Energy Detection Based Spectrum Sensing in Wi-Fi and LTE-LAA Co-Existence for 5G System

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Abstract- Presence of both Wi-Fi and small-cell LTE in unlicensed bands (particularly 5GHz), leading to their co-existence is a hot topic for research now a days. For pursuing a friendly co-existence between Wi-Fi and LTE (in unlicensed bands), assimilation of similar back-off and sensing parameters has been done and for this LTE-LAA has been made standardized by 3GPP. To define various protocols in field of telecommunication, various standard developing organizations have been amalgamated to work together under 3GPP. Many research challenges emerge from the co-existence between Wi-Fi and LTE-LAA like honing energy detection threshold, contention window size adjustment, and many others. For a rapid deployment in the field of unlicensed bands, we need a "fair access" as per the 3GPP vital protocols. All we need this time is reliable analytical models to overcome all the challenges emerging from this co-existence. In this work, we have made some amendments in celebrated Bianchi model and with a new make-up we evaluated the throughput for different scenarios of Wi-Fi and LTE-LAA in co-existence as well as without co-existence, by comparing these two we study the effects of various network parameters and right measures to be taken to make this co-existence more friendly. MATLAB software has been used to perform the proper simulations and to get a clear view.

Keywords- 5GHz unlicensed band coexistence, LTE-LAA (Licensed assisted access), Wi-Fi

1. INTRODUCTION

In this world of emerging technology, with more advancements and accessibility of communication services, number of users operating hand-held devices are rapidly increasing. Use of high-bandwidth applications like streaming video, audio and webcasting by such large number of users result in a consequent bandwidth dearth and increase in mobile data traffic. For providing every user a better networking experience by improving the throughput and data rate, we emphasis more on use of 802.11 Wi-Fi network or small cell LTE network. But high penetration areas with enormous number of mobile users have inflated demand, and from here arises the prerequisite for sharing of time between unlicensed spectrum of Wi-Fi and LTE. Wi-Fi network draw plans to function in unlicensed spectrum only where it communicates with other Wi-Fi nodes by a time-sharing mechanism contingent on Distributed Coordination Function (DCF) and communicates with non-Wi-Fi networks employing Dynamic Frequency Selection (DFS) and Energy Detection (ED) technique. But with increase in number of mobile users, their demands for better throughput and high data rate also start enhancing. So, to provide a performance boost to mobiles users LTE aggregates the use of both unlicensed and licensed bands for the maximum advantage. For the downlink communication (DL), carrier aggregation is used by combining both licensed and unlicensed bands or carriers for a better user experience and fulfilling all their demands. For uplink communication (UL), it employs its licensed bands only. With respect to co-existence for unlicensed LTE, there are two specifications: LTE Unlicensed (LTE-U) and LTE Licensed Assisted Access (LTE-LAA). This LTE-LAA has been developed by 3GPP. Both of these specifications differ in the way that LTE-LAA implements Listen-Before-Talk (LBT) mode whereas LTE-U has nothing to do with LBT. LTE-U works on duty-based approach also called as Carrier Sense Adaptive Transmission (CSAT) which is used for accessing LTE channels by modifying OFF and ON durations. LBT mechanism used in LTE-LAA works in similar fashion as CSMA/CA does for Wi-Fi. It is a sensing technique which firstly sense its environment and transmit data only when it is able to find a free channel to operate on. When a co-existence happens between LTE-LAA and Wi-Fi, it should be in such a way that it won't affect the latency and throughput of any of Wi-Fi and LTE-LAA, rather it should act as a boost for the overall performance. In this way we can give a perfect definition of "fair access or coexistence". 3GPP has its main focus on achieving this notation of fair co-existence. In our work, we will refer only LTE-LAA/Wi-Fi coexistence keeping LTE-LU/Wi-Fi co-existence for future work. In last years, many research works come in front of us related to LTE-LAA/Wi-Fi co-existence with many conflicting results.

