Research Paper

Journal of Engineering and Technological Sciences

An Enhanced Dynamic Spectrum Allocation Method on Throughput Maximization in Urban 5G FBMC Heterogeneous Network

Nurzati Iwani Othman[1,*], Ahmad Fadzil Ismail[1], Khairayu Badron[1], Wahidah Hashim[2], Mohammad Kamrul Hasan[3] & Sofia Pinardi[4]

[1]Department of Electrical & Computer Engineering, International Islamic University Malaysia, Jalan Gombak, 53100, Selangor, Malaysia
[2]College of Computer Science & Info Tech, Universiti Tenaga Nasional, Kajang, Selangor, Malaysia
[3]Faculty of Information Science & Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia
[4]Electrical Department, Universitas Muhammadiyah Prof. Dr. Hamka, Jalan Tanah Merdeka No. 6, Kp Rambutan Jakarta 13830, Indonesia

Corresponding author: nurzati.iwani90@yahoo.com

Abstract

Reports have shown that the demand for data managed by wireless systems is expected to grow by more than 500 exabytes by 2025 and beyond. 5G networks are predicted to meet these demands, provided that the spectrum resources are well managed. In this paper, an enhanced dynamic spectrum allocation (E-DSA) method is proposed, which incorporates a cooperative type of game theory called the Nash bargaining solution (NBS). It was assumed that there is one primary user (PU) and two secondary users (SU) in the network and their spectrum allocation was analyzed by testing the validity of the algorithm itself by using price weight factors to control the costs of the spectrum sharing. The solution was established by combining a proposed multiplexing method called the Filter Bank Multicarrier (FBMC) for 5G configuration, with the E-DSA algorithm to maximize the throughput of a heterogeneous 5G network. It was shown that the throughputs for 5G with E-DSA implementation were always higher than those of the ones without E-DSA. The simulation was done using the LabVIEW communication software and was analyzed based on a 5G urban macro and micro network configuration to validate the heterogeneity of the network.

Keywords: *Enhanced Dynamic Spectrum Allocation (E-DSA); Filter Bank Multicarrier (FBMC); heterogeneous network; Offset Quadrature Amplitude Modulation (OQAM); Nash Bargaining Solution (NBS).*

Introduction

Background Study

A 5G network configuration incorporates several different systems, i.e., Heterogeneous Network (H-Net), Internet of Things, relay node, millimeter-wave and device-to-device communication, as mentioned by Siddiqui *et al.* [1], which creates a multi-tier H-Net, as stated by Pirinen [2]. Figure 1 shows a representation of the 5G H-Net Network.

According to Haroon *et al.* [3], each tier requires the least amount of energy and power for transmission. If inter-tier and intra-tier interferences are adequately handled, the use of several tiers in a cellular network architecture will result in superior performance in terms of capacity, coverage, spectral efficiency, and overall power consumption, as explained by Hossain *et al.* [4] and Fooladivanda and Rosenberg [5]. A study conducted by Han *et al.* [6] reported that different transmission powers are frequently used by base stations at different tiers. Thus, it is necessary for the 5G network to provide the users quality of service, especially when they are travelling at high speeds, as mentioned by Bogale and Le [7].

ISSN: 2337-5779
J. Eng. Technol. Sci. Vol. 55, No. 1, 2023, 40-51
DOI: 10.5614/j.eng.technol.sci.2023.55.1.5

DOI: 10.5614/j.eng.technol.sci.2023.55.1.5

In a dense network configuration, in order for the user to be able to receive the extracted data from the multiplexed signal, a multiplexing method is required. Faizan *et al.* [8] mention that this method is a process of merging multiple signals into a single signal.

The Orthogonal Frequency Division Multiplexing (OFDM) is the multiplexing method that is currently being implemented for 4G. Figure 2 shows OFDM's block diagram. According to Prasad *et al.* [9], OFDM eliminates Inter-symbol Interference (ISI) by distributing the overall bandwidth into orthogonal subchannels that transforms frequency-selective multipath fading into flat fading.

