October 8, 2012

Efficient delay and energy based routing in cognitive radio ad hoc networks

Rana Asif Rehman, *Hongik University*

Efficient Delay and Energy based Routing in Cognitive Radio Ad Hoc Networks

Rana Asif Rehman[1], Muhammad Sher[1], Muhammad Khalil Afzal[2]
[1]Dept. of Computer Science and Software Engineering
International Islamic University
Islamabad, Pakistan
[2]Dept. of Information and Communication Engineering
Yeungnam University
Gyeongsan, South Korea
asifrehman7@gmail.com, m.sher@iiu.edu.pk, khalil_78_pk@yahoo.com

***Abstract*—Cognitive radio ad hoc networks (CRAHNs) are multi-hop, dynamic and self-configurable networks, which can communicate without any infrastructure support. Most of the research in CRAHNs has been already carried out on physical and media access control layers, but without effective routing protocols we cannot take full advantage of CRAHNs. In this paper, we discuss the problems in already proposed routing protocols for cognitive radio networks and proposed a novel protocol: Delay and Energy based Spectrum Aware Routing Protocol (DESAR), which consider both delay and energy for the computation of efficient path between source and destination. Simulation results show that DESAR protocol performs better than existing protocol in term of end-to-end delay.**

***Key words*—Energy aware, Routing Protocol, Ad hoc Networks**

I. INTRODUCTION

Federal Communication Commission (FCC) report shows that, the usage of licensed bands is sporadically or in discontinuous manners and most of the spectrum bands are under-utilized. In this report the FCC highlighted that these spectrum bands are assigned through static assignment policies and their usage is mostly for short period of time [1]. To solve this problem, the notion of dynamic spectrum access (DSA) has been introduced in which license spectrum may be used by unlicensed in dynamic manner.

According to the FCC report, to exploit the under-utilized portion of the spectrum, there is need of new intelligent and programmable radios that are capable for sensing, sharing and switching among the available spectrum. So, the concept of Cognitive Radio (CR) has been introduced in 1999 and research work on CRAHNs has been started in 2002. A CR is a technology that can change its transmitter parameters according to the environment in which it operates [2]. CR technology enables the cognitive user to identify, sense, and access the unused portion of the licensed radio resources. There are two types of users in CRAHNs: the primary user (PU) or licensed user and secondary user (SU) or cognitive user. PU works on traditional wireless communication systems in which spectrum allocation is static, while the SU is equipped with CR which sense and access the unused portion of the available spectrum. In CRAHNs, the CR nodes divide the available spectrum called spectrum opportunity (SOP) into multiple channels and then select the channel that not interference with the licensed users [2]. SOPs are defined as a set of frequency bands that are currently unoccupied and available for use. In CRAHNs, the PU has priority to access spectrum band at any time while SU exploit SOPs in the absence of licensed user.

The research work on CRAHNs is mainly focused on physical and medium access layers issues includes spectrum sensing, spectrum decision and spectrum sharing. Recently, some research work has been carried out on routing and transport layers issues. Based on spectrum knowledge the routing in CRAHNs can be classified in two types [3], full spectrum aware routing and local spectrum aware routing. In full spectrum routing, the nodes in the CR networks have full knowledge about the spectrum availability. In local spectrum aware routing, the spectrum availability is locally constructed at each SU.

In CRAHNs, the available spectrum bands are vary from node by node and available for limited period of time. This makes the nature of CRAHNs more dynamic and efficient routing becomes a problem in such networks as compare to traditional wireless networks. CRAHNs are non-infrastructural networks where nodes have limited battery power, so energy is of prime importance. If a node has less energy along a path, so it has less life time and dead soon after transmitting few packets. If a path has more delay as compare to other paths, so by considering this path during routing increase routing overhead and decrease network performance. Routing becomes inefficient if path contains lower residual energy nodes or experience higher delay. Therefore, we are motivated to propose a novel protocol DESAR which jointly consider delay and energy for path computation.

The rest of the paper is organized as follows. Section II highlights some of the research efforts carried out in the related to our works. Section III presents proposed solution and protocol formulation. Section IV provides simulation results and finally we conclude the paper in section V.