2. RESEARCH BACKGROUND

With the 3GPP Release 13 [6], LTE/Wi-Fi co-existence turned out to be major domain for research work and an area of great interest. In one of initial works on this topic, from a radio source management which was working to examine 5GHz LTE/Wi-Fi co-existence [7] reveals that LTE do affect the Wi-Fi in co-existence scenarios so their fair access needs to be handled carefully. In [9], LTE and Wi-Fi co-existence performance analysis by proper simulation also proved that in a co-existence scenario while performance of LTE is very less affected, Wi-Fi approach is mostly obstructed by LTE transmissions and as a result Wi-Fi has to wait in listen mode most of time. So, Wi-Fi performance gets devastated to a greater extent as compared to LTE in co-existence scenario. In [8], an experimental set-up was used to carry out research in LTE-LAA and Wi-Fi co-existence which discussed impact of carrier sensing thresholds. Other main conclusion of this research work was asymmetry in back-off parameters which are used in LTE-LAA and DCF standards which Wi-Fi use. This asymmetry is a topic of careful examination. Other issue is the recommended values of sensing thresholds. Let us take an example, Wi-Fi uses -62dBm ED threshold to detect nonWi-Fi nodes but with this threshold Wi-Fi can interfere with signals weaker than -62dBm and is very hazardous for performance. So according to this research, various factors impact fairness of co-existence like sensing threshold, contention window size and transmission duration. [9] revealed the problems which arise due to asymmetry of channel bandwidth between LTE-LAA and Wi-Fi. Depending on where bandwidth of LTE-LAA is situated with respect to 20 MHz Wi-Fi channel, Wi-Fi performance has a noticeable effect of low bandwidth (1.24 or 5 MHz) LTE transmissions. In [10], Rochman et al. by extensive simulation examined the effect of energy detection threshold on LTE-LAA and Wi-Fi and also proved that the total throughput can improved if both LTE-LAA and Wi-Fi works on a -82dBm sensing threshold value. On the other side, in [11] Qualcomm through proper simulation work explored the co-existence of Wi-Fi with both LTE-U as well as LTE-LAA and proved that without degrading the Wi-Fi performance we can make both LTE and Wi-Fi to share the same unlicensed spectrum and can achieve fair throughput gain. In [12] Ericsson after investigating different aspects of LTE-LAA system for DL like Dynamic Frequency Selection (DFS), Radio Resource Management (RRM), physical channel design proposed an enhanced LBT approach which can act as a boon for improving LTE-LAA and Wi-Fi co-existence and result in fair access as required by 3GPP. In nutshell, proper evaluation of co-existence as proposed by 3GPP [6] is still excellent.

3. WI-FI AND LTE-LAA CO-EXISTENCE: MAC PROTOCOL MECHANISM

3.1 Wi-Fi DCF

Wi-Fi DCF make use of CSMA/CA protocol which employs DCF technique to avoid collisions. It performs the operation in following ways;
1) Before transmitting data, it waits for a certain time called random back-off time. This random back-off time is specified by contention window size and is in the range of [0, 2iW0-1] where W0 is the minimum contention window size and i is the back-off stage.
2) If any packet collision occurs while transmitting data then value of i increments by 1 and back-off counter starts decrementing every σ us respective to a back-off slot.
3) During this contention period, if channel is recognized to be busy then it pauses its timer till channel becomes clear.
4) If maximum value that back stage i can take is m, then after reaching m stage it stays there for one more unsuccessful transmission and in next unsuccessful situation i resets back to zero.

5) Then it shall wait for Distributed Inter-frame Space (DIFS) if the channel turns out to be clear at the end of back-off time and check the channel again.
6) Then it sends RTS frame (Request to Send) if the channel is still free.
7) If destination station is available, it will accept the request by sending CTS frame (Clear to Send). Then data frames are allowed to send and after sending them transmitter waits for ACK (acknowledgement) frame for SIFS (Short Inter frame Space) time duration.

