A Novel Transmission Power Efficient Routing in Cognitive Radio Networks Using Game Theory

Sonia Garg, Poonam Mittal and Chander Kumar Nagpal

Abstract Owing to frequently increasing demand of wireless communication technology, the problem of spectrum shortage arises. To overcome this, Cognitive Radio (CR) came into play. CRs use the available vacant spectrum of primary users intelligently. CRs use these spectrum holes opportunistically by changing their transmission parameters. To model the performance of a wireless network, game theory has been used due to its capability to model individual, independent decision-makers. Game theory can be used in any network at various layers, to model its behavior and performance. To send data between any two nodes in network, we need a routing protocol. We aim to find out a transmission power-aware routing algorithm which routes the message packets efficiently within the network, while maximizing the overall throughput of the system. And then we compare its performance with shortest path and minimum transmission power routing scheme. Implementation is done in MATLAB-9.0.

Keywords *Cognitive* radio · Wireless network · Game theory
Physical layer · Power allocation Cooperative and Non-cooperative game

1 Introduction

Shortage of spectrum is due to the exponential growth of wireless devices and rigid allocation policies of the spectrum. Whereas large portions of the designated frequency bands are only partially occupied, this leads to inefficient spectrum utilization. So a new technique Cognitive Radio (CR) was proposed [1] which can use

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the radio resources with high intelligence and more capabilities [2]. Cognitive capability can be explained as the capability of a CRN to sense spectrum [3] and capture temporal and spatial variations.

PUs has their licensed fixed spectrum. Cognitive radio transceiver needs to sense the environment for the presence of PUs [4], before starting communicating with one another. Secondary Users (SU) or cognitive users can only use the spectrum for a secure communication with other users only when there is no PU in the communication in that spectrum [5–8].

In a CRN, if there are different types of user, i.e., they are different on the basis of their behavior, objectives, then users might not be entirely cooperative. In a multihop environment, a node will forward another packet; if there is some cooperation between the nodes, only then packets can be forwarded reliably. There are many techniques to deal with cooperation like reputation-based and price-based system but these techniques are not able to calculate cooperation incentives provided by these schemes. To overcome this, techniques are needed which can analyze the user's behavior interactively like game theory.

1.1 Cognitive Radio and Game Theory

Game theory is an advance mathematic tool [9] that helps in analyzing the user's behavior. It analyzes the behavior and makes the decisions accordingly. Game theory can be classified as 1. cooperative game model and 2. non-cooperative game model.

Cooperative games are those games in which CR players cooperate with each other to maximize network utility. In non-cooperative games, players are selfish users and take actions independently aiming to maximize their own utility functions [10]. Game theory aims toward Nash equilibrium, i.e., an optimal combination of strategies of all the present players which are normalized [11]. Main components of a game are described in Table 1.

Table 1 Mapping of cognitive radio network elements to a game

Game component	Comments	Modeled element of CRN
Players	Players aim to maximize their utility function by considering the activity of PUs	Nodes in wireless network
Strategy/Set of actions	Actions are the functionality like in a network action is forwarding a packet	Modulation scheme, coding rate, channel allocation, transmission power level, routing path selection, etc.
Utility function/ Set of preferences [12]	It is the player's objective which is obtained by the behavior of cognitive radios	Performance metrics, e.g., throughput, delay, SINR, QoS, etc.

Game theory models can be used in CRN to deal with resource allocation problem (Channel allocation, power control), trust management, and better understand of several issues. Table 1 shows how different CR elements can be mapped on to a game. In this work, power allocation in game theory is used to collect information related to residual power available at all other nodes.

2 Power Allocation: Literature Review

In CRNs, game theory may be used to model and examine CRN at different layers of OSI model. Thomas et al. [1] shows which CRN games can be applied at different OSI layers. Avoiding interference is the key challenge in CRN at physical layer. It provides good QoS to CRN users [13].

To deal with the communication in multichannel CDMA-based CRN, a non-cooperative game [14] is used for power control. It provides a path in the network where least energy is used for forwarding the data by opportunistically accessing the PU's channels.

To minimize the interference generated by SU, it may affect the spectrum sharing mechanism. Interference may be avoided by using the proposed scheme [15] based on power control. The goal is achieved by using non-cooperative game with pricing-based power control.

To provide the dynamic spectrum sharing among CR users, a non-cooperative game-based power control scheme [16] is used for CDMA-pricing cognitive radio system.

