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Delay-Minimized Routing Protocol for Mobile Cognitive Ad-Hoc Networks

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Abstract— Mobile Cognitive Ad Hoc Networks is the one of the cognitive radio networks which is the advanced networking technologies for spectrum scarcity problem constrain in the Federal Communication Commission (FCC). The cognitive radio networks are the cognitive network which abject its network parameters with respect to network environment. In cognitive radio network two users namely the primary and secondary or cognitive users will access the available spectrum to communicate each other when the spectrum is accessed by the primary user the secondary user must leave the spectrum and access the spectrum when spectrum holes available for transmission. So routing is challenging issues in cognitive networks and it is very challenging in mobile cognitive networks due to the node mobility, primary user interface and spectrum scarcity. A delay minimized routing protocol is proposed for minimum delay route selection between the source and destination, which is improved version of AODV. The numerical and ns2 simulation results for the proposed protocol significantly state that delay minimized routing protocol (DMR) is better in terms of average end-to-end delay and average throughput.

Keywords— Primary users (PU), delay minimized routing protocol (DMR), spectrum, cognitive radio networks, cognitive users, Mobile Cognitive Ad-Hoc Networks, Dynamic Spectrum Access(DSA), Federal Communication Commission(FCC).

I. Introduction

Cognitive Radio Networks (CRN) is the new technology used to overcome the spectrum scarcity problem in current wireless networks by Federal Communication Commission (FCC) [2]. In cognitive radio network is a network which have primary and secondary users which access the network based on Dynamic Spectrum Access (DSA) [3].
The primary user is the licensed user and secondary user is unlicensed user when the licensed user is accessing the spectrum the unlicensed user are not allowed so the secondary user has to sense the spectrum periodically to find the presence of primary user, presence of primary user is in dynamic in nature so the spectrum holes created by primary user is dynamic so the Cognitive user uses the DSA. While using the DSA routing is the challenging in cognitive radio networks.

Classification of Cognitive radio networks [2]

Cognitive Radio Networks (CRN) is of infrastructure and infrastructure less, in infrastructure network it has a fixed structure like base station primary users secondary users and so on, in infrastructure less network it has no fixed structure.
Centralized and Decentralized networks the Centralized network is the network in which has on base station in the central and have primary users are present. Decentralized network is the network which has no centralized base station and has the secondary users to communicate and primary users. Static and dynamic networks the static networks the position of base station, primary users and secondary users are fixed but in the dynamic (Ad-Hoc) the position on primary users and secondary user will change (Mobility is nature).

Routing in Cognitive radio networks [8]

Routing in Cognitive radio networks is based on available spectrum and knowledge of spectrum to nodes in the network. Routing solutions for the Cognitive radio networks is of two types one is Full Spectrum Knowledge routing and second is Local Spectrum Knowledge routing.
Local Spectrum Knowledge routing has Minimum Power Routing, Minimum Delay-based Routing, Maximum Throughput-based Routing, Geographic Routing and Class-based Routing. This paper is organized in the following manner Section I contains the introduction of Cognitive Radio Networks (CRN) Section II contain the related work of routing protocols in CNR, Section III contain the Problem Statement of DMR, Section IV contain Proposed System Model and Routing Algorithm of DMR, Section V contain Numerical Results of DMR, Section VI describes the

Performance Evaluation and Section VII is Concludes research work with Future directions.

II. Related Work

ROPCORN Protocol [11]
ROPCORN Protocol is the on demand routing protocol which was designed for data transportation using link modelling and used to minimized delay for a set of users in network. It broadcast the packets in link with the low cast and no primary user is affects. ROPCORN is based on RACON protocol it uses buffers in the intermediate nodes and forwards the packets there is no overhead due to the use of spectrum availability and load estimation, the optimal route selection is based on spatial or temporal locality of link disconnection.

