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Comparative Analysis and Inferences for Enhancement of Cognitive Radio Networks

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Abstract - **Cognitive Radio Network opportunistically exploits locally unused spectrum which is not heavily occupied by licensed users. It provides a new path to resolve spectral scarcity and to avoid spectral congestion, without disturbing the QoS requirements of others in the system. Of the many challenges involved in the practical ways of framing concepts for a working model of CR Network, we present its results for predominant applications of data and video, in detail. This project addresses the most plausible method of integrating a full scale CR Network capable of using TCP connections, video and data traffic.**

By providing higher priority status for video traffic over data traffic feeds, simulations for performance analysis are shown with the help of Dynamic Vertical Sharing Overlay methodology. The theoretical values of mean delay and jitter for data and TCP packets may be computed along with an analysis of the average throughput and efficiency of the system for different TCP based connections. Further simulation with higher priority video signal and data traffic will be considered. A comparative analysis of results over data and video signal will be carried out.

Index Terms – **Cognitive Radio Network, Dynamic Spectrum Allocation, Performance, Vertical Overlay Sharing.**

I. Introduction

As technological aspects continue to improve at a rapid pace, many new ways of controlling and reusing the already scarce bandwidth for more users, such their requirements are met within little response time and with *better QoS values*.

Studies made with different reports, given by various agencies and government analysis centers show the utilization of most of the spectrum is unregulated and underutilized in many ways.[13][14][15]

The underutilization of such spectrum availability may be brought down with the use of *Cognitive Radio Networking*, a way of adapting and reallocating spectrum for secondary users, as and when it is found to be idle.[4][7]

Cognitive users are given access to the primary users' spectrum range, either when the primary users do not need them or when the same is idle for a predefined short time span. This can be governed only with a system that can constantly monitor and sense the spectrum ranges and which has the power to decide such a transfer without bringing down the QoS parameters for both the parties involved.[26]

Spectrum management will also be possible within such a system. The spectrum will therefore require *Dynamic Spectrum Accessibility* and not a fixed procedure, as used till now.[12] The DSA may be divided into dynamic sharing and licensing, of which the former is given more priority for research scope. Dynamic sharing may be of two sub types – horizontal and vertical. Horizontal sharing deals with the sharing of spectrum based on the network technologies involved, while vertical sharing follows network OSI parameter changes. Of this, the vertical sharing method chosen is the Spectrum Overlay method, which is the type that allows secondary users to enter the sharing environment only when primary users are not found inside the same. For this, the decisions are either centralized or distributed.[27]

IEEE 802.22 standard provides us with excellent backgrounds specifically for regional area networking, so that the impact of a CR network may be felt in a wider region. Decisions are made through centrally utilized Base station, along with allocation methodologies like game theory, CR Medium Access Control, through the fixing of limits for cost parameters involved and so on.

However, it is also possible to make sure that the cost functions required are capable of giving the needed QoS balance, which is ironic to the already stated scenario. Expressions with closed application QoS parameters are derived with this system, such that there is one primary channel at work.[12]

The channel is considered to be handling data and video transmission, while some method is assumed to be in use, for sensing when the channel is free. Mean throughput in the connections and the video transmission's average delay are approximated.

Robust approximations are found with very simple calculations and statistics, which are seen often. The setup used here is taken to be the basic block for formulating a CR network, which gives results including multiple hops and primary channels in the CR traffic.

However, it is to be noted that not many studies for QoS parameter analysis are found in CR network related topics. Thereby, our system proposes a simple ON-OFF type distribution involved primary channel, with geometric proportions. The CR users are allowed to access the channel through CSMA approach and with p-persistent type system. M/GI/I queue with busy and idle status is used for computing the modeling periods, along with the Poisson traffic, the mean delay and throughput.

TCP traffic is ignored while the CR users access the channel with random features. Exponential distributions for CBR traffic and blocking/dropping probabilities of secondary networks are also considered. Throughput, along with mean delays, for CR network traffic in CBR / TCP connections is the primary focus here. It shows that the window controlled flow for TCP models vary from other theoretic types and

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that they can function differently in real world data scenarios.

