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A Novel Channel Sensing Mechanism for Cognitive Radio Systems

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ABSTRACT: Cognitive Radios have emerged as one of the most creative and innovative concepts to ensure that the unutilized and infrequently used portions of the spectrum can be allotted to new channels to ensure maximum utilization of the spectrum. There are several challenges involved in designing and implementing a cognitive radio. The first step of using the unallocated or unused channel is to sense if such channels are present. The channel sensing mechanism should also co-ordinate the new channels with the existing ones. In this paper, a new channel sensing mechanism has been designed and implemented. The challenges in implementing the proposed methodology included the design and configuration of the parameters for a network that is as close to the real-time network as possible. A simple network of 8 nodes has been considered and the channel sensing mechanism has been designed for specific values of bandwidth, data packet drop rate, and background traffic. The design considered many technical parameters to ensure that the existing channels are not disturbed due to interference from a new channel. The design was implemented on the QualNet simulator with a set of parameters. The results are analyzed to highlight the efficiency of the proposed channel sensing mechanism. The study can be extended to many nodes with more technical complexity similar to realtime networks. The contributions of this paper extend to the design of the network parameters and the implementation of a novel channel sensing mechanism.

Keywords: Ad-Hoc, Channel sensing, Cognitive Radio, Packet radio networks, Quality of service, Radio communication, Radio spectrum, Sensors.

I. INTRODUCTION

The Spectrum allocation in the networks is one of the most debated and researched topics in networks. The allocation of the spectrum is static in the traditional networks. The wireless spectrum is licensed and used by the organizations for the long term to cover large areas of geography. The rapid increase of the users and the organizations using the spectrum has created scarcity for new channels. It is obvious that the physical parameters do not let the authorities to expand the existing spectrum. However, the best use of the spectrum by using unallocated spaces is the only solution. It is also evident that a large portion of the wireless spectrum is not used frequently. The solution of dynamically using the channel and the spectrum for the efficient utilization of unallocated and sporadically used channels is the concept of cognitive radio.

The spectrum can be dynamically accessed and used for data transmission using a wireless medium with the concept of cognitive radio. The heterogeneous architectures of wireless networks and the allocation of spectrum using dynamic techniques have enabled the cognitive radio to be implemented in several applications.

The cognitive radio allowing the users to use the spectrum on an opportunity basis. It effectively allows the and used unallocated spectrum frequencies to be used by new users with no interference to the existing transmissions. The spectrum access is dynamically designed, and the techniques use different spectrum management methods.

The architecture of cognitive radio networks is discussed and analyzed with respect to the proposed design and implementation. There are certain components in the network architecture such as unlicensed band, licensed band 1 and 2 and primary networks. The spectrum allows both licensed and unlicensed bands to be operated in the same spectrum to transmit the data. The licensed band 1 involves a primary base station which is connected to primary network access for data transmission [5]. The network access is then connected to a cognitive radio base station with the help of a spectrum broker which is in turn connected to other cognitive radio networks from different locations.

The primary user connects to the primary base station wirelessly to communicate with the devices from the same or another network. The unlicensed band does not have a primary base station instead of the cognitive radio user directly connects to other users without the bridge of the primary base station. Licensed band 2 is a unique network in the spectrum that allows the primary user to connect between other users without the interference of network components. A peer-to-peer network configuration is allowed in licensed band 2. The Ad-Hoc network configuration is also allowed so that cognitive radio users can form a network among themselves for data transmission.

The spectrum management framework has five layers - application, transport, network layer, link layer, and physical layer. These layers are arranged in such a way that the data is transmitted from the physical to the application layer.

The spectrum mobility function is the block in the architecture that ensures the data, during transmission from one layer to another layer, is in sync with the network parameters. The channel sensing, links, routing information, delay due to handoff and loss, and the control of all the applications are managed by the spectrum mobility function [3]. The spectrum decision function is another block that is responsible for the configuration of all the parameters across the layers. The quality of service requirements at the application layer is exchanged between this block and the application layer. The reconfiguration of the data routing and the routing information required for the data packets is also exchanged between the transport and network layer. The scheduling information is the responsibility of the link layer which is monitored by the spectrum decision function. The channel sensing information, the focus of this research, is the communication between the physical and link-layer with respect to the decision function.