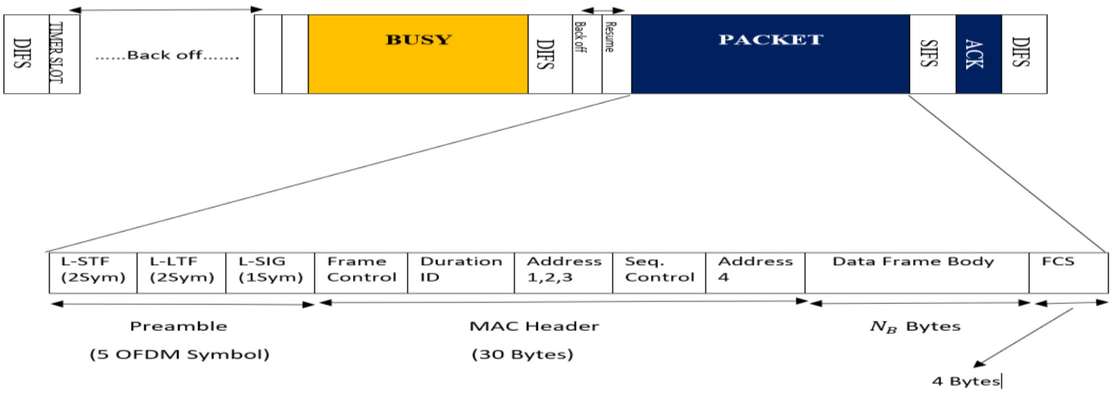

Fig 1: Wi-Fi frame structure for contention and frame transmission [1]

3.2 LTE-LAA LBT

It works in the similar way as CSMA/CA works for Wi-Fi except there are few differences.
1) For clear channel assessment (CCA), CSMA/CA in Wi-Fi use both ED and channel sensing techniques whereas LTE LAA employs only ED for CCA. Nodes in LTE-LAA senses channel for a time duration called defer period (Td) and then do through exponential back-off process at it is done in DCF.
2) Access priority class number defines the value of defer period.
3) After a slot time of TS = 9us same as of Wi-Fi nodes, back-off counter decrements.
4) Similar to that Wi-Fi, when packet collision occurs, depending on contention window size, back-off value is allotted in range of [0, 2iW0$^{/}$ -1] where W0$^{/}$ is minimum size of contention window and i is retransmission stage. In this case, if i excels the value of maximum retransmission stage m$^{/}$, then it will stay at m/ stage for el (retry limit) time and then resets to zero after el times.
5) Data is transmitted for a certain time interval called TXOP whose value also depends on access priority class number.
6) It transmits 1 subframe per 0.5ms slot boundaries where 1 subframe (1ms) is minimum resolution of data transmission.
7) For every user 1 Resource Block (RB) is smallest allotted unit that has 180kHz bandwidth for 1 subframe transmission duration. 1 subframe consists of 14OFDM symbols out of which 1st to 3rd are used as Physical Downlink Control Channel (PDCCH) and remaining are used as Physical Downlink Shared Channel (PDSCH) as shown in figure 2.

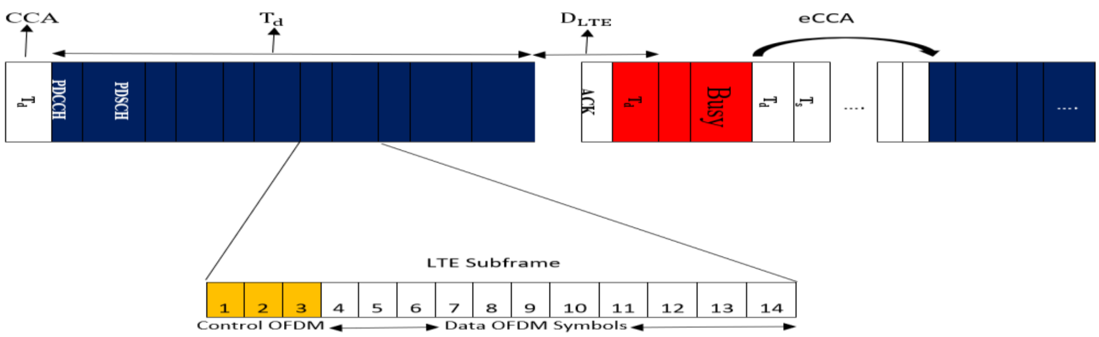

Fig. 2. LTE subframe structure and contention for LTE-LAA LBT [1]