II. Description For The System

In a typical CR network, the licensed spectrum is divided within a primary user and one secondary user, which enables the CR user network to transmit data during the absence of the licensed personnel, opportunistically.

Thus, the ON and OFF stages of the system comes into picture for the primary channel; ON state is also termed BUSY while the OFF state is called as an IDLE period. These states are quite independent of one another and the distribution followed is of the IID style.

IID stands for Identically Independent Distribution. The sequences, however, show that some amount of dependence is needed between a BUSY state and the next IDLE state. It is also taken that some form of a sensing algorithm is present to know of the state of the channel.

Thus it is possible for a primary user to generate and store packets in a queue, so that transmission of the same is done as per the user duo's needs. The arrival rate of packets and the generic sequence transmission time may be taken as λap packets per second and s_{gp} (an IID sequence) respectively.

Therefore, we take that $\rho = \lambda_{ap}E[s_{gp}]<1$, which ensures the presence of some vacant bandwidth for the use of CR networks. Renewal processes for arrivals are calculated by using the length of the primary queue. The IID sequences considered will be the ON states and the ON-OFF states with the next OFF state.

By using a single server queuing system [1] with a pair of GI/GI/I queues, the system's general structure may be represented as given in figure-I.

Preemptive priority for primary user packets ensures the stability of QoS for the licensed user, at all times.

Preemptive service with resume status is possible to implement by ignoring the fragmentation overheads of the queuing system.

Through this setup, computing parameters of a queue is easily done and the mean delay cum throughput calculation is tabulated. This setup can be useful for situations where the IID BUSY-IDLE periods for the primary users need to be approximated.

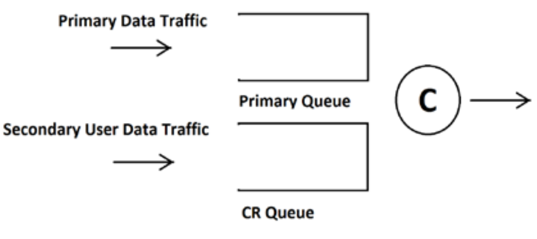


Figure 1: CR Network - Basic Model

The detection of availability of a channel through a base station may also encounter the fact that the CR user network could also be an IEEE 802.22 system, utilizing a form of cooperative sensing (CS) algorithm.

The base station will be authorized to use distributed CS sensing, in a TD duplex method. By combining all the real time data traffic, an approximate simulation for transmission is possible.

The queues can accommodate many forms of queue systems to provide good approximations to the analysis. The choices done for the queues, the ON-OFF model, the values of ρ and s_{gp} will help in getting good results for the CR user network performance. The ON-OFF period distribution of the primary channel will be obtained if many queue types for the same model are analyzed and approximated. Hence, the performance of the secondary users may be available if we choose the values of ρ and s_{gp}, with care

III. Single TCP Connection - Throughput

In a single TCP connection, it is assumed that the connection is transmitting a long file, with constant persistence. Extension of results may be carried out for other models, which is not the scope of this paper. Probability of each independent packet loss cum error and acknowledgement loss can be taken as "q", which is very apt for a wireless channel, such that it depends on the parametric features like power for transmission and the level of noise during reception. Such details are always independent of other similar parameters.

TCP connection ensures that the packet lengths form a general distribution with an IID sequence format, showing the lengths of the packets to be uniform.

Considering the TCP packet length and capacity to be L_{Tg} and C_c (bits per second), the mean service time for the channel TCP packets can be expressed as $E[S_{ST}]=E[L_{Tg}]/C_c$, which is then used for the calculation of the throughput average – QoS factor for the system.

Also, by considering the value of time needed for the queue of the CR TCP packets to be C_{QT}, we will be able to show the completion of service of the CR queue service time and the service time taken for the primary user packets in the system at that moment.

