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An On-demand Routing Technique for Cognitive Radio Ad Hoc Network

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Abstract

Cognitive radio networks are composed of spectrum-agile devices capable of changing their configurations and transmission parameters on the fly based on their spectral environment. This capability opens up the possibility of opportunistically reusing portions of the spectrum temporarily vacated by licensed primary users. This paper evaluates the feasibility of reactive routing for Cognitive Radio Ad Hoc networks (CRAHN). We set up a CRAHN simulation environment and adapt the weighted cumulative estimation of transmission time (WCETT) metric into AODV protocol to address the problem of efficient route selection between the source and destination and also evaluate the performance of both the protocol. The simulation result shows that AODV with WCETT metric performance better than the AODV because of its better route selection strategy in a CRAHN.

1. Introduction

Generally, government regulatory agencies designate different frequency bands of the spectrum to particular services or technologies. Each such allocated band is then assigned to service providers (e.g. TV broadcasters, Cellular phone operators, Military, etc.) with the exception of a few frequency bands such as the Industrial Scientific and Medical (ISM) band (unlicensed spectrum band). This allocation is done in a fixed manner, and thus, the owners of the particular bands get exclusive rights to use them. Even when they are not using these bands, others cannot use them.

Various studies conducted by the Federal Communications Commission (FCC) reveals that the spectrum utilization varies from 15% − 85%. Consequently, Cognitive Radio Networks (CRNs) are proposed to utilize the radio spectrum opportunistically [1].

At any given time and location, most of the assigned spectrum is not used by its owners. Also, the usage of the spectrum highly varies with time. These vacant frequency bands in time and space are called white spaces. The main concept of cognitive radio is to make use of these vacant bands for the communications purposes. In general, the owner of a particular band is referred as the primary user (PU) and the cognitive radio user (CU) is called the secondary user (SU). As a secondary user, cognitive radios should not cause any harmful interference to the primary users. Furthermore, when a primary user returns to the channel (its own frequency band), cognitive radios need to vacate the channel quickly and move to some other free channel. In order to identify the white spaces (free channels), the cognitive radios use advanced spectrum sensing techniques as well as white space databases [2]. If a node can use a particular channel to transmit and receive data for a reasonable amount of time, without causing/having interference to/from primary users, that channel is considered as an available channel. Each node may have a set of such available channels called an Available Channel Set (ACS).

Routing in multi-hop multi-channel Cognitive Radio Ad-hoc networks faces several new challenges. Both routings target the creation and maintenance of a routing path by selecting the proper relay nodes and the channel to be used on each link of the path. However in multi-hop CRAHNs, routing should deal with primary transmissions which dynamically change the spectrum availability. Due to this key challenge, the spectrum information is required and collaboration between the path selection and the spectrum decision is needed. Another challenge is how to measure the quality of different paths. Classical measures, such as throughput and delay, should be coupled with spectrum availability/stability and the dynamics of PU activity. A third challenge is the route maintenance and recovery. Link failure in multi-hop CRAHNs may happen after a sudden appearance of PU. Hence, effective signaling procedures are required to quickly recover the broken paths.

The rest of the paper is started with related work in section 2, followed by routing metric in section 3, Protocol description in section 4, network model in section 5, simulation and performance analysis is discussed in section 6 , future work have been discussed in section 7. Finally concluded in section 8

2. Related Work

A review paper by Matteo Cesana et al., [3] describes the different challenges and solutions to design effective routing solutions for multi-hop CRAHNs. The authors in [3], describe two categories for routing solutions as approach based on full spectrum knowledge and approach based on local spectrum knowledge. A survey paper by Ian F. Akyildiz et al., [4] explains about spectrum sharing, spectrum mobility, spectrum management and design challenges in cognitive radio networks in details.

An evaluation study by Marco Di Felic et al., [5] analyzes the impact of CRAHNs characteristics over the rout formation process by considering different routing metrics like Route discover frequency, Packet deliver ratio and Route discovery algorithms.

The routing protocol STOD-RP [6] constructs a spectrum tree in each spectrum band which helps in spectrum selection and route selection in an efficient manner but a root node is responsible for gathering all the dynamic system information which requires an important amount of energy and computation. The main objectives of routing protocol in [6] are to reduce control overhead and to shorten the average end-to-end delay.

