# RAC: Range Adaptive Cognitive Radio Networks

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*Abstract*— **In recent years, cognitive radio has received a great attention due to tremendous potential to improve the utilization of the radio spectrum by efficiently reusing and sharing the licensed spectrum bands, as long as the interference power inflicted on the primary users of the band remains below a predefined threshold level. It allows the secondary user in the cognitive radio network to access the licensed spectrum of the primary user opportunistically. In this paper, an autonomous distributed adaptive transmission range control scheme for cognitive radio networks that considers the QoS requirements of both the primary and the secondary users simultaneously is proposed. The key feature of the proposed strategy is that, the cognitive user can maximize its achievable throughput without interferring the primary user by adapting its transmission range dynamically. One of the advantages of using the proposed scheme is its implementation simplicity. Results of ns2 simulations indicate that, proposed scheme can well fit such networks and improve the network performance. Having compared to the other approaches using contemporary cognitive radio technology, RAC scheme provides better adaptability to the environment and maximizes throughput.**

***Keywords- Cognitive Radio, Adaptive Transmission Range, Performance***

## I. INTRODUCTION

It is known that communication frequency spectrum is underutilized. According to the FCC measurements, roughly 90% of the frequency spectrum is not actively in use [1]. The “spectrum shortage” is often complained about in wireless communications essentially because of the use of outdated spectrum policies, which allow little sharing [2]. The introduction of cognitive radio techniques to assign resources provides promising approach to overcome that issue. Traditionally, a regulator assigns spectrum to systems by granting operators licenses, resulting in exclusive access to certain separate frequency allocations. Cognitive radio (CR), a term first introduced by Mitola [3], is proposed to remove this problem by enabling much more efficient distributed decisions on how spectrum should be shared. CR systems can be considered as those (unlicensed, secondary) that would like to share the radio spectrum with other systems (licensed, primary) by exploiting spectral gaps intelligently. Consequently, determining the interference impact on primary receivers from a new transmitter activation is vital, especially between systems with diverse transmission ranges. In a cognitive radio system, a secondary link is activated along with the primary link in a way that it does not disrupt the primary link. There are three well known approaches for the cognitive transmission: the interweave, the underlay and the overlay approaches [4, 5]. In the underlay approach, the cognitive radio transmits in a manner that its interference at the primary receivers is negligible. In the overlay approach the cognitive radio imposes non-negligible interference at the primary receiver but it makes up the performance degradation in the primary radio with the aid of its non-causal access to the primary users data. The interweave technique is based on the idea of opportunistic communication. There exist frequency voids (referred to as spectrum holes) that are not in use by the primary owners and consequently can be used for secondary communication.

In this paper, a wireless fading system with a cognitive radio that is concurrently transmitting with a primary user is considered. The latter operates with a constant power and utilizes an adaptive modulation and coding scheme satisfying a bit error rate requirement. The successful operation of the cognitive radio network will be disturbed, if a primary user detected due to their priority in spectrum access, the operations of primary users should not be affected by unlicensed users. Regardless of the used scheme, frequent interruption in a selected route would degrade the performance in terms of the quality of service (QoS). Thus, an important concern is to design a communication protocol that provides QoS guarantee in this context. To achieve this objective, RAC: Range Adaptive Cognitive Radio Networks, an adaptive transmission range scheme is proposed, which will allow a path to be retained during a data communication session along that path between secondary nodes. Because of active primary user detection, a secondary node involved in the communication process may not be able to continue its transmission, thus disturbing the communication process. RAC mechanism is based on self-adjusting variable transmission range of secondary users, which will not allow this to happen during a communication process. An important characteristic of the proposed schemes is that no negotiation between users is required and the optimization procedure is done at the cognitive radio. It is known that a low transmission range will not guarantee proper connectivity among users to ensure effective communication when there is not sufficient number of secondary users in the network. However, providing communication among secondary users in the presence of primary user communication is important and definitely improves the overall network performance for the secondaries. On the other hand, if the transmission range is high (e.g. much higher than the optimum), it will ensure connectivity but will increase the probability of encountering a primary user in the transmission range, cause harmful interference to more primary users, increase collision and congestion of control packets.

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There has been an interest by many researchers for determining an optimal transmission range for a fixed number of secondary nodes distributed over an operating area [13-16]. To the best of our knowledge, all of these studies tries to find and allocate an optimal range (power) and assigns it statically for a given scenario. Neither of them adjusts the transmission range adaptively as RAC scheme. However, in a cognitive radio network environment, the number of both secondary and primary nodes as well as the concentration (density) of nodes in different areas of the operating zone varies. Hence, a scheme based on adaptive transmission range would be an effective solution in such a changing environment due to varying primary node activities.