This also brings out the fact that the primary packets in the system will be served even before the completion of the current TCP packets due to preemptive prioritization of the system.[2][8][9]

Furthermore, approximation is done between the value of $\lambda_{ap}E[C_{QT}]$ and the primary packets' average Poisson arrival numbers and thereby, we get the following relation;

$$E[C_{QT}] = E[S_{ST}]+\lambda_{ap}E[C_{QT}]E[S_{gp}]$$

We may reduce the relation further to be,

$$E[C_{QT}] = \frac{E[S_{ST}]}{1-\rho}$$

By approximation of the queue of the primary user sector, the stationary distribution enabled TCP arrangement is easily shown. Also the computation of the throughput for the connection is possible (λ_P).

Consider ΔT to be the propagation delay for the entire network in total, which will include the acknowledgements too. The time stationary window length for the TCP packets with 'q' probability is taken to be $E[W_{WL}]$. By considering the TCP dynamics, the CR queue is governed by the M/GI/1 structure; the preemptive priority factor for the primary queue is responsible for the CR users' mean sojourn time inside the system.

$$E[S_{ST}] = \frac{\lambda_{ap}E[S^2{}_{gp}] + \lambda_P E[S^2{}_{ST}]}{2(1-\rho)(1-\rho-\rho_{TP})} + \frac{E[S_{ST}]}{(1-\rho)}$$

where it is seen that the value of ρ_{TP} is obtained as $\lambda_P E[S_{ST}]$

The throughput of the system is carefully obtained using the mean stationary window $E[W_{WL}]$, as the above algebraic equation is unique with a positive solution. Standard Reno format is considered for stabilizing the system's output and for better approximations.[10]

IV. Multiple TCP Connections – Throughput

After taking care of the results obtained through single TCP connection, the focus of the paper turns to the same scenario with multiple connections at the same time. The TCP connections help the CR users to utilize the channel effectively when the primary is idle. First Come service for the buffering and transmission of packets is seen, where the CR system can be considered incorporated with the help of a base station. The downlink process can transmit to various users to obtain the relation for throughput of TCP packets. Considering the TCP connections with long life to be N_{LL}, the $\Delta(j)$ being the propagation delay in total and the IID connection packet length to be L_j. The average service time is $E[s_j] = E[L_j]/C_c$. The j^{th} TCP connection packets are independently dropped with probability of q; the window size and the average number of packets can be taken as $E[W_{WL}(j)]$ and the $E[n_J]$ respectively. With this, we get $E[W_{WL}]$ through the approximations with these values and the stationary throughput is $\lambda_T(j)$. Hence, we may be able to show that the values of the average arrival rate for the packet, the average service time and the next moment of the service time model distribution for the CR user queue are,

$$\lambda_P = \sum_{j=1}^{N_j} \lambda_P(j)$$

$$E[S_{ST}] = \sum_{j=1}^{N_j} \frac{\lambda_P(j)}{\lambda_P} E[S_i]$$

$$E[S^2{}_{ST}] = \sum_{j=1}^{N_j} \frac{\lambda_P(j)}{\lambda_P} E[S^2{}_i]$$

All these inferences will be the chief factor for the finding of the average sojourn time of the CR queue's packet and it is found to be,

$$E[S_{ST}] = \frac{\lambda_{ap}E[S^2{}_{ap}] + \lambda_P E[S^2{}_{ST}]}{2(1-\rho)(1-\rho-\rho_{TP})} + \frac{E[S_{ST}]}{(1-\rho)}$$

where, $\rho_{TP} = \lambda_P E[S_{ST}]$

Thus, the total time of packets inside the system of TCP connection or the mean sojourn time can be approximated to the nearest possible number, along with the throughput of the jth connection. The throughput is given by,

$$\lambda T(j) = \frac{E[W_{WL}(j)]}{E[S_{ST}] + \Delta(j)} \quad \text{Packets/sec}$$

Considering the equations above, we can obtain an order 2N nonlinear equation, from which $E[S_{ST}]$ is also obtained. For various values of j from 1 to N, we can calculate $\lambda_T(j)$.With this set of information in mind, the total system can be modeled by means of network simulator, along with a few extra assumptions during actual simulation.

