WIFI LTE COEXISTENCE
(CO-EXISTENCE OF WIFI LTE IN LTE-U 5GHZ BAND)

Submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

In

Electronics and Communication

by

SHREE HARI M NAIR – 16BEC0157

ADHEIK DOMINIK – 16BEC0620

ANUVIND ASHOK – 16BEC0790

Under the guidance of

Prof. Kishore V Krishnan

SENSE

VIT, Vellore.

May, 2020

DECLARATION

I hereby declare that the thesis entitled "WIFI-LTE Coexistence" submitted by me, for the award of the degree of *Bachelor of Technology in Electronics and Communications* to VIT is a record of bonafide work carried out by me under the supervision of Kishore V Krishnan.

I further declare that the work reported in this thesis has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university.

Place : Vellore

Date :

Signature of the Candidate

<u>CERTIFICATE</u>

This is to certify that the thesis entitled "WIFI-LTE Coexistence" submitted by Sree Hari M Nair 16BEC0157, Adheik Dominic 16BEC0620 and Anuvind Ashok 16BEC0790, SENSE, VIT University, for the award of the degree of *Bachelor of Technology in Electronics and Communications*, is a record of bonafide work carried out by him under my supervision during the period, 01. 12. 2019 to 30.04.2020, as per the VIT code of academic and research ethics.

The contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university. The thesis fulfills the requirements and regulations of the University and in my opinion meets the necessary standards for submission.

Place : Vellore

Date :

Signature of the Guide

Internal Examiner

External Examiner

Head of the Department

Electronics and

Communication

ACKNOWLEDGEMENTS

I would like to convey my heartiest thanks to our Project Guide, Prof. Kishore V Krishnan, who has given us his full co-operation and devoted his valuable time for rendering us his needy services and guidelines, during the course of imparting us practical knowledge and with those sincere and precious help we have been able to complete this project successfully.

I would also like to convey my gratitude to the Head of Department, Dr. Thanikailselvan V, and the DEAN, Dr. Kittur Harish Malliarjun, SENSE School, for providing us with this opportunity.

Student Name

Executive Summary

Cellular traffic demand has increased significantly in recent years. Furthermore, emerging areas like the Internet of Things (IOT) will add further stress to the communication infrastructure. One solution to this problem is by utilizing the LTE Unlicensed (LTE-U) spectrum to share LTE and Wi-Fi. These unlicensed bands (ISM bands) are radio bands reserved for scientific and medical purposes. There are various LTE-U technologies such as Duty Cycle and Listen Before Talk (LBT) which assumes that Wi-Fi has undistributed channel access. We show that this is a simplification that has practical impacts on the coexistence. When LTE and Wi-Fi coexist in the same spectrum, the performance of Wi-Fi drastically degrades, whereas LTE is barely impacted. In our model, we make use of the Almost Blank Subframes (ABS) of LTE to send Wi-Fi signals. There are some reference signals called pilots in the ABS that not only interfere with Wi-Fi but also adversely impact them. To reduce this impact, we send the Wi-Fi signals by grouping them. We then categorize them into safe zone and non-safe zone nodes. After the categorization we select the final Relay using Hungarian Algorithm.

TABLE OF CONTENTS

CONTENTS **Page No.**

.

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

ABBREVIATION	FULL FORM
IoT	Internet of Things
LTE	Long Term Evolutions
Wi-Fi	Wireless Fidelity
LTE-U	LTE-Unlicensed
ABS	Almost Blank Subframes
LBT	Listen Before Talk
PSR	Packet Success Rate
ISM	Industrial, Scientific and Medical Band
LASI	Low Amplitude Stream Injection
LBT	Listen Before Talk
AP	Access Point
BS	Base Station
FDD	Frequency Division Duplexing
DCF	Distributed Coordination Function
DIFS	DCF Interference Space
3GPP	3^{rd} Generation Partnership Project
GSM	Global System for Mobile Communication
GPRS	Global Packet Radio Service
EDGE	Enhanced Data for Global Evolution
UMTS	Universal Mobile Telecommunications Service

HSPA	High Speed Packet Access
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
eICIC	Enhanced Inter-Cell Interference Coordination
LTE-A	LTE Advanced
IMS	IP Multimedia Subsystems
ITU	International Telecommunication Union
IMT	International Mobile Telecommunications
CA	Carrier Aggregation
RN	Relay Nodes
HetNet	Heterogenous Networks
CRE	Cell Range Expansion
UE	User Equipment
SINR	Signal to Interference Plus Noise Ratio
PER	Packet Error Rate

SYMBOLS AND NOTATIONS

SYMBOL	SIGNIFICANCE
$\Omega_{Wi\text{-}Fi}$	Set of all nodes
M	Number of safe zone nodes
m_j	Nodes in safe zone
N	Number of nodes in the non-safe zone
N_i	Nodes in the safe zone
PSR_j	PSR of the node in safe zone
PSR_i	PSR of the node in non-safe zone
PST_{Th}	Threshold value of PSR
N_{tx}	Number of expected transmissions
ψ_j	Set of associated non-safe zone nodes
PSR_{ni}^{AP}	PSR for transmission from non-safe zone to AP
PSR_{ni}^{mj}	PSR for transmission from non-safe zone to relay
PSR_{mj}^{AP}	PSR for transmission from relay to AP
PSR_{vi}^{*}	PSR of the v_{i+1} node
PSR_{vi}	PSR of the v_i^{th} node
K	Maximum Wi-Fi device connections per group
w_{ij}	PSR values of the corresponding connection

1. INTRODUCTION

1.1. OBJECTIVE

Cellular traffic has increased drastically over the past few years. Furthermore, emerging areas like the Internet of Things (IOT) will have billions of connected sensors worldwide within next few years, which will further increase the stress in the existing communication infrastructure. One solution to this problem is to coexist LTE and Wi-Fi in the LTE Unlicensed (LTE-U) 5 GHz band. However, when LTE and Wi-Fi coexist in the same spectrum, LTE is barely impacted, whereas the performance of Wi-Fi is drastically degraded. There are various technologies that ignore this fact. Hence, we show how Wi-Fi is degraded due to these interferences. We propose the use of Almost Blank Subframes (ABS). ABS is a small time-frequency window in the LTE which carry neither control nor data information. The pilots in the ABS cause interference to the Wi-Fi signals. In order to reduce these interferences, we categorize various Wi-Fi nodes into different regions using with the help of Hungarian Algorithm and then send the Wi-Fi signals through the proposed ABS. Our aim is to reduce the interferences and attain a seamless coexistence of Wi-Fi and LTE in the LTE-U band. We also aim to show the difference in the PSR with and without our proposed optimization method. Also, we aim to show the effect on PSR for different parameter.