The routing protocol SEARCH [7], a protocol for mobile CRAHNs based on the geographic forwarding paradigm. The main idea of the protocol is to discover several paths, which are combined at the destination to form the path with the minimum hop count, and it is able to deal with reasonable levels of PU activity changing rate. However, it assumes that most of the nodes are GPS equipped and, most importantly, a mechanism for disseminating the destination location both at the source and at each intermediate node is required.

A number of routing protocols have been proposed and implemented for better routing performance of CRAHNs. But, in a particular situation they have some advantages as well as disadvantages. In the paper CRAHNs [8] the authors present properties and current challenges of CRAHNs, which mainly describes concepts of spectrum sharing, spectrum decision and spectrum mobility. It also presents a model of cooperative spectrum-aware communication protocols which integrate the spectrum management functionalities.

In this paper, we adapting a routing metric, Weighted Cumulative Expected of Transmission Time (WCETT) to Ad-hoc On-demand Distance Vector (AODV) routing protocol to select the best route between the source and destination in a CRAHN environment and we evaluates the proposed solution by comparing with the ad-hoc on demand distance vector routing protocol which uses hop-count as metric for route selection. Each SU has single or multiple interfaces and channels.

3. The Routing Metric

The routing metric used in multi-hop CRNs should reflect the bands availability, the links quality, the PU activities and QoS requirements of SUs. In this paper, we use WCETT metric that was developed to find high-throughput routing paths in multi-radio, multi-hop CRAHN. This metric assigns weights to each link based on its quality; and then, these weights are combined. In the following, we show how to calculate WCETT.

A. Expected Transmission count (ETX)

ETX, proposed by [9], is defined as the expected number of transmissions at the link-layer needed to successfully transmit a packet over a link. To calculate ETX, each node sends small probe packets and the neighboring nodes acknowledge the probe packets correctly received. Thus, every node knows the ratio of probes received in the forward and reverse directions, denoted by df and dr respectively. Then, the likelihood that a packet arrives and is acknowledged correctly is $d_f \times d_r$. It is assumed that each attempt to transmit a packet is statistically independent from the precedent ones and from the packet size which implies that the sending attempt can be considered a Bernoulli trial. Then, the ETX over link l is:

$$ETX(l) = \frac{1}{d_f \times d_r}. \quad (1)$$

The ETX of a path p,$ETX(p)$ is the summation of the ETX of all the links $l \in p$ belonging to path, p.

$$ETX(p) = \sum_{l \in p} ETX(l). \quad (2)$$

ETX selects routes with knowledge of the delivery ratios which is more pertinent information than the hop count metric, thus increasing the throughput and improving the network utilization. However, ETX has the disadvantage of only considering the link loss rate and not the link data transmission rate (related to the transmission delay).

B. Expected Transmission Time (ETT)

ETT metric was subsequently proposed by [9] to improve the ETX metric by integrating the link data transmission rate. ETT can be defined as the "bandwidth-adjusted" version of ETX since the latest is multiplied by the link bandwidth to obtain the packet transmission delay. Let S denote the packet size and B_l the bandwidth of link l, then:

$$ETT(l) = ETX(l) \times \left(S/_{B_l} \right) \quad (3)$$

By introducing the link bandwidth into the calculation of the path cost, the ETT metric captures the impact of the link capacity on the routing performance in addition of the impact of physical interference (related to the link loss rate).

