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Dynamic Spectrum Allocation in Wireless sensor Networks

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Abstract: *Radio frequency spectrum is considered the most expensive and scarce resource among all wireless network resources, and it is closely followed by the energy consumption, especially in low energy, battery powered wireless sensor network devices. These days, there is a tremendous growth in the applications of wireless sensor networks (WSNs) operating in unlicensed spectrum bands (ISM). Moreover, due to the rapid growth of wireless devices that are designed to be operated in unlicensed spectrum bands, these spectrum bands have been overcrowded. The problem with overcrowded spectrum or scarcity of spectrum can be solved by Dynamic Allocation of Spectrum. In this paper we have presented the implementation and analysis of dynamic spectrum allocation in Wireless Sensors Networks using the concept of Cognitive Radio Ad Hoc Network.*

Keywords: *Cognitive Radio Ad Hoc Network (CRAHN), Dynamic Spectrum Access (DSA), Primary Users (PU), Secondary Users (SU), Wireless Sensor Networks (WSN).*

I. Introduction

Wireless Sensor Network (WSN) refers to a group of spatially dispersed and dedicated sensors for monitoring and recording the physical conditions of the environment and organizing the collected data at a central location [1]. WSNs measure environmental conditions like temperature, sound, pollution levels, humidity, wind speed and direction, pressure etc. WSNs were initially designed to facilitate military operations but its application has since been extended to health, traffic, and many other consumer and industrial areas. A WSN consists of anywhere from a few hundreds to thousands of sensor nodes. The sensor node equipment includes a radio transceiver along with an antenna, a micro-controller, an interfacing electronic circuit, and an energy source, usually a battery. Multi-hop routing is a critical service required for WSN. WSNs are often deployed in an ad hoc fashion, routing typically begins with neighbor discovery [2]. Nodes send rounds of messages (packets) and build local neighbor tables. These tables include the minimum information of each neighbor's ID and location. This means that nodes must know their geographic location prior to neighbor discovery.

The leading areas of research and development in wireless communications are techniques and mechanisms to implement the most cost effective and efficient utilization of the radio frequency spectrum and energy. WSNs operate in the unlicensed band (ISM) of 2.4 GHz. Meanwhile, same spectrum band is shared by the other rapidly growing wireless devices with wireless applications like Wi-Fi and Bluetooth [3]. Due to which, the unlicensed spectrum band has become overcrowded. This yields interference among the WSNs nodes, which degrades the performance of WSNs. According to [4], the portions of the spectrums in 30MHz to 30GHz are underutilized. This huge imbalance in the use of different portions of spectrums can be minimized by the dynamic allocation of spectrum. This technique of dynamic spectrum allocation where licensed spectrum is accessed opportunistically is called the Cognitive Radio Technology. Including this section on introduction, the paper is organized on six sections. Brief description of CR technology is given in section 2; Sub-sections 2.1 & 2.2 gives the overview about routing protocol and MAC protocols for CR technology. A model for Cognitive Radio Ad Hoc Network is explained in Section 3. Section 4 will present simulation scenarios, results and analysis. The conclusion of the paper will be in Section 5.

Fig 1: Licensed Spectrum Usage [16]

II. Cognitive Radio Technology

Cognitive Radio (CR) is an adaptive, intelligent radio and network technology that can automatically detect available channels in a wireless spectrum and change transmission parameters enabling more communications to run concurrently and also improve radio operating behavior. CR technology aims at making use of the network resources currently used in wireless communication systems more efficiently. CR allows opportunistic use of the licensed spectrum band by an unlicensed user with minimum allowable interference to the licensed user, and without compromising on the desired quality of service required by the unlicensed user. The CR technology is well explained by the cognitive cycle (Fig. 2). Normally, cognitive cycle contains three major steps namely; Spectrum sensing, Spectrum Analysis and Spectrum Decision Making [15].

