both better off. For any given effort of individual j, the return to individual i's effort first increases, then decreases. Specially, an effort level is a non-negative number and individual i's preferences (for i = 1, 2) are represented by the payoff function. $a_i(c + a_j - a_i)$ where a_i is i's effort level, a_j is the other individual's effort level and c>0 is a constant. The following strategic game models this situation.

Players: The two individuals.

Actions: Each player's set of actions is the set of effort levels (non-negative numbers).

Definition: A Nash equilibrium of a game G in strategic form is defined as any outcome (a1*…an*) such that:

$$u_i(a_i^*, a_{-i}^*) \geq u_i(a_i^*, a_{-i}^*)a_i \in A_i$$

holds for each player i. The set of all Nash equilibrium of G is denoted N(G).

Preferences: Player i's preferences are represented by the payoff function a_i $(c+a_j-a_i)$, for $i = 1, 2$. In particular, each player has infinitely many actions, so that we cannot present the game in a table like those used previously. To find the Nash equilibria of the game, researchers can construct and analyze the players' best response functions. Given a_j, individual i's payoff is a quadratic function of a_i that is zero when $a_i = 0$ and when $a_i = c + a_j$ and reaches a maximum in between. The symmetry of quadratic functions implies that the best response of each individual i to a_j is:

$$b_i(a_j) = \frac{1}{2}(c+a_j) \tag{1}$$

Player 1's actions are plotted on the horizontal axis and player 2's actions are plotted on the vertical axis. Player 1's best response function associates an action for player 1 with every action for player 2. Thus, to interpret the function b_1 in the diagram, take a point a_2 on the vertical axis and go across to the line labeled b_1 (the steeper of the two lines), then read down to the horizontal axis. The point on the horizontal axis is that the player reach $b_1(a_2)$, the best action for player 1 when player 2 chooses a_2. Player 2's best response function, on the other hand, associates an action for player 2 with every action of player 1. Thus, to interpret this function, take a point a_1 on the horizontal axis, and go up to $b_{,2}$ then across to the vertical axis. The point on the vertical axis that you reach is $b_2(a_1)$, the best action for player 2 when player 1 chooses a1.

At a point (a_1, a_2) where the best response functions intersect in the Fig. 2, researchers have $a_1 = b_1(a_2)$ because (a_1, a_2) is on the graph of b_1, player 1's best response function and $a_2 = b_2(a_1)$ because (a_1, a_2) is on the graph of b_2, player 2's best response function. Thus, any such point (a_1, a_2) is Nash equilibrium. The Nash equilibrium is considered a consistent prediction of the outcome of a game.

In this game the best response functions intersect at a single point, so there is one Nash equilibrium. In general, they may intersect more than once; every point at which they intersect is Nash equilibrium. To find the point of intersection of the best response functions precisely, researchers can solve the two equations:

$$a_1 = \frac{1}{2}(c+a_2) \tag{2}$$

$$a_2 = \frac{1}{2}(c+a_1) \tag{3}$$

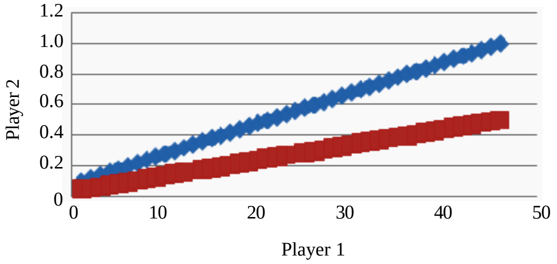

Fig. 5: Best response of Nash equilibrium

Substituting the second equation in the first, researchers get:

$$a_1 = \frac{1}{2}\left(c+\frac{1}{2}(c+a_1)\right) = \frac{3}{4}c+\frac{1}{4}a_1$$

so that $a_1 = c$

Substituting this value of a_1 into the second equation, researchers get $a_2 = c$. Researchers conclude that the game has a unique Nash equilibrium $(a_1, a_2) = (c, c)$. To reach this conclusion, it suffices to solve the two equations. However, the equations shows us at once that the game has a unique equilibrium in which both players' actions exceed 1/2c, facts that serve to check the results of the algebra. Each player has a unique best response to every action of the other player, so that the best response functions are lines. If a player has many best check the results of the algebra. Each player has a unique best response to every action of the other player, so that the best response functions are lines. If a player has many best responses to some of the other players' actions then the best response function is thick at some points.

The best response functions cross once. As, researchers have seen, some games have more than one equilibrium and others have no equilibrium. The shaded area of player 1's best response function indicates that for a2 between a2 and a2, player 1 has a range of best responses. For example, all actions of player 1 greater than a_1** and at most a1***are best responses to the action a_2*** of player 2 (Fig. 5).

For a game with these best response functions, the set of Nash equilibria consists of the pair of actions (a_1*, a_2*), all the pairs of actions on player 2's best response function between (a_1**, a_2**) and (a_1***, a_2***) and (a_1***, a_2***).

