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Research Article

Source Routing for Distributed Big Data-Based Cognitive Internet of Things (CIoT)

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Dynamic opportunistic channel access with software-defined radio at a network layer in distributed cognitive IoT introduces a concurrent channel selection along with end-to-end route selection for application data transmission. State-of-the-art cognitive IoT big data-based routing protocols are not explored in terms of how the spectrum management is being coordinated with the network layer for concurrent channel route selection during end-to-end channel route discovery for data transmission of IoT and big data applications. In this paper, a reactive big data-based "cognitive dynamic source routing protocol" is proposed for cognitive-based IoT networks to concurrently select the channel route at the network layer from source to destination. Experimental results show that the proposed protocol cognitive DSR with concurrent channel route selection criteria is outperformed. This will happen when it is compared with the existing distributed cognitive DSR with independent channel route application data transmission.

1. Introduction

In order to utilize the natural available spectrum efficiently, the current static spectrum allocation needs to be switched to dynamic spectrum access [1–4]. To achieve that, the Federal Communications Commission (FCC) has proposed a novel way of accessing the static spread spectrum through "software-defined radio networks." With this, unused spectrum holes or TV white spaces (TVWS) in existing static spectrum can be opportunistically utilized by the secondary users through "cognitive radio networks." With the distributed cognitive radio, an unused primary spectrum band can be dynamically allocated to the secondary users for temporal basis [1, 5–8]. Hence, dynamic spectrum access through "cognitive radio networks" is a prominent solution to sustain for enhanced wireless technologies and increased number of radio users [3, 6, 9, 10]. In addition to this, next-generation Internet connectivity is extending to thing-to-thing connectivity through Internet of Things (IoT). With this, end-to-end application data will be transmitted from thing to thing without any human intervention. This brings new challenges in the end-to-end IoT network connectivity to transmit IoT data. Internet Engineering Task Force (IETF) proposed an open standard protocol stack for IoT with the introduction of different light-weight protocols to existing TCP/IP protocol stack.

IEEE 802.15.4 standard is used to provide the link connectivity among different IoT leaf nodes (sensor nodes). State-of-the-art IoT networks are interconnected with the nonconstrained heterogeneous networks through the wired backbone networks. For traditional wireless ad hoc networks, interoperability with the wired backbone network to heterogeneous networks is mandatory to accommodate aggregated network traffic flows.

Devices linked to the Internet are growing gradually; the era of Internet of Things (IoT) and big data is coming. However, managing big data produced by the IoT networks will present substantial challenges for the conclusion makers. The IoT network is one of the big data sources in IoT. In such networks, a wide range of areas are monitored by thousands of smart sensors where assembled data are sent to the sink node. Unfortunately, IoT impose many challenges compared to other types of networks [11–13]. Data management is a mostly demanding task for IoT due to the huge amounts of data gathered in such networks.

Not all the attributes in the datasets produced are necessary for training the machine learning algorithms. Some attributes are perhaps not relevant, and some might not employ the outcome of the prediction. Removing or avoiding these irrelevant or less necessary attributes reduces the burden on machine learning algorithms [14]. In this article [42], we provide a comprehensive survey on blockchain for big data, focusing on up-to-date approaches, opportunities, and future directions.

However, for IoT application data, it is feasible to provide the backbone connectivity through the wireless broadband network to transmit the aggregate IoT application data to the nonconstrained networks. Since the existing static unlicensed wireless networks are deployed with multiple technologies, the available nonoverlapping channels are saturated and hard to accommodate with the new wireless technologies. Thus, it is effective to make use of dynamic spectrum to transmit the IoT application data from the IoT gateway to nonconstrained heterogeneous networks. To achieve that, this paper proposes a "reactive DSR source routing protocol for cognitive radio ad hoc networks" to transmit IoT data within the cognitive radio ad hoc networks from the IoT gateway to nonconstrained networks. Figure 1 explains the overview of the IoT gateway interconnected with the backbone distributed blockchain-based cognitive radio ad hoc networks to transmit IoT application data. [15, 16] explain how the blockchain technology gets integrated with cognitive IoT networks. Since cognitive ad hoc IoT network works on distributed coordination function, it is worthy to implement the blockchain module along with the distributed-coordination function to efficiently utilize the radio resources through reduced collisions and minimized channel saturations.

In this paper, our main contributions are as follows: distributed source routing protocol for big data-based [17] cognitive IoT is proposed to enhance the end-to-end throughput with minimized end-to-end delay. In addition, the gateway distributed CR routers will also act as IoT gateway nodes to aggregate and encapsulate the IoT data into the distributed cognitive radio ad hoc network.