The rest of this paper is organized as follows. In section II, related work in this area is reviewed. Details of the RAC approach is given in Section III. The simulation and performance analysis of the RAC is presented in Section IV. The paper concludes in Section V.

## II. RELATED WORK

Cognitive radio is a flexible and intelligent wireless system that is aware of its surrounding environment and changes its transmission or reception parameters to communicate efficiently avoiding interference with the licensed (primary) or unlicensed (secondary) users. The secondary system will benefit from this CR to utilize the licensed band of the primary system as long as the licensee's operation is not compromised [3, 6, 11]. Based on the CR's interaction with the primary network system, transmission modes are classified into three types: interweave, overlay and underlay modes [4, 5]. In the interweave mode, the secondary system can occupy the unused license band, i.e., the spectrum hole, under the assumption that the majority of the spectrum is typically under-utilized. These spectrum holes change with time and geographic location. Therefore, in this mode, the secondary transmitters need to have the real-time functionality for monitoring spectrum and detecting the spectrum holes. A number of spectrum-sensing techniques [7, 8, 11] are proposed and spectrum-sharing techniques mainly based on game-theory have been analyzed [9, 10]. Overlay mode allows the secondary system to use the license band even if the primary system is using the band. The secondary transmitter is assumed to have knowledge of the primary message [4, 5]. In the underlay mode, simultaneous transmissions of primary and secondary systems are also allowed on condition that the secondary system interferes less than a certain threshold with the primary system [4, 5]. Accordingly, the concept of interference-temperature [12] has been introduced to determine a tolerable interference level at the primary receiver.

In earlier proposed cognitive radio protocols, most of the authors deal with the optimal power allocation problem. [13] studied the power control of transmitter in cognitive radio system and employ game theory for modeling. In [14], authors considered the distributed power control problem in the CR network which shares the primary user channel while trying to guarantee the QoS requirements for both the primary and secondary user simultaneously. In [15], the authors proposed an opportunistic power control strategy for the cognitive user, which they proved to be optimal in the sense that it maximizes the achievable rate of cognitive user while guaranteeing the outage probability of the primary user not to be degraded.

As seen in these previous studies, researchers focused on deciding the optimal transmit power of both primary and secondary users in a cognitive radio network. However, to the best of our knowledge, noone studied the problem to optimize the network throughput as an autonomous distributed adaptive transmission range scheme. However in [17], a mechanism based on self-adjusting variable transmission range of mobile hosts in a conventional 802.11 networks is proposed. But authors state that if two mobile nodes are moving away from each other, both of them have to progressively increase their transmission range in order to protect the link between them to ensure connectivity. In order to protect a path during data communication, all of the node-pairs in the path have to protect their links by increasing their transmission range. They use the adaptive transmission range term only for increasing the transmission range in the proposed protocol.

## III. ADAPTIVE TRANSMISSION RANGE SCHEME

This study presents, RAC: Range Adaptive Cognitive Radio Networks, a simple yet an efficient approach to utilize throughput by dynamically changing transmission range when needed. Range adaptivity is done autonomously upon primary user detection. As soon as primary user communication is detected by the cognitive radio engine, each communicating secondary node that interferes with the detected primary node reduces its transmission range trying to retain the communication path while decreasing the interference on the detected primary user.

### *A. Details*

In this study, a cognitive radio ad hoc network environment with primary and secondary nodes, where all nodes communicate with each other in their own networks, is considered. There is no communication (i.e., no cooperation) between primary and secondary networks. The network is modeled as a graph $G = (N, L)$ where $N$ is a finite set of nodes, $N=\{x_1, x_2, \ldots, x_n\}$ and $L$ is a finite set of unidirectional links, $L=\{(x_i, x_j)\}:1\leq j\leq n$ for $x_i \in \Re^d$, $1\leq i\leq n$. If a node $m$ is within the transmission range of node $n$, then $n$ and $m$ are assumed to be connected by an unidirectional links $l_{nm} \in L$, such that whenever $n$ transmits a message, it will be received by $m$ via $l_{nm}$ and vice versa. A *route* or *path* from node $s$ to node $d$ is an alternating sequence of nodes and links, representing a continuous traversal from node $s$ to node $d$. Each node $n$ has a wireless optimal transmitter range $R_{opt}$ that is used in normal operation and is allowed to use different transmission ranges $R_n$ independently from other nodes to communicate with other nodes in their neighborhood, $R_{min}<R_n<R_{max}$, to retain the communication path if needed.

