Content Centric Networking Approach in Cognitive Radio Ad hoc Networks

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Abstract—Content Centric Networks (CCN) is recently proposed scheme for next generation Internet communication in which nodes do not need to communicate based on locations information instead they used contents names. In cognitive radio ad hoc networks (CRAHNs), nodes have dynamic network situation due to intermittent channels conditions as well as the presence of primary users activities. Based on IP-based communication approach, it is hard to maintain end-to-end connections among cognitive radio (CR) nodes in CRAHNs. In this paper, by leveraging the benefits of CCN, we propose a new cross layer architecture, named content centric networking for cognitive radio ad hoc networks (CCN-CRAHNs). Proposed scheme is evaluated by using simulation which shows the advantages of CCN-CRAHNs as compare to IP-based CRAHNs in term of average end-to-end delay in cognitive environment.

Keywords—Content, Interest, Cognitive Radio, Named Data Networking, Ad Hoc Networks

I. INTRODUCTION

FCC report [1] brings a great revolution in the field of dynamic spectrum access (DSA). Now-a-days various intelligent and smart programmable devices have been used to share, sense and utilize the spectrum opportunities (SOPs) [2]. Cognitive Radio (CR) is one of the technology that can adjust their attributes based on operational environment. Two types of users named licensed or primary users (PUs) and unlicensed or secondary users (SUs) formalized the cognitive radio networks (CRNs), in which, SUs utilize the SOPs in the absence of PUs while PUs exploits the spectrum by using fixed spectrum allocation policies [2]. CRNs can also be distributed into further two famous networks named Infrastructure-based cognitive radio networks and Cognitive radio ad hoc networks (CRAHNs). Due to rapid advancement in technology, various devices such as tablets, smart phones etc. have been evolved. As a result, Internet traffic has increased exponentially, specially in the case of video traffics, will be around 80% of the total traffic in 2016 [3]. Now-a-days, users are more interested in fetching their required contents from different online resources like YouTube, Facebook etc. by experiencing less delay as well as decoupling from their locations. IP-based communication is also called location-based communication and has number of issues like data availability, security, location dependent etc., which is not suitable for future communication and applications requirements.

Initially, the fundamental concept of content based networking approach is described in [4]. In which, the authors propose two new models: called datagram and predicate models. Moreover, they also describe the relationship between traditional and content-based networking. For futuristic Internet paradigm perspective, Information-Centric Networking (ICN) [5] is a newly proposed scheme in which communication is receiver-driven and rely on content names instead of their locations. It provides the more efficient and faster routing mechanism specially in peer-to-peer communication without any need of overlay systems.

Many active ICN project like 4WARD [6], CCN [7], COAST [8], COMET [9], PURSUIT [10], CONVERGENCE [11] etc. are currently working in this arena, in which content centric networking (CCN) [7] more attracts the research community, thanks to the simple, due to its uncomplicated communication procedure. It provides built-in mobility support and nodes do not need to perform handover whenever some node travel from one position to another [12]. By using this approach, there is no need to assign IP address to each participating node. Furthermore, there is no any routing loops exists during communication. Early research on CCN is more investigated in wired networks. However, it also shows its fruitful benefits in wireless ad hoc networks [13], [14], [15], [16], [17], [18], [19].

In CRAHNs, CR nodes need to preserved single end-to-end connection in order to communicate and do not fully exploit the broadcast nature of the wireless channels. Due to channel fluctuations, channel errors and unpredictable PU activity, it is hard for CR nodes to hold accurate routing state and machine-to-machine connectivity.

Therefore, in this paper, by leverages the benefits of simple CCN communication paradigm, we proposed a new fine grained cross layer architecture, named content centric networking for cognitive radio ad hoc networks (CCN-CRAHNs). In CCN-CRAHNs, CR nodes do not need to keep alive machine-to-machine path connectivity in order to communicate specially in the presence of unpredictable channel conditions and PUs activities. In addition, every CR nodes have capability to store the contents, which is further unique characteristic of proposed scheme to reduce the content retrieval latency in the network.

The rest of the paper is organized as follows. In Section 2, we describe the proposed architecture in detail. Section 3 provides the simulation results and analysis, and finally the conclusions are presented in Section 4.
II. PROPOSED ARCHITECTURE

Fig. 1 shows the proposed cross-layer architecture of CCN-CRAHNs. At the bottom, spectrum sensing, sharing and mobility are performed by conventional cognitive medium access control (MAC) and Physical (PHY) layers.