The rest of the paper is organized as follows. Section 2 explains the pros and cons for the state-of-the-art cognitive routing protocols to transmit the aggregate IoT data. Section 3 briefly explains the proposed "reactive-based dynamic source routing protocol for cognitive-based IoT networks. Section 4 explains the experimental results whereas Section 5 ends with the conclusion and future work.

2. Related Work

End-to-end network performance of the routing protocol in cognitive radio-based IoT networks is mainly based on achievable network throughput, end-to-end packet delays, and node energy consumption. In order to achieve that, common control channel (CCC) [7, 18] plays a significant role to provide efficient end-to-end route discovery and route maintenance during the application packet transmission. It is noteworthy that channel route discovery is concurrently selected from the IoT gateway (source node of cognitive radio) to the destination whereas the default RPL route will be used as an end-to-end route from IoT leaf node to the IoT gateway.

Furthermore, a directional antenna is being proposed to provide increased number of simultaneous noninterfering transmissions within the cognitive radio network [19–21]. This will further enhance the achievable end-to-end throughput in multihop communication with efficient spatial reuse and reduced node power consumption. In other words, directional cognitive control and IoT application transmission will help to attain the increased end-to-end throughput by reducing the interference through directional antennas [21–25]. State-of-the-art routing protocols in "cognitive radio-based IoT networks" use omnidirectional transmission for application data (DATA/ACK) and cognitive control message exchange. But there will be great packet loss and frequent channel route failures due to cochannel interference with both primary users and secondary users [26, 27]. To overcome that, this paper designs a dynamic source routing protocol with directional antennas to transmit control and data transmission using directional antennas from the LBR gateway to the cognitive destination. In general, the IoT application data at the gateway may be destined to either IoT destination or destination of nonconstrained networks (cloud networks). The two different scenarios of IoT application data transmission from the IoT gateway to IoT destination and the IoT gateway to nonconstrained networks are briefly explained in Figures 2 and 3.

3. Proposed Work

State-of-the-art routing protocols in IoT networks are well explored in proactive-based routing protocols (RPL) to transmit the data from the leaf node (IoT end device) to the IoT boarder router. From LLN boarder router (IoT gateway router) to the non-IoT networks, a high-speed wired backbone network is being used to transmit the application data to the destination that are at nonconstrained networks. Using proactive-based source routing from the IoT gateway to the destination of the nonconstrained network is not a feasible solution in terms of control message exchange and the achievable application network throughput. In addition, it is beneficial to use wireless or opportunistic cognitive radio-based networks to retransmit the IoT application data from

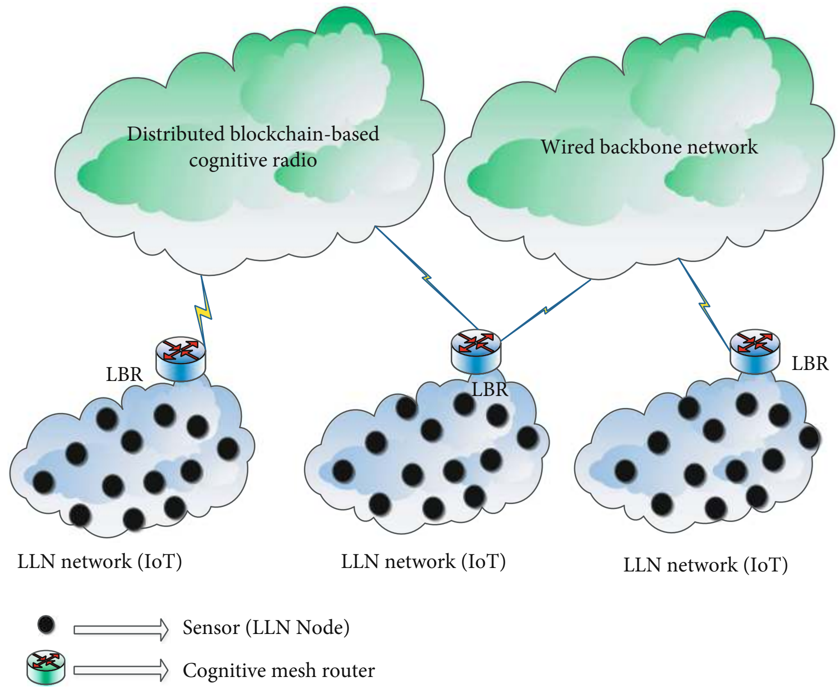

FIGURE 1: Overview of the cognitive IoT network.