1.2 MOTIVATION

It is clear that soon the wireless network capacity will become a little-neck for serving the increased wireless traffic. Concurrently, the licensed spectrum used by the mobile operators becomes very scarce. This increased demand for spectrum resources for multimedia communications and a limited licensed spectrum have led to widespread concern regarding the operation of long-term evolution (LTE) in the unlicensed (LTE-U) band. There exist various technologies such as Duty Cycle, Listen Before Talk (LBT) that uses the LTE-U band however, these technologies raise concerns on the adverse impact of scheduled LTE frames on Wi-Fi Packet Success Rates (PSR). They assume that Wi-Fi has an undistributed channel access. We show that this is a simplification that has practical impacts on the coexistence. Our proposed method ensures high Wi-Fi PSR by creating node-groups based with dedicated contention-based medium access intervals.

1.3 BACKGROUND

INTRODUCTION TO LTE-U

LTE-U is a proposal that was originally developed by Qualcomm, for the use of the 4G LTE radio communications technology in unlicensed spectrum such as the 5GHz band. LTE networks are carrying an increasing amount of data. One solution is to use the unlicensed spectrum alongside the licensed bands. Known in 3GPP as LTE-U, it enables access to unlicensed spectrum especially in the GHz ISM band

LTE-U BACKGROUND

There is some amount of unlicensed spectrum available around the world. These bands are called Industrial, Scientific and Medical bands and are allocated in different parts of the spectrum. These are used for various applications that includes microwave ovens, Wi-Fi Bluetooth and much more.

The frequency band that we are interested in for LTE-U is the 5GHz band. There are several hundreds of MHz of spectrum bandwidths available, although the exact bands available varies across countries.

LTE IN UNLICENSED SPECTRUM

LTE-U will allow cellphone carriers to boost coverage in their cellular networks, by using the unlicensed GHz band which is already in use by the Wi-Fi devices. While cellphone providers usually depend on the radio spectrum to which they have exclusive licenses, LTE-U will share space with the Wi-Fi devices already using that band. Some of them are smartphones, laptops and tablets connecting to home broadband networks, free hotspots provided by businesses and so on.

LTE-U is intended to let cell networks boost data speeds over short distances, without the user requiring to use a separate Wi-Fi network. There still remains a control channel using LTE, but all data flows over the unlicensed GHz, instead of the carrier's frequency.

There is a technology that make use of the duty cycle of LTE. They analyze the performance of coexistence of LTE and Wi-Fi by which Wi-Fi allocated the channel when the duty cycle of LTE is in the "off" status. They propose a method called Low Amplitude Stream Injection (LASI) for resolving the conflicts between the Wi-Fi and the LTE which is a very complex and tedious method. There also exists a technology that makes use of a method called Listen Before Talk (LBT). This LBT mechanism is a simple and fixed mechanism for sharing the medium. Here the LTE is expected to perform a carrier sensing and backoff before capturing the unlicensed channel. This proposal has not been adopted in many key markets worldwide.

2. PROJECT DESCRIPTION AND GOALS

We propose a system to have a seamless connection between Wi-Fi and LTE using the LTE unlicensed (LTE-U) 5GHz band which will not only help in reducing the current traffic but also provide a faster connection. In order to achieve this, we make use of the Almost Blank Subframes (ABS) within the LTE standard that offer short channel access windows for Wi-Fi signals. Since the reference signals known as the pilots in the ABS interferes with these Wi-Fi signals. Our solution to this is to partition the Wi-Fi network into self-organizing groups based on the observed Packet Success Rate (PSR). We set a threshold value for this PSR and if the PSR of a node is higher than the threshold then that node is categorized as a safe zone node, and if the PSR is lower than the threshold then that node is categorized as a non-safe zone node. We then select the node with the maximum PSR value as the Group Owner (relaying node) with the help of Hungarian Algorithm. Rest of the nodes acts as a Wi-Fi Direct group and forwards the signal to the group owner. The group owner forwards the signals to/from the nodes that are vulnerable and distant from the AP. Finally, we evaluate our proposed system. We find the optimum PSR threshold value that will allow us to gain the maximum PSR for the system. We show the difference in the Average PSR for the optimized and the non-optimized system. We also evaluate the impact of number of nodes on the Average PSR.

Our goal is to achieve a seamless and traffic free connection between the Wi-Fi and LTE in the LTE-U 5GHz band.

3. TECHNICAL SPECIFICATIONS

MATLAB

Figure 1: *MATLAB*

We use MATLAB for the simulation of our project. MATLAB is useful for simulating communication systems. By making use of the vast number of toolboxes provided we can create a networking environment suitable for our project. We make use of LTE toolbox and WLAN Toolbox to create our simulation environment.

LTE TOOLBOX

LTE toolbox provides many functions and apps for simulation of communication system which use LTE. This toolbox is useful for Physical layer development. Physical Layer is the lowest layer in the OSI model of computer networking. We use LTE toolbox to map PSR. It is done by creating a PHY table. This toolbox is also useful for waveform generation. This toolbox supports Release 10 of LTE which is what we use in our project.

WLAN TOOLBOX

This toolbox is used for design and simulation of wireless communication systems. For the Wi-Fi part of our project this toolbox is useful. We can perform many measurements such as channel power calculations. You can generate waveforms using Wireless waveform generator app. Link models can be analyzed using metrics such as Packet Error rate, Bit Error rate and throughput.