In the proposed adaptive range scheme, a modified version of AODV adapted to cognitive radio networks [18] is used as routing algorithm. Upon primary user communication detection by the cognitive radio engine, actively communicating nodes on the active path start to decrease their transmission range by $\Delta R$ iteratively. If the node density is high enough to retain the active path without interfering the primary user, communication session is continued without any disruption. If this is not possible, a route error message is sent to the source node.

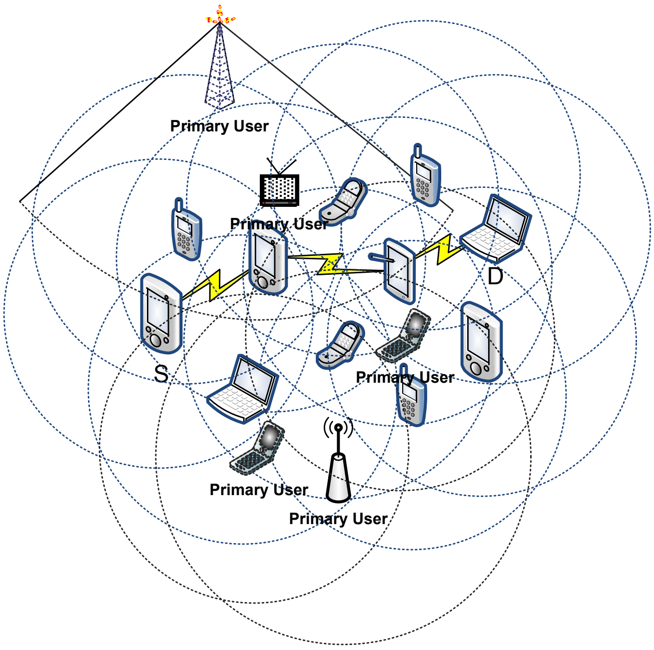

Figure 1. An example CR network example

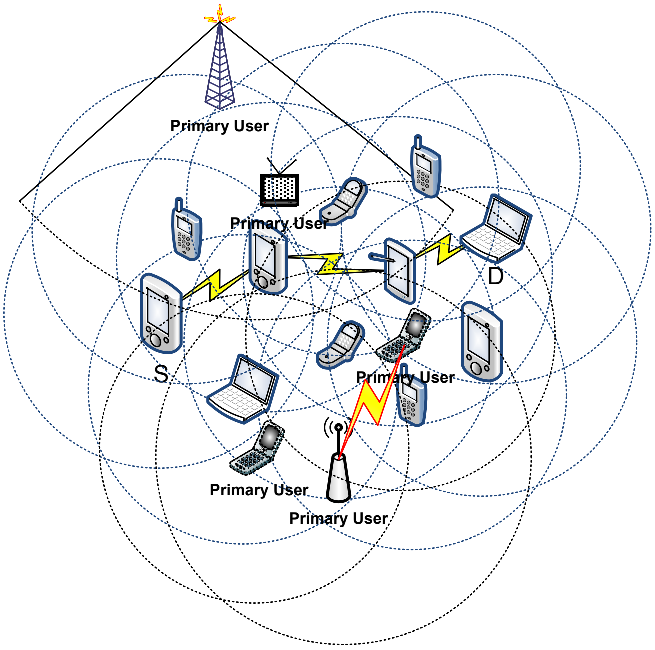

Figure 2. A primary user starts communication

To clarify, the example cognitive radio network shown in Fig. 1 can be considered. In this network, node S has some data to send to node D and therefore needs to find path to destination D. As stated above, a modified version of AODV adapted to cognitive radio networks [18] is employed. The protocol starts by sending out a broadcast Route Request (RREQ) message seeking destination D. The destination node D knows the spectrum opportunity distribution of all nodes on the path when receiving RREQ message, and assigns a frequency band to its cognitive radio transceiver. It then, sends back a Route Reply (RREP) message to the source node, encapsulating the assigned band. Intermediate node assigns frequency band with the help of the band choices extracted from the RREP, and the spectrum hole (spectrum opportunity) information from previous RREQ. Then the node establishes path to the destination via its cognitive radio and generates new RREP message to send back to the source. Once the path is constructed, communication session continues normally.