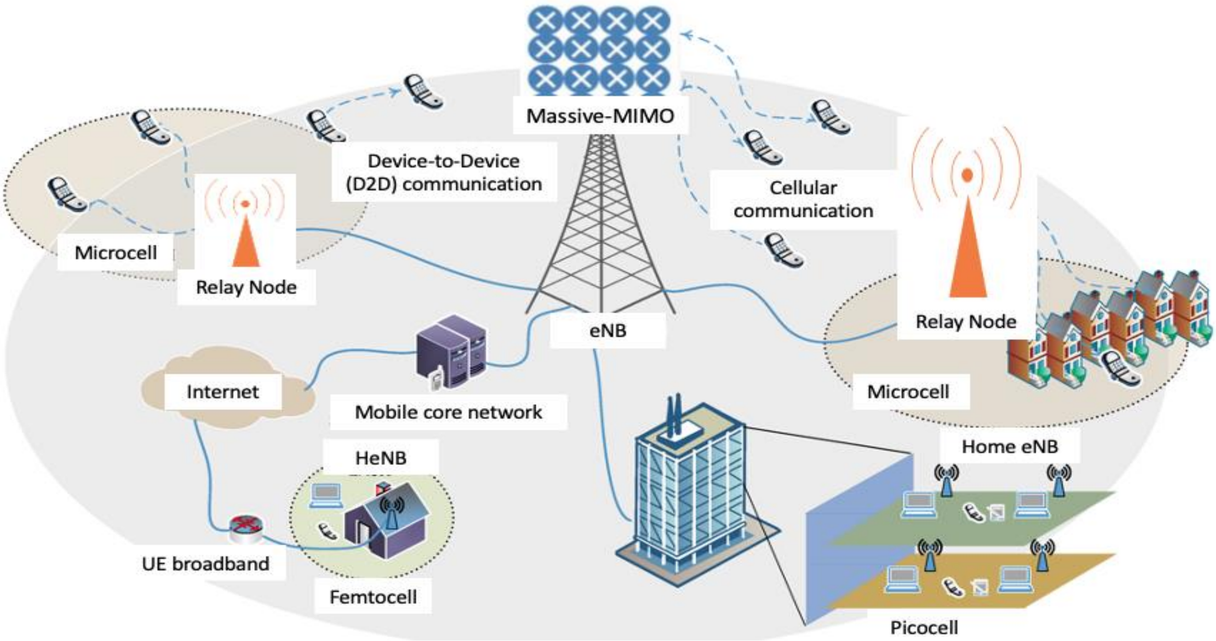

Figure 1 Representation of 5G H-Net.

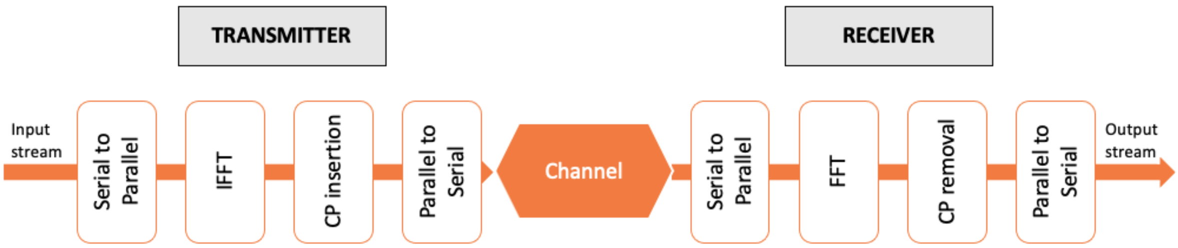

Figure 2 OFDM block diagram.

A promising approach to meet future bandwidth requirements, mentioned by Kumar and Payal [10], is also important to achieve seamless communication. For 5G, Khudair and Singh [11] considered FBMC to be the best choice as multiplexing method among other 5G waveform contenders such as Filtered-OFDM (F-OFDM), studied by Nekovee *et al.* [12], Universal Filtered Multicarrier (UFMC), studied by Roessler [13] and Generalized Frequency Division Multiplexing (GFDM), studied by Anish *et al.* [14], mainly because of FBMC's low out-of-band (OOB) radiation, as mentioned by Baltar *et al.* [15]. According to Sangdeh and Zeng [16], OFDM systems suffer from high out-of-band radiation originated from the sidelobes of the modulated subcarriers, unlike in FBMC, as explained by Kumar and Bharti [17]. The FBMC configuration is shown in Figure 3.