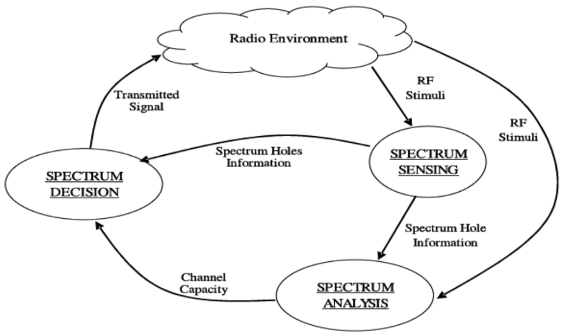

Fig.2: Cognitive Cycle [15]

Spectrum sensing is the first step which determines the presence/absence of primary user on the band. After sensing the spectrum, the cognitive radio can share the result of its detection with other cognitive radios. Spectrum sensing is the ability to measure, sense and be aware of the parameters related to the radio channel characteristics, availability of spectrum and transmit power, interference and noise, radio's operating environment, user requirements and applications, available network (infrastructures) and nodes, local policies and other operating restrictions. It is done across Frequency, Time, Geographical Space, Code and Phase. There are various ways of spectrum sensing. Hypothesis testing, Likelihood ratio test, use of Detectors etc are few candidates.

Spectrum Analysis is based on spectrum sensing which is analyzing the situation of several factors in the external and internal radio environment (such as radio frequency spectrum use by neighboring devices, user behavior and network state) and finding the optimal communication protocol and changing frequency or channel accordingly. It is also known as channel estimation.

Spectrum Decision Making calls for reconfiguration for the channel and protocol required for constantly adapting to mobile changing environments and adjustment of output power or even alteration of transmission parameters (such as modulation formats (e.g. low to high order QAM), variable symbol rates, different channel coding .

Development of cognitive radio technology involves extensive areas of research from physical to network layer. The studies on physical layer focus on various topics including development of Software-Defined Radio (SDR), modulation scheme based on Orthogonal Frequency- Division Multiple Access (OFDMA), spectrum sensing, channel characteristics and power control etc. Most of the research and published papers are focused on the layer above the physical layer namely Medium Access Control (MAC protocol) and Routing Protocol.

2.1 Routing Protocol for CR Technology

Mobile Ad hoc network is network where nodes communicate without any central administration or network infrastructure. They are connected via wireless channels and can use multiple hops to exchange data. Routing protocols are needed for communication in such Ad hoc networks, where it targets for efficient and timely delivery of message. A Cross Layer Routing Protocol has been proposed in [6] which operate with CHARN. This routing protocol exploits the passage of CR performance information from the physical/MAC layers up to Network layer as contributing factors within the route selection algorithms. The proposed routing protocol takes suitable sub-channel information of each hop into account. With the sensing capability of each node, the condition of all sub-channels between two neighbours will be fully captured and the information will be forwarded from the Physical layer to MAC and Network layers via the cross layer mechanism in each node. Location- Aided Routing Protocol [7] is a routing protocol for Cognitive Radio Networks that uses a common control channel to convey the message among the secondary users. This routing protocol has a minimal route setup delay, prefers stable routes, handles primary user's heterogeneity, and handles secondary user's mobility.

2.2 MAC Protocol for CR Technology

In Cognitive radio networks, the spectrum can be divided into several channels, either non-overlapping or partially overlapping. When we say a channel is available for a secondary user to use, it means either no primary user works on that channel or the interference from this secondary user to the active primary users is tolerable. MAC protocols are used to utilize these available channels. The cognitive radio MAC acts as a bridge between the cognitive radio physical layer and the cognitive radio network layer. On the one hand, it can utilize the spectrum-sensing results from the cognitive radio physical layer, characterize the channels, and decide which channel to use and when to access. On the other hand, it can help the cognitive radio network layer to decide the routing path by reporting the characteristic information and the list of available channels. Also, the cognitive radio network layer can tell the cognitive radio MAC to choose a suitable channel for a dedicated quality-of-service (QoS) requirement.

A Simple Greedy MAC for Cognitive Radio Networks [8] has been proposed for CR networks. This Greedy MAC is the combination of Simple Sequential MAC [9] and Greedy algorithm where the secondary users excess the channel in greedy manner. The network works on Simple Sequential MAC for certain time and later it works on Greedy MAC. The channel with maximum received packets is recorded and the secondary users try to access the channel which has received more packets. Packet Reservation Multiple Access (PRMA) based MAC protocol [10] for cognitive machine-to-machine communications uses cognitive radio technology at the physical layer. PRMA is a combination of slotted ALOHA, TDMA and a reservation scheme. This MAC protocol tries to access the vacant TV channels for audio transmission.