C. Weighted Cumulative Expected Transmission Time (WCETT)

The WCETT metric [10] is an extension of ETT metric which suggests to compute the path metric as something more than just the sum of the metric values of the individual links belonging to this path. Considering only the summation does not take into account the fact that concatenated links may interfere with each other, if they use the same channel. Hence, WCETT aims to specifically reduce intra-flow interference by minimizing the number of nodes using the same channel in the end-to-end routing path. Let N be the total number of channels of a system, the sum of transmission times over all hops on channel j, 1 ≤ j ≤ N, is defined as:

$$X_j = \sum_{j \text{ is used on link } l}^{n} \text{ETT(l)} \quad (4)$$

As the total path throughput will be dominated by the bottleneck channel, which has the largest X_j , [10] propose to use a weighted average between the maximum value of X_j and the sum of all ETTs. This results in the formula:

$$\text{WCETT} = (1-\beta)\sum_{l \in p} ETT(l) + \beta \times max_{1 \le j \le N} X_j . \quad (5)$$

Where β is the tunable parameter $(0 \le \beta \le 1)$.The $max_{1 \le j \le N} X_j$ term explicitly captures the intra-flow interference since the paths having more channel diversity will have lower weights. Therefore, (5) can be seen as a tradeoff between the path latency (first term) and the channel diversity of the selected path (second term). In [10], the authors studied thoroughly the impact of β on routing performance in multi-channel multi-radio multi-hop wireless networks and show its minor effect on the throughput. The impact of β in our system is model is similar to [10] and hence we select β = 0.5 to balance the channel diversity and the latency of the path.

4. Protocol Description

A. Route Discovery Process:

The proposed routing is an on-demand WCETT metric based routing protocol that is similar to Ad hoc On Demand Distance Vector (AODV) protocol. The proposed protocol uses the WCETT metric to select the best path between source CU node and Destination CU node. The routing process starts when a route is needed between two nodes. The source node broadcasts a route request (RREQ) message across the network. The RREQ packet transmitted by a node X on channel i contains the measured WCETT. When a route request (RREQ) message arrives at a node, it starts rebroadcasting the RREQ if:

- The sequence number of RREQ is new. In that case, the WCETT value of the path is stored in a local table.
- The sequence number of RREQ is not new, which means an RREQ with the same sequence number has been processed, but its WCETT value is smaller than the one of previous RREQ with the same sequence number. This condition will help raising the probability of finding the lowest cost route.

When an intermediate node receives a RREQ message, and have fresh enough route to the destination specified in the RREQ, it send a route reply (RERR) message back to the source if the received RREQ's destination sequence number is less than or equal to destination sequence number in the route entry. When a node receives the RREQ is the destination node, it sends back a route reply (RREP) if the received RREQ's cost is smaller than the previous received RREQ with the same sequence number. The source will finally use the path having the lowest cost for data transmission and stores locally the other best paths. Fig. 1 shows the flow chart of route discovery process of proposed WCETT based routing protocol.

