IMPROVEMENTS FOR UPLINK LONG TERM EVOLUTION (UL-LTE) IN HETEROGENEOUS NETWORK USING DYNAMIC SPECTRUM ALLOCATION TECHNIQUE

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ABSTRACT

Several interference mitigation strategies can be used in LTE networks to meet the consumers' increasing need for faster data speeds. Dynamic Spectrum Allocation (DSA), which maintains spectrum in a converged radio system and distributes it across all participating radio terminals, is one of the most promising solutions. However, the fundamental obstacle to achieving increased network capacities is increased inter-cell interference. The aim of this paper is to analyse the effectiveness of a newly proposed DSA technique by comparing its bit error rate (BER) and throughput (TP) with a typical uplink LTE configuration. To maximise throughput in a heterogeneous network, the suggested DSA technique utilises the Nash Bargaining Solution (NBS) scheme, a cooperative game theory that could correlate with the bit error rate. The software tool GNU Radio, which offers signal-processing blocks to develop software-defined radios and signal-processing systems, was used to create the setups. After the simulations were performed, the BER values were recorded and compared, while the TP values were established and computed appropriately. According to the results, the uplink (UL-LTE) architecture with DSA has an improved TP and a lower BER value. As a result, spectral efficiency can also be improved.

KEYWORDS

Long Term Evolution (LTE), Dynamic Spectrum Allocation (DSA), Single Carrier-Frequency Division Multiple Access (SC-FDMA), Bit Error Rate (BER), Throughput (TP).

1. INTRODUCTION

The radio spectrum has become increasingly crowded since the invention of radio communications due to a variety of applications. Such a circumstance undoubtedly contributed to the point at which various users practically used the entire available radio spectrum. In turn, this will cause interference to develop within the network. User equipment (UEs) and diverse base stations (BS), such as macrocell, picocell, and femtocell, are frequently components of heterogeneous networks. Both uplink (UL) and downlink (DL) transmission can be used to communicate between them. Data transmission from the user device (UE) to the BS takes place during the UL communication, and vice versa during the DL communication. These communications occasionally tend to use the same carrier frequencies, which can lead to

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interferences known as cross-tier interference within the network. A network scenario including a macrocell BS, a femtocell BS, macrocell users, and femtocell users is shown in Figure 1. To fulfil the increased demand for high-speed data services, previous researchers suggested that a new network deployment consisting of a normal cellular network and femtocells may be established [1].

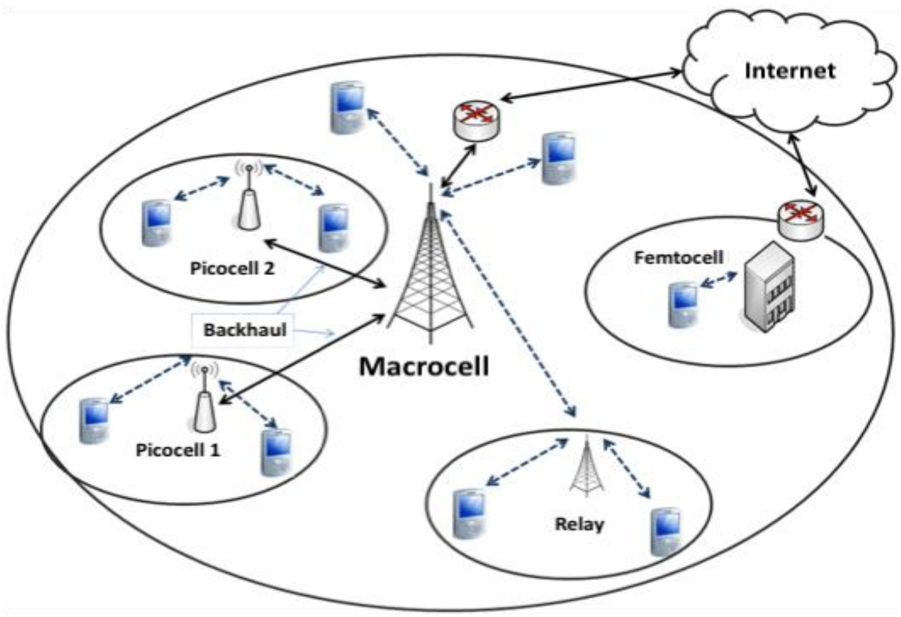


Figure 1. UL and DL communication scenario in a heterogeneous network

Due to the lower received signal strength from the macrocell, femtocells are typically installed indoors. In turn, by regulating the attenuation when signal transmission flows through walls, interior coverage can be made better. Femtocells also aid in increasing network capacity by decreasing the distance between users and BSs. Researchers have also highlighted how a heterogeneous network can increase capacity, maximise spectrum, lower capital, and operating costs, and enhance the network architecture from the standpoint of the user in addition to these advantages [2]. In a heterogeneous network, macrocells and small cells can be assigned a radio frequency spectrum that is similar [3]. Femtocells, on the other hand, prefer to operate in Closed Subscriber Group (CSG) mode, which only permits a small number of authorised small cell customers to join. As a result, there are coverage gaps within the macrocells known as "black holes," where users who are macro and who are within the femtocells' transmission range but who experience substantial inter-cell interference cannot be served by either device (ICI). This prevents reliable DL transmission, which is why it is known as the victim user equipment (UE). Next-generation heterogeneous network deployments consider operating small cell densification because it is the limiting element for increasing network capacities [4].