4. DESIGN APPROACH AND DETAILS

4.1 DESIGN APPROACH

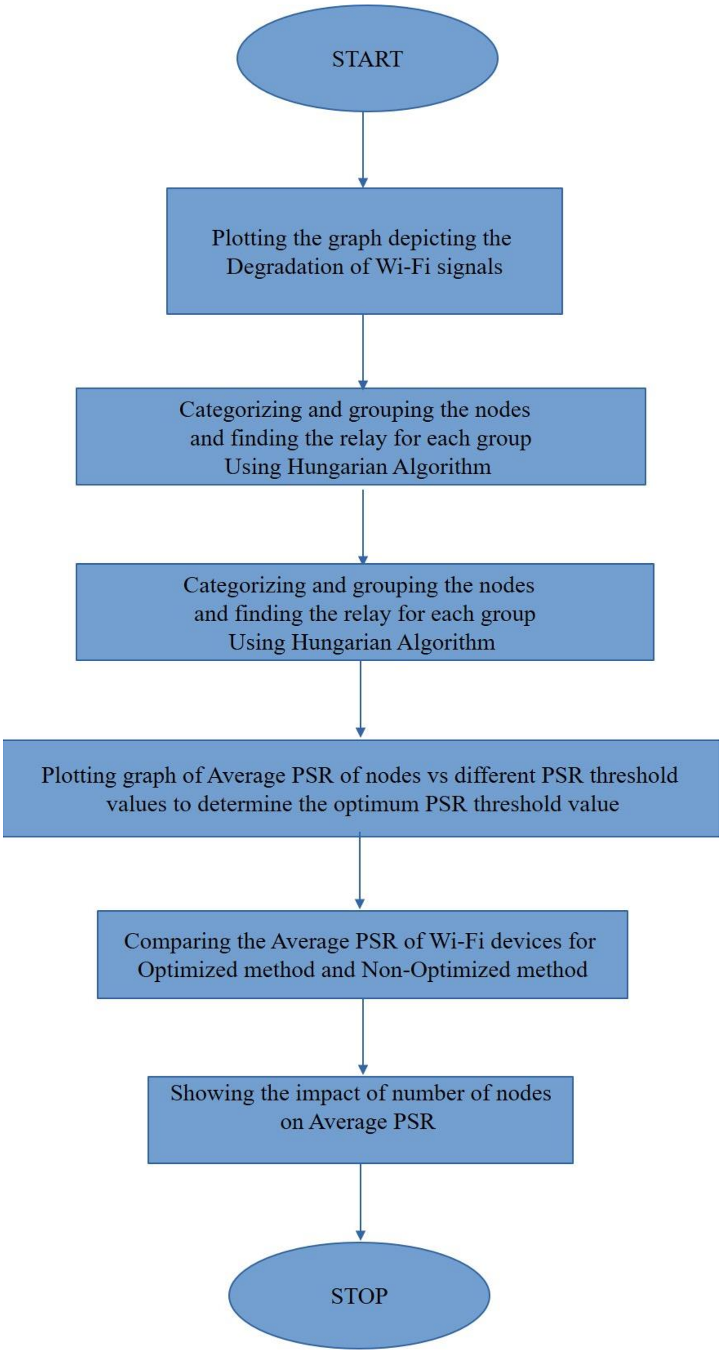

Figure 2: *Flowchart of our project*

ALMOST BLANK SUBFRAMES (ABS)

LTE Release 10 includes enhanced Inter-Cell Interference Coordination (eICIC) that defines the Almost Blank Subframes (ABS). This ABS carry neither control nor data information. Using of ABS is primarily aimed for the interference management between neighboring LTE small cells.

ABS allow Wi-Fi to gain access to channel for a short time-frequency window, and by making use of multiple ABS frames devoid of cellular traffic, this window can be extended.

There exists a fundamental assumption that the Wi-Fi has an undistributed channel access during the entirety of ABS. But the current LTE standards describe mandated reference signals called pilots within the ABS that has a significant impact on the Wi-Fi.

The figure below is a simple representation of the ABS:

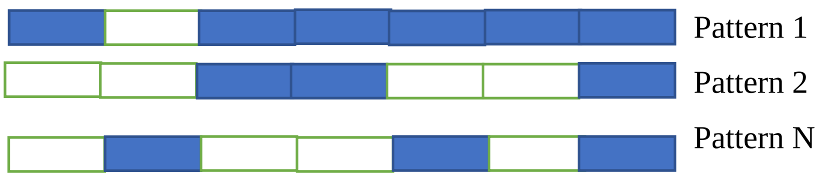

Figure 3: *Almost Blank Subframes*

The above figure represents various patterns of LTE transmission. Each of these patterns has 7 windows. The blue colored window represents the transmission of data by LTE and the blank (or white) window represents the ABS. These are the windows that are utilized by the Wi-Fi.

MATERIALS AND METHODS

We make use of the MATLAB LTE and WLAN System toolboxes to create a standard compliant LTE. The LTE BS is deployed as an indoor small cell occupying 20MHz channel in the 5GHz band. The LTE BS operates in Frequency Division Duplexing (FDD). We select the industry-standard TGn model B with 100ns Delay Spread for indoor propagation model. The transmission power is 17dBm and with the noise floor set to -95dBm. The LTE BS is separated by a distance of 60m from the Wi-Fi AP. The converging radius of the Wi-Fi AP is also 60m.

SIMLUATION PARAMETERS

PARAMETERS	**VALUE**
Transmission Power	17dBm (50m Watts)
LTE Bandwidth	20MHz
Distance between LTE-BS and Wi-Fi AP	60m
PSR_{Th}	90%
Propagation Model	Indoor model with 100ms Delay Spread
Noise Floor	-95dBm
Number of Wi-Fi Devices	20

SYSTEM MODEL

Our project is a simulation-based work which is done with the help of MATLAB software. The main objective of our project is to reduce the interference on the Wi-Fi signals and provide a seamless connection between LTE and Wi-Fi. In order to obtain this, we propose a method to categorize the Wi-Fi nodes into different zones based on their Packet Success Rate (PSR).

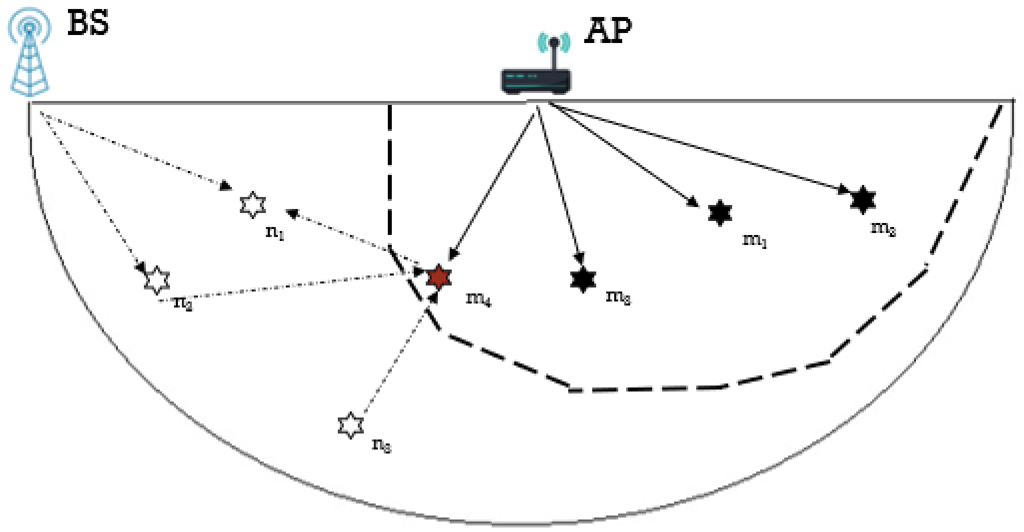

Figure 4: *System Model*

The above figure is our proposed system model. In the figure, there is an LTE Base Station (BS) and a Wi-Fi Access Points (AP) the stars represent the Wi-Fi nodes. We categorize these nodes based on their PSR value. We select a certain value as the threshold and if the PSR of a node is greater than the threshold, then the node is categorized as a safe zone node, whereas is the PSR of a node is lesser than the threshold, then that node is categorized as a non-safe zone node. In the above figure, the dotted lines represent the threshold value of the PSR, and the nodes inside the dotted line, that is, the nodes m_1, m_2, m_3 and m_4 (black stars) are safe zone nodes, whereas the nodes outside the dotted line, that is, the nodes n_1, n_2, n_3 (white stars) are the non-safe zone nodes.