![Proposed CCN-CRAHNs architecture](image)

However, in this work, our focus is only on upper layers. We introduced a new layer named CCN layer in the stack, in which content names are used for communication instead of IP addresses. In addition, two types of messages named Cognitive Radio Interest (CR-Interest) and Cognitive Radio Data (CR-Data) are proposed for CCN-CRAHNs. Both CR-Interest and CR-Data messages contain the following important fields as shown in table I and II. In CCN-CRAHNs, each CR node has two types of tables, named Content Store (CoS) and Unsatisfied Interest Table (UIT). CoS is used for the storage of data contents while UIT keeps tracking of the CR-Interest messages. Proposed CCN-CRAHNs further introduce four main components: CCN-Cognitive Strategy, Security, Caching, Naming. In next sections, each component is described in detail.

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR-Interest Name</td>
<td>Requested content name</td>
</tr>
<tr>
<td>CR-Interest Lifetime</td>
<td>It shows the lifetime of the CR-Interest and specified in seconds</td>
</tr>
<tr>
<td>Nonce</td>
<td>Random value use to avoid duplication of CR-Interests</td>
</tr>
<tr>
<td>Channel Information</td>
<td>Contains the PU activity free channels information</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR-Data Name</td>
<td>Requested content name</td>
</tr>
<tr>
<td>CR-Data Length</td>
<td>Length of the requested content</td>
</tr>
<tr>
<td>CR-Data Content</td>
<td>Actual data payload</td>
</tr>
<tr>
<td>Channel Information</td>
<td>Contains the PU activity free channels information</td>
</tr>
<tr>
<td>Signature Type</td>
<td>That represents the type of signature such as SHA256 etc.</td>
</tr>
</tbody>
</table>

A. Naming Mechanism

All contents naming related activities are considered in this component. Since the communication in CCN-CRAHNs are based on content names instead of their locations, so naming is an indispensable module of the proposed CCN-CRAHNs architecture. Basically, proposed scheme uses hierarchy based naming scheme for the sake of simplicity. In this scheme, the content names are represented such as URI (i.e. Content/Broadcasting/Image/V1), which are highly expressive, human-readable, and customized. Other naming schemes like flat naming can also be used. However, it should be persistent and normally naming technique depends upon applications requirements.

B. Security Mechanism

In proposed CCN-CRAHNs architecture, each CR-Data message has a signature over the actual data and its name which is produced by a key information that is included besides the actual data in a packet. In traditional IP-based CRAHNs, we need to secure data plus channels itself as well. On the other side, in proposed scheme, we only need to secure our contents. In CCN-CRAHNs, every CR nodes experience robust security procedures which are decoupling from their locations. Moreover, in CCN-CRAHNs, it is difficult for an adversary or attacker to find some victim based on its location. Therefore, well-known attack such as distributed denial of service (DDoS) is almost impossible in this environment, in which many nasty agent and handler nodes send their traffic to some specific victim nodes based on their location.

C. Caching Mechanism

Unlike IP-based CRAHNs, proposed scheme provides in-networking caching mechanism which is one of the unique feature of it. Through this mechanism, the content availability in the network is also increased. In traditional approach, every content packet is fetched based on its source location information. However, in CCN-CRAHNs, if available, the relay CR nodes can also send the desired contents to the requesters. As a result, the content retrieval time is also reduced. Due to rapid proliferation in technology, each communication device has huge storage capacity. In CCN-CRAHNs, all CR nodes also have capability to store contents packets and least recently used (LRU) technique is used for contents replacement in CoS. In addition, different other cache replacement and decision techniques [20] can also be used in this regards.

D. CCN-Cognitive Strategy

In this section, the core processing of proposed CCN-CRAHNs is described in detail. CCN-Cognitive strategy module deals with all the communication mechanisms of the proposed scheme in cognitive environment. CR-Interest and CR-Data messages utilize the underlying layers information (i.e. primary user activity, channel information etc.). In addition, this module provides the efficient transport and forwarding mechanisms for both CR-Interest and CR-Data messages. CCN-Cognitive strategy contains two further main components, named forwarding and transport which will be explained in detail in next sections.

Fig. 2 describes the basic communication process in CCN-CRAHNs. In which, consumer node S wants to download data from provider node U. It sends a CR-Interest message towards node U which contains the name of the desired data. Node
T acts as relay node and after reception of CR-Interest, it checks its CoS and UIT tables. If there is no any information available, it forwards the CR-Interest message towards node U after adding the corresponding entry in its UIT table. Provider node U sends back the required data towards consumer node S which follows the same UIT table entries. Relay node T also saves the data in its CoS. Furthermore, in future, if some other node R requires the same data, then the node T will fulfill the request by using its CoS.