SEARCH A Routing Protocol [11]
It is the on demand routing protocol and enhanced version of AODV which is based on the geographic routing and follow the greedy forwarding and PU avoidance for joint channel-path optimization algorithm to find the best path. SEARCH undertakes both the path and selection to avoid PU activity region and tries to maintain end-to-end latency it has routing overhead due to the RRE, RREP, RERR and ROP messages.

Link Prediction-Based Adaptive Routing [11] [12]
Link Prediction-Based Adaptive Routing is based on link-availability prediction. The link –availability prediction considers primary user activity and user mobility. This routing reduces the energy consumption and gives least delay by enhances network performance. It works based on link prediction and topology control

Joint Routing and Channel Assignment [6]
Joint Routing and Channel Assignment (JRCA) approach based on delay prediction and a heuristic algorithm which used the collision probability and Link Stability *Prediction*. It is and on demand routing protocol which user AODV type of routing with heuristic values and can find out the path with minimal end-to-end (e2e) delay.

Adaptive Delay Tolerant Routing Protocol (ADTRP) [10]

The ADTRP algorithm finds a stable sequence of instances of the mobile graph and the communication topology of interest such that the number of transitions from one instance of the topology to another in the sequence is the global minimum. The algorithm uses the average lifetime of the mobile graphs in the stable sequence for communication topology and it is a generic for stable sequence of any communication topology it uses the heuristic topology for routing so it improved throughput, better packet delivery ratio, decreased packet drop and reduced delay.

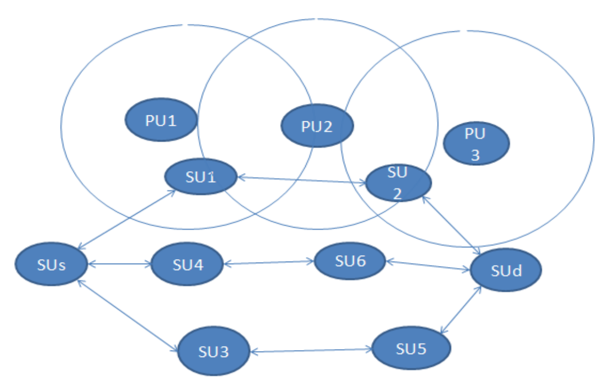
STOD-RP: A Spectrum-Tree Based On-Demand Routing Protocol [7]
STOD-RP is an on demand routing protocol which was designed for reduces the control overhead and average end-t-end delay minimization and it is an extension of the original Ad-hoc On-demand Distance Vector (AODV) protocol which uses spectrum tree addresses, spectrum decision and route selection in an efficient way for this route matrix is used. Fast and efficient spectrum-adaptive route recovery method is used when path is damaged.

III. Problem Statement

Mobile Cognitive Ad Hoc Networks is the one of the cognitive radio networks which is the advanced networking technologies for spectrum scarcity problem constrain in the Federal Communication Commission (FCC). The cognitive radio networks are the cognitive network which abject its network parameters with respect to network environment. In cognitive radio network two users namely the primary and secondary or cognitive users will access the available spectrum to communicate each other when the spectrum is accessed by the primary user the secondary user must leave the spectrum and access the spectrum when spectrum holes available for transmission. So routing is challenging issues in cognitive networks and it is very challenging in mobile cognitive networks due to the node mobility, primary user interface and spectrum scarcity for sending data.

IV. Proposed System Model and Routing Algorithm

The system has 8 secondary users with q cognitive radios and traditional wireless interface and cache to store packet. 3 primary users with 3 channels c1, c2, c3. All nodes uses identical transmit power and two ways of symmetrical link. Each node is assigned an identical bandwidth. Due to the mobility, the time is serialized as discrete time slots. In each time slots the topology of network is fixed with available channels.