II. RELATED WORK

Cheng at al. [4] proposed an on-demand protocol for routing and spectrum assignment in Cognitive Radio Networks, where route is selected based on the cumulative delay metric which includes different types of delays like switching and medium access delay. Authors in [5], enhanced the concept of delay metric, and proposed a more generalized metric by including queuing delay in it. But, there is no concept of path energy in route calculation.

Delay based routing mechanism is proposed in [6]. Optimal route is selected on the basis of cumulative delay. Cumulative delay includes node delay, path delay and queuing delay. This paper does not consider node or path energy for the computation of optimal route.

Perkins and Royer [7] proposed an AODV protocol and describe its functionality. In AODV protocol, destination sequence number is used to find latest route to the destination. In [8], a routing protocol is proposed for cognitive radio networks. This protocol use single transceiver while performs routing. This paper introduces a mechanism to solve deafness problem that is cause by switching channels. A delay metric is used for the selection of best route without consideration of node or path energy.

An energy aware routing protocol is proposed in [9] for CRAHNs, which is based on Dynamic Source Routing (DSR). Connection setup delay of DSR is higher and its performance decreases as the mobility is increased. This proposed protocol select path which has higher or more energy efficient as compare to other routes. This protocol also increases the life time of the individual CR user and overall network. In this protocol, there is no any concept is use that is related to node or path delay.

In [10], power aware routing (PAR) protocol is proposed that minimize the energy consumption during route establishment and increase the network lifetime. In this paper, the authors introduced the concept of path energy which is the combination of the entire nodes energy form source to destination.

Our proposed protocol considers both path delay and node energy for the selection of efficient path. In this way, more efficient and reliable route can be selected among multiple paths.

III. PROPOSED PROTOCOL

Unlike papers [6] and [9], DESAR protocol is proposed which perform routing by considering both delays and energy of the nodes. In the following sub-sections, we will describe the DESAR in detail.

A. DESAR overview

DESAR is a reactive protocol that select paths for routing by consideration both energy and delays of the nodes. In CRAHNs, there is a dynamic environment and the available spectrum band is heterogeneity, i.e. the available spectrum varies from node by node. To cope with this situation the proposed DESAR protocol select both route and spectrum band jointly.

Many proposed routing protocols in CRAHNs use dedicated radio for data and control messages. To avoid SU having very poor energy in a route, intermediate SU's should have threshold energy [9]. In proposed DESAR protocol, a single radio is used for both data and control messages. Because in energy efficient CRAHNs, the uses of extra radio on each SU is costly [8].

B. DESAR Protocol Formulation

DESAR protocol formulation is as follows. From [4], the node delay is describe as

$$DN = D_{switching} + D_{backoff} \quad (1)$$

where $D_{switching}$ and $D_{backoff}$ are delays caused by switching among active frequency band and multi-flow interference within a frequency band respectively.

$$D_{switching} = 2k.\,|Band_M + Band_1| \quad (2)$$

where k is a positive constant.

$$D_{backoff(Num_i)} = \frac{1}{(1-p_c)\left(1-(1-p_c)^{\frac{1}{Num_i-1}}\right)} W_0 \quad (3)$$

where p_c is the collision probability of the node contending for channel access. Num_i is the total number of contending nodes and W_o is the value of contention window size. Path delay also consists of switching and backoff delay which depends on frequency bands assigned to all the nodes along the path. Path delay at node$_i$ can be described as [5]:

$$DP_i = D_{switching,i} + D_{backoff,i} \quad (4)$$

The switching delay along the path can be calculated as:

$$D_{switching,i} = \sum_{j=i}^{H} k|Band_j - Band_{j+1}| \quad (5)$$

where H represents total number of hops between node $_i$ and the destination.

From [6], the backoff delay along the path can be expressed as:

$$D_{backoff,i} = \frac{S_{data}}{B}\left(\frac{\left\lfloor \frac{h_x+1}{2} \right\rfloor - U(h_x)}{U(h_x)}\right) \quad (6)$$

where S_{data} represent packet size, B is bandwidth and h_x is number of nodes sharing a band W.