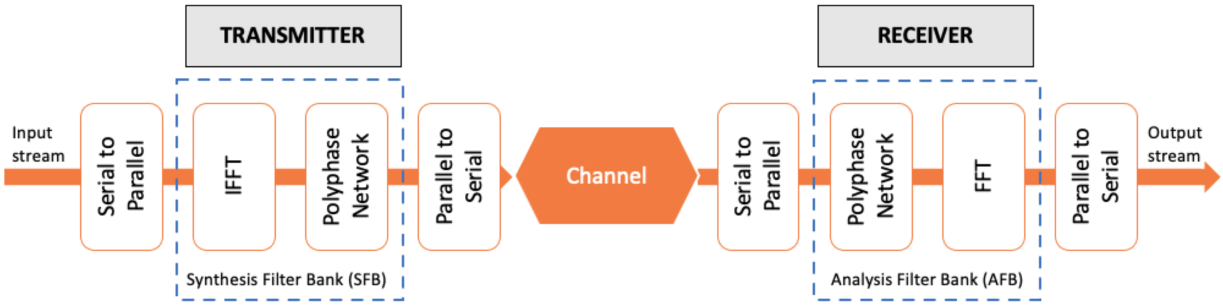

Figure 3 FBMC block diagram.

The transceiver block diagram of the typical FBMC multiplexing method is illustrated in Figure 3 (adapted from Franzin and Lopes [18]). The key modification is the substitution of OFDM with a multi-carrier system with the implementation of filter banks in the polyphase network section. The prototype filters (PF) in the filter banks need to be carefully designed to obtain a more enhanced spectral shaping of subcarriers as compared to OFDM. In addition to that, the prototype filter also promises an efficient spectral utilization by lessening interference among subcarriers. The transmission bandwidth's maximum capacity can also be achieved in FBMC configuration by implementing Offset Quadrature Amplitude Modulation (OQAM).

Related Works

Based on the review by Azari and Masoudi [19], 5G H-Nets can have issues with several interferences that cause attenuation, fading, reflection, refraction, scattering and shadowing effects. As a result, implementing an effective interference mitigation mechanism for 5G is critical. Qamar *et al.* [20] have already started investigating several interference management approaches for 5G. One of the approaches is the hybrid inter-cell interference coordination, studied by Huang *et al.* [21]. Another comprehensive study, by Alzubaidi *et al.* [22], determined that modeling methods for interference management are also effective. Such methods are Poisson cluster process, proposed by Yang *et al.* [23], and stochastic geometry, proposed by Tarriba-Lezama and Valdez-Cervantes [24]. However, these methods produce a large processing burden and lack appropriate backhaul. Thus, in this study, the Dynamic Spectrum Allocation (DSA) technique was found to be the best interference mitigation technique for 5G.

Previous researchers have proposed several dynamic spectrum allocation strategies for 4G, such as Hasan *et al.* [25] and Othman *et al.* [26], to improve the effectiveness of heterogeneous networks in 4G. Then, Rony *et al.* [27] improved the technique for 5G to promote proper utilization and fair distribution, following the dynamic traffic requirements of each cell. However, the study did not thoroughly focus on the setup of the heterogeneous network. To substantiate future data requirements and support a diverse set of devices, 5G networks are predicted to meet user demands with competently managed spectrum resources. Hence, an enhanced spectrum allocation technique (E-DSA) is an essential tool for optimizing the spectrum management practices for 5G. Several DSA techniques were studied and compared in order to choose the best type of DSA for 5G. Table 1 shows a summary of existing 5G DSA techniques.

Table 1 Summary of 5G DSA techniques.

Author and year	Method	Strengths	Limitations
Dong, W. et. al. 2015 [28]	Auction	Well adapted to competitive environment	Not well adapted to cooperative environment
Koley, S., 2019 [29]	Markov models	Well adapted to modeling and prediction of the channel behavior	Not well adapted to modeling the interaction between users
Jaishanthi, B. et. al., 2019 [30]	Multi agent system (MAS)	Well adapted to modeling the interaction between users	Must implement other techniques to perform more complex processing
Gayathri, R. N. et. al., 2016 [31]	Game theory (GT)	Well adapted to both competitive and cooperative environments	Does not consider how players should interact to reach this equilibrium

DOI: 10.5614/j.eng.technol.sci.2023.55.1.5

In this study, GT with NBS properties was chosen as the E-DSA method because it is a cooperative game that optimizes the objective functions' product instead of computing its total, which may result in a larger pay-off per user, as mentioned by Han *et al.* [32].