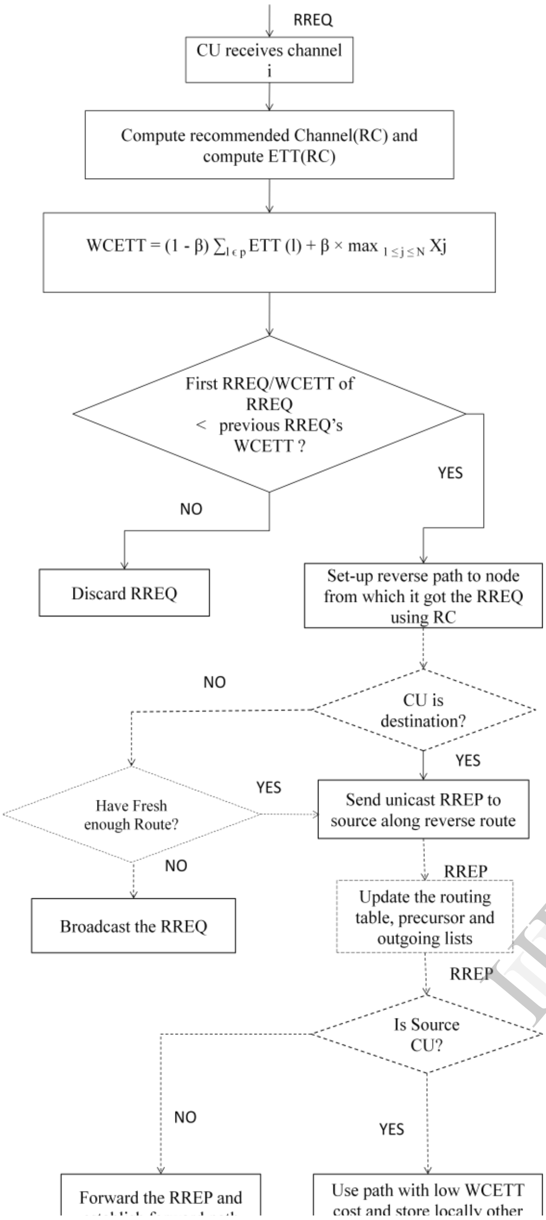

Fig. 1: route discovery process of WCETT metric based on-demand routing protocol

B. Route Maintenance and Recovery

Overcoming the sudden onset of PUs is the responsibility of the route recovery process which is critical in any CRAHN routing protocol. In our proposed solution we have extended local route maintenance and recovery mechanism of AODV protocol to multi-channel on-demand WCETT metric based routing protocol.

5. Network model

We consider CRAHN environment with available channel set and we assume that the CRAHN is composed of little mobile cognitive users (CUs) and stationary primary users (PUs). The locations, the number and the transmission standards of the PUs are assumed unknown to the CUs. The transmissions of PUs are sensed by a spectrum sensing mechanism, which is out of the scope of this paper. We assume that ACS is provided by the lower layers of CRAHN, and if a node has multiple radios, they are tuned to deferent, non-interfering channels. The channel assignment is carried out by Mac layer.

6. Simulation and Performance Evaluation

In this section, we evaluate the performances of our proposed solution (that we call WCETT protocol) by carrying out the multiple simulations with increasing the number of flows via Network Simulator-2 (ns-2) [11], based on the Cognitive Radio Cognitive Network (CRCN) simulator [12].

We have used the following metrics for evaluating the performance of proposed WCETT based routing protocol in CRAHN environment.

Average end-end Throughput: Average end-end Throughput is the ratio of total number of packets received successfully to total simulation time elapsed.

Average End-End Delay: It is defined as the time taken for a data packet to be transmitted across the CRAHN from source to destination.

Normalized Routing Load: Normalized Routing Load is the sum of all transmissions of routing packets per total delivery packets and each transmission over one hop the packets transmitted count as one transmission.

Packet Delivery Ratio: Packet delivery ratio (PDR) is performance evaluation parameter which measures effectiveness, reliability and efficiency of a protocol and defined as the percentage of the ratio between the number of received packets at destination and the number of packets sent by sources.

We carry out simulations with random topology where 25 SUs placed in 500×500 m^2. We use IEEE 802.11 with FTP as the traffic source. Each simulation is run for 150 seconds. Simulation's parameters are summarized in the following table:

Table I
The Parameters of Simulation

Parameter	Values
Topology	500 × 500 m^2
Number of nodes	25
Traffic type	FTP
Packet Size	512 bytes
Simulation duration	150 seconds
Nodes speed	10 m/s
MAC layer	IEEE 802.11
Transport layer	TCP

We start the simulation by setting the number of channels to 3 and other simulation parameter as given in the Table I. Fig. 2 shows that end-to-end throughput of the WCETT based routing while raising the number of flows, and it is observed that WCETT metric based protocol outperforms the AODV. Since it assigns better available channels and the WCETT metric increases the performance of the routing protocol because it takes into account the interference among links that use the same channel, while AODV simply use the number of hops as metrics.

In the second result, we evaluate the WCETT protocol for average end-end delay. We can notice from the Fig. 3 that average end-to-end delay of WCETT protocol is very low as compare to that of AODV, as the number of flows increases the delay in data transmission also increases.

In the Third result, we evaluate the WCETT based protocol for Normalized Routing Load; it is the ratio of total number of routing packets generated to total number of data packets routed successfully. We can notice from the Fig. 4 that normalized routing load of WCETT protocol is very low as compare to that of AODV, this is due to the better route selection strategy of the WCETT as wells as the better channel selection with the help of cognitive radio of CRCN, which reduces the number of control packets required by avoiding the bottleneck channels which may cause the link failure in CRAHN.