In [6], the cumulated delay metric along the path ($D_{route,\,i}$) is described as:

$$D_{route,i} = DP_i + \sum_{i}^{M} DN_q \quad (7)$$

Another type of the delay is queuing delay that can be calculated through two different situations according to [6]. The queuing delay when the sending node brings flow data is calculated as:

$$ED_{queuing} = \frac{2\rho f_2}{f.C(1-2\rho)(1-\rho)} \quad (8)$$

where f represent finite mean, f_2 is second moment, C is system capacity and ρ is system load. The queuing delay when last particle of the flow arrives at the relaying node is derived as:

$$ED^*_{queuing} \approx \sum_{n=0}^{\infty} \pi_n E\left(\frac{Q^*_{relaying}}{C}\right) \quad (9a)$$

$$= \sum_{n=0}^{\infty} \frac{\pi_n}{C}\left(\frac{2\rho^2 f_2}{f(1-2\rho)(1-\rho)} + \frac{2f\rho}{1-\rho}\right) \quad (9b)$$

where π_n represent distribution P (N=n) of the number of nodes in the system. $Q^*_{relaying}$ the queue depth of a particular flow. So, the cumulated delay metric becomes

$$Delay\,Metric(DM) = D_{route,\,i} + D_{queuing} \quad (10)$$

DESAR protocol considered both delay and path energy for routing. The accumulated energy of the path can be express in the following equation [10]:

$$Path\,Energy(E_{ij}) = \sum_{i=1}^{j-1} Ei \quad (11)$$

where E_{ij} is the total energy of the path from node i to node j and E_i is the residual energy of an intermediate node. Energy consumed by a node is depends upon the number of packets transmits and received by that node. According to this paper, energy consumed by a node at time t can be calculated as:

$$E_{c(t)} = N_t * \alpha + N_r * \beta \quad (12)$$

where α and β are the constant factors, N_t and N_r is number of packets transmit and received by a node. If E is the total energy of a node the remaining energy $E_{r(t)}$ of a node can also be calculated as:

$$E_{r(t)} = E - E_{c(t)} \quad (13)$$

From Eq. 10 and Eq. 11, the proposed cumulated routing metric for DESAR protocol can be expressed as:

$$\text{Cumulative Metric} = \text{Delay Metric (DM)} + \text{Path Energy}(E_{ij}) \quad (14)$$

From this cumulative metric, DESAR protocol select path which is efficient both in terms of energy and delay.

C. Route Discovery Mechanism

DESAR protocol performs a spectrum aware route discovery procedure. The route discovery procedure is based on AODV [7] with some modification. When source S want to communicate with destination D, the source broadcast a route request (RREQ) message to its neighbor nodes who forward them on. Each node maintains a list of locally available channel currently not occupied by the PU. Unlike AODV, proposed protocol allows multiple paths to propagate to the destination.

The RREQ message also contains the information of available channels of all the nodes along the path to the destination. Each RREQ message is uniquely identified by source and destination IP addresses. When an intermediate or relying node receive a RREQ message its determine itself that is it a destination node, if not then the intermediate node attached its identifier, energy status, delay status and its available channel list with the RREQ message and rebroadcast the message. In DESAR, the RREQ message contains the following fields:

TABLE I. ROUTE REQUEST (RREQ) MESSAGE FIELDS

Fields	Description
rreq_id	Unique route request sequence number
src_id	Address of the source CR user
des_id	Address of destination CR user
node_id	Node unique id
sop_list	List of available spectrum band free from PU activity
d_status	Delay caused by switching, backoff and queuing
p_energy	Energy of the path which is combination of residual energy of the each intermediate node

The initial route discovery mechanism is shown by the following flow chart:

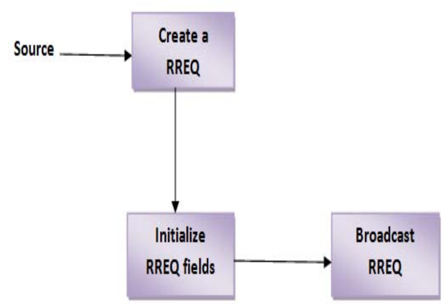

Fig.1. Flow chart of initial route discovery

The RREQ handling procedure is described in fig. 2. DESAR can also limit the number of RREQ forwarded or broadcast by each node using a parameter P_{max}. Each node keep a per-flow counter and only forward the first P_{max} RREQ messages. In this way, the network overhead due to overloaded traffic can also be minimized.