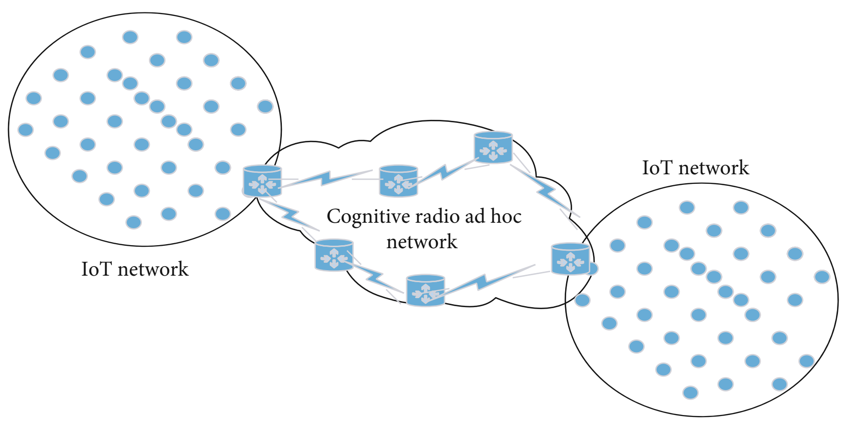

FIGURE 2: Communication between constrained IoT networks through CRAHNs.

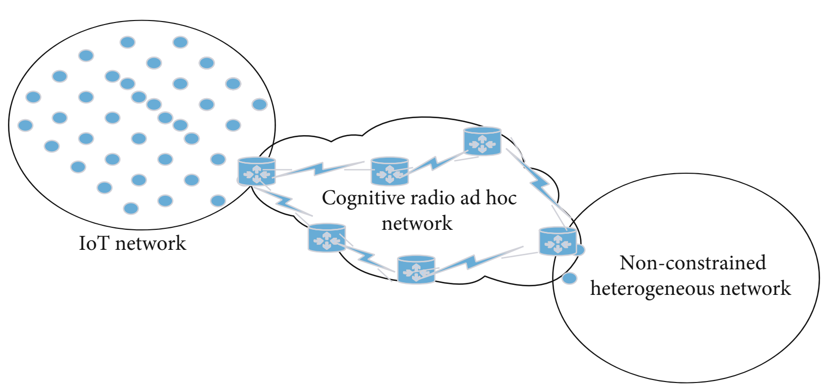

FIGURE 3: Communication between IoT and nonconstrained networks.

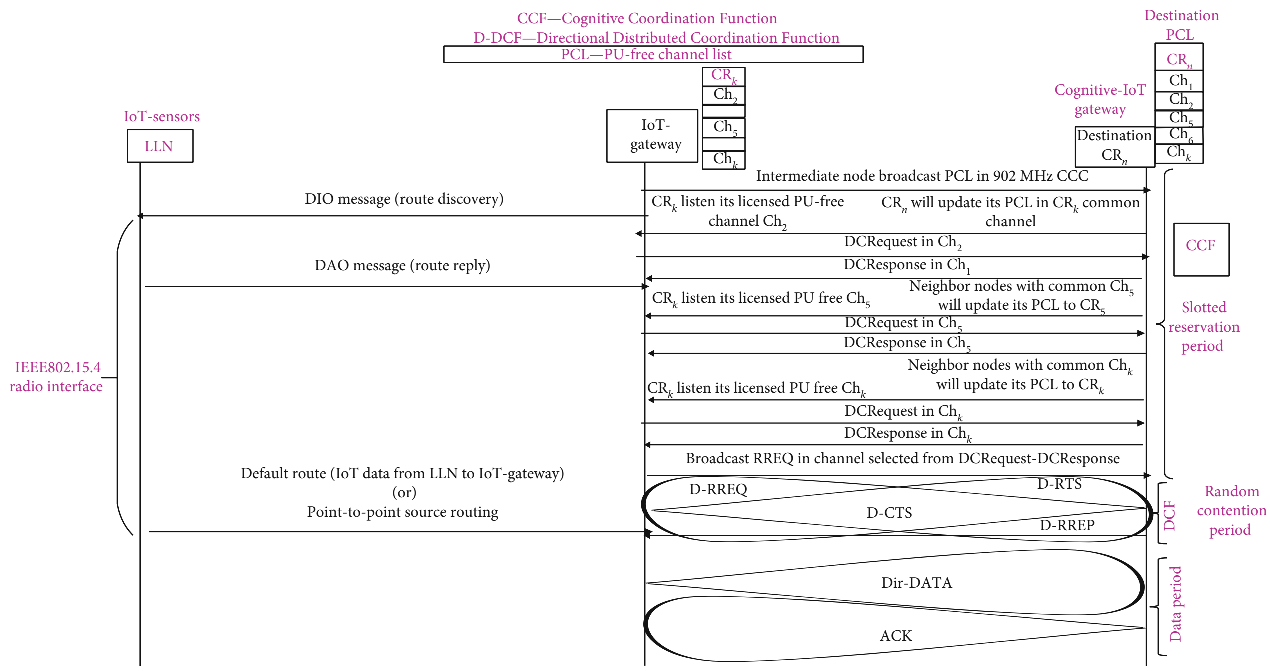

Figure 4: Overview of source routing in cognitive radio-based IoT networks.