Cross-tier interference was found to occur for both the UL and DL segments in propagation scenarios involving macrocells and femtocells [5]. Numerous ways had been presented to reduce this interference, including those reported in [6] and [7]. These tactics have been created to increase the effectiveness of heterogeneous networks when compared to those stated in [8] and [9]. However, there are still several issues with these methods, and neither do they completely remove the interference, nor do they demonstrate any appreciable effects. Manufacturers of femtocells have expressed their opinion about selecting what may be regarded as the optimal mitigation strategy to be implemented into the "enhanced" femtocell design configuration since time is of the essence. A viable mitigation method that can reduce the aforementioned cross-tier interference is urgently needed.

The rest of the papers are organized as follows: Section 2 discusses the related works discussing interference mitigation techniques, the implemented DSA technique using GNU Radio software, section 3 details LTE configuration simulation setups for typical and DSA UL-LTE and throughput calculation expressions, section 4 presents the results and discussions and lastly, section 5 summarizes the conclusion.

2. RELATED WORKS

Currently being studied are a wide variety of interference mitigation strategies. A method based on time domain muting (TDM) that uses symbol efficiency (SE) and projected cell load circumstances as metrics to determine the muting ratio of resources has been suggested [10]. To verify the projected higher throughput performances, system-level simulation was carried out. The dynamic cross-tier interference coordination mechanism (D-CTIC) was established and only used when the interfered user equipment is unsure of its quality-of-service constraint, according to research on the Spectral Efficiency and Management of Cross-Tier Interference in a Femtocell Network [11]. As a result, a higher cell spectral efficiency can be attained by tolerating some cross-tier interference. Additionally, a soft frequency reuse strategy was created, which makes the promise that it will reduce interference while increasing cell throughput [12]. The plan was created when the user equipment detected significant interference from femtocells that were nearby. In addition, earlier researchers have suggested a technique for managing interference that involved single-hop, multi-hop, and multi-way network setups. The investigation revealed several issues, including inter-cell interference, out-of-cell interference, and more [13]. Table 1 shows the Comparison of Different Interference Mitigation Techniques.

Table 1. Comparison of various techniques for mitigating interference

Author(s) name and year	Technique	Description	Advantages	Disadvantages
Singh, R., et. al., 2014	Resource partitioning [10]	Suggests tiny cells' muting	Provide users of macrocells with greater service quality by reducing holes in their macrocell coverage	The spectrum efficiency factor, which can increase throughput, is not taken into account
Zhou, F. et. al., 2013	D-CTIC [11]	Utilized once the interfering UE is unable to maintain its effectiveness.	Maximizes spectrum efficiency	Due to its exclusive concentration on femtocells, it is unsuitable for heterogeneous networks
Khandare, R., 2015	CASFR method [12]	When a UE acknowledges significant interference from nearby femtocells, the scheme is formed	Decreases interference, which enhances the cell's throughput	The spectral efficiency factor is neglected
Sirhan, N. N. and Martinez-	Multi-Agent Q-Learning (MAQL)	Produces collaborative and	Maximizes spectrum	Lack of heterogeneity factor

Ramon, M., 2022	[14]	competitive scheduling algorithm	efficiency	
Cheng,H., 2014	Dynamic spectrum allocation [15]	Utilize the fluctuating traffic of various wireless network systems	Maximizes spectrum efficiency	Requires the additional study to determine how well the DSA design performs

The Dynamic Spectrum Allocation (DSA) technique, another interference mitigation method, has undergone extensive research for a variety of implementations. Researchers have hypothesised that the DSA scheme might guarantee the equity of the spectrum allocation by taking the economic element, spectrum use, and restricting the incidence of inter-system interference correspondingly [16]. The concept of the throughput maximization factor, which is crucial for mitigating interference, was left out of the study. Additionally, for cluster-based cognitive radio ad hoc networks, other researchers presented a novel cross-layer DSA that permits the improvement of throughput, power consumption, and packet transmission latency. By grouping the networks into clusters according to the power level of the nodes, the current speed, and the availability of the spectrum, the proposed strategy was put into practise [17].

3. The Implemented DSA Technique Using GNU Radio Software

The Nash Bargaining Solution algorithm, which is also known as the DSA algorithm, was used in earlier research [15] and has been enhanced in this study. The improvement made in this algorithm is that the algorithm is simplified so that it promotes low complexity in circuitry which can conserve the bandwidth of a network.

It is assumed that the UEs sends the request notification which is low data transmissions to the BS during UL communication. The entire bandwidth is consumed by one symbol at a time because the data modulation of the UL connection stipulates that the signal is to be transmitted in serial mode. As a result, the allocation of subcarriers is not considered for UL transmission. Figure 2 shows the flow chart for the BS's inclusion of packet allocation and recognition. The BS's scheduler, which controls packet release, dynamic resource allocation, and detection of UEs, is its central processing unit. First off, the BS offers a buffer where the identifier (ID) and message type (MT) of the active UEs can be placed. When the UE's ID appears in the buffer, the BS will transmit a notification or data to the UE.

