1 To analyze how the allocation of frequency spectrum to the Incumbent (Primary), CR CPE (Secondary User) affects throughput (Level 1)

1.1 Introduction

An important component of the cognitive radio concept is the ability to measure, sense, learn, and be aware of the parameters related to the radio channel characteristics, availability of spectrum and power, radio's operating environment, user requirements and applications, available networks (infrastructures) and nodes, local policies and other operating restrictions.

NetSim simulator models IEEE 802.22 Cognitive Radio per the theory explained below.

A spectrum hole has been defined as a band of frequencies assigned to a primary user, but at a particular time and specific geographic location, the band is not being utilized by that user. Cognitive Radio was proposed as the means to promote the efficient use of spectrum by exploiting the existence of spectrum holes.



Figure 1-1: Spectrum holes are used by SU for its transmission scheme is often referred to as opportunistic spectrum access (OSA)

These spectrum holes are used by the SU for its transmission. This scheme is often referred to as opportunistic spectrum access (OSA). No concurrent transmission of the PU and the SU is allowed. The SU must vacate the channel as soon as the PU reappears, which leads to the forced termination of the SU connection (if there is no other available channel for the SU). Since the SU has no control over the resource availability, the transmission of the SU is blocked when

the channel is occupied by the PU. The forced termination and blocking of a SU connection is shown in the below figure. The forced termination probability and blocking probability are the key parameters which determine the throughput of the SU, and thus its viable existence. The forced termination depends on the traffic behavior of the PUs and the SUs (e.g. arrival rates, service time etc.). In the case of multiple SU groups with different traffic statistics, the forced termination and blocking probabilities lead to unfairness among the SU groups.



PU and SU access is continuous, Active

Figure 1-2: Illustration of forced termination and blocking of a SU connection

Performance metrics

The different parameters used to analyze the performance are explained as follows:

- Throughput: It is the rate of successfully transmitted data packets in unit time in the network during the simulation.
- Spectral Efficiency: It refers to the information rate that can be transmitted over a given bandwidth in a specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized by the physical layer protocol, and sometimes by the media access control protocol.

1.2 Network Setup

Open NetSim and click on Experiments> Cognitive Radio Networks> Cognitive Radio Impact of frequency allocation to PU and SU on throughput then click on the tile in the middle panel to load the example as shown in below Figure 1-3.

NetSim Home				- a ×
NetSim Standard Network Simulation/Emulation F Version 13.2.35 (64 Bit)	latform			
New Simulation Ctrl+N Your Work Ctrl+O	Experiments D Internetworks D Advanced Routing	Cognitive Radio Impact of frequency alloc Understand how the secondary uses differe the primary.	Search cation to PU and SU on throughput ent channels for transmission from those used by	् हो
Examples Experiments	IOT-WSN SO NR: Cognitive Radio Networks Cognitive Radio Networks Cognitive Radio Networks Cognitive Radio Networks Control Networks	Min Prequency SMMHz Max Prequency GMMHz frecughput III Cognitive Radio-Physical layer properties Min frequency: 54 MHz Max frequency: 60 MHz	Min Prequency SMMts Max Frequency 80Mts Cognitive Radio-Physical layer properties Min frequency: 54 MHz Max frequency: 90 MHz	Bare Station 1 CR, CPE, 2 CR, CPE, 2
License Settings Exit Alt+F4	Learn networking concepts through simulation experiments. Documentation middle panel to load the simulation. Cick on the book icon on the left (5)	ion comes with objective, theory, set-up, results, and discussion. Expo	and and click on the file name to display experime	In both the samples, the Secondary Law (CR-CPE) lies within the specialization region of Primary Max Information, Neural The Workshow Comparison of Primary Max Information, Neural The Workshow Comparison of Internal and Primarhadic as at to term, i.e., the fourtheet all continuously use the dament abstrate is it.
Support Answer/FAQ Contact Technical Support	Learn Videos Experiment Manual	Documentation User Manual Technology Ubarnes	Contact Us Email - sales Phone - + 91 Waleries	@tetcos.com 767-605-4321

Figure 1-3: List of scenarios for the example of frequency allocation to PU and SU on throughput NetSim UI displays the configuration file corresponding to this experiment as shown below Figure 1-4.





1.3 Procedure

Min Frequency 54MHz Max Frequency 60MHz Sample

The following set of procedures were done to generate this sample:

Step 1: A network scenario is designed in NetSim GUI comprising of 1 Base Station and 2 CR CPE's in the **"Cognitive Radio"** Network Library.

Step 2: The device positions are set as follows Table 1-1.

	Base Station 1	CR CPE 2	CR CPE 3
X/Lat	100	100	120

	Y/Lon	100	120	100
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Table 1-1: Device positions

Step	3:	Go t	to Base	Station	Properties	Interface_	_1(Cognitive	Radio)>	Datalink	Layer	>
Incur	nbe	ent 1,	the follo	wing are	set as show	wn below F	igure 1-5.				