The rest of this paper is organized as follows: Section 2 discusses the system configuration and parameters for the FBMC and E-DSA configurations as well as the mathematical expressions used for BER and throughput calculations. Section 3 presents the results and discussions and, lastly, Section 4 provides the conclusion.

System Configuration and Parameters

Proposed FBMC Configuration for 5G

The assumed parameters for FBMC configuration using Labview Communications are summarized in Table 2.

Table 2 Assumed parameters for FBMC using Labview Communications software.

Parameters	Description
Prototype Filter	Lowpass Windowed FIR
IQ rate (Hz)	5M
Bandwidth (Hz)	20M
Subcarrier spacing	15kHz
QAM order	4
FFT size	256
Number of subcarriers	128
Channel Estimation	Linear mean square

The transmitter configuration for FBMC is like that of OFDM, except additional programming blocks are added into the configuration, namely OQAM pre-processing and Synthesis Filter Bank blocks, and there is no Cyclic Prefix. The simulation design for FBMC Transmitter is shown in Figure 4 below.

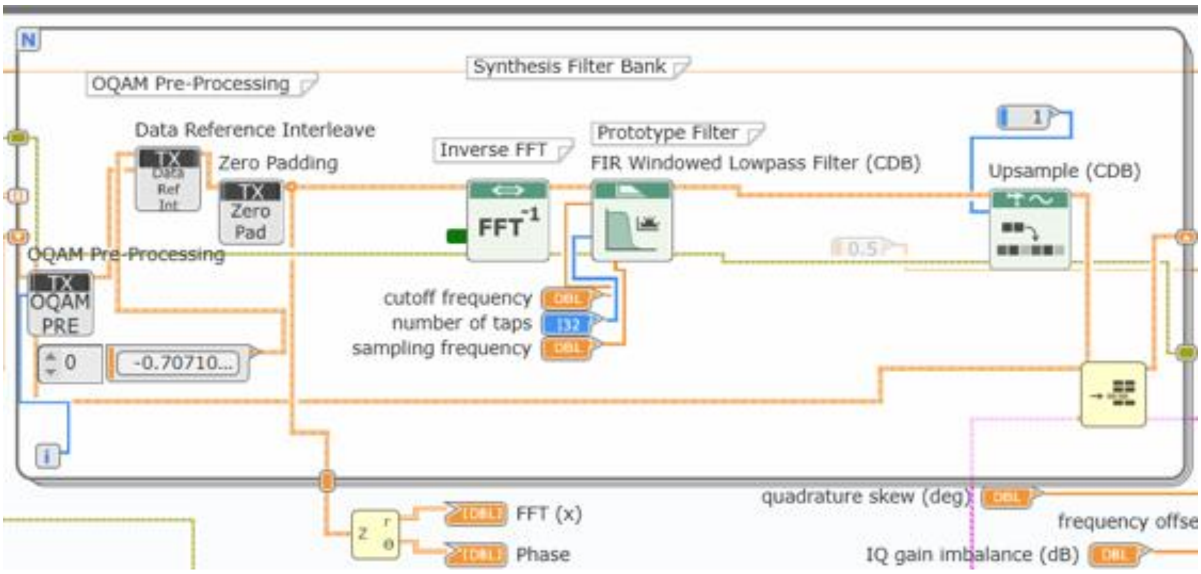

Figure 4 FBMC transmitter configuration.

The receiver configuration for FBMC, shown in Figure 5, is similar to that of OFDM, except additional programming blocks are added into the configuration, namely the Analysis Filter Bank and OQAM post-processing blocks.

