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PERFORMANCE ANALYSIS OF COOPERATION AND NON COOPERATION OF RELAY NODES IN COGNITIVE RADIO AD HOC NETWORKS - A GAME THEORETIC APPROACH

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ABSTRACT

Cognitive radio (CR) technology is a solution to solve the problems in wireless networks resulting from the limited available spectrum and the inefficiency in the spectrum usage by exploiting the existing wireless spectrum opportunistically. CR networks, equipped with the intrinsic capabilities of the cognitive radio, will provide an ultimate spectrum aware communication paradigm in wireless communications. In cognitive radio ad hoc networks (CRAHN's), the relay selection with user cooperation could be advantageous to both primary and secondary transmissions. This paper deals with both cooperative and non cooperative relay node games. 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 Nash equilibrium strategies. The Non co operation of Relay nodes can be converted into co operative nodes based on Markov Process. The results reveal, 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

Keywords: *Cognitive Radio Adhoc networks, Nash Equilibrium, Markovian processes, Ergodic process*

1. INTRODUCTION

Cognitive radio (CR) is a promising technology and a new paradigm shift in communication. It tries to utilize free parts of unlicensed spectrum and even uses licensed frequency bands during silent periods of primary licensed users. The term cognitive radio was first coined by Mitola. The terms *software-defined radio* and *cognitive radio* were promoted by Mitola in 1991 and 1998, respectively. Software-defined radio, sometimes shortened to software radio, is generally a multi band radio that supports multiple air interfaces and protocols and is reconfigurable through software run on Digital Signal Processing or general-purpose microprocessors. Cognitive radio, built on a software radio platform, is a context-aware intelligent radio potentially capable of autonomous reconfiguration by learning from and adapting to the communication environment. It deals about communication between two computers to detect user communications. Wherever the user goes, cognitive device will adapt to new environment allowing user to be "always connected".

Federal Communication Committee on the other hand describes cognitive radio as a system which could negotiate cooperatively with other spectrum users to enable more efficient sharing of spectrum. A cognitive radio could also identify portions of the spectrum that are unused at a specific time or location and transmit in such unused 'white spaces'. This results in more intense and efficient use of the spectrum while avoiding interference to other users. To make decision about a change of transmission parameters only cognition cycle is used in radio domain. Other sources of information are not used. An opportunistic cognitive radio is an intelligent wireless communication system that periodically monitors the radio spectrum. It intelligently detects occupancy in different parts of the spectrum and opportunistically communicates over spectrum holes with minimal interference to active primary users. 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 resource suggests the notion of secondary use, which allows licensed but unused parts to become available temporarily. Cognitive radio , featured with cognitive capability and reconfigurability enables the wireless devices not only to rapidly sense the information from the radio environment but also to dynamically adapt operational parameters ,so that more efficient and intensive spectrum utilization is possible. 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 technology is the key technology that enables a CRAHN to use spectrum in a dynamic manner. The term, cognitive radio, can formally be defined as follows A ‘‘Cognitive Radio” is a radio that can change its transmitter parameters based on interaction with the environment in which it operates. The figure 1 shows the basic model of a cognitive radio ad hoc network.

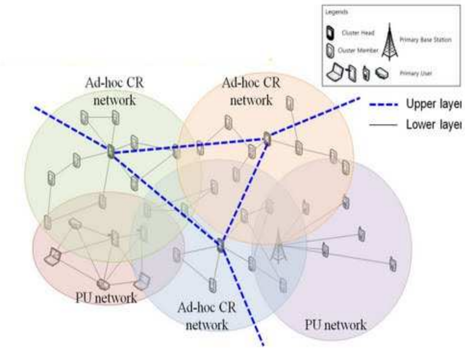


Figure 1.Cognitive Radio Ad Hoc Networks

Cognitive radio technology enables secondary users to sense, identify and intelligently access the unoccupied spectrum [6]. A notable difference of a cognitive radio network from traditional wireless networks is that (i) 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.(ii) 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 Adhoc networks), multiple source and destination node pair exist and there is no central node managing the network. In cognitive radio, adhoc network relay node plays vital role.