the IoT gateway to the nonconstrained destination. To achieve that, this paper proposes a "reactive source routing protocol for IoT networks" to transmit the IoT application data from the IoT gateway to the destination of the nonconstrained network. IEEE 802.15.4 MAC protocol is being used to transmit the IoT application data from the IoT leaf node to the IoT gateway whereas the opportunistic TVWS (TV whitespace) is being used to transmit the IoT application from the IoT gateway to the destination. At the IoT gateway, the IP packet from the IoT network is being encapsulated with IP-in-IP encapsulation to provide the compatibility with the nonconstrained opportunistic-based cognitive radio ad hoc networks. 6lo and ROLL working groups in IETF worked on RFCs (Request For Comments) that enable the IP-based packet transmission from the IoT leaf node to the destination (within IoT network or outside of the IoT network). In general, with proactive-based routing, IoT leaf nodes will be periodically (trickle timer) sending the control messages to its one-hop neighbor nodes to maintain the route connectivity from the IoT leaf node to the IoT gateway. Whenever there is an application data at the IoT leaf node, then it will transmit to the IoT gateway through the proactive-based RPL routing protocol or any other proactive/reactive routing protocols. From the IoT gateway, the application data is being encapsulated and rerouted in dynamic spectrum access-based cognitive radio networks. Figure 2 depicts the channel route discovery overview within the cognitive radio ad hoc network for IoT application data transmission. Whenever there is an IoT application data at the CR source node (IoT gateway), then the CR node tries to find the shortest end-to-end channel route path towards the destination. The existing channel route path is being used if the intermediate node knows the channel path towards the destination CR node. In traditional reactive-based source routing protocols, nodes will record the IP address in its IP header while broadcasting the route discovery messages. Once the route control message reaches to the destination mobile node, it unicast the route reply message based on the IP address within the IP header. When it comes to cognitive radio ad hoc networks, the available PU-free channel needs to be concurrently selected along with the IP address for each and every intermediate CR node between cognitive source and destination. In this work, we considered that there can be a maximum of 256 PU channels that are available for opportunistic IoT application data transmission. In order to concurrently select the PU-free channel along with the channel route path, we have introduced channel ID information along with the 128-bit IP address in "source routing header." The step-by-step procedure to establish a channel route connectivity to transmit end-to-end IoT application data is explained in Figure 4. Firstly, DIO messages will be broadcasted within the LLN to provide the link and network connectivity with the LLN network. From the LLN gateway, the CR node will perform the IP-in-IP encapsulation and reinitiate the RREQ within the unlicensed opportunistic PU spectrum band. Once the RREQ message is reached to the destination CR node, then it will deencapsulate the encapsulated packet and send the LLN packet to the destination IoT node. Subsequently, destination nodes will uncast the RREP message back to the LLN gateway. From the LLN gateway (CR target node), the RREP packet will be encapsulated and sent back to the source CR node (source LLN gateway) through the cognitive radio network with opportunistic licensed spread spectrum.

Once the RREP message is reached back to the originating node, then it will start transmitting the IoT application data within the discovered channel route path. With this,

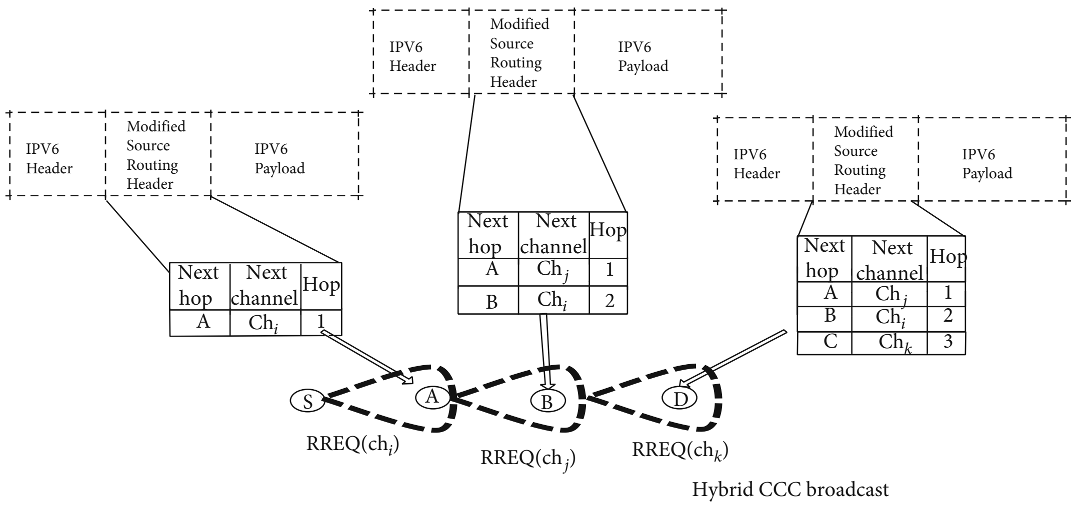

Figure 5: Channel RREQ from source CR node to destination-CR node through hybrid CCC-based source routing protocol.