D. Route Selection Mechanism

During route discovery procedure, there are multiple RREQ messages are forwarded along different paths towards the destination. Each RREQ message has a full path from the source. When a destination node receive a first RREQ message for a given flow, destination D starts a timer (T_r) and collects all the RREQ messages while the timer is not expire. When the timer is expire all the subsequent RREQ messages are discard. The destination node knows about all the SOPs distribution information of all nodes along the path, when receiving the RREQ. The route is selected by the destination on the basis of proposed cumulative metric.

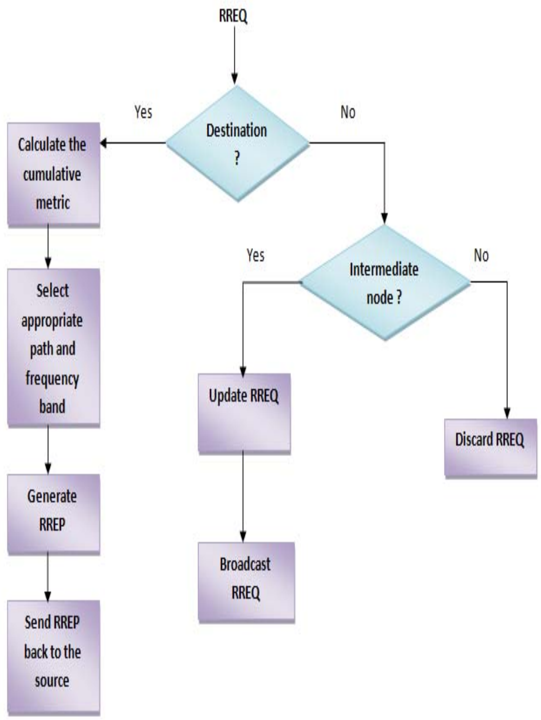

Fig. 2. Flow chart of handling RREQ

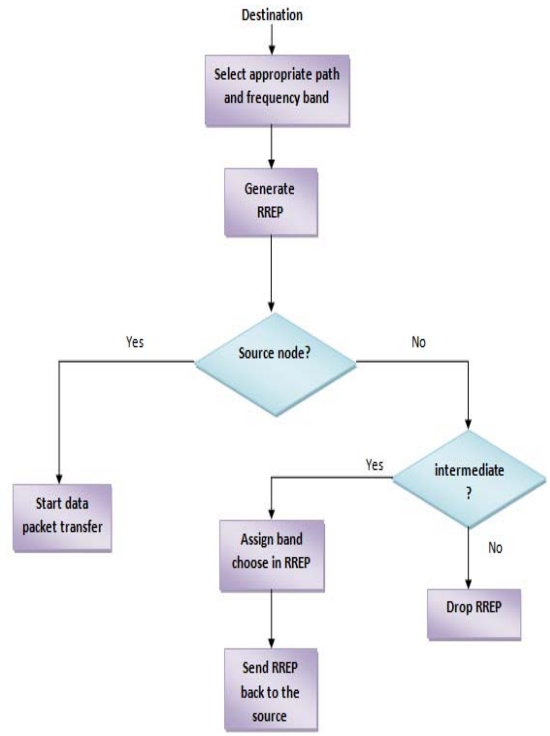

Fig. 3. Flow chart of handling RREP

The handling of route reply mechanism is shown in fig. 3. After select the best path, the destination send a unicast route reply (RREP) message back to the source which encapsulate the appropriate assigned frequency band. The intermediate nodes assign the frequency band with the help of route RREP message and path information from the previous RREQ message. Finally, after receiving the RREP message by the source CR user then the data transmission begins between source and destination.

IV. SIMULATION

We have used Network Simulator (NS-2) [11] version 2.31 to implement the DESAR protocol over Fedora 15 Linux platform. For cognitive support in NS-2, we used a cognitive radio patch [12]. Simulation parameters are described in table II.

TABLE II. SIMULATION PARAMETERS

Parameter	Value
Simulator	NS-2 (version 2.31)
Radio Propagation Model	Propagation/TwoRayGround
Channel Type	Channel/WirelessChannel
Mobility Model	Random Way Point
MAC Type	Mac/Macng
Area (M*M)	1000*1000
Simulation Time	200 sec
No of Nodes	20, 40, 60, 80, 100
Initial Node Energy	100 joules
Traffic type	CBR traffic
Packet Size	512 bytes

Initially average end-to-end delay metric is used to measure the performance of DESAR protocol with AODV [7]. Figure 4 shows average end-to-end delay of both protocols. In case of AODV, the average end to end delay is increase when we increase the number of nodes from 20 to 100. The reason is that AODV protocol doesn't consider any type of delay and energy when select route and that path is selected during routing that experienced long delay or has less energy. On the other side DESAR consider both delay and energy when choosing the path and choose that route which has experienced less delay and more energy efficient. In case of DESAR protocol, the average end to end delay remains constant up to 60 nodes then slightly increase up to 100 nodes.