4. Mathematical model on impact of energy detection threshold on LTE-LAA and Wi-Fi co-existence

Now, we will study how throughput performance of co-existence scenario of Wi-Fi and LTE-LAA get changed by modifying ED threshold values. Wi-Fi uses CS detection for other Wi-Fi nodes and ED detection for external networks whereas LTE-LAA employs only CCA-ED for detection of both in and out networks. Generally, for an LTE-LAA system, ED threshold value is - 72dBm and is -62dBm for Wi-Fi system. CS based detection has better accuracy in low threshold scenario in comparison to ED detection. This disadvantage of ED detection gives birth to a serious problem of hidden node that greatly affects the networks and their threshold values.

4.1 Energy detector: Detection Probability

Let rs(n) be the received signal, $x_s(n)$ is the modulated interference signal, wn(n) is the AWGN noise and h(n) is the channel impulse response. With a 20MHz Wi-Fi channel and a sampling rate of 50ns, received signal in the presence of interference (H1) and no interference (H0) is:

H1: (With Interference) $rs(n) = x_s(n) * h(n) + wn(n)$

H0: (Without Interference) $rs(n) = wn(n)$ (1)

For the energy detection, test statistic is

$$\in = \frac{1}{M}\sum_{i=1}^{M}|r(i)|^2 \quad (2)$$

Here for the test statistics, received sample sequence's length is M.

For Wi-Fi, with M = 680 and DIFS duration of 34us, probability of detection is estimated by:

$$P_d = P(\in > n) = Q\left(\frac{n-(\sigma_n^2+\sigma_x^2)}{\frac{2}{M}(\sigma_n^2+\sigma_x^2)^2}\right) \quad (3)$$

Here σ^2_n is the noise power, signal power is denoted by σ^2_x and η is the threshold of energy detection.

4.1 Capturing ED Threshold

We need to introduce new terms P_{dl} and P_{dw} as cross-network energy detection probability of LTE-LAA nodes and cross-network energy detection probability of Wi-Fi nodes to study the effects of Energy Detection threshold on cross network detection.

Wi-Fi collision probability can be written as

$$P_w = (1 - (1 - \tau_l)^{nl}) (1 - \tau_w)^{nw-1} + 1 - (1 - \tau_w)^{nw-1} \quad (4)$$

where $(1 - (1 - \tau_l)^{nl})$ is the probability that at least one of the LTE-LAA node transmit.

As a modification, we multiply this term P_{dw} by $(1 - (1 - \tau_l)^{nl})$ as LTE-LAA act as a cross-network for Wi-Fi so cross-network probability need to be included and as a resulted we get our modified equation as

$$P_w = [(1 - (1 - \tau_l)^{nl}) P_{dw]} (1 - \tau_w)^{nw-1} + 1 - (1 - \tau_w)^{nw-1} \quad (5)$$

Similarly, for LTE-LAA modified equation turned out to be

$$P_l = [(1 - (1 - \tau_w)^{nw}) P_{dl]} (1 - \tau_l)^{nl-1} + 1 - (1 - \tau_l)^{nl-1} \quad (6)$$

With these above modified equations, we will do our experimental study and deep analysis on this topic practically.

5. Result discussion

To validate our LTE-LAA/Wi-Fi co-existence model, we use MATLAB software and results have been presented in this section. Then we further work on our analysis part to encapsulate the impact of various parameters used in the model on the output throughput values by varying their values.