III. A Model for Cognitive Radio Ad Hoc Networks

A Cognitive Radio Ad Hoc Network model [5] has been proposed which doesn't use any specially designed Routing Protocol or MAC protocol for CR technology. It uses 802.11 MAC (wireless LAN) protocol and Ad Hoc on- Demand Distance Vector (AODV) protocol. This CR Ad Hoc network takes the information about channels and number of Primary users, their arrival and departure time and the range of primary users from two different files namely' map.txt and channel.txt. In order to describe the dynamic nature of CR networks, a new metric that captures the statistical behaviour of primary networks called primary user (PU) activity is introduced. In this model, the PU traffic can be modelled as a two state birth–death process with death rate ά (Alpha) and birth rate β (Beta). An ON (Busy) state represents the period used by PUs and an OFF (Idle) state represents the unused period. Since each user arrival is independent, each transition follows the Poisson arrival process. According to [5],

The changing spectrum environment and the importance of protecting the transmission of the licensed users of the spectrum mainly differentiate classical ad hoc networks from CRAHNs. In CRAHNs, the available spectrum bands are distributed over a wide frequency range, which vary over time and space. Thus, each user shows different spectrum availability according to the PU activity. As opposed to this, classical ad hoc networks generally operate on a pre-decided channel that remains unchanged with time. Also, classical Ad hoc Network sends periodic beacon message in the channel for topology control, whereas in CRAHNs, as the licensed spectrum opportunity exists over large range of frequencies, sending beacons over all the possible channels is not feasible.

This model of Cognitive Radio Ad Hoc network uses Cross- Layer Repository to enable channel information sharing between MAC and routing protocols. The receiver channel for each node is set randomly. Each sending channel is initialized as NOT active for each node. When a PU is detected, a pre-defined threshold is used to decide whether to stay or leave the current channel. Spectrums are decided based on allocation policy namely Random Switch and Round Robin Switch. Frequent handoff of spectrum is performed as per requirements. We have followed this model of Cognitive Radio Ad Hoc Network in order to implement the dynamic Spectrum Allocation in Wireless Sensor Networks. For the analysis of dynamic spectrum allocation in WSNs, we have used three different parameters namely Throughput, Packet Drop Rate and Average Packet End to End delay.

IV. Simulation Results and Analysis

For implementation of dynamic spectrum allocation in WSN, we've used Network Simulator-2(ns-2.31) as a Simulator. We've modified the network simulator for the implementation of dynamic spectrum allocation in WSN. During the simulation, primary users may vary from one to ten in numbers. The arrival and departure of PUs are set in a manner that we can see the effect of primary users on the communication of secondary users. For e.g.: In a case of 10 primary users, 5 of them arrive at the beginning of the simulation and departure after 70secs. Similarly, next 5 primary users arrive at 30secs and remain till end. Hence in the simulation time of 30-70secs there are maximum numbers of primary users. The effect due to the presence of maximum number of primary users can be seen in the throughput plot.

We have taken three different cases for analysis, first case contains ten primary users, second case contains eight primary users and the third case contains four primary users in the network. The resulting throughput, average end-to-end delay and packet drop rate plot depicts primary user activity behavior on secondary users.The simulation specifications are as follows:

Total no. of channels	11
Number of PUs	Varies from 1 to 10
Number of SUs	10
Transport Protocol	UDP
Packet Rate	300Kbps
Packet Size	512
Node speed	10, 15 m/s
Simulation Time	100 s
Height of Antenna	1.5m
Tx /Rx Gain	1
Bandwidth	2.4 GHz
Propagation Loss	0.5

Table.1: Simulation Specifications

4.1 Ten Primary Users

In this case, for the first 30secs, there are only five PUs; during 30 to 70secs there are ten PUs and after 70secs five PUs departure from the network. So there is heavy PU traffic activity at 30 to 70secs of Simulation time.