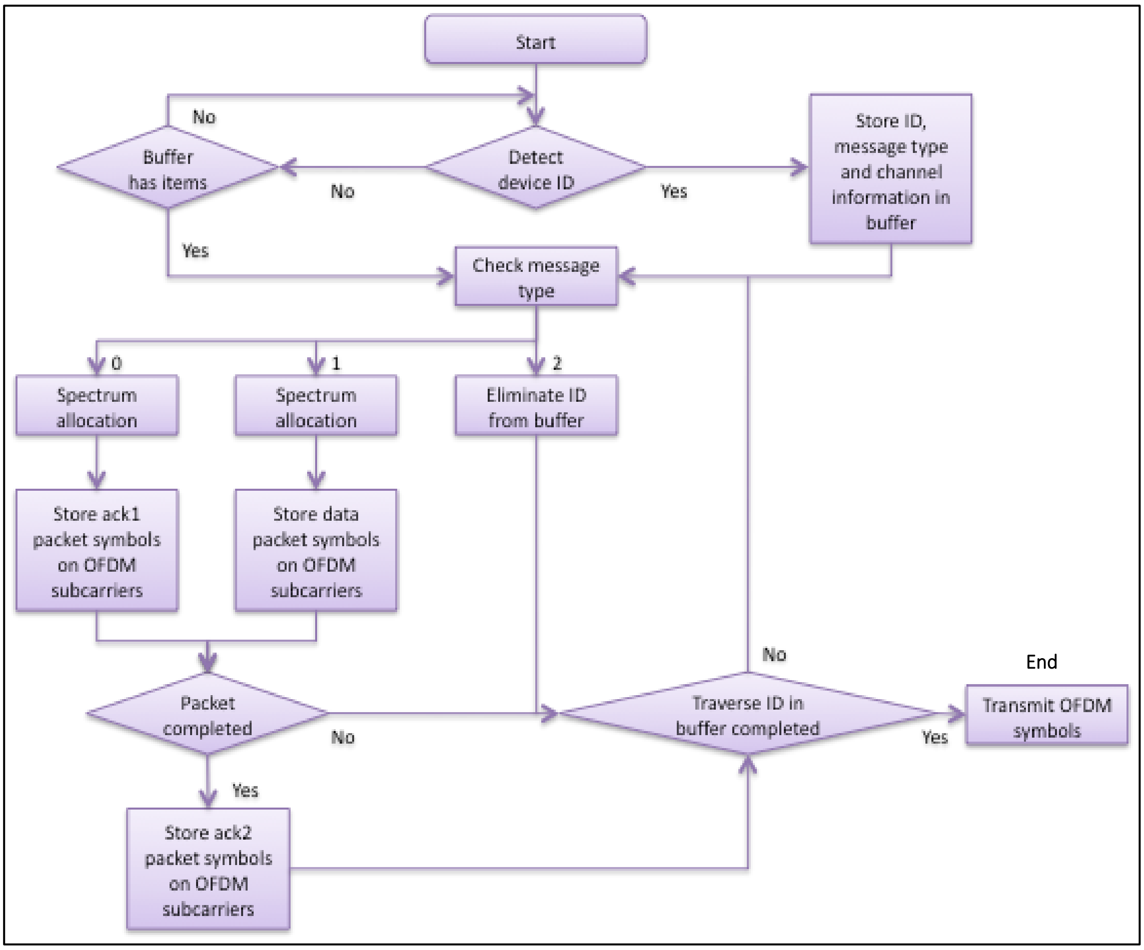


Figure 2. The flow chart of the scheduler of the BS

Table 2 displays the various message formats for packets sent from UEs.

Table 2. The MTs sent between UE and BS.

MT	**UE**	**BS**
0	Request	BS notifies UE
1	UE notifies BS	Transmission of data
2	UE notifies BS of the end of transmission	BS notifies UE of the end of transmission

From Table 2, it is understood that MT 0 specifies that the packet is being requested by the UE, whereas type 1 specifies that the packet is a confirmation that the UE has received the notification from the BS and lastly, type 2 specifies that the packet is an acknowledgement that the data transmission has been completed.

4. LTE CONFIGURATION SIMULATION SETUPS

4.1. Typical Uplink LTE (UL-LTE) Configuration

For UL setup in LTE, the Single Carrier-Frequency Division Multiple Access (SC-FDMA) modulation is utilised. It combines OFDM's resistance to multipath with the low peak-to-average power ratio (PAPR or PAR) of single carrier techniques. Figure 3 and Figure 4 respectively depict the flow diagram of the UL-LTE configuration for the modulator and demodulator.

The upper portion of Figure 3 depicts the data packets' mapping for transmission whereas SC-FDMA transmission is implemented in the lower portion. Because SC-FDMA is utilised as the multiplexing technique, this setup is regarded as an UL-LTE configuration. Data are generated by the Random Source block and sent to the stream blocks, where they are transformed into stream data. Later, the header and payload bits of the stream data are separated, and they are sent via the Chunks to Symbols blocks to be transformed into symbols. They are then translated into symbols and sent to the SC-FDMA Carrier Allocator block, where the parallelization of the original resultant data was accomplished. The system then carried out subcarrier mapping and allocated the frequency domain data symbols to the larger subcarrier group before passing them through to FFT and SC-FDMA Interleaver. The Cyclic Prefix block is then applied to the pre-OFDM symbols to cancel the Inter-Symbol Interference (ISI).