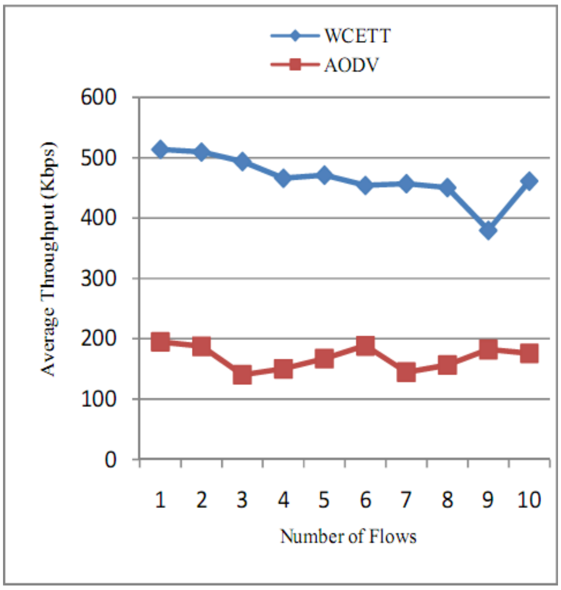

Fig. 2: Average throughput

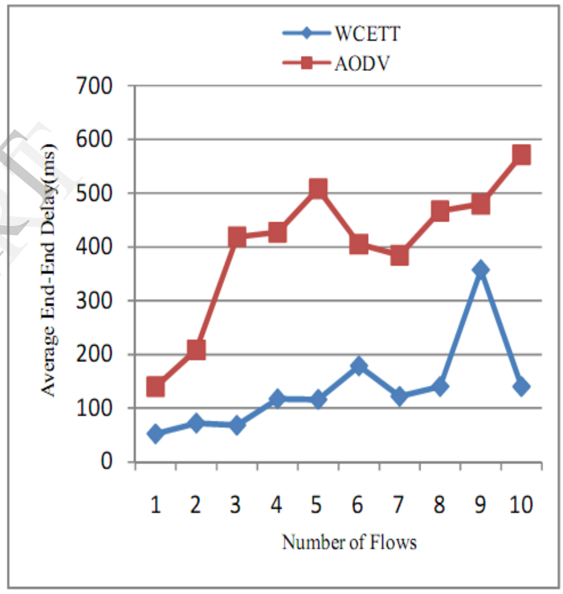

Fig. 3: Average End-End Delay

In the Fig. 5 we can observe that packet delivery ratio of the WCETT based routing remains higher than that of the AODV routing throughout the simulation. Fig 6 shows that number of packets dropped increases as the traffic increases.

1203 packets are dropped in case of WCETT routing and 1472 packets dropped in case of AODV routing. Packet drop is less when we use proposed protocol. Fig. 7 shows the average interference experienced by an each CU node, with increasing number of flows, interference also increases. Since WCETT metric based protocol reduces the intra-flow interference, routing with WCETT metric reduces the average interference at each node as compare to AODV routing.