Cr_Bs			×						
Cr_Bs	DATALINK_LAYER	DATALINK_LAYER							
GENERAL	INCUMBENT1								
	Name	Incumbent 1							
INTERFACE_1 (COGNITIVE_RADIO)	ID	1							
	X_Co_Ordinate	90							
	Y_Co_Ordinate	90							
	Z_Co_Ordinate	0							
	Oper_Freq_Start(MHz)	54							
	Oper_Freq_End(MHz)	60							
	ON_Duration(s)	10							
	OFF_Duration(s)	0							
	Keepout_Distance(m)	100							
	Oper_Distribution	Constant 👻							
	INCUMBENT2		•						
	Name	Incumbent 2	~						
			~						
	ОК	Reset							

Figure 1-5: Datalink Layer properties window

Step 4: In the **Interface_1(Cognitive Radio)> Physical Layer**, the Min Frequency and Max Frequency parameters are set to 54 and 60 MHz respectively.

Step 5: Right click on the Application Flow **App1 CUSTOM** and select Properties or click on the Application icon present in the top ribbon/toolbar.

A CUSTOM Application is generated from CR CPE 2 i.e., Source to CR CPE 3 i.e., Destination with Packet Size remaining 1460Bytes and Inter Arrival Time remaining 20000µs.

Step 6: Enable the plots and run the Simulation for 100 Seconds.

Min Frequency 54MHz Max Frequency 90MHz Sample

The following changes in settings are done from the previous sample:

Step 1: In the **Interface_1(Cognitive Radio) > Physical Layer**, the Min Frequency and Max Frequency parameters are set to 54 and 90 MHz respectively.

Step 2: Enable the plots and run the Simulation for 100 Seconds.

1.4 Output

Once after the simulation is complete, go to the Results Dashboard and check the **"Application Metrics**" Table. Throughput of the application will be 0.

In the Left-Hand-Side of the Results Dashboard Figure 1-6/Figure 1-7, click on the arrow pointer indicating **"CR Metrics"**, from the drop down select the **"Channel Metrics"** which gives you the Spectral Efficiency.

🔡 Simulation Results										
TCP_Metrics	Application_Metrics_Table									
IP_Metrics	Application Metrics								Detailed View	
> IP_Forwarding_Table	Applica	ation ID	Throughpu	t Plot	Application Name	Packets Generated	Packets Received	Throughput (Mbps)	Delay (microsec)	
V CR Metrics	1		Application	<u>Throughput_plot</u>	App1_CUSTOM	75000	0	0.000000	0.000000	
Base station metrics										
Incumbent metrics										
Channel metrics										
Application_Metrics	- -									
V Plots										
> Application Throughput										
	Channel metrics_Table								□ ×	
	CR Ch	CR Channel Metrics								
Export Results (.xls/.csv)	BS Id	Channe	l number	Frequency(MHz)	Spectral efficiency					
Print Results (.html)	1	1		54-60	0.00004					
Open Packet Trace										
Open Event Trace										

Min Frequency 54MHz Max Frequency 60MHz Sample

Figure 1-6: Results of Min Frequency 54MHz Max Frequency 60MHz Sample

Min Frequency 54MHz Max Frequency 90MHz Sample

🔡 Simulation Results									
TCP_Metrics Application_Metrics_Table									
IP_Metrics	Application Metrics							Detailed View	
 > IP_Forwarding_Table UDP Metrics CR Metrics Base station metrics 	Applica 1	tion ID Through Applicati	out Plot <u>on Throughput plot</u>	Application Name App1_CUSTOM	Packets Generated 75000	Packets Received 74998	Throughput (Mbps) 0.583987	Delay (microsec) 19958.371348	
CPE metrics Incumbent metrics Channel metrics Application_Metrics									
 Plots Link_Throughput Application_Throughput 	<								
	Channel metrics_Table								
	CR Ch	annel Metrics						Detailed View	
Export Results (.xls/.csv)	BS Id	Channel number	Frequency(MHz)	Spectral efficiency					
Print Results (.html)	1	1	54-60	0.00004					
Open Packet Trace	1	2	60-66	0.00000					
Open Event Trace	1	3	66-72	0.00010					
Log Files	1	5	78-84	0.00510					
	1	6	84-90	0.15571					

Figure 1-7: Results of Min Frequency 54MHz Max Frequency 90MHz Sample

1.5 Inference

In both the samples, the Secondary User (CR-CPE) lies within the operational region of Primary User (Incumbent), hence the frequency spectrum used by operational Primary User (Incumbent) will not be used by Secondary User (CR-CPE). Also, the Operational Interval under Incumbent is set to zero, i.e., the Incumbent will continuously use the channel allocated to it.

In the **Min Frequency 54MHz Max Frequency 60MHz** sample, both the Primary User (Incumbent) and the Secondary User (CR-CPE) has been allocated the same channel (frequency band of 54 - 60 MHz). As Incumbent will continuously use the channel allocated to it, so there will be no Spectrum Hole, hence the secondary user will not be able to transmit any data in an opportunistic manner. Therefore, the throughput of the application in the CR-CPE and the spectral efficiency is almost equal to zero.

In the **Min Frequency 54MHz Max Frequency 90MHz** sample, the Primary User (Incumbent) has been allocated frequency band of 54 - 60 MHz and the Secondary User (CR-CPE) has been allocated the frequency band of 54 - 90 MHz Incumbent will continuously use the channel allocated to it, but the rest channels will remain free i.e. there will be Spectrum Hole, which the CR-CPE will utilize to transmit data.

NOTE: The results are highly dependent on position/velocity/ traffic etc. Any modifications with the abovementioned input parameters will change the final output result.