We then select the node with the highest PSR value as the relaying node (Group Owner). In the figure, the node m_4 (red star) is the relaying node. The rest of the nodes acts as a Wi-Fi direct group that forwards the signals to the relaying node (m_4). The relaying node (m_4) forwards the signals to/from the nodes that are vulnerable and distant from the AP.

DEVICE GROUPING

As in the figure, let there be Wi-Fi AP that is connected V nodes in its coverage area represented by the set $\Omega_{\text{Wi-Fi}} = (v_1, v_2, \ldots, v_V)$. Let there be a set of M nodes ($m_j\ \forall\ j \in \{1,M\}$) that are in the safe zone and has PSR values $PSR_j \geq PSR_{Th}$, $\forall\ j \in \{1,M\}$ where PSR_{Th} is the threshold PSR value. Let there be a set of N nodes ($n_i\ \forall\ i \in \{1,N\}$) that are in the non-safe zone and has PSR values $PSR_i \leq PSR_{Th}$, $\forall\ i \in \{1,N\}$. Now, any node ($m_j\ \forall\ j \in \{1,M\}$) within the safe zone, is a potential relay candidate.

Our aim is to get maximum possible connections between the non-safe zone nodes to the relay and also to minimize the number of transmissions so that we can get a high PSR per node.

$$\min \overline{N_{tx}} = \min\Big(\sum_{j\geq 1} \frac{1+|\psi_j|}{PSR_{m_j}^{AP}} + \sum_{i\in\psi_j} \frac{1}{PSR_{n_{i_j}}{}^{m_j}} \Big) + \sum_{i\in\psi_C} \frac{1}{PSR_{ni}^{AP}}$$

The above equation is to minimize the overall expected transmissions, subject to maximum number of W-Fi device connections (K) per group. The (ψ_j) represents the set of associated non-safe zone nodes and its cardinality is represented by $|\psi_j|$.

Also, PSR_{ni}^{AP}, PSR_{ni}^{mj} and PSR_{mj}^{AP} represents the estimated PSR for the direct transmission by the AP and received at the non-safe zone node, the PSR for transmissions by the relay and received at the non-safe zone node and the direct transmissions by the AP and the received relay.

The above equation is subjected to the following constraints:

$$PSR_{vi}^{*} \geq PSR_{vi} , \forall \; v_i \epsilon \; \Omega_{Wi-Fi}$$
$$|\psi_j| \leq \mathrm{K} , \forall \; \mathrm{j} \; \epsilon \; \{1, M\}$$

The first constraint means that the PSR value of a node (PSR_{vi}^{*}) should be greater than the previous node (PSR_{vi}) so that we can get maximum possible PSR for the entire connection.

The second constraint means that the cardinality of set of associated non-safe nodes is less than equal to the maximum possible number of Wi-Fi connections (K).

On receiving replies from the non-safe zone nodes, the candidate relay m_j finds which neighbor node *i* would experience improved PSR through a one-hop Wi-Fi Direct based relaying over a direct AP connection. It is done by calculating the PSR of the link between itself and the non-safe zone nodes (PSR_{ni}^{mj}) and also by checking whether the expected number of transmissions of the signal from the non-safe zone node to the AP through one-hop communication lesser than the direct one to the AP. By the equation:

$$\frac{1}{PSR_{ni}^{mj}} + \frac{1}{PSR_{mj}^{AP}} < \frac{1}{PSR_{ni}^{AP}}$$

HUNGARIAN ALGORITHM

It is possible that a same non-safe zone node connects to more than one relay in the group of candidate relays. But Wi-Fi direct requires each node to be connected to only one group owner. Hence, we need to finalize the group such that the nodes connect to one relay only. For this purpose, we use a modified Hungarian Algorithm to match nodes to relays. The Hungarian algorithm or the Munkres algorithm is used for Assignment models. Assignment model is nothing but assigning the number of resources to equal number of activities based on a parameter. For example, assigning number of electricians to fix an electric post based on the distance.

ALGORITHM DESCRIPTION

A matrix W is created with rows as non-safe zone nodes, and columns as relays and the last column as Wi-Fi-AP. The contents of the matrix are w_{ij}. Where w_{ij} denotes the PSR values. Now our goal is to assign a non safe zone node to any of the given relays or to the AP based on its connectivity.

$$W = \begin{array}{c} \\ n_1 \\ \vdots \\ n_N \end{array} \begin{array}{c} \begin{array}{ccccc} m_1 & \dots & m_M & & AP \end{array} \\ \begin{pmatrix} w_{11} * & \cdots & w_{1M} * & \left\{ \begin{matrix} w_1 \\ \vdots \\ w_N \end{matrix} \right. \\ \vdots & \ddots & \vdots & \\ w_{N1} * & \cdots & w_{NM} * & \end{pmatrix} \end{array}$$

Munkres Algorithm Example:

In the example there are three non-safe zone nodes and 3 relays (3 rows and columns). For the example random variables are given to the matrix.

Step 1- Row Reduction

Firs we find the minimum of each row. Which is 15,25 and 25 respectively. Then these values are subtracted from each row. After subtraction, each row will have at least one zero.

40	60	15
25	30	45
55	30	25

Step 2- Column reduction

Same as step 1 but here it is done for the columns. Find the minimum of each column.

Column 1 minimum=0

Column 2 minimum=5

Column 3 minimum=0

Subtract these values from the respective columns.

25	45	0
0	5	20
30	5	0

Step 3- Test for an optimal assignment

After step 2 there will be at least one 0 in each row and column. Draw straight lines on matrix to cover all 0s.

25	40	0
0	0	20
30	0	0

Step 4- Final Assignment

We choose n 0s (n=number of rows and column) making sure each rows and columns of matrix only contain one chosen 0.

25	40	0*
0*	0	20
30	0*	0

By looking at the above example, we can say that non-safe zone node 1 is assigned to relay 3. Non-safe zone node 2 is assigned to relay 1. Non-safe node 3 is assigned to relay 2.