Modeling of the GI/GI/1 queue system is made for the primary user ON-OFF occupancy model [22]. Pareto distribution is used for governing the system of its inter-arrival time.

Mean values and packet sizes of values 40 ms and IID uniform distribution (1500 bytes) mean are taken into account while fixing the primary channel's capacity to be not more than 1Mbps.Two TCP connections are considered; one with the values of packet size and Wmax to be 1000 and 8, while the other 1500 bytes and 10.Throughputs and packet loss probabilities may be computed for different propagation simulations while tabulating the results separately. This method shows that the throughput can be predicted quite easily and to the very nearest value, for different values of delays and losses.

V. CBR Connections – Average Delay

A system with one primary user channel and one or many CBR connections is taken to the primary network in use here. The notations and other assumption parameters may be considered to be the same. The sum of the packet's average time or sojourn time in the queue with the value of propagation delay is termed to be the mean end to end delay. With this, we are able to calculate the value of average time of life of CBR packets as well. [24]

The approximations of the primary and CR queue are seen to follow an M/GI/1 format and it is justified using the comparison of results obtained from simulations. An increase in the number of CBR connections will certainly show an improvement in the approximations.

Taking λ_{AR} to be the CBR packets' mean total arrival rate, the average time of service for each CBR packet to be $E[S_{CBR}]$ and $\rho_{CBR} = \lambda_{AR}E[S_{CBR}]$, we can compute the CBR packet's mean sojourn time $E[S_C]$ to be,

$$E[Sc] = \frac{\lambda pE[S2p] + \lambda c[S2_c]}{2(1-\rho p)(1-\rho p - \rho_{cbr})} + \frac{E[S_{CBR}]}{(1-\rho p)}$$

VI. Data And Video - Traffic Simulation

Taking into account, the primary network made of one primary channel, along with CBR and TCP connections, the Cognitive radio environment for the final simulation set is prepared.

The priority for TCP packets is lesser than that of the CBR packets in the simulation as CBR data is of real time data traffic. The mean throughput of the system shows the handling of the TCP connection QoS.[19][20]

Since throughput of the TCP connections can be obtained, using the approximation of the primary queue with the TCP/CBR flows in terms of Poisson arrivals, the mean sojourn time is taken to be,

$$E[SST] = \frac{\lambda_p E[S^2{}_p] + \lambda_{AR} E[S^2{}_{CBR}] + \lambda_T E[S^2{}_T]}{2(1-\rho_T-\rho_{CBR})(1-\rho_T-\rho_{CBR}-\rho p)} + \frac{E[ST]}{(1-\rho_T-\rho_{CBR})}$$

where, $E[S_{ST}]$ and $E[S^2{}_{ST}]$ are already computed. Now, the value of throughput of the TCP connections, in general, is provided by,

$$\lambda_T = \frac{E[W_{WL}]}{E[S_{ST}]+\Delta} \quad \text{(Packets/second)}$$

Thereby, the value of throughput for different TCP connections will be obtained through the use of all the above equations together.

a) Results for simulation – improvement suggestions

- The system needs to use overlay method for ease of use and for avoiding noise exchange.
- CR network concepts may be recommended for systems when ρ is well between 0.5 and 0.8

- Preemptive priority for packets is a must for simplifying sensing abilities of the system
- During video frame transmission, it is best to keep packet frame size below 1500 bytes to reduce retransmission time.
- Number of CR users per network should be as low as possible for effective sharing of resources.