5.1 IEEE 802.11 – Validation of Bianchi Model

To get a crystal-clear view before going into co-existence scenario of LTE-LAA and Wi-Fi, where we need to simulate their equations simultaneously, we prefer to start from the basic and simplified model first. So, we opt to study the individual models first and by simulating their equations analyse the results by varying various parameters. So, we study Bianchi Model for Wi-Fi and examined it deeply by simulating it on MATLAB. In this model, CSMA/CA mechanism with binary exponential back-off also termed as distribution co-ordination function [DCF] is explained.

Considering the mathematical model of Bianchi's paper, we simulate its equations. Results obtained are very accurate and resemble to the theoretical ones. As it is clear from the figure 3 with increase in the number of stations, density increases so chances of collisions are more too. This is the reason why we have a decreasing graph with increase in number of stations.

5.1.1 Analysis for different values of m

For this part of analysis, we have to observe our results for different values of m (maximum back-off stage value) by keeping other parameters like W (minimum size of contention window) constant.
As we can see in the output graph in figure 3, blue and red lines are depicting how output waveform gets changed on changing the values of m. With increase in the value of m, throughput of the system also increases. This happens because according to CSMA/CA protocol which employs DCF technique with the increase in number of back-off stage value, there are less chances of collision and saturation throughput increases.

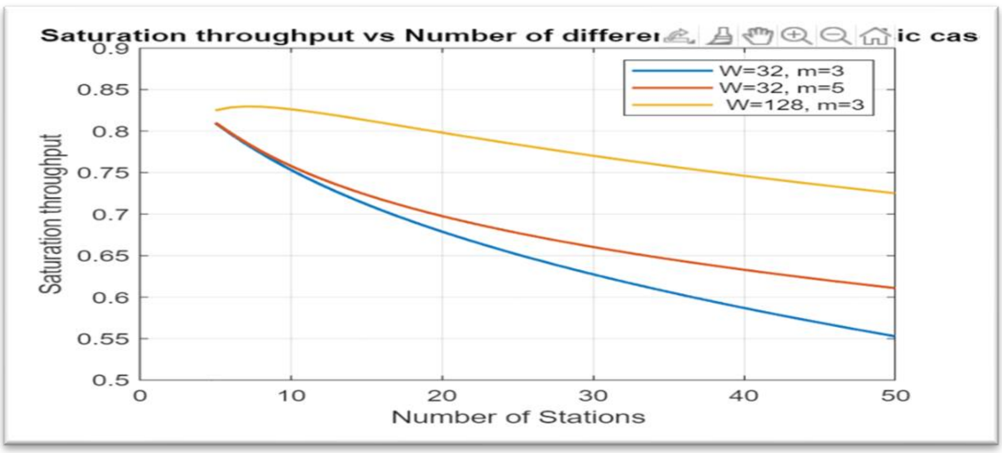

Fig. 3. Throughput of Wi-Fi system with W =32, m=3 and 5, and W=128, m=3

5.1.2 Analysis for different values of W

Under this analysis part we check our output result for different values of W (minimum size of contention window of LTE-LAA), keeping rest of parameters like m (maximum back-off stage value) as constant.
As we can see in the output graph in the figure 7, blue and yellow lines are clearly showing how our throughput changes with change in the value of W. As the value of W increases, throughput also increases. This happens because when the minimum contention window size increases, it ensures that highly dense network can be recuperated when the situation of collision will come. As

a result, it can increase latency but reduce the loss of data and increase the overall throughput increases.

5.2 Validation of throughput of LTE-LAA / Wi-Fi coexistence

For this analysis, we have to simulate equations mentioned in mathematical model section. To do this analysis, we have taken nw =10 (Wi-Fi station number), and check the variations in output for different values of nl (number of LTE substations).