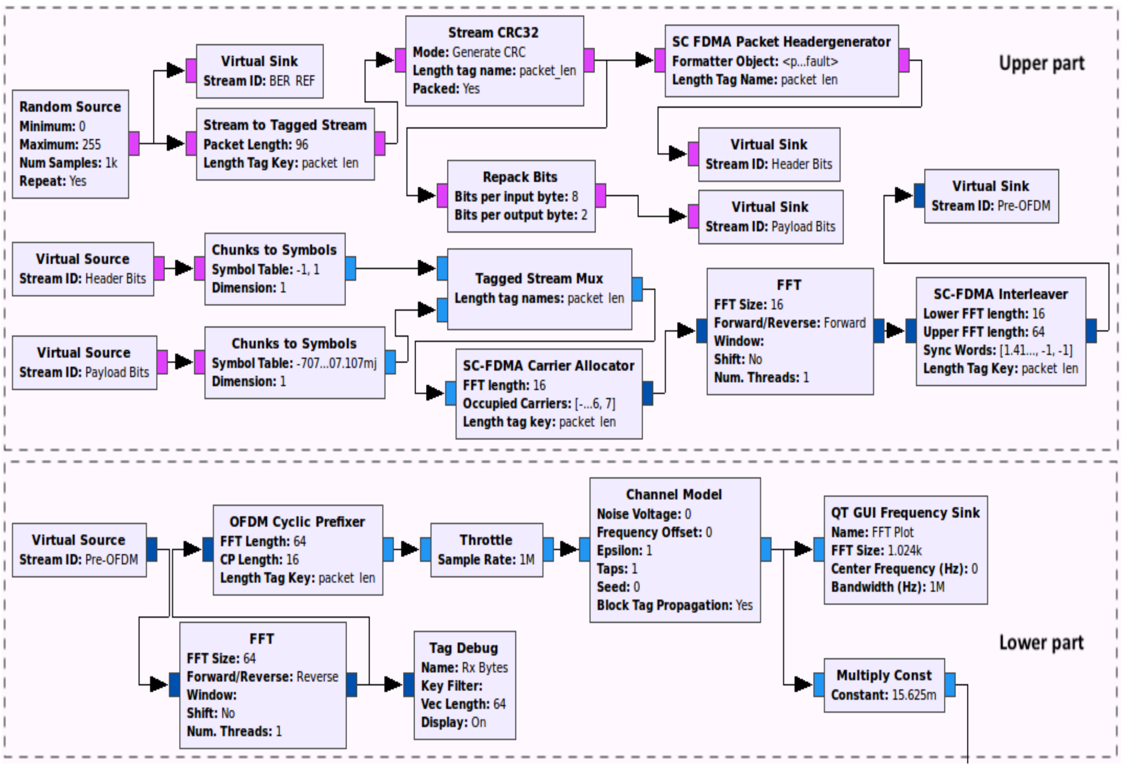


Figure 3. The modulation of UL-LTE setup with SC-FDMA

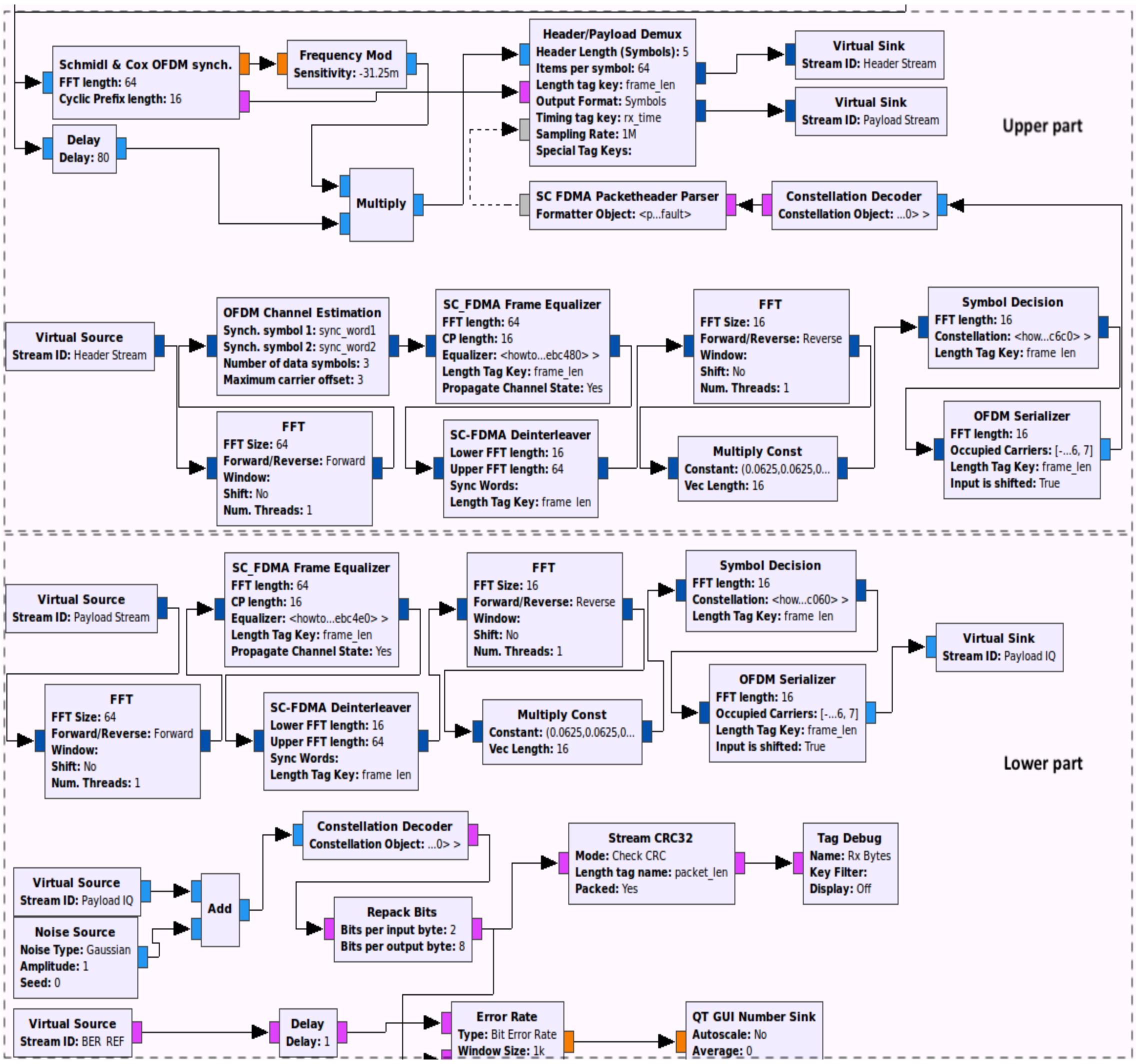


Figure 4. The demodulation of UL-LTE setup SC-FDMA

Figure 4 depicts the assembled demodulator portion of the setup. Through the Schmidl and Cox OFDM Sync block, the SC algorithm was implemented in this arrangement. The processing of the received data is carried out by the Header / Payload demultiplexer. The first channel taps are calculated by the Channel Estimator and are then transmitted via tags to the others. other programming blocks such as the SC-FDMA Frame Equalizer, SC-FDMA De-interleaver, and SC-FDMA Packet Header Parser are implemented in the process of receiving and equalising the reception. The Payload stream was then converted into Payload IQ for demodulation, which is shown in the lower portion, by passing via the FFT, Symbol choice, and OFDM Serializer blocks. The Error Rate block was also used to determine the bit error rate of the flow graph when the configuration was actuated by interference, which was created by the Noise Source block.