The basic functions to be executed by the cognitive radio are sensing and analysis, management and head off, and allocation and sharing. These functions should be executed in the appropriate order and efficiency so that the data transmission and efficiency are maintained in a cognitive radio network. Spectrum sensing and analysis is a function that detects the white spaces in the spectrum to check if any portion of the frequency band is used by the current users. It is also possible that certain users are not using the spectrum at the current time which is available and recognized as white space. Once the white space has been sensed, the spectrum management functions will be initiated which allows the users to find the frequency and hopping mechanism suitable for the data transmission. There are various time and frequency characteristics that should be met to meet the required quality specifications for the current users who initiated the data transmission in the spectrum. It is also possible that the primary users and secondary users share the resources available in the spectrum for data transmission. The design of a sharing mechanism is exclusive to each cognitive radio. The efficiency is also influenced by the spectrum management functions.

There are various challenges involved in sensing the spectrum in a cognitive radio network.

Multi-user network: The biggest challenge when the spectrum is sensed for available channels in the presence of multiple users in which the environment will consist of several primary users. The multi-user environment is complex because each user in the network will have different requirements which may interfere with the functionality of the existing spectrum sensing technique. It is also possible that each user requires a specific value of the network parameters that should be considered during the implementation of the channel sensing mechanism [2].

There are certain challenges involved due to the interference of the temperature and other physical parameters in a channel. The cognitive radio networks allow the channel sensing mechanism and data transmission features to be functional only if certain physical parameters are within the limits. The interference temperature and other parameters that are responsible to influence the efficiency of the data transmission are to be analyzed before the channel sensing and data transmission is implemented.

The efficiency of the spectrum and channel - The channel sensing mechanism is the first step and it cannot be carried out when the data transmission is active. It is, therefore, necessary that the sensing mechanism monitors the activity of data transmission before any sensing mechanism is initiated.

The latest research in the field of channel sensing in cognitive radio networks is concentrated towards sensing of multiple channels and the status of resource allocations [19], energy efficiency in using the concept of cooperative sensing mechanisms [20] and idle times [21, 22]. However, these approaches do not offer high accuracy while keeping the lowest packet drop ratio, the highlight of the proposed system.

II. RELATED WORK

Spectrum sensing in cognitive radio is a hot topic for researchers in the network field. The opportunistic spectrum sensing concepts has a particular set of research challenges and opportunities to be explored. There are various types of spectrum sensing mechanism with respect to cognitive radio. Different types of spectrum sensing mechanism and the technical specifications of the same are reviewed in brief.

Cognitive radio spectrum sensing can be proactive or reactive. Proactive sensing is sensing the unutilized channels all the time and keeping the data of the new channel space to be allocated ready at all times. A reactive mechanism, on the other hand, senses the channel when there is a requirement for the allocation to a new channel within the same spectrum. The standards used in deploying the spectrum sensing mechanism are IEEE 802.11k, IEEE 802.22, and Bluetooth. The approaches are simple with internal sensing, external sensing, Beacon, and Geo-Location with the database. These approaches define the mechanism and its basis on which the sensing mechanism has been designed and implemented. Another approach is the concept of cooperative sensing in which the local or cooperative (centralized or distributed) sensing is implemented [1].

The algorithms used for sensing the spectrum consider one or more parameters as a Priority in designing the system. The technical parameters such as energy, spectral correlation, radio identification, or waveform-based sensing may be used in cognitive radio. There are certain design implementations in which multidimensional spectrum sensing has also been implemented.

The dynamic allocation of resources in cognitive radio networks has been discussed in the literature. The dynamic environment of cognitive radio does not follow a simple and effective method to sense the spectrum and other resources. The heterogeneous services in cognitive radio networks require certain imperfection in the channel sensing mechanism.