To deal with the decentralization of users, an MC-CDMA cognitive radios system with hand-off technique [17] was proposed for cognitive users. Sigmoid efficiency function and nonlinear pricing are used with non-cooperative game which is related to SINR value of the user. Frequency band of PUs is fixed but it may vary for SU according to the availability of spectrum. So modulation and demodulation do not affect the system.

To deal with the channel allocation and power control in CRN jointly, a game theoretic approach is designed which is based on physical interference [18]. SINR may be considered as a physical interference to establish a link. This is an efficient realistic protocol that can handle opportunistic spectrum access by interaction. This technique is valid only for a small local less scalable system but its performance is comparable with global centralized system.

An iterative method is used for resource allocation if the system has incomplete information. There are two techniques used to deal with this incomplete information system for resource allocation like MQAMI method [19] and game theory based technique. Game theory based technique achieves better results than MQAMI-based results but MQAMI is more distributed than this.

A heuristic technique is used to deal with the spectrum allocation problems [20] which mainly exist when there are two networks Primary User Network (PUN) and Cognitive Radio Network (CRN) which are operating on the same frequency band.

This approach is well suited for distributed network.

3 Proposed Work

In this work, an effort is done to design a routing protocol that aims toward optimizing the QoS parameters of the CR system by considering the constraints like power constraint and interference from and to the licensed band (primary users).

Total power can be defined as the sum of residual energy available at all the nodes. Residual energy is the energy contained in the node, i.e., the energy available at the node for consumption. Transmission energy is the energy required for transmission between two or more nodes. Initially, each node in the network has some fixed residual energy, but as the time passes, communication takes place and some transmission energy is required to send the messages in the network and thus the residual energy decreases. The more be the residual energy of a node, the node will be active for more time in the network. On the other hand, the more distant the node is, the more transmission power will be needed to receive the signal at receiver node. The more transmission power needed implies increased interference to other users in the network. In an obstacle-free path, the transmission power needed to send a signal from node1 to node2 is calculated as

$$P_{tr} \alpha \left(\mathrm{Distance}_{1,2}\right)^2 \tag{1}$$

If we consider the realistic environment having obstacles like rivers, buildings, factories, etc., then fading of signal may be there. In such a scenario, transmission power needed to send a signal from node1 to node2 is calculated as

$$P_{tr} \alpha \left(\mathrm{Distance}_{1,2}\right)^4 \tag{2}$$

Game theory is used to analyze and obtain information about the user behavior, network configuration, and other details. This information is collected through a non-cooperative repeated game theory. One of the ways to collect the information is by hidden and exposed terminal. Another way is that source node first sends a hello packet to all its neighbors and then waits for a reply. And all the neighbor nodes flood this packet throughout the network till it reaches the destination node. In reply to this hello message, all the nodes send an ACKnowledgement (ACK) packet back to the sender of hello message. The ACK contains the details about the residual energy at the node and the position of the node in the network. This information is then utilized by the source node to take decision about the routing path. Based on this information, source finds out all paths available from source to destination node. Then, for every path, calculate the transmission energy required on that path. Then, find out the most cooperative path which requires minimum energy. Game theory model is described in Table 2.

Table 2 Game for reputation system

	Node *i*		
Node *j*		Cooperative	Non-cooperative
	Cooperative	(p, c)	U (Ci, Ij)
	Non-cooperative	U (Ii, Cj)	(0, 0)

Here,

$$\begin{array}{lll} \mathrm{U}(\mathrm{C}\ i,\ \mathrm{I}\ j) = & (-c, p) & \text{if}\, \mathrm{R}(j) > \mathrm{Tr} \\ & (0,\ 0) & \text{if}\ \ \mathrm{R}(j) < =\ \mathrm{Tr} \\ \mathrm{U}(\mathrm{I}\ i,\ \mathrm{C}\ j) = & (p,\ -c) & \text{if}\ \ \mathrm{R}(i) > \mathrm{Tr} \\ & (0,\ 0) & \text{if}\, \mathrm{R}\ (i) < = \mathrm{Tr} \end{array}$$