This paper contents are organized as follows: The relay node concepts are discussed in section 2. Related work and cooperative communication are discussed in section 3.The concepts of game theory are discussed in section 4. In section 5, the parameters for simulation setup is discussed. In section6, simulation results are discussed. In section 7 conclusions are discussed.

2 . RELATED WORK

The most relevant research to our work includes relay node assignment and selection. Michiardi et al 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 [2].Zhao et al 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 [7]. In Wang et al showed how game theory can be used by a single session to select the best cooperative relay node [8]. 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. In the cooperative system, more information should be transmitted and as a result, the communication overhead is increased which impacts the system negatively. Therefore it needs to be taken into consideration in the cooperative node selection algorithm. 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.

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.

3. RELAY NODE

In most of wireless 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 network, 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. 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. 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.

3. 1 Cooperative Communication

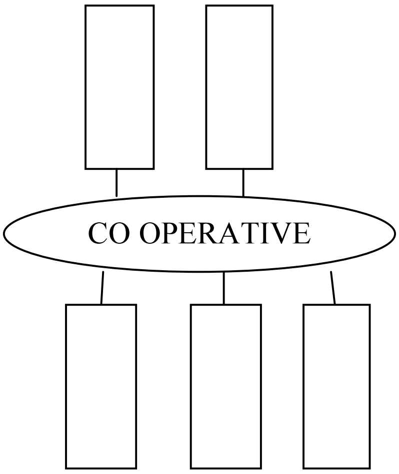


Figure 2: Co Operative Communication

The main objective of the cooperative system is to increase the network capacity, reduce power consumption and expand network coverage. The tradeoff is in network capacity, power consumption and network coverage. But cooperation for relaying will also increase energy consumption and decrease throughput of relay nodes. The different cooperation modes significantly impact the selection algorithm of the cooperative node. For example in the 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 that enable 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. [2] Game theory is a set of tools developed in economics for the purposes of analyzing the complexities of human interactions.

3.2 Our Work

In this paper, a basic relay network consists of a source, relay node and a destination node. This system can be modeled as a two player Game, including source and relay nodes. The co operation of relay nodes can be considered in Nash equilibrium and non co operation of relay nodes can be considered as two way approach. One way is using Nash equilibrium and the other one is Markov chain process.

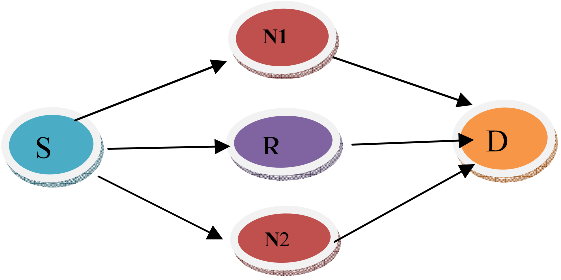


Figure 3.Model of Relay Nodes

4. BASICS OF GAME THEORY

In cognitive radio networks, the network users make intelligent decisions on spectrum usage and communication parameters based on the sensed spectrum dynamics and other users' decisions .The network users who compete for spectrum resources may have no incentive to cooperate with each other and behave selfishly. Therefore, it is natural to study the intelligent behaviors and interactions of selfish network network users from the game theoretical perspective.

Game theory is a discipline aimed at modeling scenarios where individual decision-makers have to choose specific actions that have mutual or possibly conflict consequences. 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.

The importance of studying cognitive radio networks in a game theoretic framework is multifold. First, by modeling dynamic spectrum sharing among network users (primary and secondary users) as games, network users' behaviors 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. 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 modeled 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.

4.1 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 nonnegative 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 (nonnegative numbers).

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

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

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

Two Player Game: Let X1 and X2 be the probability of u1 and u2being an agent respectively. The payoff matrix of u1 and u2 .