4.2. Uplink LTE (UL-LTE) Configuration incorporating DSA (DSA UL-LTE)

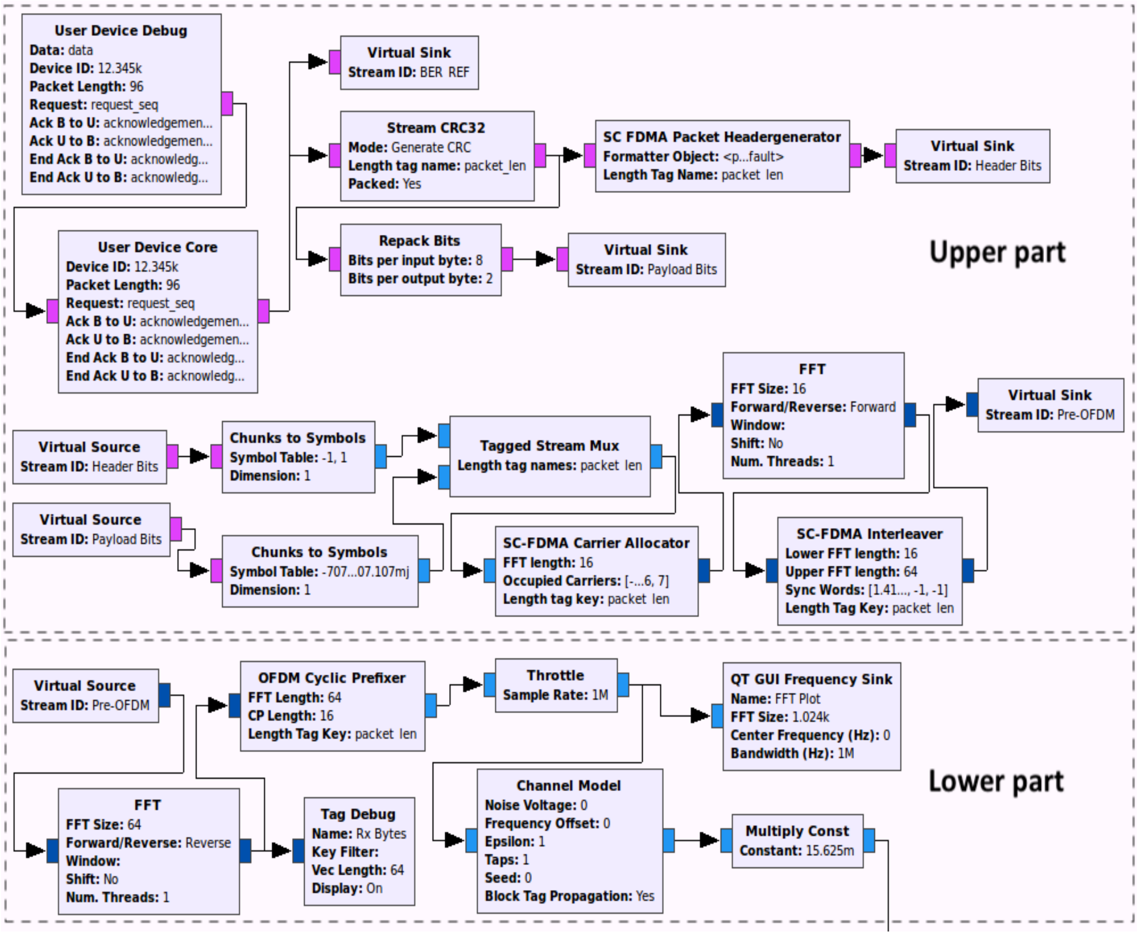


Figure 5. Flow graph of DSA UL-LTE configuration with SC-FDMA modulator

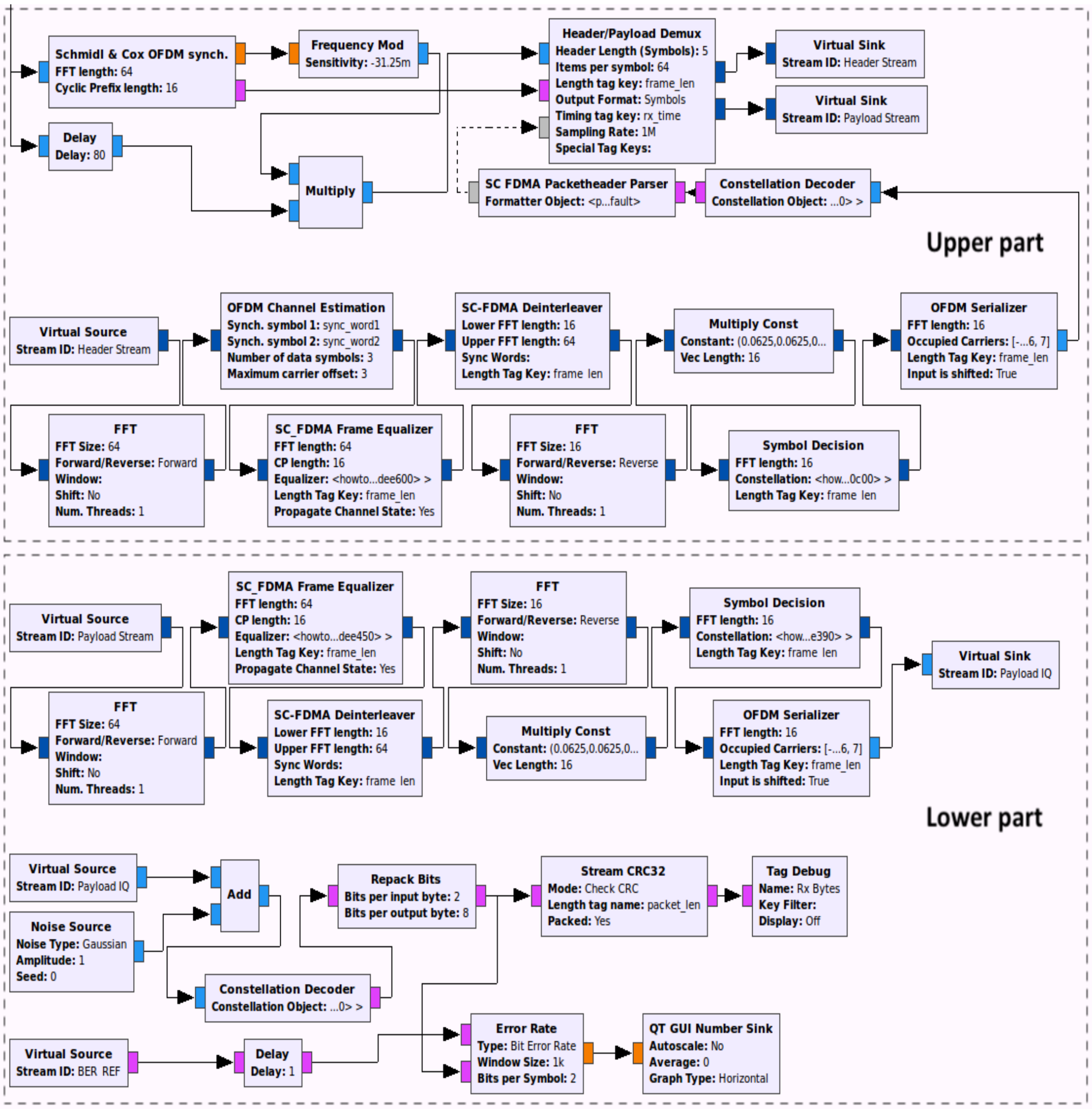


Figure 6. Flow graph of DSA UL-LTE configuration with SC-FDMA demodulator

The blocks used in the flow graph for the DSA UL-LTE configuration are essentially the same as those used for the typical UL-LTE configuration. The source block is the only difference; in a typical design, this source block generates a random set of data. The UE Core block serves as the data source for the flow graph that incorporates DSA. As a result, the DSA UL-LTE setup operates very identically to the one without DSA implementation. Figure 5 and Figure 6 both depict the flow graphs for the modulator and demodulator components of the DSAUL-LTE setup.

4.3. Throughput Calculation

The following formula is used to determine the throughput for both the standard LTE configuration and the UL configuration with DSA implementation. The set of formulas used to determine capacity and the Signal-to-Interference Plus Noise Ratio (SINR) were modified from previously conducted research [18]. Based on the constraints of the laboratory, some parameter values in these calculations were assumed. The parameters for the typical UL-LTE configuration and the configuration with DSA implementation are listed in Table 3. The building is assumed to be a single-story structure, which accounts for the absence of any penetrated floors.

Table 3. Assumptions for the mathematical expressions.