Heuristic Algorithm

The term heuristic is used for algorithms which find solutions among all possible ones, but they do not guarantee that the best will be found, therefore they may be considered as approximately and not accurate algorithms. These algorithms, usually find a solution close to the best one and they find it fast and easily. Sometimes these algorithms can be accurate, that is they actually find the best solution, but the algorithm is still called heuristic until this best solution is proven to be the best. The method used from a heuristic algorithm is one of the known methods, such as greediness, but in order to be easy and fast the algorithm ignores or even suppresses some of the problem's demands.

Transmission Time is the amount of time form the beginning until the end of a message transmission
Media Access Time is the time taken the packet to access the available channel or link
Maximal Lifetime is the maximal time period that a currently available link can keep if no change in velocities occurs.

Heuristic values
Delay

$$D_{e_{u,v}^c}^{f^k} = EMAT_{v,u}^c + ETT_{v,u}^c \quad (1)$$

Expected Transmission Time (ETT)

$$ETT_{v,u}^c = ETX_{v,u}^c * \left(T_{v,u}^{c,DATA} + T_{v,u}^{c,ACK}\right) \quad (2)$$

$$ETX_{v,u}^c = \frac{1}{1-P_{v,u}^c} \quad (3)$$

Table 4.1: Notations

$e_{u,v}$	A link from SUs *v* to *u*
$e_{u,v}^c$	A link-channel pair (i.e., $e_{u,v}$ is assigned channel *c*)
f^k	The k^{th} dataflow $f^k = (s_k, d_k)(1 \le k \le K)$ where s_k and d_k are source and destination nodes of f^k
P	Collision probability
$D_{\sum v,u}^c$	The average number of waiting time slots for a link channel $e_{u,v}^c$
W_0	The initial contention window size.
$ETX_{v,u}^c$	The expected times that a given packet is transmitted from *v* to *u* on a channel *c*.
$T_{v,u}^{c,ACK}$	The time of transmitting a ACK packet over a link channel
$T_{v,u}^{c,DATA}$	The time of transmitting a data packet over a link channel
R	the back-off algorithm constant
$D_{e_{u,v}^c}^{f_k}$	Delay of f^k over a link $e_{u,v}$ and a channel *c*
$P_{v,u}^c$	The collision probability of a link channel $e_{u,v}^c$
$MLT_{v,u}^c$	Maximal Lifetime of a link channel $e_{u,v}^c$
$ETT_{v,u}^c$	Expected Transmission Time (ETT) of a link channel $e_{u,v}^c$
$EMAT_{v,u}^c$	Expected Media Access Time (EMAT) of a link channel $e_{u,v}^c$
$EMAT_{v,u}^c$	Expected Maximal Lifetime of a link channel $e_{u,v}^c$

Expected Media Access Time (EMAT)

$$EMAT_{v,u}^c = D_{\sum v,u}^c * slot \quad (4)$$

$$D_{\sum v,u}^c = \frac{1}{2}\left(\frac{1}{1-P_{v,u}^c} + \frac{W_0}{1-r*P_{v,u}^c}\right) - 1 \quad (5)$$

Expected Maximal Lifetime (EMLT)

$$EMLT_{v,u}^c = MLT_{v,u}^c * P\left(MLT_{v,u}^c\right) \quad (6)$$

Algorithm for minimum delay routing protocol

Step 1: Let each node have two route tables with minimum delay of the node to all next Hop nodes to zero and cache to store data packet

Step 2: If the node is source node the RREQ packet is dropped and set minimum delay to infinite and channel is zero

Step 3: For every channel form node to next Hop node calculate the minimum delay and Expected maximal lifetime of a channel and stored in table 2

Step 4: If the Expected maximal lifetime of a channel “c” is greater than the packet delay + minimum delay and calculated minimum delay is less than the minimum delay between the nodes in the network

Step 5: Then minimum delay is calculate, the minimum delay and “c” is the channel to use.

Step 6: Packet delay is replaced to calculated minimum delay. If the calculated minimum delay is smaller than the packet delays in the route table this node. Then

Step 7: This node will replace the route table 1 with new reverse route from this node to source.