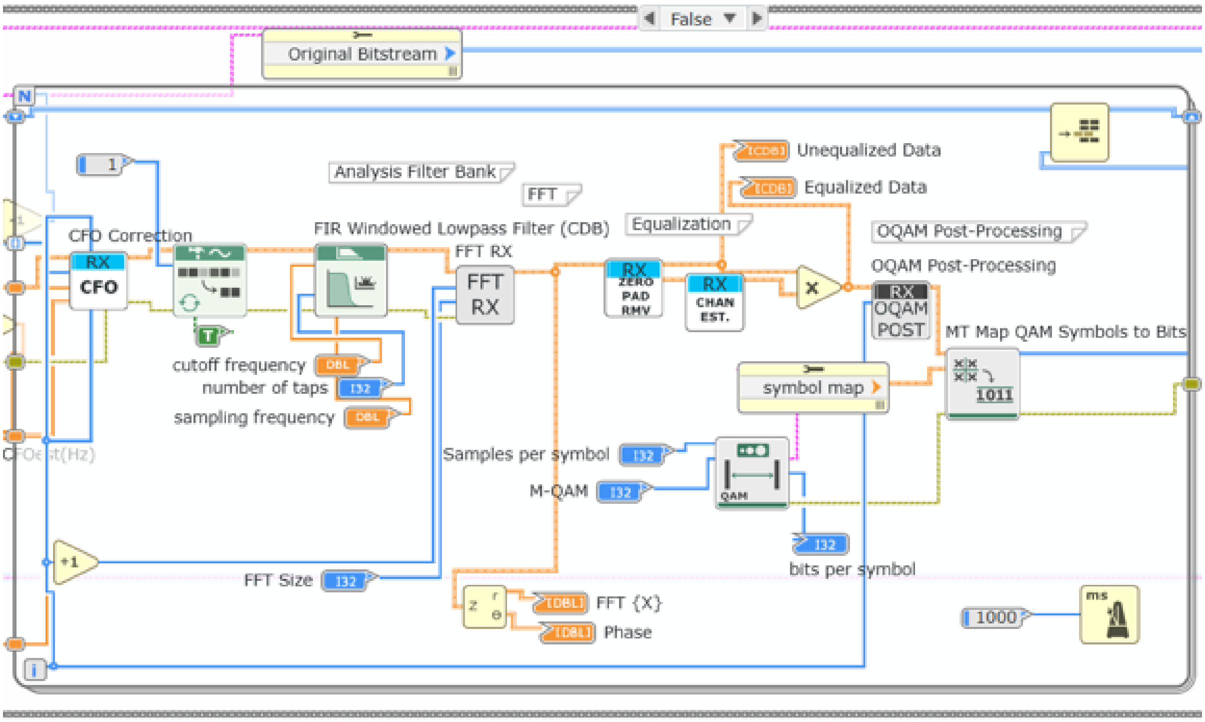

Figure 5 FBMC receiver configuration.

Proposed E-DSA Design and Parameters

The system model for the present research is shown in Figure 6. It is assumed that one primary user (PU) system and N SUs were incorporated into the spectrum distribution system. The SUs' base stations and the total spectrum of the PU system are denoted by B_{full}. To obtain additional revenue, the PU system auctions free spectrum resources to the *i-th* SU at unit bandwidth price, which is a function of the spectrum price. It is worth noting that the size of spectrum B_{empty} ($B_{empty} \leq B_{full}$) provided by the PU for SUs varies from time to time.