Description	**Value**
Transmitter and receiver distance $d_{TX\text{-}RX}$ [m]	20
Factor of outshadowing, Θ^{ut} [dB]	10
Number of penetrated floors, n	0

According to Table 3, $d_{TX\text{-}RX}$ represents the separation between the transmitter and receiver, and Θ^{ut} represents the outshadowing factor, which has a Gaussian distribution with a mean and standard deviation of zero. Equation (1) below, where is the subcarrier assignment and $C_{m,n}$ is the capacity of the serving macrocell, expresses the total system throughput, T_X.

$$T_X = \sum_X \sum_N \beta_{x,n}.C_{x,n} \quad (1)$$

The capacity formula was depicted from [9] and is expressed in Equation (2) below,

$$C_{m,n} = \Delta f.\log_2(1 + a\gamma_{m,n}) \quad (2)$$

where $\gamma_{m,n}$ is the total SINR for the system and $a = -1.5\ln(5BER)$.

5. Result and Discussion

5.1. Generated Waveform and BER values for Typical UL-LTE Configuration and DSA UL-LTE Configuration

Table 4. Generated Waveform and BER values

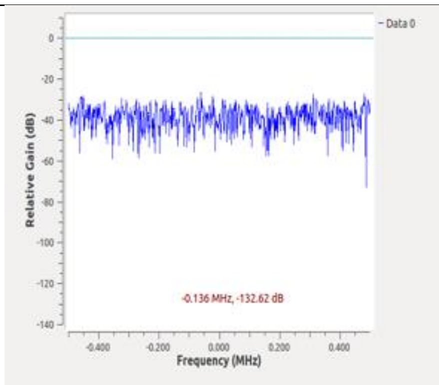
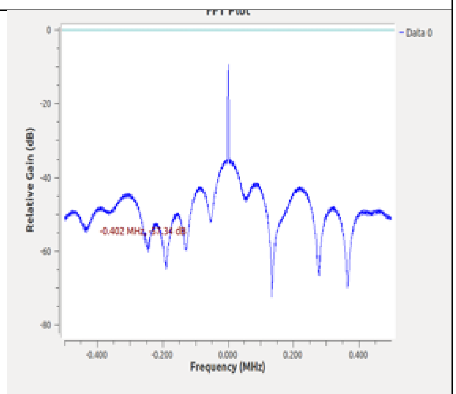
<table>
<tr><th>Type of configuration</th><th>Typical UL-LTE</th><th>DSA UL-LTE</th></tr>
<tr><td>Waveform</td><td>
</td><td>
</td></tr>
<tr><td>BER (%)</td><td>0.5</td><td>0.1</td></tr>
</table>

Table 4 displays the generated signals and BER values for both configurations with the noise amplitudes set to 1. Both configurations' signals have unique forms that are easily distinguished. When compared to a signal with DSA implementation, the signal produced for the usual LTE configuration demonstrates that it has higher peaks. The interference for the conventional LTE design is also stated to be more than it is for DSA deployment.

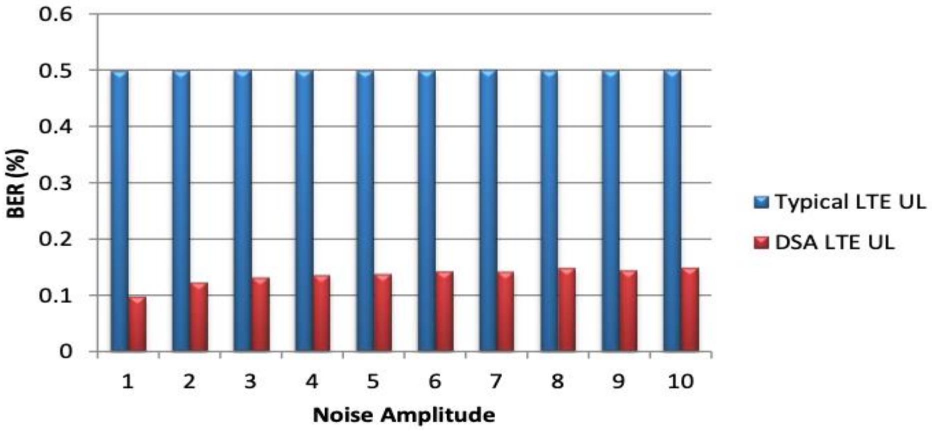


Figure 7. Comparison of BER values for typical UL-LTE and DSA UL-LTE configurations

Figure 7 compares the UL communication BER values between the typical UL-LTE configuration and the DSA UL-LTE configuration. The figure shows that, with a very high difference of at least 0.35 percent, the value of BER of the DSA UL-LTE configuration is always lower than that of the typical UL-LTE configuration when the noise amplitude spans from 1 to 10. Furthermore, it is also clear that the BER values for the typical UL-LTE arrangement remain constant at 0.5. For a typical UL-LTE arrangement, there are no significant differences in the BER values, and the readings appear to be nearly static when the noise amplitude is changed from 1 to 10. When compared to the case with DSA UL-LTE, it is clear that the BER values increase for noise amplitudes between 1 and 4 and decrease only slightly for noise amplitudes above 5. When the noise amplitude is set to 6, it then gradually increases once again. Up until the noise amplitude reaches 10, the pattern persists. Therefore, it can be concluded that the range of noise amplitudes affects the DSA UL-LTE configuration but not the BER values of the typical LTE setup. As can be seen, the typical UL-LTE configuration has far larger BER values than the DSA UL-LTE design.

The regression line for the DSA UL-LTE configuration is shown in Figure 8. The benefit of modelling BER as a function of noise amplitude is that it will allow future researchers to test the efficacy of DSA UL-LTE configurations by simply inserting their preferred noise amplitudes into the model, from which the BER value can be obtained. To compare the differences between the typical UL-LTE and the DSA UL-LTE configuration, the root mean squared error (RMSE) for both configurations will first be determined. The comparison of the RMSE values is done using the BER data gathered from the simulations.

