Cognitive radio technology is a solution for 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, the relay selection with user cooperation could be advantageous to both primary and secondary transmissions. This section 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 his/her own stationary utility function to reach the best response Nash equilibrium strategies. The non cooperation of Relay nodes can be converted into Co-operative nodes based on Markov Process. The results reveal that the summation of node utilities in cooperating 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.

6.1 INTRODUCTION

Cognitive radio 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. 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 with
communication between two computers to detect user communications. Wherever the user goes, cognitive device will adapt to new environment allowing users 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 utilization of the spectrum while avoiding interference to other users. To make a 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 the 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 6.1 shows the basic model of a cognitive radio ad hoc network.
Cognitive radio 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 (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 a certain fixed spectrum block while each device in cognitive radio networks dynamically senses its Spectrum Opportunity, 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 a base station or bus 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 a vital role.
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 status is more reasonable.

6.2 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 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 the Amplify and Forward, the cooperative mode 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 a 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 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 analysing the complexities of human interactions.

**Game Theory**

In game theory a Markov strategy is one that depends entirely on state variables that summarize the story of the game in one direction 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 a Nash equilibrium in every state of the game.

For a precise formulation of a non-cooperative game, we have to specify (i) the number of players, (ii) the possible actions available to each player, and any constraints that may be imposed on them, (iii) the objective function of each player which she attempts to optimize (minimize or maximize, as the case may be), (iv) any time ordering of the execution of the actions if the players are allowed to act more than once, (v) any information acquisition that takes place and how the information available to a player at each point in time depends on the past actions of other players, and (vi) whether there is a player (nature) whose action is the outcome of a probabilistic event with a fixed (known) distribution.

### 6.3 MARKOVIAN STRATEGIES

Assume, at each time $t \in [0, T]$, Player $i$ can observe the current state $x(t)$ of the system. Still, he receives 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 $S_i$ of strategies available to the $i$-th player will thus consist of all measurable functions $(t, x) \to u_i(t, x)$ from $[0, T] \times \mathbb{R}^n$ into $U_i$.

### 6.4 PROPOSED WORK
In this work, 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 the two way approach. One way is using Nash equilibrium and the other one is a Markov chain process.

**Figure 6.2 Model of Relay Nodes**

**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 solely on state variables that summarize the level 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 a Nash equilibrium in every state 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 final result at any stage depends on more or less probability.

**Definition 2**

A Markov process is a stochastic process with the following attributes:

(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.

**6.5 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 is either differentiable, or continuous, or possess at most a finite bit of jump points.

6.6 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 6.1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of nodes</td>
<td>25</td>
</tr>
<tr>
<td>Area</td>
<td>700m*700m</td>
</tr>
<tr>
<td>Fading model</td>
<td>Rayleigh</td>
</tr>
<tr>
<td>Shadowing model</td>
<td>Constant</td>
</tr>
</tbody>
</table>
Routing protocols | OLSR
---|---
Simulation time | 120sec
Channel frequency | 2.4 GHZ
Traffic source | CBR

6.7 SIMULATION RESULTS

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

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

Summation of utilities is directly proportional to the packet generation rate of relay node are shown in figure 6.4 and 6.5. Summation of players' utilities decreases as the delay cost of the
system increases and players adaptively take an appropriate strategy profile to maximize their usefulness. A higher value is defined in the systems where low latency is desirable. The maximum achievable utility in the system is less than the systems without strict delay requirements.

Figure 6.4 Two Relay Node output at the receiver
From the above results the summation of node utilities in cooperating 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 6.6 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 6.7 Comparison of co operation and non co operation of Relay Nodes

Figure 6.7 shows that the comparison between the cooperation and non cooperation relay node equilibrium performance. It is clearly proven that the cooperation 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 cooperation is more suitable than the cooperation mode. The conversion of non cooperation to cooperation is also possible.

6.8 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 maximise 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 set. The conversion of non cooperation to cooperation is also possible.