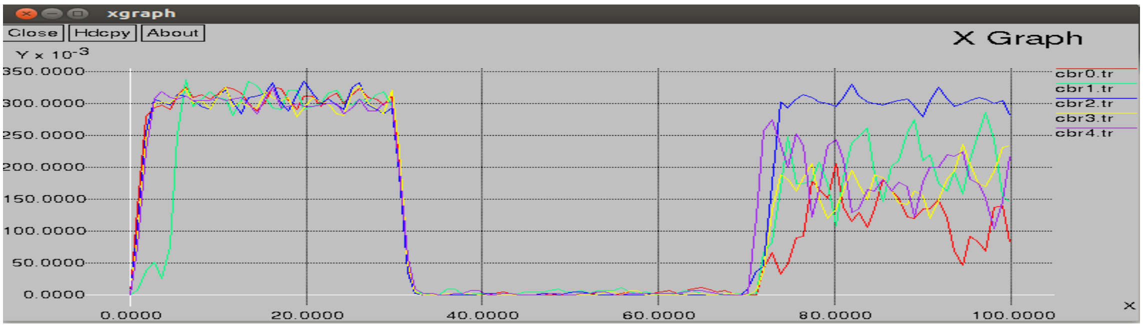

Fig.3: Throughput Plot (X: simulation time/ Y: Throughput)

As shown in Fig.3, in the first and last 30secs of simulation time, only five PUs exist, so throughput of SUs is high. But during 30 to 70secs of simulation time there exist ten PUs, only one channel is left for secondary users, so throughput of the SUs has reduced to almost zero.

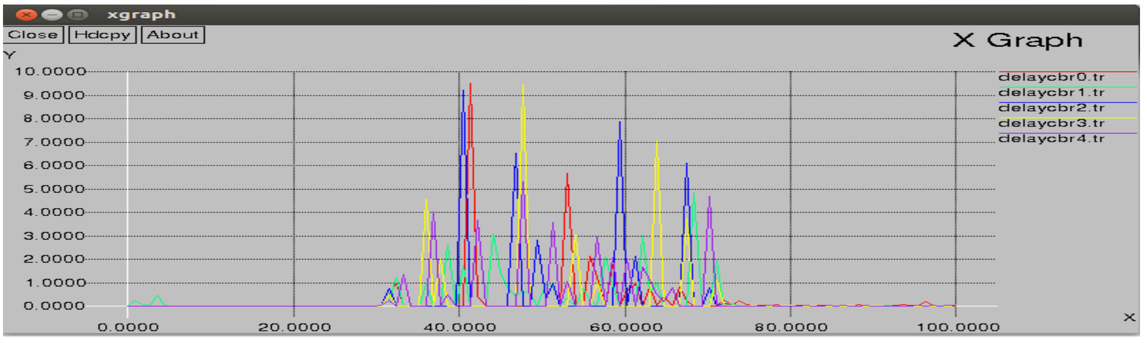

Fig.4: Average Packet End-to-End delay(X: Simulation time/Y: Delayed packets)

As shown in Fig.4, when there is enough channels for secondary users, there is no packet end-to-end delay. But when only one channel is available for all the SUs, all the SUs try to access it resulting into high packet end-to-end delay.

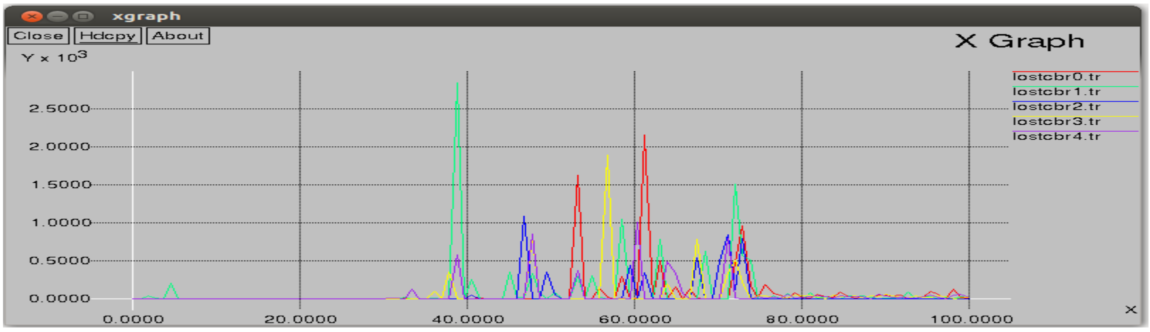

Fig.5: Packet Drop Rate.