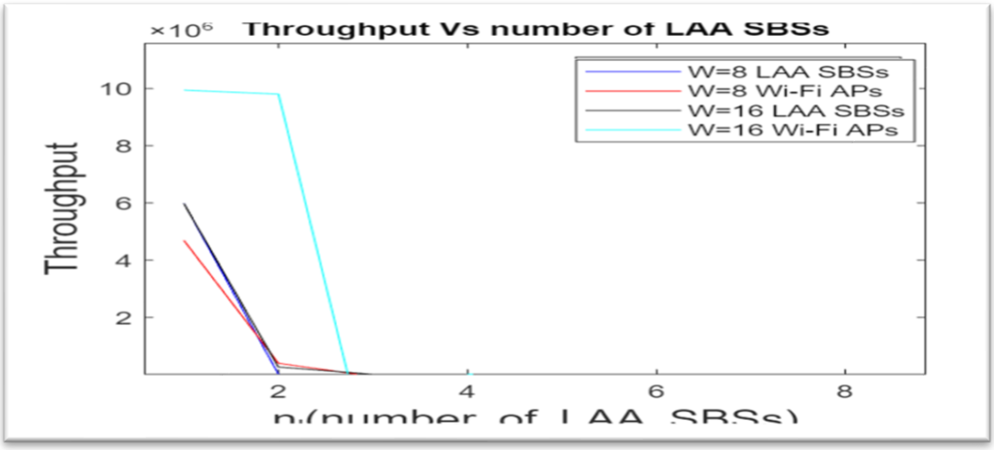

Fig. 4. Throughput of Wi-Fi substations compared with the LTE-LAA substations for W=8 and W=16

5.2.1 Analysis for different values of n_l

As it is clear from the result in figure 4, with the increase in number of nl (number of LAA SBSs) throughput in all the scenarios decrease because with increase in the number of nl, density increases and chances of collision are more. For smaller values of nl, nw (number of Wi-Fi Aps) are more so Wi-Fi nodes as a result have more access of channel than LTE-LAA. As a result of it, Wi-Fi throughput is high as we can see from the blue line initially and as nl value increases, Wi-Fi throughput keeps decreasing as LTE-LAA starts taking access of channel. Comparing red and blue lines, large number of LTE-LAA eNBs denotes more for throughput because TXOP of LTE is large than Wi-Fi so can transmit data for more duration.

5.2.2 Analysis for different values of W

On comparing the graph for LTE-LAA and Wi-Fi for different values of W i.e. blue and black for LTE-LAA and red and sky blue for Wi-Fi, we can see that ss the value of W increases, throughput also increases. This happens because when the minimum contention window size increases, it ensures that highly dense network can be recuperated when the situation of collision will come. As a result, it can increase latency but reduce the loss of data and increase the overall throughput increases.