Modeling ad hoc networks as games: In a game, players are independent decision makers whose payoffs depend

Table 1: Mapping of ad hoc network components to a game

Components of a game	Elements of an ad hoc network
Players	Nodes in the network
Strategy	Action related to the functionality being studied
Utility function	Performance metrics

on other players actions. Nodes in an ad hoc networks are characterized by the same feature. This similarity leads to a strong mapping between traditional Game theory components and elements of an adhoc network. Table 1 shows the mapping of an ad hoc network component to a game. Game theory can be applied to the modeling of a cognitive radio adhoc networks at the lower layers.

Non-cooperation of relay nodes: In cooperative games, it requires additional signalization or agreements between the decisions makers. The solution based on that might be more difficult to realize. In a non cooperative scheme, number of decision makers called players exist who have potentially conflicting interests. In the wireless networking, the players are the users or network operators means that they try to maximize their payoffs. In Game theory, a Markov strategy is one that depends only on state variables that summarize the history of the game in one way or another. A state variable can be the current play in a repeated game or it can be any interpretation of a recent sequence of play. A profile of Markov strategies is a Markov perfect equilibrium if it is Nash equilibrium in every states of the game.

Markovian strategies: Assume, at each time t∈[0, T], player i can observe the current state x(t) of the system. However, he has no additional information about the strategy of the other potentially confliction player. In particular, he cannot predict the future actions of the other player. In this case, each player can implement a Markovian strategy (i.e., of feedback type): the control $u_i = u_i(t, x)$ can depend both on time t and on the current state x. The set Si of strategies available to the ith player will thus consist of all measurable functions (t, x) u_i (t, x) from $[0, T]\times IR^n$ into Ui.

PARAMETERS FOR SIMULATION SETUP

The QUALNET simulator is mainly developed for wireless scenario simulations but wired networks also supported. It includes a graphical user interface for creating the model and its specification. So, it is very easy to specify small to medium networks by using the GUI. It includes a variety of advanced libraries such as mesh networking, battery models, network security tool kit and a large number of protocols at different layers. The parameters of the QUALNET simulators are given in Table 2.

Table 2: QUALNET simulation parameters

Parameters	Values
No of nodes	25
Area	700×700 m
Fading model	Rayleigh
Shadowing model	Constant
Routing protocols	OLSR
Simulation time	120 sec
Channel frequency	2.4 GHz
Traffic source	CBR

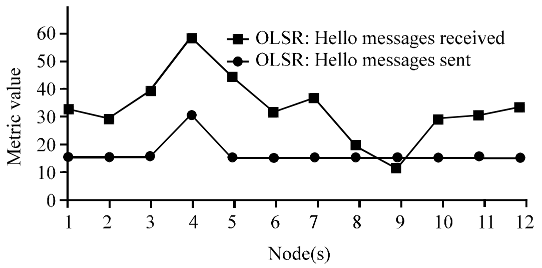

Fig. 6: Cooperative relay node output at transmitter

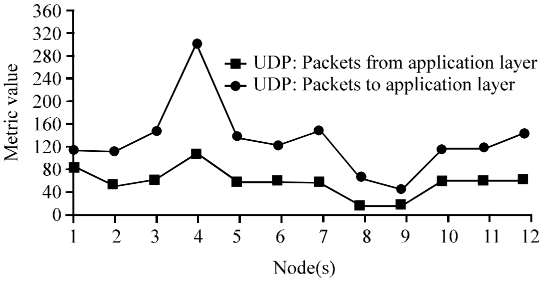

Fig. 7: Two relay node output at the receiver

SIMULATION RESULTS

This study deals with numerical results of cooperative relay nodes in the transmitter and receiver. In the cooperative scenario, more number of relay nodes are considered and the output is shown the figures. Best response Nash equilibrium strategy profile is evaluated. In cooperative scenario, the summation of utilities is investigated as the system performance. In this case, both nodes try to maximize the sum utility and jointly select the best strategy profile. Summation of players' utilities has been considered as a criterion to evaluate system performance.

Figure 6 depicts sum of utilities of source and relay nodes versus the packet generation rate of relay nodes at

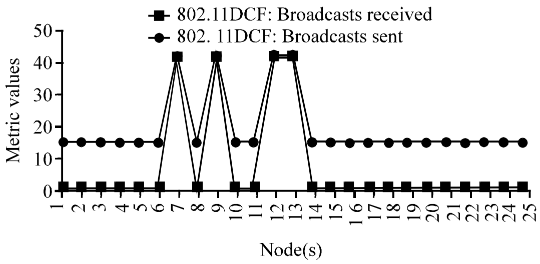

Fig. 8: Cooperative five relay node output

the transmitter side. Summation of utilities is directly proportional to packet generation rate of relay node are shown in Fig. 7 and 8. Summation of players' utilities decreases as the delay cost of system increases and players adaptively take an appropriate strategy profile to maximize their utility. A higher value is maximum set in the systems where low latency is desirable. The achievable utility in the system is less than the systems without strict delay requirements.

CONCLUSION

In cooperative scenario both nodes jointly select the strategy profile of the game in order to maximize the total utility. While in non-cooperative scheme, nodes selfishly try to maximize their own payoffs. Therefore, the summation of nodes utilities in cooperative game is always greater than non cooperative game. However, non-cooperative approach is more applicable in practical systems, in which nodes are not aware of each other's strategy sets.

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