Here, p is the profit gained in forwarding a packet and c is the cost of forwarding a packet. Figure 1 presents an algorithm for proposed routing protocol.

```
1. Fix energy for all nodes.
2. Find SN and DN.   // find source and destination
3. SN broadcast HM.       // to collect behavior of
   neighboring nodes
4. SN receives residual energy, position of node
   from NN. Repeat same process for all NNs until
   HM reaches DN.         // non cooperative game
   is implemented with multiple iterations
5. Find all paths between SN and DN. // multiple
   paths are there with corresponding cooperation
   value
6. Calculate TE for each path.
7. Select path having minimum TE and better
   cooperation
8. If($TE_1$=$TE_2$)   // two paths require same TE
                 Choose path having maximum RE.

9. If(path $N_{i,i+!}$>=RTE) (for all ith nodes on path)
   i.  Route data.
   ii. Calculate available RE at every node; $RE_i$=$RE_i$-
         $RTE_i$
              Else
   i.    Check for next minimum TE path.
   ii.   GO TO 8.
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Fig. 1 Algorithm for proposed system

Here, SN = Source Node, DN = Destination Node, RTE = Required Transmission Energy to transmit a packet from one node to next node on the path, NN = Neighbor Node, HM = Hello Message, and RE = Residual Energy.

4 Implementation

In the implementation of proposed routing scheme and existing scheme, we consider 16 primary user nodes and 24 secondary users. Transmission range of each node is 400 m. PU nodes are fixed and SU can wander in a region of 1500 m * 1500 m with random velocity and direction. Setup parameters used for simulation are shown in Table 3.

4.1 Setup Parameters

See Table 3.

4.2 Snapshots

Figure 2 shows the path generated by proposed routing, shortest path routing, and minimum transmission power routing. Node 22 is the source and node 31 is the destination. Three routing strategies were used, namely shortest path, Minimum Total Power Routing (MTPR), and optimal routing to establish a route from source

Table 3 Set up parameters

Region	1500 m * 1500 m
Transmission range	400
Nodes(SU)	24
Nodes (PU)	16
Position of SU	Random
Position of PUs	Fixed
Max velocity	15 m/sec
Pause time	0 s
Number of iteration	25
Source node	Chosen randomly from SU
Destination node	Chosen randomly from SU
Number of channels per user/node	1