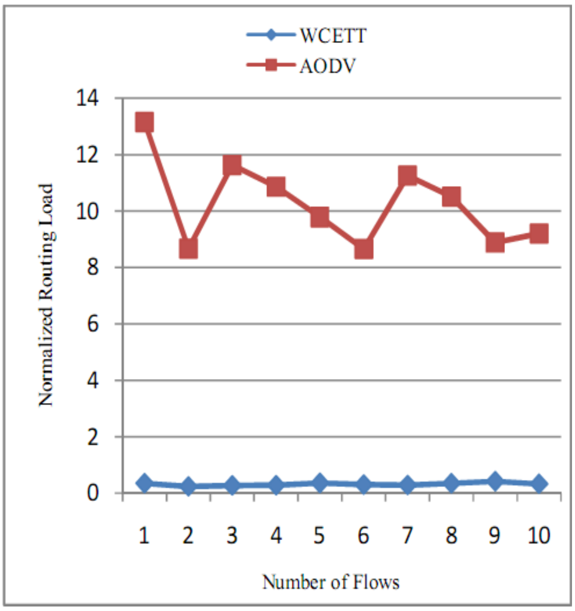

Fig. 4: Normalized Routing Load

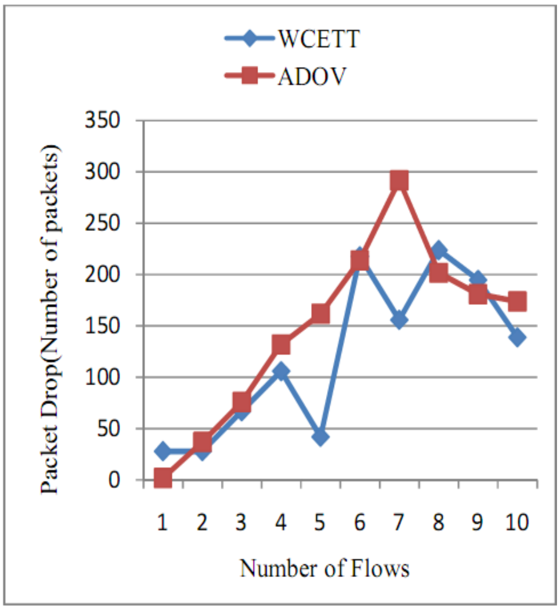

Fig. 6: Number of Dropped Packets

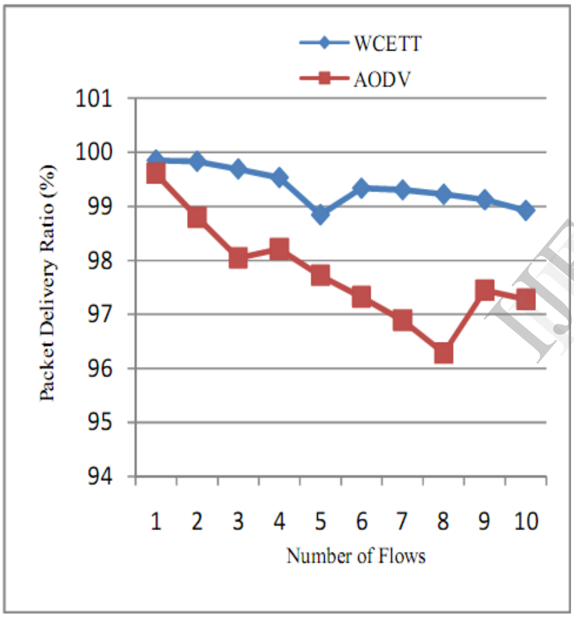

Fig. 5: Packet Delivery Ratio

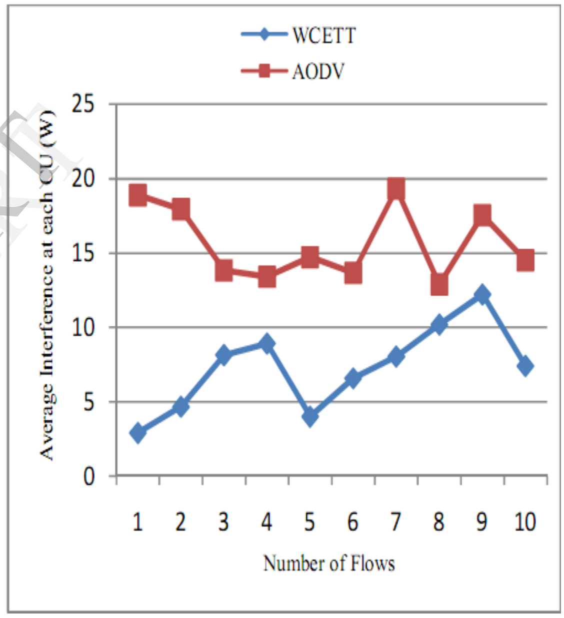

Fig. 7: Average Interference at each node of CRAHN

7. Future Work

We have adapted WCETT metric to AODV protocol, which performance very well in selecting the best path between source and destination CUs. In future, we will focus on introducing the better channel assignment and we also focus on how to reduce the inter-flow interference.

8. Conclusion

In this work, we have proposed an on-demand routing solution for multi-hop multi-channel cognitive radio networks. We evaluated the proposed routing protocol on a multi-channel CRAHN using the CRCN simulator and compare its performance with performance of AODV protocol. WCETT metric based protocol outperforms the AODV.

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