Hence, we can successfully assign only 1 relay to a node. We continue doing this until all the nodes are assigned to a relay and then group the nodes according to the relays.

PERFORMANCE ANALYSIS

We evaluate the proposed system using MATLAB with the help of WLAN and LTE System toolboxes.

- We find out the optimum range of PSR threshold to improve the system.

- We show the difference in the Average PSR for the optimized and the non-optimized system

- We also evaluate the systems performance for several network densities and a selected range since we know that the systems performance is related to the number of potential relays.

4.2 CODES AND STANDARDS

3GPP RELEASE 10

3rd Generation Partnership Project (3GPP) is an umbrella for a number of standard organizations which develop protocols for mobile telecommunication. Its best known work is the development and maintenance of

- GSM and related 2G and 2.5G standards, including GPRS and EDGE
- UMTS and related 3G standards, including HSPA and HSPA+
- LTE and related 4G standards, including LTE Advanced and LTE Advanced Pro
- 5G NR and related 5G Standards
- An evolved IP Multimedia Subsystem (IMS) developed in an access independent manner.

3GPP is a consortium with seven national or regional telecommunication standards organizations as primary members and a variety of other organizations as associate members. The 3GPP organizes its work into three different streams: Radio Access Networks, Services and System Aspects, and Core Network and Terminals.

The project was established in December 1998 with the goal of developing a specification for a 3G mobile phone system based on the 2G GSM system, within the scope of the International Telecommunications Union’s International Mobile Telecommunications-2000, hence the name 3GPPP.

RELEASE 10

3GPP release 10 is the driving force to further develop LTE technology towards LTE-Advanced. LTE Release 10 was introduced to provide higher bot rates in a cost efficient way and simultaneously completely fulfill the requirements set by International Telecommunication Union (ITU) for International Mobile Telecommunications (IMT)-Advanced referred to as 4G

- Increased peak data rate
- Higher spectral efficiency
- Increased number of simultaneously active subscribers
- Improved performance at cell edges

The main new functionalities introduced in LTE-Advanced are Carrier Aggregation (CA), enhanced use of multi-antenna techniques and support for Relay Nodes (RN).

ENHANCED INTER-CELL INTERFERENCE COORDINATION (eICIC)

In LTE/LTE-Advanced (LTE-A), one key challenge for operators is that they have to increase network capacity to keep up with fast-growing traffic. Especially, crowded areas in metropolitan cities have hotspots with extremely high traffics. For these hotspots, just reducing the size of macro cells is not quite enough to handle the high traffic. So, network operators want to increase the network capacity in a more economical way, that is, by installing small cells.

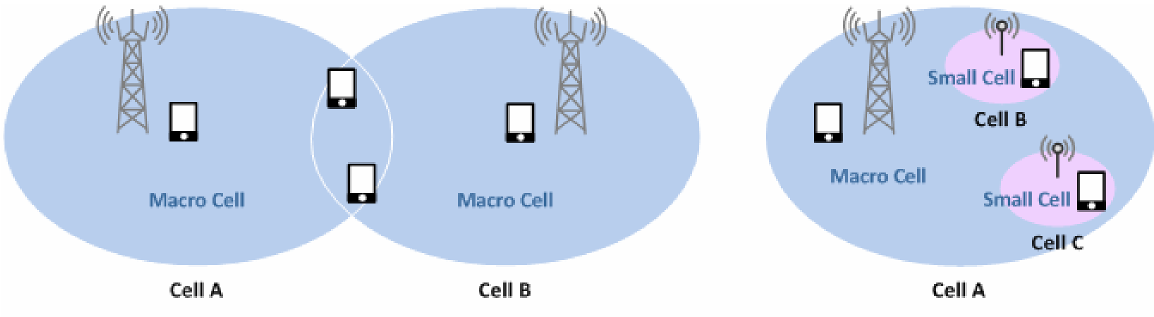

Figure 5: *(i) Homogeneous network. (ii) Heterogeneous network (HetNet)*

Networks consisting of the same type of cells are called homogenous networks while ones with different types are called heterogenous networks (HetNet). So HetNet is a network where small cells are deployed within a macro cell coverage. From Release 10, HetNet environments are also considered discussing LTE-A standards

eICIC is an interference control technology defined in 3GPP release 10. It is an advanced version of ICIC, previously defined in 3GPP release 8, evolved to support HetNet environments. To prevent inter-cell interference, ICIC allows cell-edge UEs in neighbor cells to use different frequency ranges. On the other hand, with eICIC allows them to use different time ranges (subframes) for the same purpose. That is, with eICIC, a macro cell and small cells that share a co-channel can use radio resources in different time ranges.

The two main features of eICIC are: Almost Blank Subframes (ABS) technology defined in Release 10 and Cell Range Expansion (CRE) technology defined in Release 11. ABS can prevent cell-edge UEs in small cells from being interfered with by the neighboring macro cell by having both cells still use the same radio resources, but in different time ranges (subframes). CRE expands of a small cell so that more UEs near cell edge can access the small cell.

4.3 CONSTRAINTS, ALTERNATIVES AND TRADEOFFS

CONSTRAINTS

- Choosing specific value for threshold PSR (PSR_{Th})
- Assigning the random probability factor in order to solve the channel contention problem
- Modifying the Hungarian algorithm in order to find the maximum vale instead of the minimum value.

ALTERNATIVES

- We could have used python and ns2 to conduct the project but that would require us to learn a new technology which is time consuming

TRADEOFFS

- There is a small set of nodes which are closest to the BS, for which we cannot find an improvement given the high levels of interference.
- The PSR metric does not consider the impact of channel availability, but it just considers the reliability of the link against the LTE interference

5. SCHEDULE, TASKS AND MILESTONES

5.1. SCHEDULE AND TASKS

SR.NO	MONTH	TASK
1	DECEMBER	• Deciding the area of project • Literature Survey • Coming up with the topic and problem statement
2	JANUARY	• In-depth research about existing systems and their drawbacks • Research about the interference in the ABS • Establishing a relation between power and the PSR of a Wi-Fi signal and also between the SINR and the PSR of the Wi-Fi signal
3	FEBRUARY	• Research about categorizing the nodes and finalizing the system model • Implementing the Hungarian Algorithm to categorize the nodes
4	MARCH	• Implementing the random probability factor α • Preparing for Project Report
5	APRIL	• Preparing poster for the project. • Final review