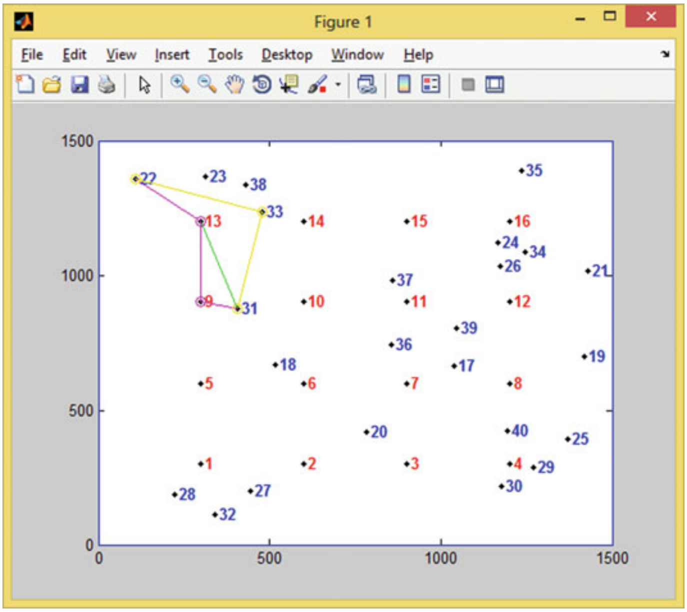

Fig. 2 Snap shot of simulation process, routing from (22) to (31)

to destination. The path from node (22) to node (31) shown in pink color shows the path formed using MTPR, in green using shortest path routing, and in yellow using optimal routing (see Fig. 2).

4.3 Results

Following observations were recorded for 25 iterations (Figures 3, 4, 5, and 6). Figure 3 shows the PDR values for all the three routing techniques. PDR value is quite high for optimum routing protocol.

Figure 4 shows average transmission power consumption for all the three approaches. The transmission power is required least in case of MTPR and may be equal to the optimum and maximum in case of shortest path routing approach, because a distant node requires more transmission power for transmission.

Figure 5 shows the variation of intermediate nodes in the path calculated. A path is considered to be more reliable if numbers of hops are lesser but as the same time nodes should not be much distant. Shortest path routing focuses on hops only, whereas MTPR focuses on less distant node, so hop count will be much higher. Hence, the hop count of optimal routing lies in between shortest path routing and MTPR.

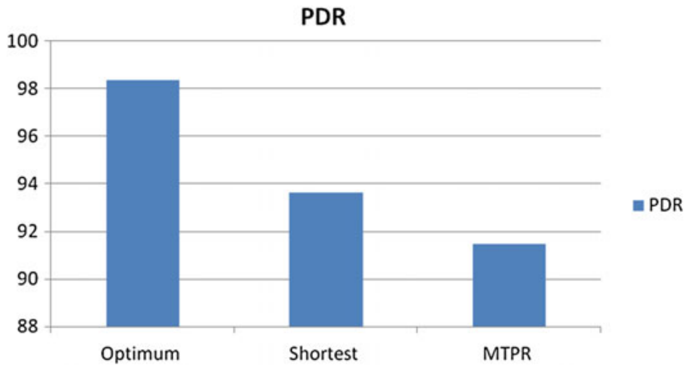

Fig. 3 Average PDR comparison

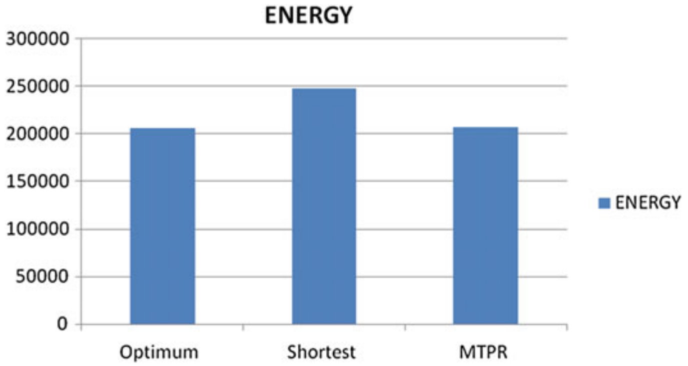

Fig. 4 Average energy comparison

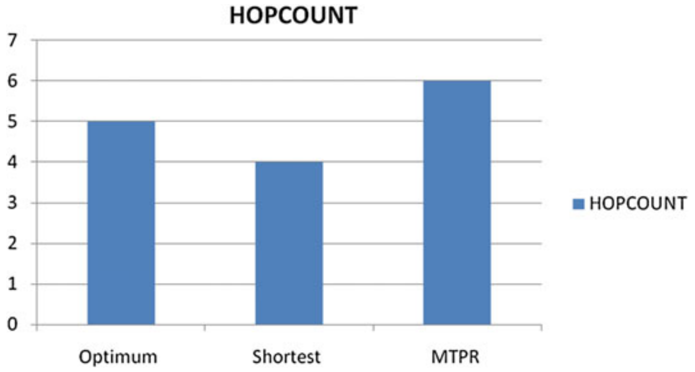

Fig. 5 Average hop count comparison

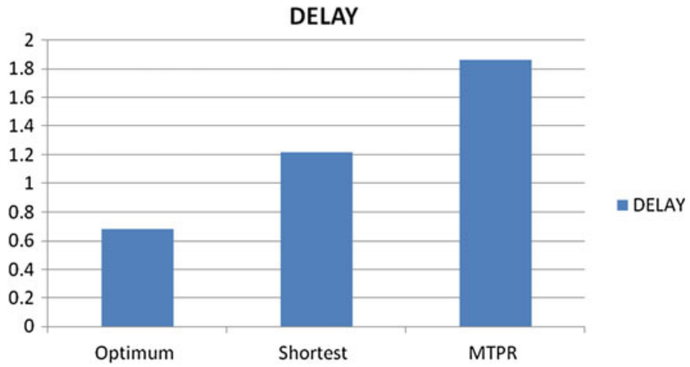

Fig. 6 Average delay comparison

Figure 6 shows the variation of end-to-end delay in different routing schemes. The value of end-to-end delay is much low for shortest path routing. But the delay will be highest in MTPR because there are maximum intermediate nodes. Delay in optimum routing mechanism is least because in shortest path routing delay may be contributed by unreliability of path.

5 Conclusion

Proposed routing protocol performs better than the traditionally used shortest path routing and MTPR. Because game theory analyzes the behavior of the nodes continuously, hence, the path obtained through optimized routing scheme will be more reliable. QoS parameters are optimized using proposed routing scheme. Game theory can be further used in CRN for dealing with various security issues.

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