Step 8: If this node has route to destination in its route table 1 or this node is destination then it makes RREP packet and send along with a current reverse route. Otherwise it broadcast RREQ.

Step 9: When the node receives an RREP packet form a node then it gets route form table 1 to source and destination.

Step 10: If the node is source node and the minimum delay in RREP packet is lower than destination route, then source node update its route table.

Step 11: If this node is not the source then it updates its route table 1 to destination route and copy the route in route table 2. After that this node forward the RREP packet to the next hop using source route.

Algorithm for Local Route Repair while data transfer (Continue…)

When a route fails at link channel then the packets is stored in the cache with the pervious Hop count and send to other route which is in table 2, with route error packet. When neighbour receives the route error packet it perform route repair as follows

Step 1: This node checks its route table 1 if it found a route to destination it removes that route

Step 2: If there is still an active route to the destination node in the route table 2 then this node sends the packet with error response packet with same state information of the packet to route node and minimum delay routing protocol will be executed for that node form Step 4 on words

Step 3: If there is no active route is present then route error packet will be broadcasted in source route.

Step 4: The node which receives will perform Local Route Repair.

Step 5: If the route error packet reaches the source node. Then minimum delay routing protocol will be executed once again.

V. NUMERICAL RESULTS

The system has 8 secondary users with q cognitive radios and traditional wireless interface and cache to store packet.
3 primary users with 3 channels c1, c2, c3.
PU1==c1, PU2==c2 and PU3==c3
SU1, SU2, SU3, SU4, SU5, SU6, SUs, SUd.
SUs use c1, c2 and c3 channels SU1, SU4and SU3.
Delay= SUs and SU4 = 104 ms
Delay= SU4 and SU6 = 92 ms
Delay= SU6 and SUd = 104 ms
Delay= SUs and SU = 92 ms
Delay= SU3 and SU5 = 92 ms
Delay= SU5 and SUd = 92 ms
By taking the routed presented in base paper for the topology
The routes are PATH 1= Sus- SU1- SU2- SUd
PATH 2= Sus- SU4- SU6- SUd
PATH 3= Sus- SU3- SU5- SUd
Each SU has two tables
The tables are of the form

Table 5.1: Table 1

Destination	Next	Delay
SUs	SUs	104

Table 5.2: Table 2

Destination	Next	Delay
1 SUs	SUs	104

PATH 2 is not in use because it has primary user interface and dint have channel to communicate
Delay of PATH 2=104+92+104=300 ms
Delay of PATH 3=92+92+92=276 ms
So PATH 3 is used for communication.
The PATH 2 is stored in stored in all SU’s table 2
The PATH 3 is stored in table 1
Consider Route error is occurred at node SU5
Then packet is stored in cache, after that is has route to SU3.
SU3 checks for connection then it dint find any connection then it send back to Sus
SU is source so it performs entire minimum delay routing protocol and find PATH 2 for transmission of data.
The numerical calculations show that the delay minimized routing protocol user caches to the nodes so that it is to minimized the route repair process when link failures is occurred while data transmission is going on.
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VI. Simulation and Performance Evaluation

Ns2.31 with CRCN patch is used to simulated the DMR protocol
Ns2 is the network simulator – 2 which is open source for network related simulations ns3 is the latest among several versions. Though they are several versions in ns2 only ns2.31 with Ubuntu 16 and with additional patch crcn-ns-2.31-ubuntu10_i386.deb is used to simulate the Cognitive radio networks.
The simulation is conducted taking 10 Secondary users and 2 Primary users as topology and taking CAODV, WCETT and DMR routing protocols, calculated average throughput and average end-to-end delay.