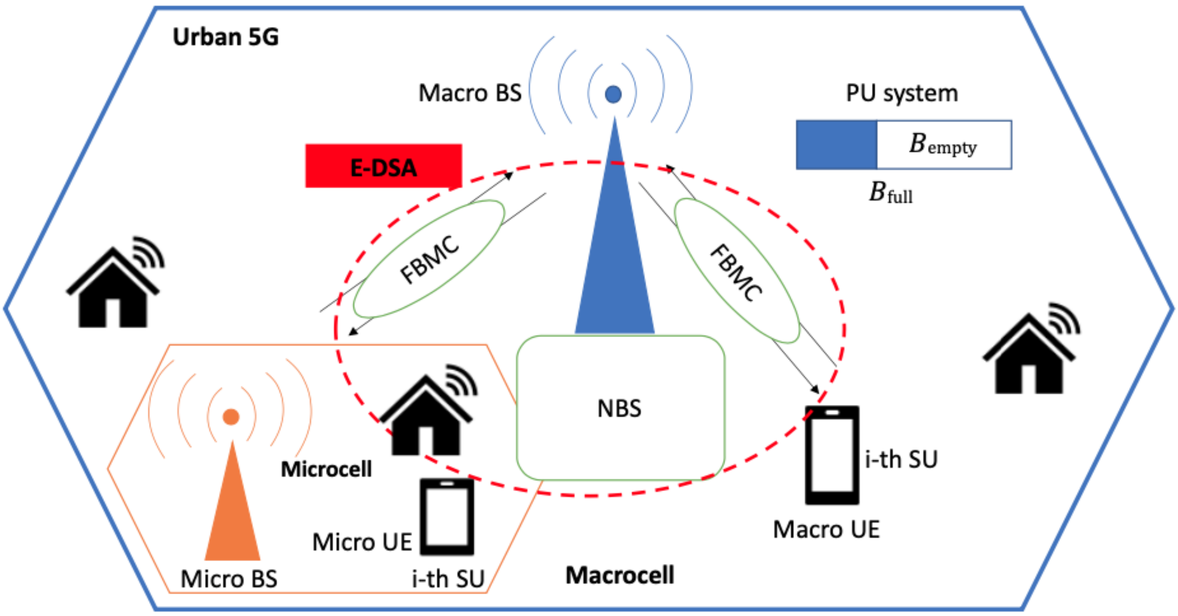

Figure 6 System model for E-DSA 5G FBMC network.

DOI: 10.5614/j.eng.technol.sci.2023.55.1.5

Firstly, the SUs obtain the available spectrum information of the PU through spectrum sensing, including the spectrum quality and the available spectrum size, and transmit it to the base station. Then, under the guidance of the base station, the SUs obtain the spectrum through the Nash bargaining method to meet the communication requirements, and maximize the total revenue of the SU system. According to Han *et al.* [32], the description of spectrum allocation using the Nash bargaining scheme are explained in Table 3 below:

Table 3 Description of spectrum allocation using the Nash bargaining scheme.

Item	Description	Remarks
N	Set of secondary users (SUs)	{*1, 2,..., N*}
A	Set of allocations where SUs cooperate with each other	Revenue received by the *i*-th SU < *A* No cooperation for *i*-th SU
$U_{i,min}$	Minimum revenue that the i-th SU is required to gain	$U_i > 0$. ($U_{1,min}, U_{2,min}, \ldots\ldots, U_{N,min}$)
(A, U_{min})	N-person bargaining game problem	$\{U \in A \mid U \geq U_{min}, \forall \hat{\imath} \in N\}$ is a non-empty bounded set

In this paper, the following optimal solution is used based on [33].

$$\max_{U_i \in, U_i \geq U_{i,min}, \forall i} \sum_{i=1}^{N} (U_i - U_{i,min}) \tag{1}$$

When the revenue of each SU satisfies $U_i \geq U_{i,min}$, the SUs will cooperate with each other. Therefore, it is assumed that $U_{i,min} = 0$, i.e., $U_i > 0$. To obtain spectrum from the primary user (PU) system, the SUs are required to pay a cost to the PU by means of bargaining. Thus, this study contains two sections to define the utility function, firstly, the revenue $Y_i(b_i) = \emptyset_i \eta_i b_i$ determined once the *i*-th SU has been allocated to spectrum b_i and secondly, the payment of cost $Z_i(b_i) = p_i b_i$ that the *i*-th SU is responsible for. The utility function is defined as follows:

$$U_i(b_i) = Y_i(\emptyset_i, b_i) - Z(p_i b_i) = \emptyset_i \eta_i b_i - p_i b_i \tag{2}$$

where $\eta_i = \log_2(1 + K\gamma_i)$ is the spectrum efficiency function of the *i*-th SU, $K = \frac{1.5}{\ln\left(\frac{0.2}{\varepsilon}\right)}$, and $\emptyset_i$ is the revenue factor of unit transmission rate of the *i*-th SU. $\emptyset_i$ is inversely proportional to the bandwidth request size, which results in $\emptyset_i = x + y(\frac{1}{b_i})$, where x and y are constants. Furthermore, $\eta_i b_i$ is the throughput, ε is the target BER, and γ_i is the SINR of the *i*-th SU. Therefore, the SUs' utility function is formulated as:

$$U_i(b_i) = b_i \eta_i \left(x + y\left(\frac{1}{b_i}\right) \right) - c_i b_i \left(\sum_{i=1}^{N} b_i\right) \tag{3}$$