The power and channel allocation issues have been overcome using a mixed-integer programming method

using technical constraints. The optimal power allocation issue has been addressed first in the implementation; the challenge has been addressed by using a stochastic Optimization mechanism [2].
In certain cases of cognitive radio networks, the channel with multiple data transmission in place is not known. The channels in such a case are sensed in the descending order of the values of technical parameters until an optimum channel has been detected [18]. The resource utilization using this method is efficient because the available channels and the spectrum have already been arranged in the order of the technical parameters and resources available. The probability of collision, in this case, decreases because the unlikeliest of the available channels for data transmission has been neglected in the first place, as per the design parameters [3].
Energy Efficiency is another important parameter that should be considered in the design of the channel sensing mechanism. The energy efficiency has been considered as the primary parameter in designing an efficient channel sensing mechanism in the literature. Energy Efficiency is a requirement because both transmission and channel sensing mechanism consumes energy which is a crucial and scare resource for the network [17]. The power levels of the sensing mechanism are determined and then the channel has been identified. The sensing order of the available channels with specific technical parameters is prioritized during the implementation of the channel sensing mechanism. Therefore, the design of the sensing mechanism prioritizes Energy Efficiency by designing an order, and parametric formulation has been used to determine the same. Energy Efficiency requires an optimal mechanism and strategy which requires the combination of several approaches [4].
The channel sensing mechanism cannot be extended to sense every channel available because of a limited number of resources and consumption issues. There are certain hardware limitations which do not let all the channels to be sensed. A matrix completion and resource allocation method has been proposed which works in combination and checks the information of multiple channels [7]. A large number of reports are analyzed before the required channel has been identified for the given parameters. The design has been efficient and considered in the implementation of the proposed design [5].
There are several challenges involved in implementing the spectrum sensing mechanism. The details of the hardware employed in the network design and the security of the network data are the major challenges. The technical aspects of frequency, duration, user profile, and decision-making mechanism are other challenges that should be overcome during the design of the channel sensing mechanism for cognitive radio [1].The research loopholes and the implications of the current research is that the channel sensing mechanism has been discussed in the literature with respect to many traditional approaches that are related to the basic characteristics of the process such as energy efficiency. However, the issues such as packet loss is often ignored.

III. DESIGN

To ensure that the quality of service provided by the wireless network during transmission the following points should be implemented appropriately [12].
(a) Determination of the spectrum portions that are available for wireless transmission without disturbance to the existing channels [6]. This is the first and foremost requirement of a cognitive radio network in which the portions of the spectrum that are rarely used and not used at the current point of time are to be allocated to the news channels in the spectrum. The determination of this unallocated and used spectrum is the task of the design. The design should be modeled in such a way that various methods are used to determine if the allocated frequency is available for new channels or not.
(b) Selection of a channel - Once the unused and available channel in the spectrum has been identified; the best available channel within the spectrum should be selected. There are several technical requirements in selecting the channel for appropriate wireless transmission.
(c) The other users who are already using the available spectrum for wireless transmission should be coordinated with the new channel who is the latest entrant to the existing spectrum of cognitive radio. The coordination between the new and the existing users is one of the challenging tasks because the wireless transmission is always dynamic and does not what follow the predicted operations [8]. There could be several undesirable and unforeseen situations during the data transmission which may cause interference or signal degradation for the new is the existing channels of wireless transmission.
(d) It is also important that the channel should be vacated when a licensed user demands to use the spectrum for transmission.
The design of the channel sensing mechanism is explained as in Fig. 1. There are several technical parameters considered and a set of steps help understand the process as shown in Fig. 1.
All the available channels are scanned and with the preset bandwidth value. The bandwidth value has to be determined for particular channels and frequencies based on the number of channels available. The bandwidth value can also be changed before the process [9, 11]. The value also depends on the number of channels and the amount of data transmitted through the wireless.
– During the scanning process, the specification including the value of other channels is stored in the database.
– After the scan process is completed and all the details of the channels available are stored for analysis, the next step is to check if the channel/destination is available to be reached. If the channel is reachable, the next step of technical specs such as the details of data packets is to be analyzed.
– If the destination is available for transmission, the flag status is set to 1, which indicates that this channel is available.

The flag status indicates to all the other channels and the new channels scanning for other destinations that this destination has been reserved for a particular channel [16].
The flag value is also set to 1 until all the data packets are transmitted.