Table 6.1: Simulation parameters

Channel type	Wireless Channel
Radio-propagation model	Two Ray Ground
Network interface type	Wireless Phy
MAC type	802_11
Interface queue type	Queue/Drop Tail/Pri Queue
link layer type	LL
Antenna model	Antenna/Omni Antenna
Max packet in Queue	50
Bandwidth	11 mbps
No of Pus	2
No of Sus	8
No of data flows	2
No of channels	2
Transmission range	125 m
Interference range	250 m
Window size	256
Length of slot	$50*10^6$
Maximal speed	10 m/s
Packet sending	Poisson distribution
Pause time	5 sec
Transport layer	TCP/UDP
Packet size	512
Data generation	FTP
Power of nodes	Identical power
Bit rate	1 mbps
Time of simulation	100 sec
Ns2.31	CRCN patch

Evaluate the DMR protocol by comparing it with the CAODV and WCETT (Weighted cumulative expected transmission time) protocols.

Cognitive Ad-hoc on-demand distance vector (CAODV) [9][11] routing protocol was designed in accordance with three principles

1. During the process of route establishment and packet discovery the area of PU's activity is avoided
2. Applying a joint path and channel selection to reduce the route cost.
3. Multichannel communication is provided to improve the overall performance.

WCETT (Weighted cumulative expected transmission time) [6] protocol is similar to AODV protocol. Which uses the metric based routing the weighted cumulative expected metric to select the best path between the source node and destination node.

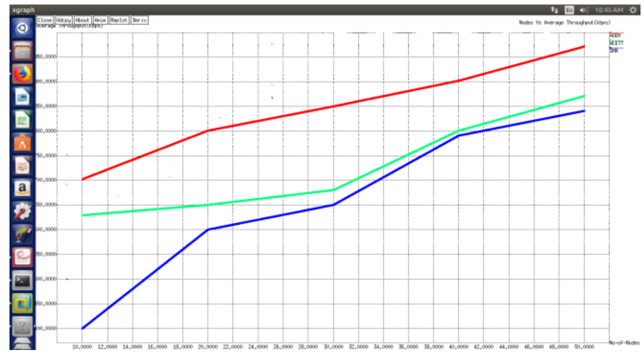

Fig: 6.1. Nodes Vs Average Throughput

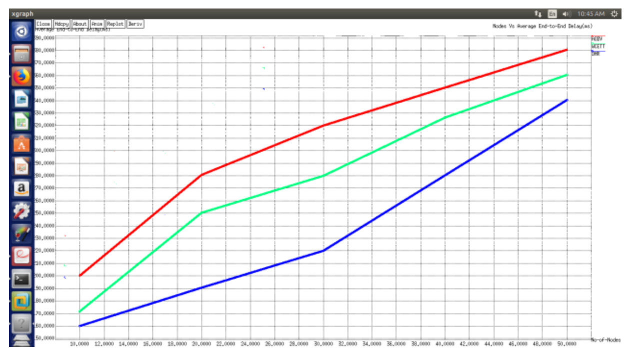

Fig: 6.2. Nodes Vs Average End-to-End Delay

Using different number of SU's to test the CAODV, WCETT and DMR, the fig: 6.1 and fig: 6.2 average delays and average throughput rate increases as the SU's increased.
But DMR gives the low delay and high throughput among three protocols.

VII. Conclusion and Future Work

Routing is challenging issues in cognitive networks and it is very challenging in mobile cognitive networks due to the node mobility primary user interface and spectrum scarcity this paper conclude that every protocol is designed for overcome certain problem in networks one is for multiple problems and one is for single problem like improving performance, minimized end-to-end delay, overall throughput increasing and so on.
There are more protocols or improved versions of protocols for increasing problems and recruitments.
The simulation results for the proposed protocol significantly state that, delay minimized routing protocol (DMR) is better in terms of average end-to-end delay and average throughput

when compared with other protocols like CAODV and WCETT routing protocols.

The future work of this paper is to incorporate machine learning algorithms to predict the flow of primary user data in networks which is used in minimized delay in network and implement it in matlab2017.

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