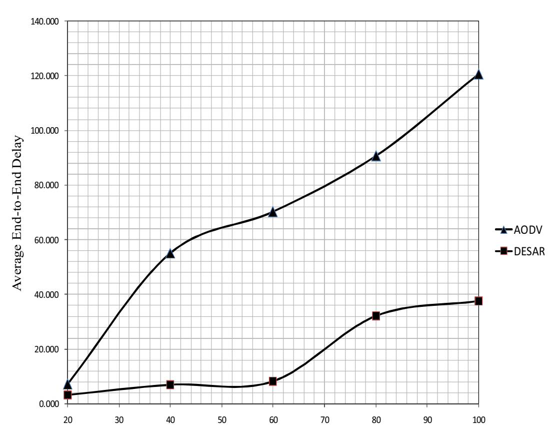

Fig. 4. Avg end-to-end delay of AODV and DESAR

V. CONCLUSION

In this paper, we proposed a reactive protocol named delay and energy based spectrum aware routing protocol (DESAR) for cognitive radio ad hoc networks. DESAR has two features: firstly, its handle spectrum heterogeneity by selecting spectrum band and route jointly. Secondly, select efficient path based on cumulative metric which consider delay and energy together. Simulation results show that, DESAR protocol performs better than AODV. We will provide a detail analysis of DESAR by considering other QoS parameters as future work.

REFERENCES

[1] FCC, "Spectrum policy task force report," *ET docket no.02-155*, Nov. 2002.

[2] I. F. Akyildiz, W. Y. Lee and K.R. Chowdhury, "Crahns: cognitive radio ad hoc networks", *Ad Hoc Netw.*, vol.7, no. 5, pp. 810-836, Jan. 2009.

[3] M. Cesana, F. Cuomo and E. Ekici, "Routing in cognitive radio networks: challenges and solutions", *Ad Hoc Netw.*, vol.9, no. 3, pp. 228-248, Jul. 2011.

[4] G. Cheng, W. Liu, Y. Li and W. Cheng, "Spectrum aware on-demand routing in cognitive radio networks", in *Proc. IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Netw.*, 2007, pp. 571–574.

[5] G. Cheng, W. Liu, Y. Li and W. Cheng, "Joint on-demand routing and spectrum assignment in cognitive radio networks", in *Proc. IEEE International Conference on Communication*, 2007, pp. 6499–6503.

[6] Z. Yang, G. Cheng, W. Liu ,W. Yuan and W. Cheng, " Local coordination based routing and spectrum assignment in multi-hop cognitive radio networks", *Mobile Network and Applications*, vol.13, no. 2, pp. 67-81, May. 2008.

[7] C.E. Perkins and E.M. Royer, "Ad hoc on-demand distance vector routing", in *Proc. IEEE Workshop on Mobile Computing Systems and Applications*, 1999, pp. 90–100.

[8] H. Ma, L. Zheng, X. Ma and Y. Luo, "Spectrum aware routing for multi-hop cognitive radio networks with a single transceiver", in *Proc. International Conference on Cognitive Radio Oriented Wireless Networks and Communications*, 2008, pp. 1–6.

[9] S.M. Kamruzzam, E. Kim and D.G Jeong, "Spectrum and energy aware routing protocol for cognitive radio ad hoc network," in Proc. *International Conference on Wireless Communication and Sensor Netw.*, 2011, pp.16-21.

[10] Rishiwal, M. Yadav, and S. Verma, "Power aware routing to support real time traffic in mobile ad hoc networks," in *Proc. International Conference on Emerging Trends in Engineering and Technology*, 2008, pp. 223-226.

[11] Network Simulator-2 [Online]. Available: http: //www.isi.edu/ nsnam/ns/

[12] Cognitive Radio Cognitive Network Simulator [Online]. Available: http: //stuweb.ee mtu.edu/~ljialian/