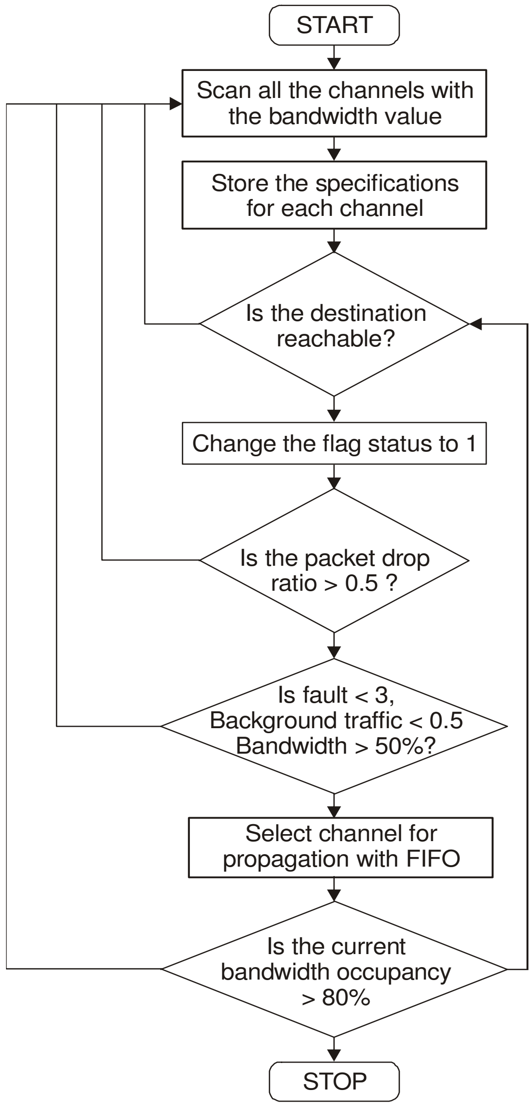

Fig. 1. Flowchart of the proposed algorithm for channel sensing.

The packet drop ratio is determined in this step. The packet drop ratio should be greater than 0.5 so that there is a minimum number of packets that are lost during transmission. This value is determined for the specific number of packets transmitted and reached the destination.
– The second set of parameters includes fault, background traffic, and bandwidth. If the fault value is <3, background traffic <0.5, and bandwidth >50%, a Particular available channel can be selected for transmission.
– The channel is selected for data transmission and the data packets are sent in FIFO order.
– If the bandwidth has reached over 80%, it is an indication that the transmission is complete. If the bandwidth is less than 80%, then the above steps from 4 are repeated until the bandwidth reaches 80% or the value which has been present in the design.

Tools used for design and implementation: The analysis of the existing tools and why QualNet has been selected to implement the project is discussed as follows:
QUALNET: QUALNET is based on the GloMoSim used by Scalable Network Technologies (SNT) and has a full graphical user interface to accomplish almost all the jobs. In NS2, the interfaces are limited and programming is required for every functionality [10]. QualNet can support real-time speed to enable developers and network designers to run multiple analyses by varying models, networks, and traffic parameters in a short time [13]. It can model thousands of nodes by taking advantage of the latest hardware and parallel computing techniques. It is a very powerful simulation tool that can support the simulation of 500 to 20,000 nodes.
QualNet can run on the cluster, multi-core, and multiprocessor systems to model large networks with high fidelity. It also facilitates to design new protocol models and to optimize new and existing models it facilitates the users to change the backend code to achieve our functionality or logic.
NS3: NS3 needs a lot of specialized maintainers in order to avail of the merits of NS3 as the commercial OPNET network simulators. Active maintainers are required to respond to the user questions and bug reports, and to help test and validate the system. Implicitly, it does not show all the graphs like propagation delay, throughput, latency, link utilization as shown in QualNet.
OMNeT++: This tool is free for academic and non-profit use. Commercial users must obtain a license. It does not offer a great variety of protocols and very few protocols have been implemented, leaving users with significant background work. Poor analysis and management of typical performance and the mobility extension is relatively incomplete.

IV. RESULTS

Five channels are considered and configured in this particular design with different bandwidths. Technical specifications such as packet drop ratio and background traffic are also different for each channel. The design is such that the traffic from nodes 1 to 5 should reach Node 8 as depicted in Fig. 2.