the IoT application data will be transmitted using the cognitive radio network instead of the wired broadband network for end-to-end communication. Since cognitive radio makes use of the licensed PU-free spectrum band for secondary data transmission, it is crucial to select the reliable channel route during channel route discovery. As shown in Figure 4, there will a PU-free channel list (PCL) available at each and every CR node within the cognitive radio ad hoc network. Since CRAHN operation is based on distributed networking, each and every CR node should be capable of handling the resource allocation and network management. We assume that each and every CR node will have the PU channel list available through the spectrum sensing and spectrum management. In this paper, the authors assume that the PU-free channel is available to every next-hop neighbor CR nodes along with the per-hop link. This can be known through the distributed spectrum management or centralized spectrum management policies at the MAC layer of the cognitive radio ad hoc networks. The detailed operation of how exactly the end-to-end channel route discovery happens at the source (CR) node is explained in Figure 5. Once the channel route discovery is being initiated by the source CR node, then the channel RREQ will be broadcasted in the hybrid common control channel to the next-hop CR nodes. During the channel RREQ broadcast, the source CR node will initially update its 128-bit IP address along with the available PU-free channel (PCL) list to the next-hop neighbor nodes. Since the PCL list and 128-bit IP address occupy more space within the control packets, it is strongly recommended to compress the control information before broadcasting within the hybrid control channel. Once the channel RREQ is being broadcasted to the next-hop CR nodes, then next-hop CR nodes will check the PCL list of the source node with its PCL list. Whenever there is a common PU-free channel available between the source CR node and the next-hop neighbor CR nodes, then only the next-hop CR nodes will rebroadcast the received channel RREQ control messages. Since this paper proposes to work with the source routing-based cognitive radio networks to transmit IoT application data, every CR node will update its IP address within the source routing header of the channel RREQ message (see Figure 5).

Once the channel RREQ message is being reached to the destination CR node, then the destination CR node will initiate the unicast channel RREP message back to the source CR node. In general, when a channel RREQ message is being reached to the intermediate CR node and if the intermediate CR node is having the path to the destination CR node, then the intermediate CR node will send the channel RREP back to the source CR node. Subsequently, the intermediate CR node will initiate the gratuitous channel RREP message to the destination CR node so that the destination CR node will update its routing table with the IP address of the source CR node. Once the channel RREP message is transmitted back to the source CR node, then the source CR node will start transmitting the application data transmission. Figure 6 explains the application data transmission from the source CR node to the destination CR node through the source routing protocol. It is noteworthy that the source routing header will have the PU-free channel along with the 128-bit IP address of the next-hop CR node. In other words, the PU-free channel between every hop from destination to the source CR node will be updated at the time of transmitting the unicast channel RREP message. Later, this channel route from the source header of the encapsulated IPv6 packet will be used to forward the IoT application data from the source CR node to the destination CR node. In general, at the time of application packet transmission, there can be three types of packet failures, namely, spectrum handover packet failures, node mobility handover packet drops, and bandwidth degradation due to high network traffic flows. In this work, the performance of the CR network is being simulated with and without packet failure. In addition, packet drops at the edge of the PU receiver are being tested to check the performance degradation of the source CR routing protocol.