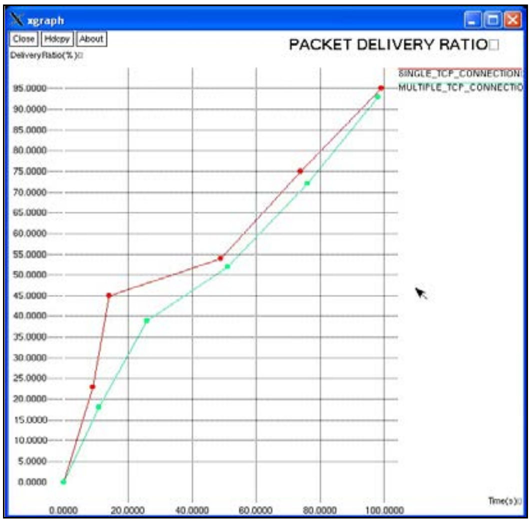
VII. CONCLUSION

A performance analysis based on all the results obtained was made and such inferences were made for a traffic environment of data and video, through a single primary channel. Throughput and mean delay for the cognitive TCP traffic connections are obtained. Thus, the system is improved if number of users per system is kept well within the limits of an ideal environment, along with preemptive priorities for easier sensing capabilities.

VIII. FUTURE DIRECTIONS

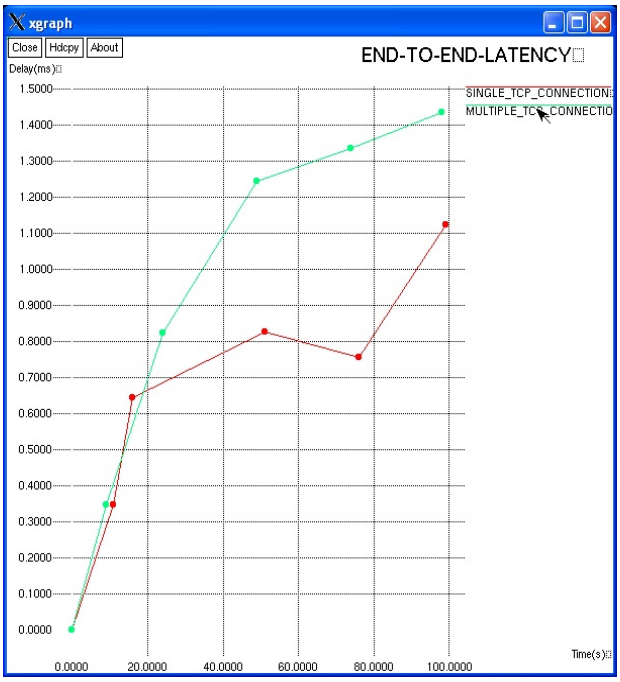
Further enhancements and similar inferences can be made for environments based on underlay modeling and with multiple traffic systems – data along with voice and video.

IX. SIMULATION RESULTS



A. Delivery ratio

B. Throughput



C. Latency Calculation

	SINGLE TCP	MULTIPLE TCP
	DIFFERENT INSTANCES (AT 40ms, 80ms & 100ms)	
AVG. MAX. HOP COUNT	5 (Includes retransmission path count)	10 (Includes retransmission path count)
THROUGHPUT	10 Bytes, 15 Bytes, 20 Bytes	14 Bytes, 20 Bytes, 24 Bytes
END-END DELAY	0.75 ms, 0.8 ms, 1.15ms	1.1 ms, 1.35 ms, 1.45 ms
DELIVERY RATIO	53%, 80%, 95%	47%, 75%, 90%
SIMULATION TIME	For 5MB video, ~ 1 minute	For 5MB video, ~ 1 minute, 23 seconds

D. QoS Table with a few vital parameters

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BIOGRAPHY

V.P.Ajay received his B.E from Anna University Chennai in the year 2004 and has shown interest in many add-on studies in the field of Networks and Communication Systems. Currently, he is in the final year of his Master's degree in Communication Systems from Anna University Coimbatore. He has presented many of his ideas, in national level conferences and technical symposiums. He has served as a Research and Development Engineer and also as a Research article writer for over a period of two years. His research interests are in the domain of Wireless Networks, Wireless Communication techniques, switching techniques, security protocols and intelligent systems.

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