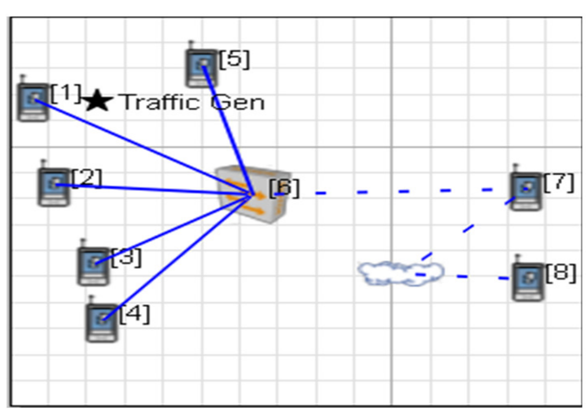

Fig. 2. The network Diagram of 5 nodes 1-5 ready to send data packets to destination node 8.

The MAC protocol 802.15.4 has been used for the design. The poll interval has been set to 1 second and the device type is set to Reduced Function Device (RFD) [14, 17]. The device type ensures that they are one-way communication channels which are able to only transmit the data. There are several other technical specifications such as super frame order, device starting time, device ending time, and configuration of MAC address which are appropriately set in the design as demonstrated in Fig. 3.

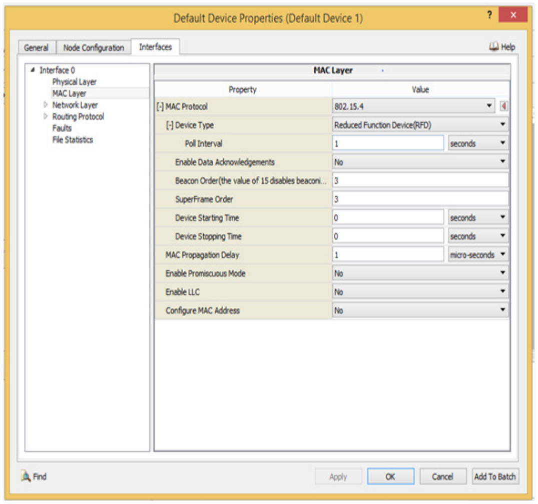

Fig. 3. Device properties for the proposed design.

Once the parameters of nodes 1 to 5 have been set, the design of nodes 7 and 8 are configured as fully functional devices. These devices communicate with both end-user and the base station and hence they are configured as fully functional. The appropriate technical specifications have been set in the software tool as shown in Fig. 4.

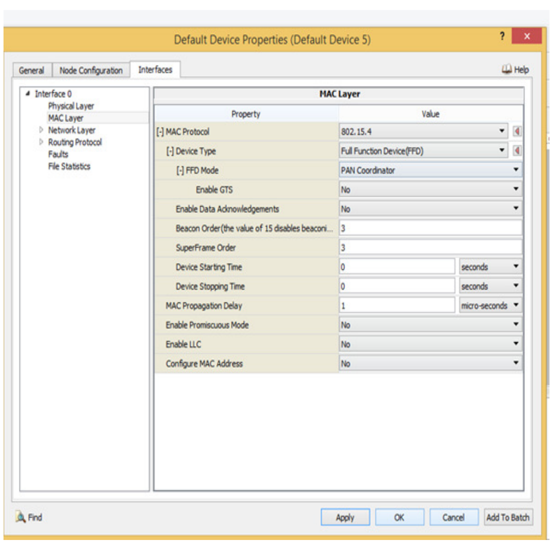

Fig. 4. Device properties for sender and receiver nodes.

Once the data of parameters and the channels are defined in the tool, the nodes start sending the data in First-In-First-Out (FIFO) order. The data will be enqueued before sending the first data packet as explained in Fig. 5.