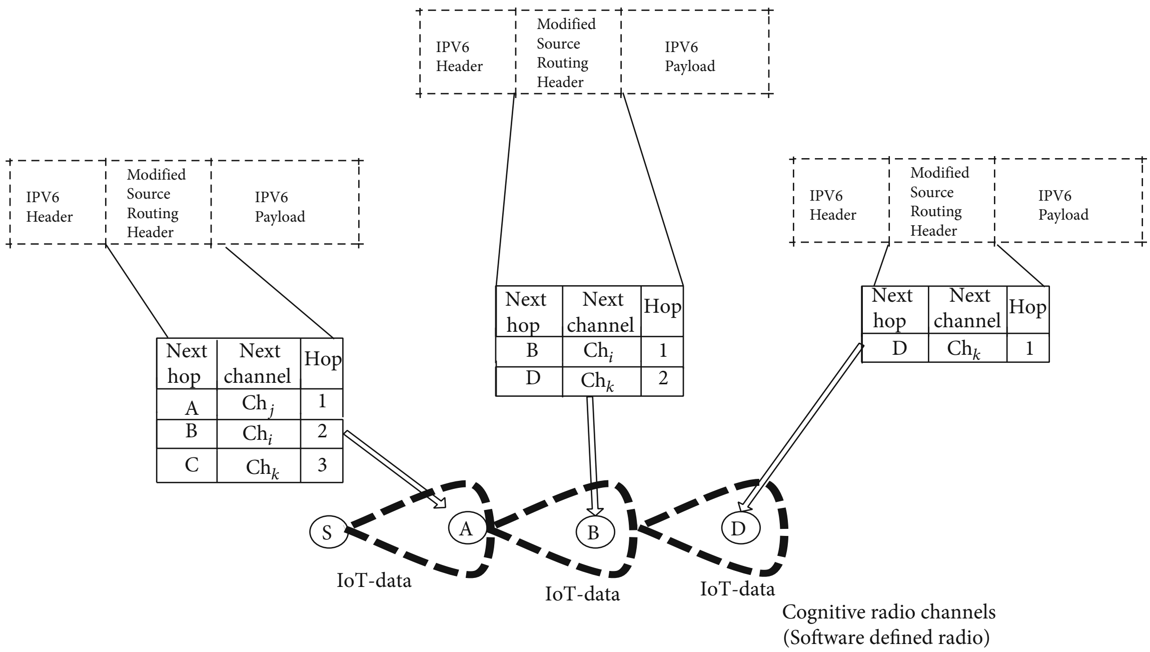

FIGURE 6: IoT application data transmission through source routing-based cognitive routing protocol.

3.1. IP-in-IP Encapsulation at the Source CR Node. Once the IoT application data is being transmitted from the LLN node to the LBR, then the constrained packet will be aggregated and encapsulated to transmit within the cognitive radio ad hoc networks. Once the message is reached to the destination CR node, then the received IP packet will be decapsulated and transmitted back to the constrained destination LLN node. In this paper, the authors assumed that the gateway routers support both the LLN and CR networks. In other words, the interfaces of both the CR network and LLN network will be deployed at the gateway nodes. Thus, the IEEE 802.15.4 standard protocol is being used within the LLN network whereas licensed PU-free spectrum bands are used at range of spectrum bands to transmit the data at the cognitive radio network.

3.2. PU Receiver Protection at CRAHNS. To implement dynamic and opportunistic spectrum access in software-defined cognitive radio, FCC introduces a fundamental requirement of "peaceful" coexistence between primary and secondary users. Hence, it is extremely important to protect the primary user communication during cognitive radio communication. In general, it is very hard to predict the PU receiver communication at the edge geographical location (see Figure 7). During cognitive radio communication, the highest spectrum utilization should be achieved by detecting all spectrum opportunities and accessing the spectrum so that collisions with the other secondary users get minimized. In addition, synchronization between the secondary transmitter and the primary receiver is also required to avoid the interference for both cognitive and primary networks. CR nodes that are close to the PU transmitter need to find out which PU spectrum bands are being used by the PU transmitter. In addition, it is equally important to know whether there are continuous data transmissions occurring or noncontinuous data transmission is being done within the primary transmitter spectrum bands. It is extremely hard to concurrently transmit the primary and secondary data within the continuous transmission. But, in the case of noncontinuous PU transmission, secondary nodes can make use of the PU spectrum band opportunistically without interrupting the primary user transmission. Let us consider that there are CR nodes that are located in 3 layers within the no-talk zone in Figure 7.

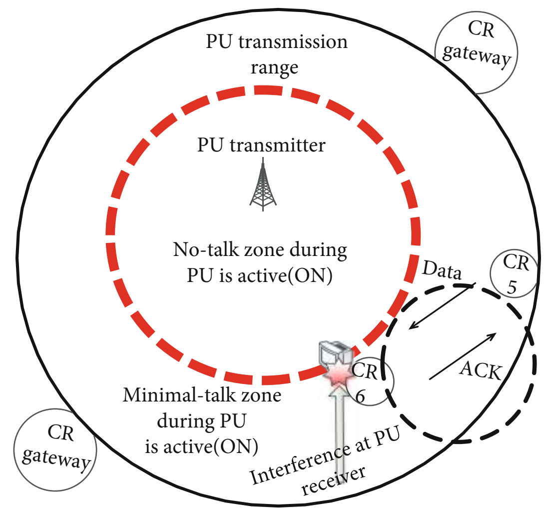

FIGURE 7: PU receiver protection for IoT data at CRAHNs.

Level 1 area coverage is $\pi R1^2$.

Level 2 area coverage is $3\Pi r2^2$.

Level 3 area coverage is $5\Pi r3^2$.

Let us consider the area that is being covered by CR nodes within the minimal-talk zone:

Level 4 (minimal talk) area coverage is $7\Pi r4^2$.