5.3 Validation of energy detection spectrum sensing model

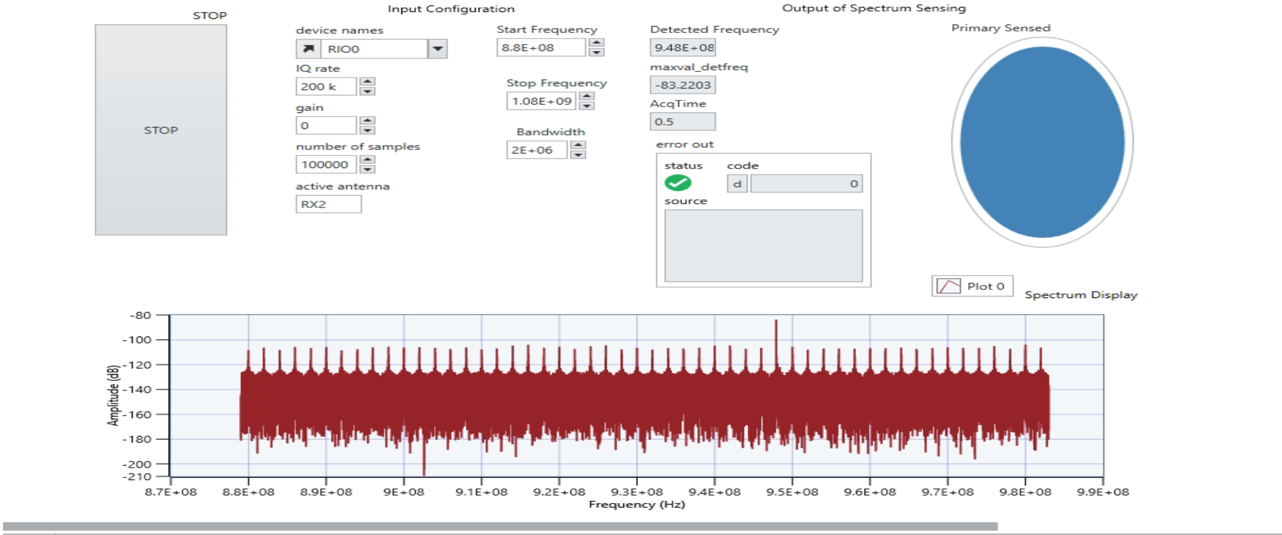

Fig. 5. Receiver panel view on LabVIEW

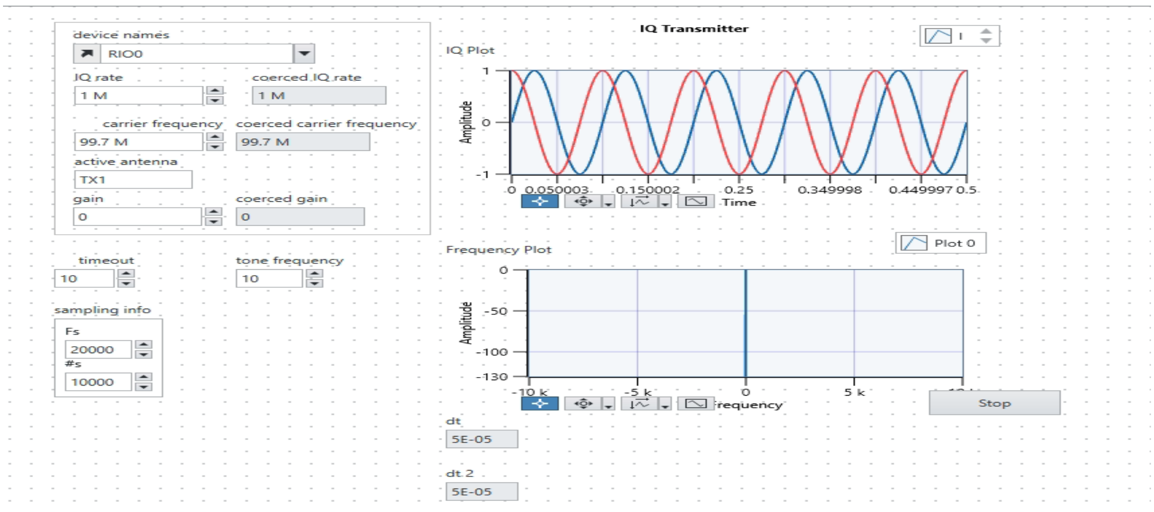

Fig. 6. Transmitter panel view on LabVIEW

As we can see from the result in figure 6, this energy-based sensing model detect the frequency at which spectrum is used by some primary user or not.

6. Conclusions

In this work, we have made some amendments in celebrated Bianchi model and with a new make-up we evaluated the throughput for different scenarios of LTE-LAA and Wi-Fi in co-existence as well as without co-existence, by comparing these two we study the effects of various network parameters and right measures to be taken to make this co-existence more friendly. MATLAB software and LabVIEW has been used to perform the proper simulations and to get a clear view. A new analytical model has been presented along with inclusion of effect of ED threshold in the main mathematical model and analyse for its impacts on threshold values. Under the proposed scheme section, we presented some new ideas and work to be done as a modification in the model. Then we try to execute those ideas and after simulating them on MATLAB and LabVIEW, we analysed the results and discussed them in result and analysis section. From this term project, main conclusion which we can draw is that we can increase the throughput of LTE-LAA and Wi-Fi in a co-existence scenario by managing channel access parameters like minimum size of contention window of LTE-LAA(W), number of LTE-LAA substations, data rates, TXOP values. These all things can contribute a lot in achieving "fair co-existence or access" scenario as proposed by 3GPP.

7. Acknowledgement

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