Preferences : Player i's preferences are represented by the payoff function $a_i\left(c + a_j - a_i\right)$ 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, we 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

$$b_i\left(a_j\right) = \frac{1}{2}\left(c + a_j\right) - - - - (1)$$

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 that the player reach is 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 figure 2, we 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.[3] 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, we can solve the two equations.

$$a_1 = \frac{1}{2}\left(c + a_2\right) - - - - (2)$$

$$a_2 = \frac{1}{2}\left(c + a_1\right) - - - - (3)$$

Substituting the second equation in the first, we get $a_1 = \frac{1}{2}\left(c + \frac{1}{2}\left(c + a_1\right)\right) = \frac{3}{4}c + \frac{1}{4}a_1$, so that $a_1 = c$. Substituting this value of a_1 into the second equation, we get $a_2 = c$. We 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 $\frac{1}{2}c$, facts that serve to check the results of our 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 we 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. For a game with these best response functions, the set of Nash equilibrium 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***).

4.2 Non –Cooperation Of Relay Nodes

In a non cooperative scheme, nodes selfishly try to maximize their own payoff total utility. 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.

A Markov Process has the following attributes.

1. The state of the process at any point in time belongs to a finite set of possible states.

2. The state of the process at the next point in time depends only on its current state and does so according to fixed transition probabilities.

3. It is possible through a series of transitions to get from any one state to any other.

4. The system does not produce a deterministic cycle through a sequence of states.

The Ergodic Theorem states that any Markov Process converges to a unique statistical equilibrium that does not depend on the initial state of the process or any one time changes to the state during the history of the process.

Definition 1: A stochastic process is a sequence of events in which the outcome at any stage depends on some probability.

Definition 2: A Markov process is a stochastic process with the following properties:

(a.) The number of possible outcomes or states is finite.
(b.) The outcome at any stage depends only on the outcome of the previous stage.
(c.) The probabilities are constant over time.

Theorem 3: Let M be the transition matrix of a Markov process such that Mk has only positive entries for some k. Then there exists a unique probability vector xs such that Mxs = xs. The vector xs is called the steady-state vector

.

Markovian strategies: Assume, at each time t Є [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 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 i-th player will thus consist of all measurable functions (t, x) $u_i(t, x)$ from [0, T] × IR^n into U_i.

Markov Perfect Nash Equilibrium: In this section we consider the auxiliary system for general feedback Nash equilibrium in a dynamic game with a single state variable. In this game, *n* players choose Markov strategies, $u_i(x)$, to maximize the pay off function. The strategies determine the level of a total outcome , *x*, that is governed by the state dynamics. For this game we characterize Markov perfect Nash equilibrium that are either differentiable, or continuous, or have at most a finite number of jump points.

5. Parameters for Simulation setup

QualNet Simulator is a state-of-the-art simulator for large, heterogeneous networks and the distributed applications that execute on those networks. QualNet Simulator is an extremely scalable simulation engine, accommodating high-fidelity models of networks of tens of thousands of nodes. QualNet makes good use of computational resources and models large-scale networks with heavy traffic and mobility, in reasonable simulation times. QualNet Simulator has the following attractive features:

•Fast model set up with a powerful Graphical User Interface (GUI) for custom code development and reporting options

•Instant playback of simulation results to minimize unnecessary model executions

•Fast simulation results for thorough exploration of model parameters

•Scalable up to tens of thousands of nodes

•Real-time simulation for man-in-the-loop and hardware-in-the-loop model

•Multi-platform support

The parameters of the QUALNET simulators are given below in table I.