In fig.5, since throughput of SUs at simulation time 30-70secs is almost zero, increasing average end to-end delay boosts up the Packet Drop Rate.

4.2 Case II. Eight Primary Users

Similar to case I, four PUs exist in first 30secs; eight PUs in between 30-70secs and among eight PUs four PUs departure after 70secs.

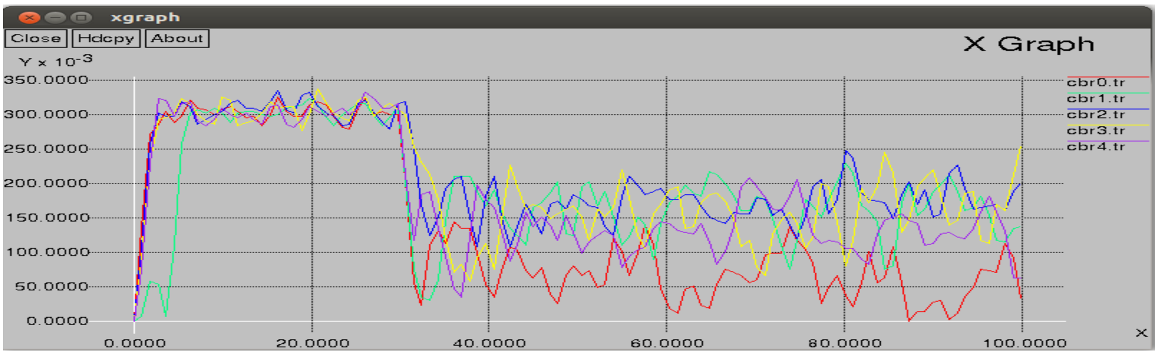

Fig.6: Throughput Plot.

In Fig.6, after the first 30secs of simulation time, SUs still can transfer their data because total no. of channels is not fully utilized by the PUs. The fluctuation in throughput of SUs is due to the several handoffs of channels. After the departure of four PUs (after 70secs), the throughput of SUs does not raise significantly due to the movement of SUs nodes.

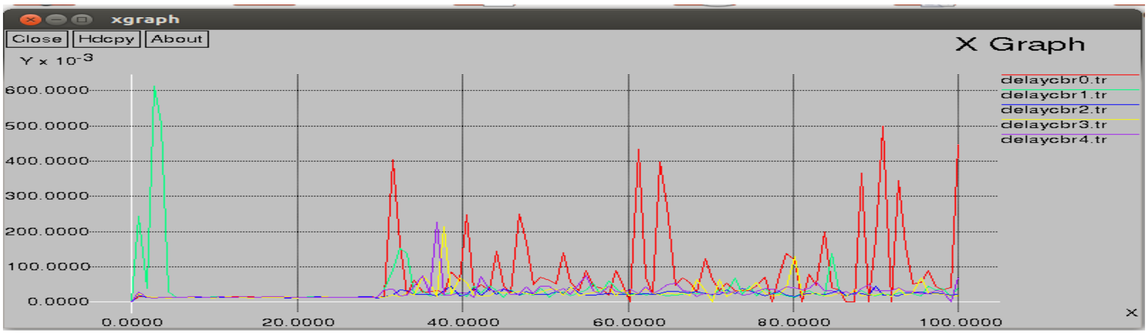

Fig.7: Average Packet End-to-End delay

Here, due to the several handoff operations and movement of WSNs nodes, few packets are delayed after 30secs of run time.