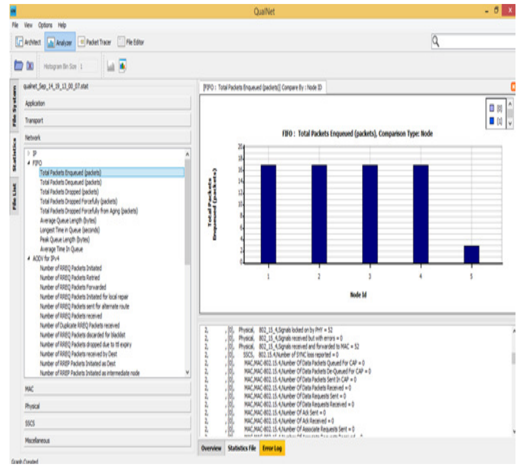

Fig. 5. Transmission of Data Packets.

To avoid packet-drop in the network, the enqueued data packets are to be dequeued in case the load is more, and the data packets cannot be delivered due to the traffic density. This phenomenon has been illustrated in Fig. 6.

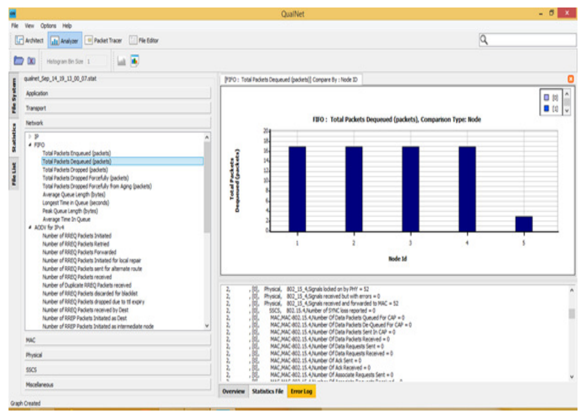

Fig. 6. Data packet drop due to channel not available for transmission.

The data transmission uses the File Transfer Protocol (FTP). The number of data items has been set to 100000. There are several properties of the file transfer protocol which can be modified as required in the software tool, as in Fig. 7.

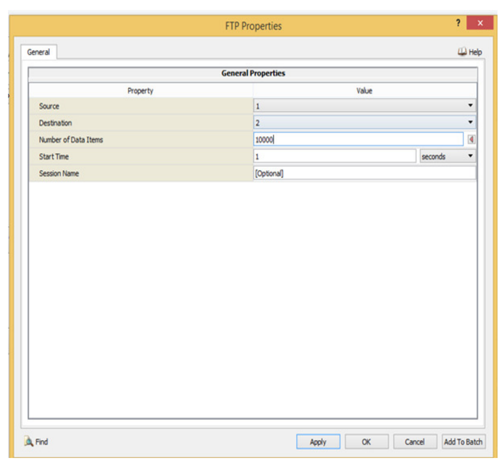

Fig. 7. File Transfer Protocol properties.

Data packet technical specifications have been set in the previous steps. The next step is to configure the network parameters that use 802.15.4 protocol with details such as gain, efficiency, loss and other parameters. The same has been indicated in Fig. 8.

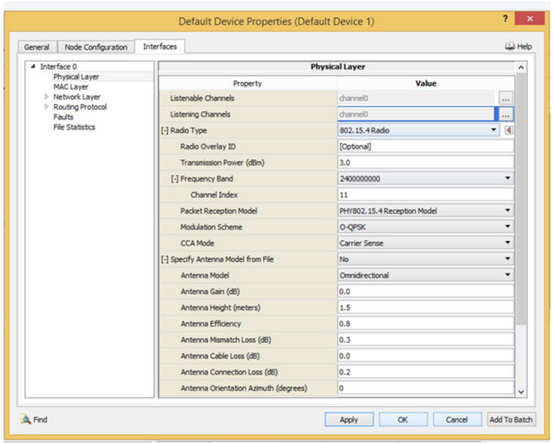

Fig. 8. Device properties and modulation methods schemes for the data transmission.

The transmission power has been set to 3.0 dBm. The channel index 11, O-QPSK modulation scheme with carrier sense mode activated. The antenna height is set to 1.5 meters and efficiency 0.8.

With all the parameter set and the data transmission in place, the details of the signals and data packets that have been transmitted from each of the RFD devices are analyzed in the next step [17]. Signals transmitted are compared for each node and the data shows that there are several signals transmitted from each node to compete with each other and reach Node 8, as shown in Fig. 9.