In general, the area covered by the N layers within the no-talk zone is as follows.

Level N area coverage is $(2N-1)\Pi rN^2$.

The probability of the CR node that is being transmitted concurrently with the PU spectrum band in the no-talk zone is

$$\begin{aligned} P_T(r) &= \text{probability of CR transmission in level}_1 \\ &\quad + \text{probability of CR transmission in level}_2 + \cdots \\ &\quad + \text{probability of CR transmission in level}_n \\ &= \frac{(2r-1)\pi R_1^2}{n^2\pi D^2} + \frac{((2r+1)-1)\pi R_2^2}{n^2\pi D^2} + \cdots \frac{(2r-1)\pi R_n^2}{n^2\pi D^2}, \end{aligned}$$

$$P_T(r) = \frac{1}{n^2}\sum i = r^n\,(2i-1). \quad (1)$$

Equation (1) explains the general formula to calculate the level range with respect to the PU transmitter.

4. Experimental Results

The cognitive radio network simulator (NS-2.35) is used to simulate and check the performance of the proposed source routing-based cognitive source routing protocol for IoT application data [28–34]. In this work, we assume that the IoT network is being simulated in the Cooja simulator to reach the IoT data from the LLN node to the LNN gateway node (LBR) which also acts as a cognitive source node. Once the packet is reached to the CR source node, then the packet gets encapsulated with IP-in-IP encapsulation and is transferred through the cognitive radio network simulator. The simulation parameters are incorporated in Table 1. A practicable end-to-end cumulative network throughput within the CRAHNs is a subject matter to the channel route detection and restoration delays through local/global channel route recovery mechanisms. In addition, in the current CR communication channel, primary node transmitters are active randomly from 15th to 45th in available 8 MHz TV channels.

Due to this, the PU spectrum handoff probability is higher as compared to the nonexistence of active PU transmitters. Hence, the performance of source routing is being tested with different PU transmitter nodes to calculate the aggregate network throughput of IoT data within the CR ad hoc network. The performance of the cognitive source routing protocol is compared with the existing hybrid cognitive AODV routing protocols, licensed control channel-based AODV routing protocol, unlicensed AODV-based routing protocol, and traditional multichannel-based IEEE 802.11 DCF-based routing protocol. Figure 8(a) represents the comparison of delivery aggregate network throughput between existing protocols and the hybrid source routing protocol. It can be clearly seen that as the data rate increases, the network throughput for hybrid source routing performs better than hybrid cognitive AODV, licensed source routing, etc., since the routing table overhead is reduced by storing information in the network as well as packet.

Table 1: Simulation parameters.

Parameters	Descriptions
Topology type	1000 * 1000 flat grid
Number of cognitive radio nodes	10-100 nodes
Number of primary user channels	8 MHz channels
Number of primary user transmitters (PUT)	1-10 nodes
Unlicensed channels	ISM-902 MHz
Primary user active probability	10, 15, and 20 msec
Type of mobility model	Random waypoint model
Input of CR transmit power	10 mW
Receiver's threshold value	-95 dbm
Carrier sense (CS) threshold	-115 dbm
Cognitive radio transmitter (Tx) range	200 m (licensed channel)
Primary user transmitter (Tx) range	500 m (licensed channel)
Network data rate (DR)	2 Mbps
Interface queue length	50
Simulation time (s)	100 sec

Also, in dynamic environment where PU behavior is unknown, the route recovery process is faster in the case of source routing. Similarly, Figure 8(b) compares the average throughput with data rate 1024 bytes/sec. Figures 8(c) and 8(d) demonstrate the average end-to-end Delay for the hybrid source routing (HSR) approach.

The simulation is done for 200 ms with data rate of 512 and 1024 bytes, respectively. The HSR approach discovers multiple routes to a given destination which takes time. However, in a cognitive radio channel, switching occurs frequently due to dynamic PU behavior which results in obsolete links. Thus, having an alternative route will help in node to resume its transmission with minimum switching delay. Also, route cache property helps in faster route discovery. Hence, the delay is comparatively less when compared with cognitive AODV which requires a large number of control packets which link failure occurs. Figures 8(e) and 8(f) demonstrate the performance of HSR comparing average throughput to no. of PU transmitters. With the increase in the number of transmitters, the channel occupancy increases. Hence, the coverage area of the channel is decreased resulting in the use of multiple channels to make end-to-end connectivity. The number of links increases the probability of link failure increases. Even with multiple backup links in the HSR approach, there is drop in the throughput. However, HSR performs better than cognitive AODV-based routing due to its feature of channel route caching, less channel route control overhead, and rapid discovery time.