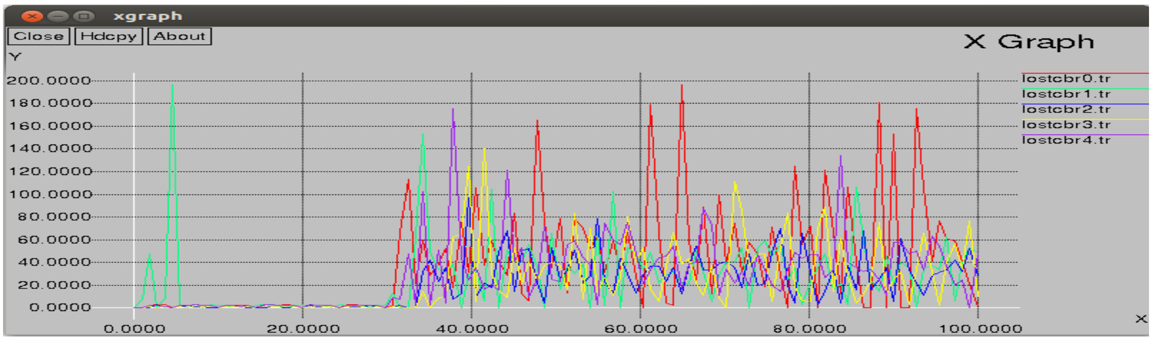

Fig.8: Packet Drop Rate

Fig.8 shows the packet drop rate due to the packet end-to-end delay in run time.

4.3 Case III. Four Primary Users

In case III, we reduced the number of PUs to half of Case II. The arrival and departure of PUs is in the same fashion as earlier cases.

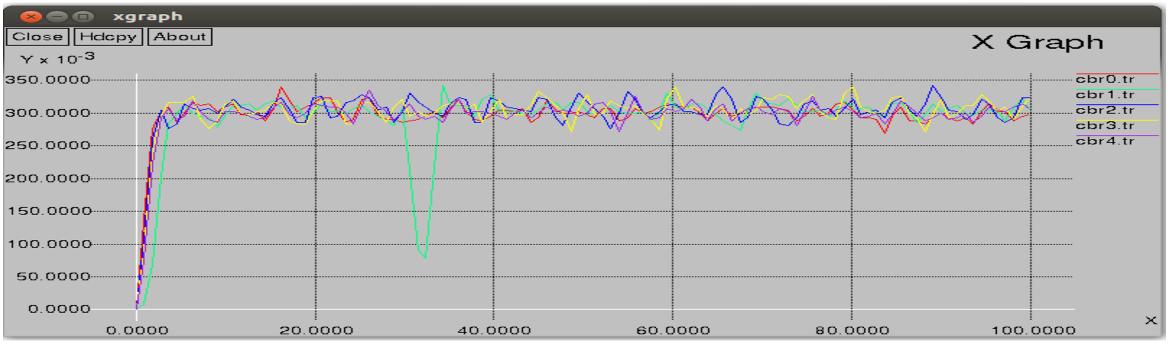

Fig.9: Throughput Plot.

Here, after the simulations starts, there is always surplus amount of channels in the network for the SUs, hence throughput of SUs does not decrease gradually, but fluctuates due to handoffs.

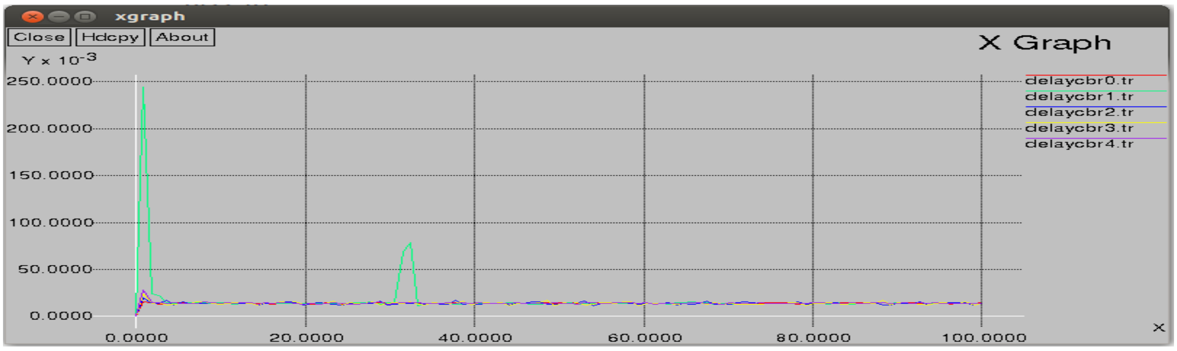

Fig.10: Average Packet End-to-End delay.

In fig.10, Packet end-to-end delay has been reduced drastically due to the availability of enough channels for data transmission.