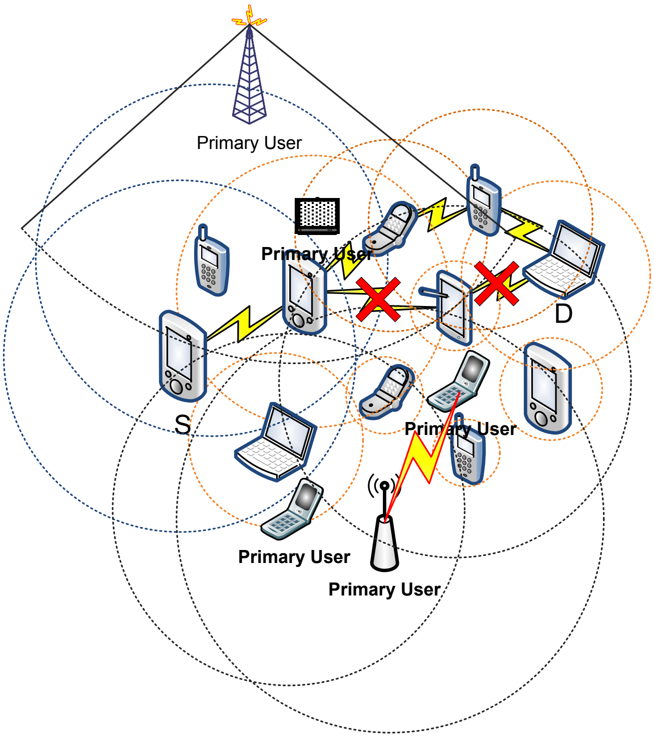

Figure 3. Re-route with adaptive range and local repair

Whenever a primary node activity is sensed by the cognitive radio engine (Fig. 2), every node detecting the primary user activity in the active path, it adapts its transmission range. If the node density is high enough, the best transmission range that enables the retaining the active path without causing any harmful interference to primary node is selected. All nodes in the active path tries to adapt their transmission ranges to a value which is the maximum range for it that is not causing any harmful interference to the primary user (Fig. 3) by decreasing their transmission range by $\Delta R$ iteratively. After this adaptation, nodes that detected the primary user activity in the active path, multicasts received packets of the ongoing communication session to its available neighbors table along with a route request message to the destination node *D*. As a consequence the new path is constructed with only local update upon the first route reply message received. If this is not possible, a route error message is sent to the source node.

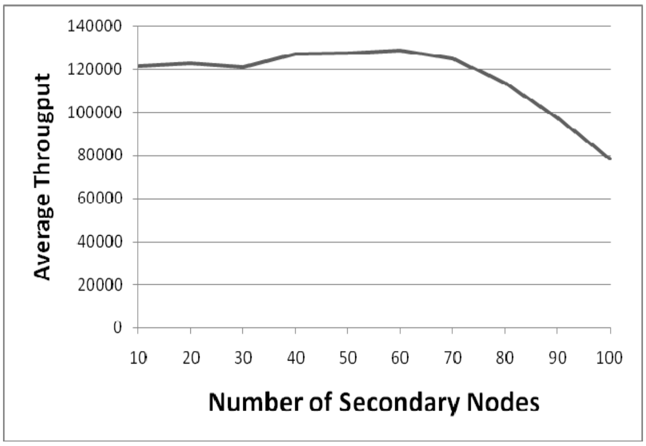

Figure 4. Average throughput of RAC scheme with 20 primary nodes in the network.

## IV. SIMULATION AND PERFORMANCE ANALYSIS

Through simulations constructed in ns2 [19], the performance and functional correctness of RAC and its relative performance compared to that of SORP [18] is evaluated. Unless otherwise noted, simulations are run with the following parameters. Two-ray ground propagation model is used at the radio layer. The bit rate for each channel is 2Mbps. Variable number of mobile nodes up to 100 moving in a rectangular area 1800 m x 1800 m in dimension is modeled. Each node picks a random spot in the rectangle and moves there with a speed uniformly distributed between 0-20 m/s. Upon reaching this point, the node picks a new destination and repeats the process. These parameters are very similar to the default values used in previous study of various protocols. The following default communication pattern is used. Each source node generates and transmits constant bit rate (CBR) traffic and each message is 1 KB in length. The transmission interval for each node is set to 100ms. 50 experiments are performed, for each different parameter settings.