5.2. MILESTONES

1. Proving that the ABS is not interference free and that it affects the Wi-Fi signals.

2. Implementing the Hungarian algorithm in order to find the relay in each group

3. Introducing a random probability factor in order to solve the contention problem

4. The project didn’t cost us anything as the project is totally software-based

6. PROJECT DEMONSTRATION

WI-FI SIGNAL DEGRADATION IN ABS

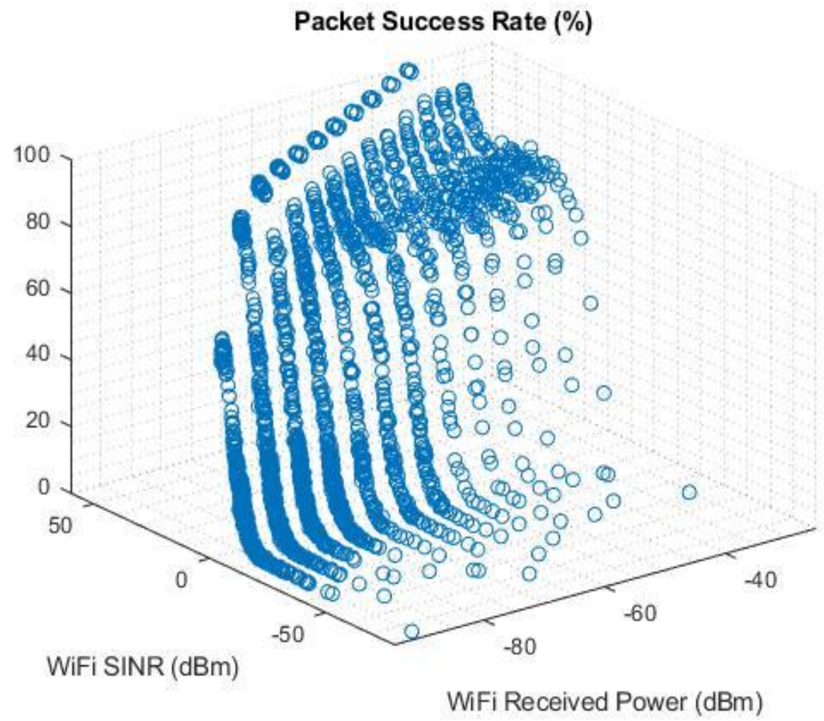

Figure 6: *Observed PSR*

The above graph shows the observed PSR during an ABS window, plotted as a function of the SINR and its own received power from the AP.

The circles in the graph represents a Wi-Fi node.

From the graph, it is clear that the nodes with high power and high SINR value has a higher PSR value (i.e., $PSR > PSR_{Th}$).

Also, the nodes with lower power and SINR value has a low PSR (i.e, $PSR < PSR_{Th}$) and hence the probability of successfully transmitting data is low.

The SINR represents the Signal to Interference and noise ratio. In other word, the SINR is defined as the power of a certain signal of interest divided by the sum of the interference power and the power of some background noise.

Low SINR means more interference. Hence from the above graph it clearly shows some nodes with low SINR value (i.e. more interference) has a lesser PSR value.

Hence, this proves that the ABS is not interference free and that the Wi-Fi Signals are getting degraded.

NODE CATEGORIZATION

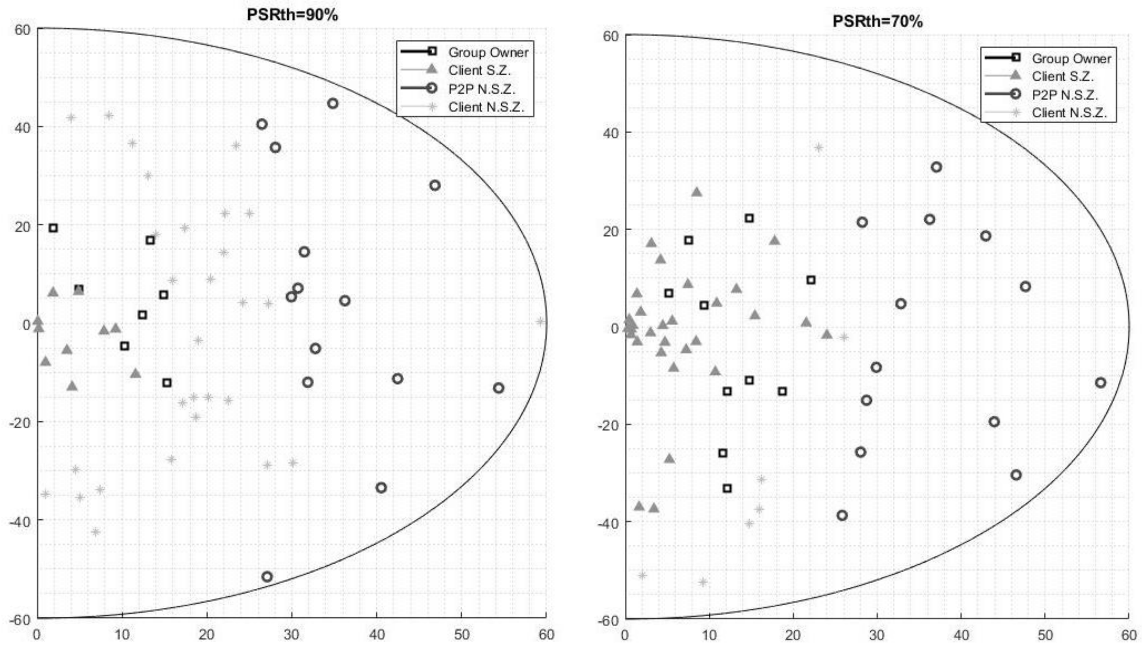

Figure 7: *Categorized nodes (i) For PSR_{Th} = 90% (ii) For PSR_{Th} = 70%*

We consider an LTE BS that is separated by a distance of 60m from the Wi-Fi AP. In the above graph the y-axis represents the distance. The Wi-Fi AP is located at (0,0) and the LTE BS at (60,0). The x-axis represents the distance in meters. The converge radius of the Wi-Fi AP is also 60m.

The above images are the output we obtained after node categorization. We can see that the nodes have been categorized into the different zones (safe zone and non-safe zone). The 1st image has a PSR threshold of 90% and the 2nd image has a PSR threshold of 70%

The triangle represents the nodes in the safe zone, and the squares are the group owners (or the relay nodes). These are also safe zone nodes.

The stars represent the non-safe zone nodes that are connected to the relay, and the circles represent the non-safe zone nodes that are directly connected to the AP.

The safe zone is directly defined by the PSR threshold. It determines the number of nodes that can become the Group Owner (Relay). As the PSR threshold decreases more devices can become the relay. We can also see that the devices elected as the Wi-Fi direct clients are the ones closest to the BS and thus are the ones that are suffering more interference.