**Algorithm 1: CR-Interest processing at relay node**

1: If (CR-Interest is Duplicate or Expired) then
2: Discard the CR-Interest packet
3: else if (CR-Interest found in CoS) then
4: Send data back to the requester
5: else if (CR-Interest found in UIT) then
6: Discard the CR-Interest packet
7: else
8: Update UIT table
9: while (PU free channel is not available)
10: If (channel available) then
11: Update channel information
12: Forward CR-Interest packet
13: else
14: Wait for channel availability
15: end if
16: end-while
17: end if

Algorithm 2 exemplifies the CR-Data processing at the relay node. When CR-node receives some CR-Data message, it looks up in its UIT table for any corresponding entry regarding this CR-Data message. If there is not, then the CR node considers it as unsolicited CR-Data message and discards it. Otherwise, it saves the incoming message in its CoS and looks for any channel availability. If there is some channels available, then it updates the channel information in its CR-Data message, discards the corresponding entry from UIT, and forwards it to next nodes.

2) Transport Mechanism: Proposed CCN-CRAHNs also follows some transport operations of conventional transmission control protocol (TCP) from IP-based CRAHNs. Due to mobility and dynamic condition of channels, it is possible that some CR-Interest or CR-Data messages may be lost during communication. Therefore, if some CR-Data messages are not received by consumer CR node within some specific time interval (RTO), it is responsibility of the CR node to send again the corresponding CR-Interest messages, if it still needs the CR-Data.
III. Performance Evaluations

Network Simulator 3 (NS3) [21] is used for simulation purpose and some simulation parameters are shown in Table III. Performance of the proposed scheme is compared with IP-based CRAHNs by taking an assumption that all the CR nodes can get information about primary users activities as well as channels by exploiting some centralized database [22].

<table>
<thead>
<tr>
<th>TABLE III. SIMULATION PARAMETERS</th>
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</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>Propagation Delay Model</td>
</tr>
<tr>
<td>Propagation Loss Model</td>
</tr>
<tr>
<td>Technology</td>
</tr>
<tr>
<td>Routing Protocol</td>
</tr>
<tr>
<td>Area (m×m)</td>
</tr>
<tr>
<td>Tx Power</td>
</tr>
<tr>
<td>Content Size</td>
</tr>
<tr>
<td>Simulation Time</td>
</tr>
<tr>
<td>CoS Size</td>
</tr>
<tr>
<td>Nodes</td>
</tr>
<tr>
<td>Data Rate</td>
</tr>
<tr>
<td>Replacement Policy</td>
</tr>
<tr>
<td>Traffic Type</td>
</tr>
<tr>
<td>Packet Size</td>
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</tbody>
</table>

Initially, we take 10×10 grid topology. In IP-based CRAHNs, AODV is used as main routing protocol. In proactive or geolocation based approaches, nodes need to periodically exchange the information with other nodes. As a result, it makes the routing mechanism worst especially in the presence of PUs and dynamic channel condition in cognitive ad hoc environment. Therefore, we apply reactive message forwarding mechanism in our proposed architecture and also compare the performance with reactive-based routing protocol (i.e. AODV).

Content store (CoS) utilizes the least recently used (LRU) replacement policy and each CR-node can store up to 10000 data packets. Five different types of contents are used in simulations, in which each content consists of 100 to 500 data packets of size 1024 bytes. Total simulation time is 600 seconds and results are averaged value of 10 times simulation runs. Average end-to-end delay is used as a performance metric to evaluate the performance of both approaches (i.e. CCN-CRAHNs and IP-based CRAHNs).

According to Fig. 3, as we increase the number of packets, the average end-to-end delay increases as well in both cases. However, proposed CCN-CRAHNs outperforms as compare to IP-based CRAHNs because in CCN-CRAHNs, CR nodes do not require any end-to-end path establishment as well as maintenance mechanism for communication. On the other hand, in IP-based CRAHNs, before forwarding any data packets, CR nodes need to find and keep active some suitable path from source to destination. Moreover, in the presence of PU activities and channels fluctuations, this condition looks unrealistic and hard to find in dynamic cognitive environment.

In addition, in IP-based CRAHNs, the delay is high because if some path is broken due to some channel errors, CR nodes again need to perform rerouting, which further exacerbates the network performance. However, in CCN-CRAHNs, communication is totally based on content names despite of their locations.

IV. Conclusion

In this paper, we have proposed a new cross layer architecture, named content centric networking for cognitive radio ad hoc networks (CCN-CRAHNs). Proposed CCN-CRAHNs has two unique features as compared to conventional IP-based CRAHNs. First, in CCN-CRAHNs, CR nodes do not need to keep alive machine-to-machine path connectivity in order to communicate specially in the presence of unpredictable channel conditions and PU activities. Second, every CR nodes has capability to store the contents in its CoS which is further unique characteristic to reduce the content retrieval latency in the network. Initially, performance evaluation shows that CCN-CRAHNs performs better than traditional IP-based CRAHNs in terms of end-to-end delay.

As a future work, we will more investigate the performance of proposed CCN-CRAHNs by using real time applications and topologies.

ACKNOWLEDGMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2013R1A1A2005692).

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