The characteristics of RAC are explored under a number of different scenarios. The robustness of RAC is investigated for various numbers of both primary and secondary nodes, stressing the impact of adaptive transmission range on the throughput performance. The simulations are run for networks of sizes 10 to 100 secondary nodes and 20 to 100 primary nodes. Since the node density has a great importance on the performance of the RAC scheme for retaining the path, RAC performs high throughput for dense networks. However, after a certain threshold throughput starts to decrease due to the congestion. This situation is illustrated in Fig. 4. As expected, average throughput is inversely dependent on the number of primary nodes as seen in Fig. 5.

As noted earlier, a recently proposed modified version of AODV: SORP[18] for a baseline comparison is used and a throughput comparison between SORP, and RAC to show that RAC can well fit the multi-flow multi-channel environment and effectively exploit the potential large communication capacity in CRNs is evaluated. In the simulations, the rate of flows is varied from 100Kbps to 1800Kbps. The nodes are randomly placed in the area, and 8 flows having the same traffic generation rate.

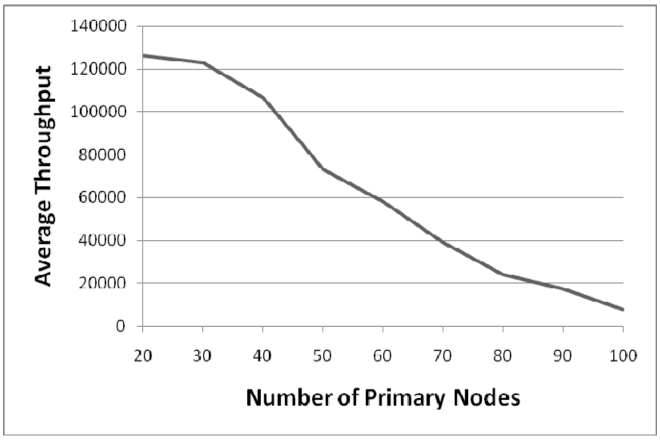

Figure 5. Average throughput of RAC scheme with 50 secondary nodes in the network

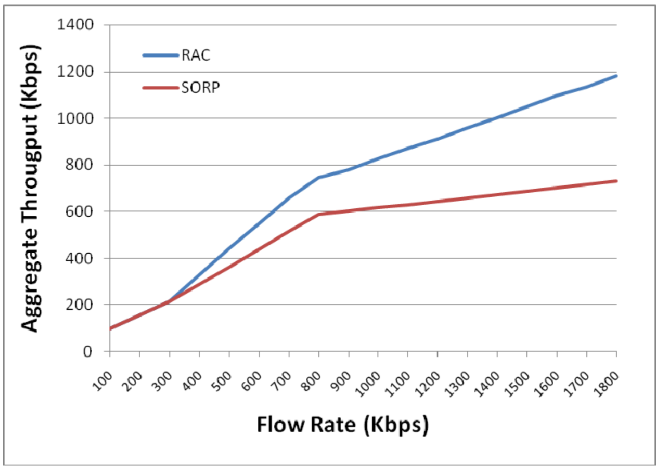

Figure 6. RAC performance: throughput observed with different protocols when two hosts, S and D communicates

When the traffic load is low, SORP also do slightly better due to the overhead in RAC. As the flow rate increase, the throughput of SORP increases slowly towards the limit of that path. Also in SORP, nodes become disconnected due to primary user activity, and no packets are forwarded. As the traffic load becomes large, the performance improvement of RAC over other schemes becomes more significant due to path retaining. In a dynamic environment, which means the network topology varies frequently, RAC adapts nodes transmission range to retain the secondary nodes communication path when the distance to the destination is not reachable without harmful interference to the primary user. Therefore, the established route in RAC is better than the route built in SORP in a frequently varying environment. The result is illustrated in Fig. 6.

## V. CONCLUSION

In this paper, Cognitive Radio Ad Hoc Networks are investigated and RAC: Range Adaptive Cognitive Radio Networks is proposed to enhance throughput of these networks. RAC is an autonomous distributed adaptive transmission range control scheme for cognitive radio networks that simultaneously considers the QoS requirements of primary and secondary users. It is a simple yet an efficient approach to utilize throughput by dynamically changing transmission range when needed. The key feature of the proposed strategy is that, a cognitive user can maximize its achievable throughput without interfering any primary user by dynamically changing its transmission range. Through an implementation in the ns2 simulator, it has been shown that RAC scheme achieves significant improvement on the throughput. The adaptability and efficiency of the scheme is proved in simulations such that it outperforms the previously proposed approaches.

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