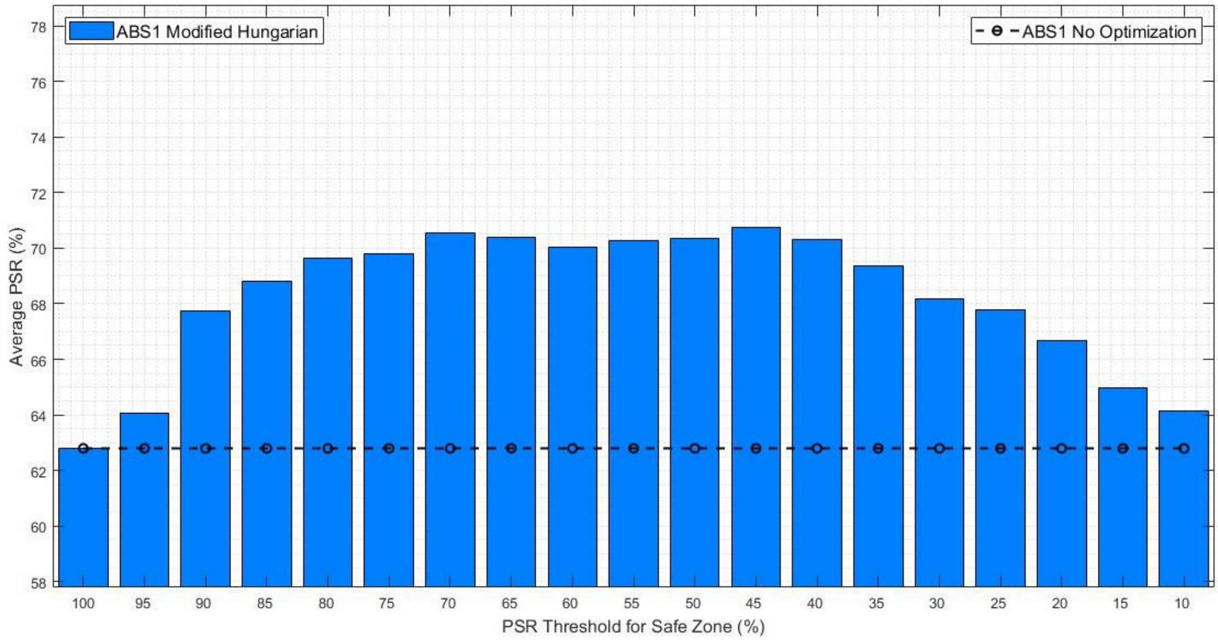

Figure 8: *Average PSR (%)*

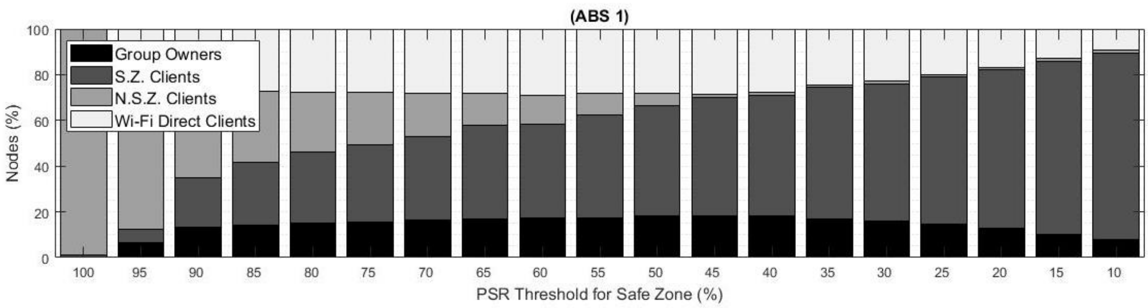

Figure 9: *Node Distribution vs different PSR Threshold values*

Figure show us the optimum value for the PSR threshold so that our system can provide maximum PSR. The optimum range can be defined as the one that provides the highest average PSR for the considered AP-BS distance. The Hungarian Algorithm finds the maximum average PSR.

From the figure, we can see that the maximum PSR is obtained within the range of 45-70%. This will be the place where the AP has enough Group Owners (relays), and nodes with low PSR that lies outside the Safe Zone becomes Wi-Fi Direct Clients.

The figure depicts the distribution of nodes into the safe zone, non-safe zone, relay and the Wi-Fi direct groups according to the different PSR threshold values. We can see that for PSR 100%, all the nodes are in the non-safe zone area. This is the case when there is no optimization, that is grouping is not performed. So, the Average PSR value at this threshold is considered as the non-optimized PSR value. This value is low because of the interference.

From figure, it is clearly visible that for all other PSR threshold values, the average PSR is greater than the one for the non-optimized one. Hence, we can safely say that our optimization method has a much better Packet Success Rate and hence can send and receive without much degradation than the non-optimized one.