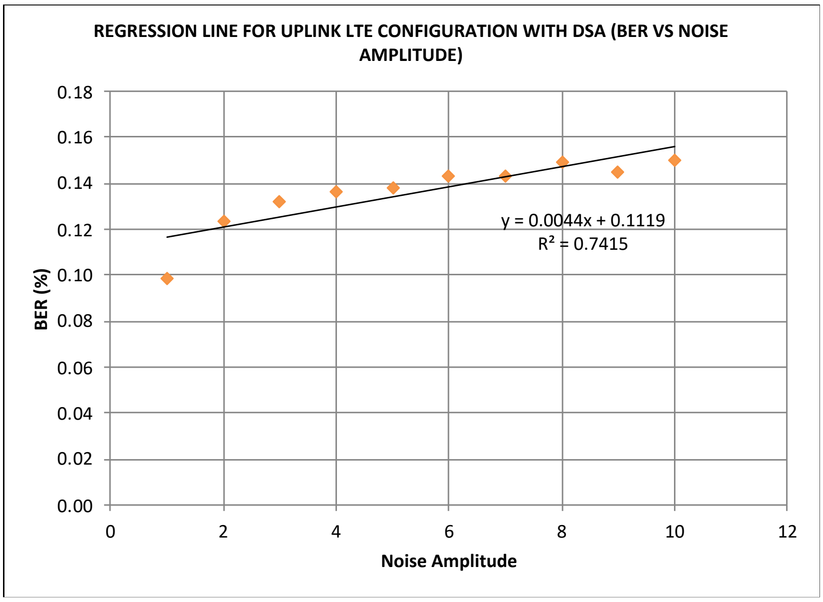


Figure 8. Regression Line for DSA UL-LTE Configuration

Equation 3 illustrates the BER model derived for the DSA UL-LTE configuration as a function of noise amplitude.

$$\mathbf{B_{DSA\ UL\text{-}LTE} = 0.004N + 0.11} \tag{3}$$

where $B_{UL\text{-}LTE}$ is the throughput and N is the noise amplitude.

Figure 9 depicts the throughput graph comparing typical UL-LTE configuration with DSA UL-LTE configuration. When the noise amplitude is between 1 and 10, it can be shown that for the typical UL-LTE arrangement, the graph nearly maintains a straight horizontal line. The graph displays a smooth curve for the DSA UL-LTE setup when the noise amplitude is between 1 and 10. The typical UL-LTE configuration's throughputs are not significantly impacted by the range of noise amplitudes because the throughput values are nearly constant. Additionally, the throughput figures for DSA UL-LTE configurations are consistently higher than those for the typical UL-LTE setup. Moreover, it can be seen that the throughput for the DSA UL-LTE setup decreases as the noise amplitude increases.

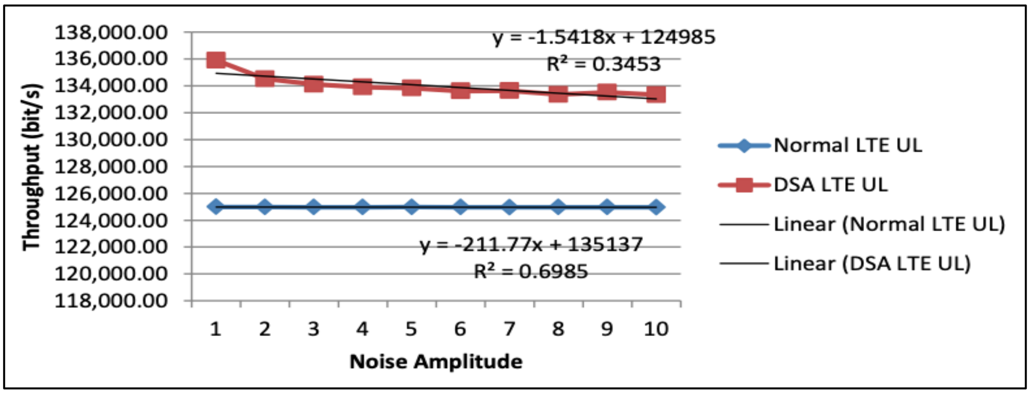


Figure 9. Comparison of throughputs for typical UL-LTE configuration and DSA UL-LTE

Equation 4 illustrates the throughput model for the DSA UL-LTE configuration as a function of noise amplitude.

$$\mathbf{T_{DSA\ UL\text{-}LTE} = -1.54N + 124985} \tag{4}$$

where $T_{UL\text{-}LTE}$ is the throughput for DSA UL-LTE and N is the value of noise amplitude.

6. CONCLUSION

The LTE design has been proven to offer higher throughput than a heterogeneous network setup without the DSA implementation. The simulation results provided evidence in favor of the proposition that interference in a heterogeneous network can be successfully decreased. The TP values were established and calculated per the BER values, which were recorded and compared. According to the results, the DSA UL-LTE architecture has an improved TP and a lower BER value. To increase spectral efficiency, interferences must be minimized, and system throughput must be maximized. In the very near future, it is also intended to pursue empirical inquiry involving implementation using USRP hardware. Given the limitations of the lab, the experimental design will be based on the hypotheses developed in this study. The outcomes can show that the system is hardware compatible and thus usable in real-world applications.

CONFLICTS OF INTEREST

All authors declare no conflicts of interest.

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