Table 1.Parameters of QualNet

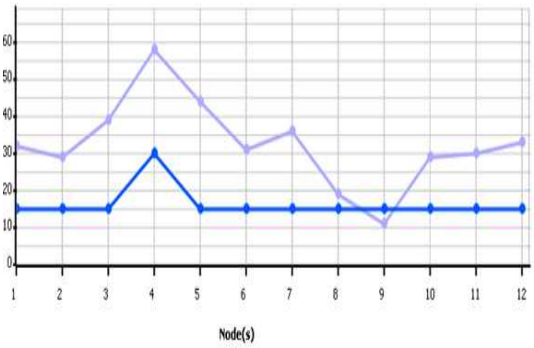
Parameters	Values
No of nodes	25
Area	700m*700m
Fading model	Rayleigh
Shadowing model	Constant
Routing protocols	OLSR
Simulation time	120sec
Channel frequency	2.4 GHZ
Traffic source	CBR

6. SIMULATION RESULTS

This section deals with numerical results of both cooperative and non-cooperative scenarios. In non cooperative scenario, Best response Nash equilibrium strategy profile is evaluated.

Figure 4.Cooperative Relay Node Output at Transmitter

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. 3 depicts sum of utilities of source and relay nodes versus the packet generation rate of relay nodesIn cooperative scenario, the summation of utilities is investigated as the system performance

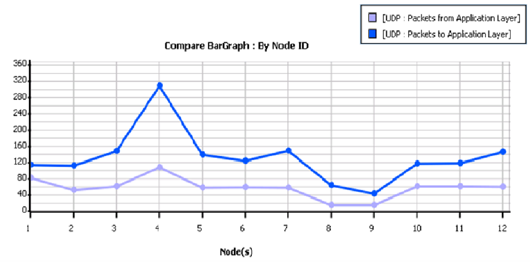


Figure 5.Two Relay Node output at the receiver

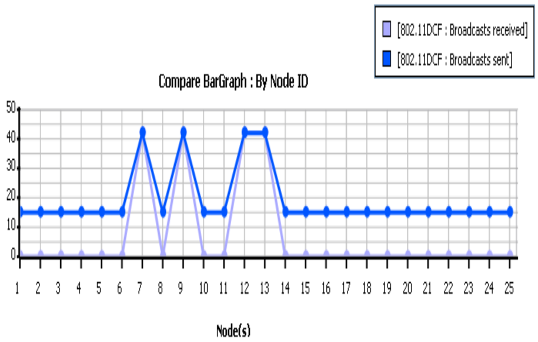


Figure 6.Cooperative Five Relay Node Output

Summation of utilities is directly proportional to packet generation rate of relay node are shown in figure 5 and 6. 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 set in the systems where low latency is desirable. The maximum achievable utility in the system is less than the systems without strict delay requirements.

From the above results 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.

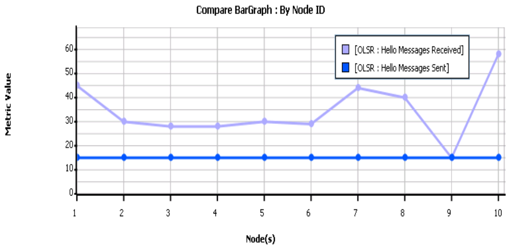


Figure 7. Non Cooperative Relay Node Output

Figure. 7 shows that the achieved performance of proposed non-cooperative scheme asymptotically approaches the cooperative system performance and confirms the appropriate performance of the proposed mode.

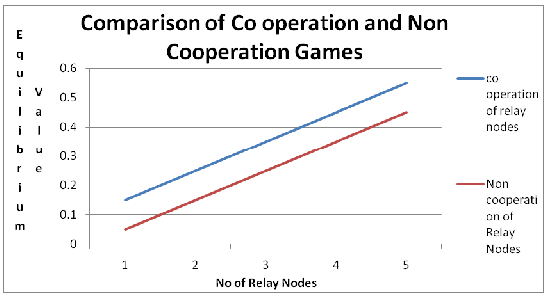


Figure 8.Comparison Of Co Operation And Non Co Operation Of Relay Nodes

Figure 8 shows that the comparison between the co operation and non cooperation relay nodes equilibrium performance. It is clearly proven that the co operation relay nodes will give the best result compare to the non cooperation of relay nodes at the same time depends on the dynamic scenario, non co operation is more suitable than the cooperation mode. The conversion of non co operation to co operation is also possible.

7 . 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.The conversion of non co operation to co operation is also possible.

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