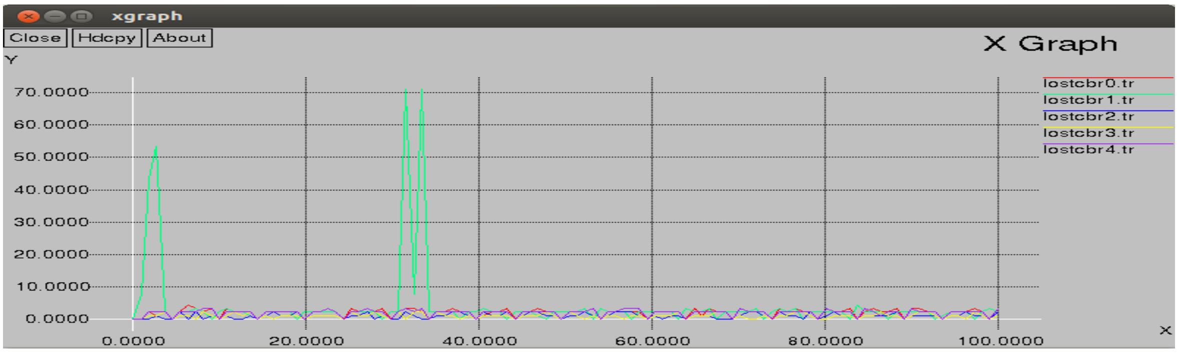

Fig.11: Packet Drop Rate.

Since there is no significant Packet end-to-end delay, no significant packet drop rate is present. The packet drop in cbr1 (green) is due to the movement of nodes.

These three cases are the cases where we can see the effect of available channels on the throughput of secondary users distinctly. Moreover we calculated the throughput due to secondary users in the presence of various numbers of primary users. Here, arrival and departure of PUs is in similar fashion, with same transmission range (of PUs) throughout the simulation. The location of PUs may slightly vary.

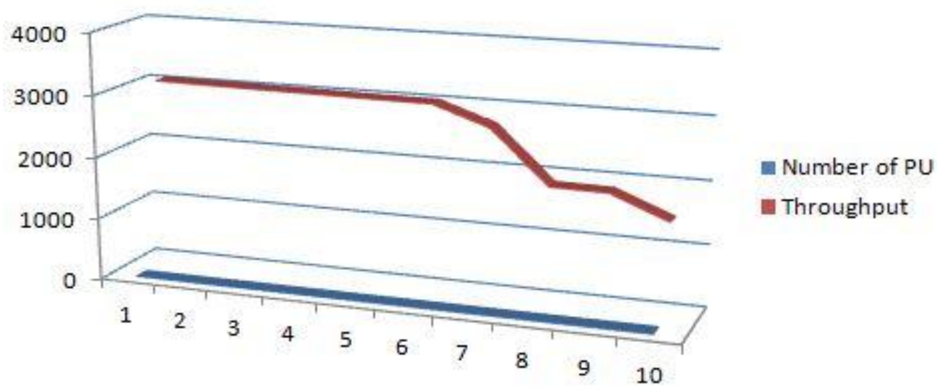

Fig.12: Average throughput by SUs in the presence of different no. of PUs.

Here, we can see the drastic change is average amount of throughput by SUs when the number of PUs increases from six to ten. It is so because, in our simulation, all the WSN nodes transfer data in pairs. So for a pair of five WSN nodes, five channels are enough to transfer data.

V. Conclusion

We would like to conclude our experiment on two aspects namely; throughput and energy. Since Wireless Sensor Nodes are deployed in environment in huge numbers, it's not pragmatic to change the energy source (battery) of the WSN nodes frequently**.** Hence, along with spectrum, energy source is also precious in case of WSNs. In our experiment we got a good throughput even in the presence of lots of Primary users. Spectrum sensing, spectrum analysis, spectrum decision and handoff operations require a lot of computations which results in the consumption of heavy energy source. Therefore, only throughput cannot be the major parameter in the dynamic spectrum allocation of WSNs. Future work will be focused on the design of a good MAC protocol for dynamic spectrum allocation in Wireless Sensor Networks which can access the licensed spectrum opportunistically with fewer computations and less consumption of energy source.

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