IMPACT OF NUMBER OF NODES ON THE AVERAGE PSR

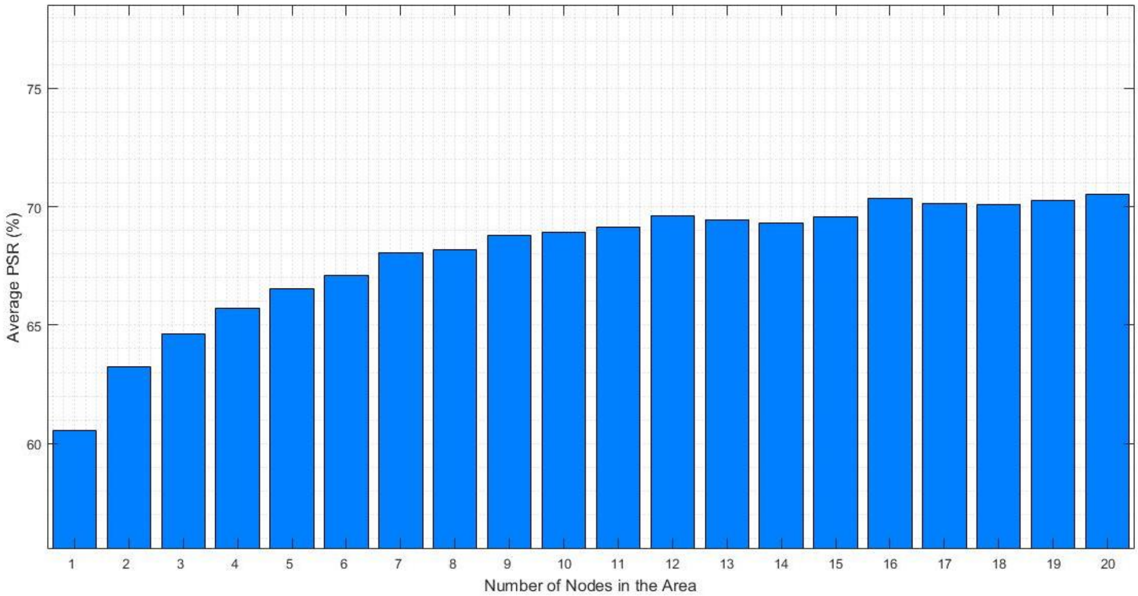

Figure 10: *Average PSR (%) vs number of nodes*

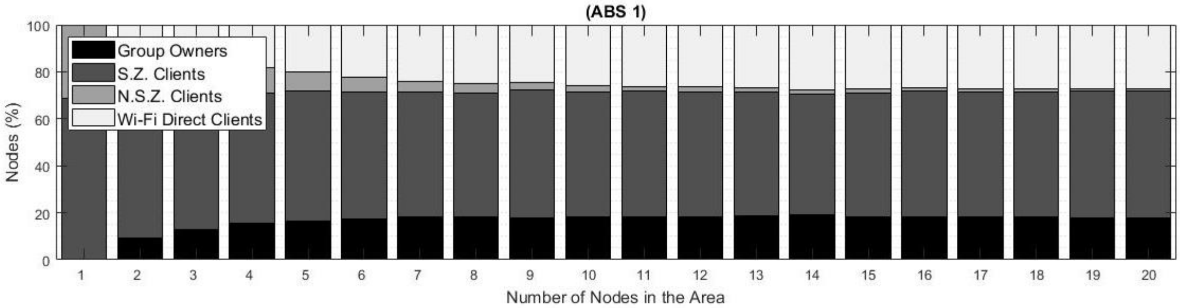

Figure 11: *Node Distribution vs number of nodes*

Our proposed system depends on the number of nodes that can perceive high PSR (safe zone nodes) so that we can enable its relaying capacities. The figure shows the change in the average PSR as the number of nodes increases. We can see that the devices follow a trend of increasing the average PSR as the number of nodes increase.

The figure depicts the distribution of nodes into the safe zone, non-safe zone, relay and the Wi-Fi direct groups according to the number of nodes. We can see that as the number of nodes increase, the number of nodes in the safe zone, and the Wi-Fi direct group increases and the number of non-safe zone nodes decreases. This indicates that, a greater number of relays and one-hop connections are formed.

One tradeoff here is, the increasing trend is because the PSR metric does not consider the impact of channel availability, but it just accounts for the reliability of the link against LTE interference.

RESULT AND DISCUSSION

From the figure, we can observe that the method we proposed provides a good way to counter the problems faced by the Wi-Fi when Wi-Fi and LTE coexists in the LTE-U 5GHz band.

In this method we proposed categorizing and grouping of different nodes and then use the ABS in order to counter the effects of interference from the pilots in the ABS. We show that Wi-Fi can intelligently adapt its operation to handle the high Packet Error Rate (PER) and lack of channel access opportunities through the use of ABS frames.

We proved that an optimal solution uniquely exists to the proposed scheme. We also proposed an algorithm to achieve the optimal solution. The evaluation and simulation results demonstrated that our proposed Grouping method can benefit for a low interference and a seamless coexistence between LTE and Wi-Fi.

SUMMARY

The coexistence of Wi-Fi and LTE in the LTE unlicensed 5GHz band is a topic of great interest amongst the researchers. We selected a few research papers, and evaluated how each topic studied by them have played a role in the coexistence of LTE and Wi-Fi. We were able to get inspiration from each of the research paper and were able to make appropriate modifications.

In this thesis, we proposed a system, which allows Wi-Fi devices to survive uncoordinated LTE transmissions through the grouping of nodes into relays. We show that Wi-Fi can intelligently adapt its operation to handle high Packet Error Rates (PER) and lack of channel access opportunities through the use of ABS frames. Simply sending the Wi-Fi signals through the ABS leads to a great degradation in the signals. In order to overcome this, we proposed a method to categorize the nodes into different categories to find out suitable relays and Wi-Fi direct groups. We propose a modified Hungarian Algorithm to find the best possible relay in order to group them with the Wi-Fi direct nodes. This method helps us to attain maximum possible Packet Success Rate (PSR) and a minimum possible number of transmissions. We evaluated our system for both optimized and non-optimized types. We also found the optimum threshold value for PSR. Finally, we evaluated our system to find the effects on Average PSR by the number of nodes

REFERENCE

1. Hongyu Sun, Zhiyi Fang, Qun Liu, Zheng Lu, and Ting Zhu. 2017. Enabling LTE and WiFi Coexisting in 5 GHz for Efficient Spectrum Utilization. J. Comput. Netw. Commun. 2017 (February 2017)
2. A. M. Cavalcante, E. Almeida, R. D. Vieira, S. Choudhury, E. Tuomaala, K. Doppler, F. Chaves, R. C. Paiva, and F. Abinader, “Performance evaluation of LTE and Wi-Fi coexistence in unlicensed bands,”
3. E. Almeida ***et al***., "Enabling LTE/WiFi coexistence by LTE blank subframe allocation," *2013 IEEE International Conference on Communications (ICC)*, Budapest, 2013,H. W. Kuhn, “The Hungarian method for the assignment problem,” Naval research logistics quarterly
4. Zhang H, Chu X, Guo W, Wang S (2015) Coexistence of WiFi and heterogeneous small cell networks sharing unlicensed spectrum. IEEE Commun Mag
5. S S. Chatterjee, M. J. Abdel-Rahman and A. B. MacKenzie, "Optimal distributed allocation of almost blank subframes for LTE/WiFi coexistence," *2017 15th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt)*, Paris, 2017
6. J. Xiao and J. Zheng, "An adaptive channel access mechanism for LTE-U and WiFi coexistence in an unlicensed spectrum", *Proceedings of the IEEE ICC Conference*, pp. 1-6, 2016.
7. Abinader Junior, Fuad & Almeida, Erika & Chaves, Fabiano & Cavalcante, André & Vieira, Robson & Paiva, Rafael & Muniz Sobrinho, Angilberto & Choudhury, Sayantan & Tuomaala, Esa & Doppler, K. & Jr, Vicente. (2014). Enabling the Coexistence of LTE and Wi-Fi in Unlicensed Bands. IEEE Communications Magazine
8. Aliasghar Keyhanian, Aris Leivadeas, Ioannis Lambadaris, and Ioannis Marmokos. 2018. Analyzing the Coexistence of Wi-Fi and LAA-LTE Towards a Proportional Throughput Fairness. In Proceedings of the 16th ACM International Symposium on Mobility Management and Wireless Access (MobiWac’18). Association for Computing Machinery, New York, NY, USA