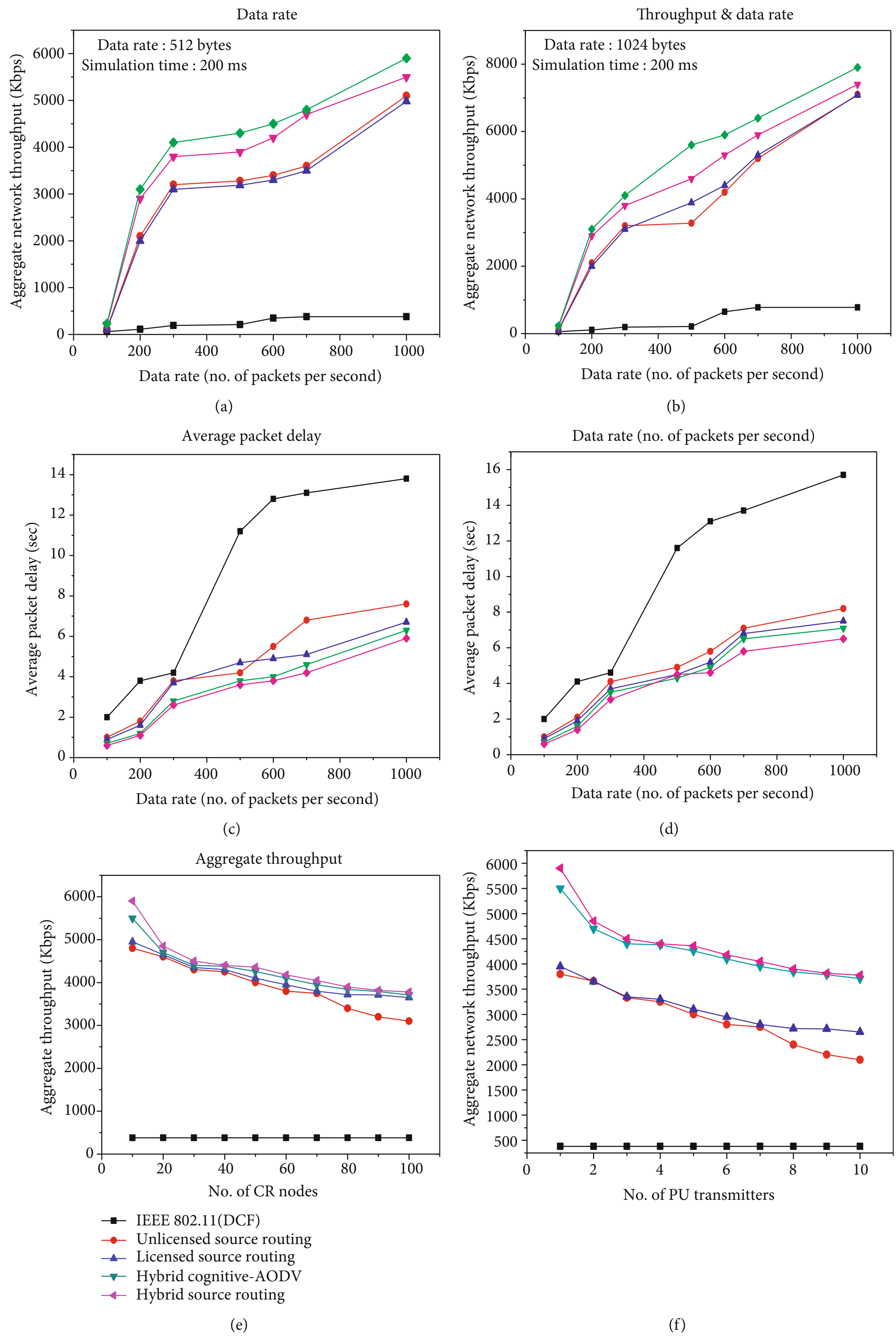

Figure 8: (a) Data rate, (b) throughput and data rate, (c) average packet delay, (d) average packet delay and data rate, (e) aggregate throughput, and (f) performance analysis of proposed source routing-based distributed cognitive IoT networks.

5. Conclusion

End-to-end channel route failure, spectrum mobility, and node mobility at the intermediate CR nodes during application data transmission play a significant role in the performance of distributed cognitive IoT networks [35, 36]. In this work, the distributed source routing protocol for big data-based [17] cognitive IoT is proposed to enhance the end-to-end throughput with minimized end-to-end delay. In addition, the gateway distributed CR routers will also act as IoT gateway nodes to aggregate and encapsulate the IoT data into the distributed cognitive radio ad hoc network [37]. The detailed simulation for each and every channel route failure with respect to different performance metrics will be analyzed as a future work. In the future, directional antenna-based source routing is planned to be implemented within the current cognitive source routing to efficiently reuse the unlicensed spectrum bands, minimize the interference, and enhance the achievable aggregate network throughput.

Data Availability

All the data are available in the paper.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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