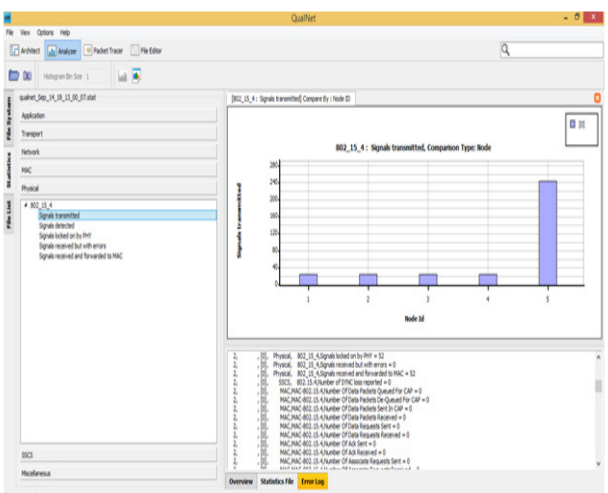

Fig. 9. Comparison of signals transmitted through different nodes in the network.

It is clearly shown that node 5 has the highest data transmission which has more chances of reaching the destination node.

It is possible that certain channels cannot be chosen properly during transmission. The number of channels not available for transmission should be minimal. If there exists any such channel, the data packets will be dropped which will result in the degradation of the signal. Node 1 has many packets lost because the channel was inappropriately chosen, as indicated in Fig. 10.

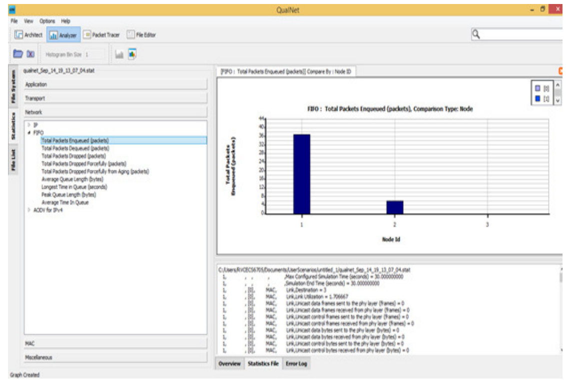

Fig. 10. The total number of data packets enqueued in the process compared to all the nodes.

The channels that send the data packets have full bandwidth and have been selected for transmission. The rest of the channels do not send data packets.

V. ANALYSIS

The proposed design is a simple and effective method of channel sensing which considers various technical parameters [15, 16]. The design shows that a flag status is used to ensure that the current mechanism is in progress. The data packet drop ratio is taken as 0.5 which is a standard across the network design. The fault level is 3 and the background traffic 0.5. The maximum bandwidth utilization is set to 80%. The network will not be efficient in transmission of data packets if the bandwidth is set for more than 80% because there are certain parts of the bandwidth that are lost and usually the efficiency is not 100%. The advantages of the proposed method are reduced packet drop rates and high accuracy.

The updated research in the field of channel sensing provides evidence on different parameters regarding resource allocation, energy efficiency, and channel allocation at idle times. These methods have issues with a higher drop ratio because of the parameters considered for detecting the idle channels. These approaches were analyzed before the design of the proposed system. The results establish a fact that the proposed approach is not just focusing on the packet drop ratio but also does not lower the values of energy efficiency and idle time in the existing channels [19, 20-21].

VI. CONCLUSION

Channel sensing is one of the most important steps in the design of cognitive radio. The channel sensing mechanism is the first and the most influencing mechanism on the performance of the rest of the network. Several technical parameters have been considered to ensure that the channel sensing mechanism is efficient without any signal degradation. The design also ensures that the technical parameters are close to the values of real-time applications so that the results are comparable to the applications in the real world.

VII. FUTURE SCOPE

The proposed system is a novel method with focus on design of a new network and packet drop ratio as the parameters under consideration. Several other technical parameters can be considered with careful design as the future scope. The design should also be tested for prototyping with real-time network traffic and signals.

Conflict of Interest. There is no conflict of interest regarding the previous research work and the proposed system.

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