Eq. (3) can be optimized by solving the model under the following constraints:

$$\max_{b=(b_1, b_2, \ldots, b_N)} U = \sum_{i=1}^{N} U_i \tag{4}$$

$$\begin{cases} b_i \eta_i \geq r_{i,min} \\ \sum_{i=1}^{N} b_i \leq B_{empty} \end{cases} \qquad \forall i = 1,2, \ldots., N$$

where b_i is the bandwidth size obtained in the solution, η_i is the spectrum efficiency, and $b_i \eta_i$ is the throughput obtained. The constrained optimization problem of Eq. (4) can be solved by using the Lagrange multiplier extremum method according to Kuhn-Tucke theory. The Lagrange function M is formulated in Eq. (5).

$$M = \sum_{i=1}^{N} \left(b_i \eta_i \left(x + \frac{y}{b_i}\right) - c_i b_i \left(\sum_{i=1}^{N} b_i\right)\right) - \mu\left(\sum_{i=1}^{N} b_i - B_{idle}\right) + \sum_{i=1}^{N} \varsigma_i (b_i \eta_i - r_{i,min}) \tag{5}$$

The E-DSA solution for the *i*-th SU can be solved via a series of the Lagrange multipliers' iterations. Eq. (6) defines the solution of the spectrum request strategy b_i,

$$b_i^{(T+1)} = \frac{x\eta_i - c_i\left(\sum_{j \neq i}^{N} b_j\right) - \sum_{j \neq i}^{N} c_j b_j - \mu^{(T)} + \eta_i \varsigma_i^{(T)}}{2c_i} \tag{6}$$

The assumed parameters of the E-DSA algorithm are listed in Table 4.

Table 4 Assumed parameters for E-DSA algorithm.

Parameters	Description
Total spectrum of PU, B_{full}	20 MHz, $0 \leq B_{empty} \leq B_{full}$
x, y	5, 1
Minimum rate requirement, $r_{i,min}$	0.2 Mbps, ∀i
Initial value of Lagrange multipliers	$\mu^{(0)} = 10,\ \varsigma_i^{(0)} = 5$, ∀i
Price weight factors, c1=c2	1, 2

Proposed Theoretical Bit Error Rate (T-BER) and Throughput Calculations for 5G Urban Macro and Micro Configurations

Several analysis methods were reviewed on how to analyze the proposed configurations, such as the spectral density analysis, as performed by Handyarso and A. Kadir [34], as well as the study conducted by Susanti *et al.* [35], and throughput analysis, as studied by Hmamou *et al.* [36]. In this study, a throughput analysis was chosen. The set of formula was implemented from the 3GPP technical report by ETSI [37] to calculate the throughput of 5G FBMC configuration with and without E-DSA implementation. Table 5 lists the assumptions for the parameters for the throughput calculation.

Table 5 Assumed parameters for throughput calculation.

Parameter	Values
Distance between TX (Macrocell BS) and RX (Microcell UE) *dma,mi[km]*	0.15 – 0.40
Distance between TX (Microcell BS) and RX (Macrocell UE) *dmi,ma[km]*	0.01 – 0.13

The path loss between macrocell users and the macrocell base station denoted by PL_{ma}, is formulated in Eq. (7).

$$PL_{ma} = 28.0 + 22\log_{10}(d_{ma}) + 20\log_{10}(f_c) \tag{7}$$

where d_{ma} is the distance between transmitter and receiver for the macrocell network. Besides that, the path loss in the microcell network, denoted by PL_{mi}, is formulated as follows:

$$PL_{mi} = 32.4 + 21\log_{10}(d_{mi}) + 20\log_{10}(f_c) \tag{8}$$

Secondly, the channel gain for both the macrocell and the microcell network is formulated as follows:

$$G = 10^{\frac{-PL}{10}} \tag{9}$$

After that, the signal to interference plus noise ratio (SINR), $\boldsymbol{\gamma_{ma}}$ for the macrocell network is as follows:

$$\gamma_{ma} = \frac{G_{ma,ma} \times P_{ma}}{\sigma^2 + (\sum_{neig(ma)} G_{ma,ma} \times P_{ma}) + (G_{ma,mi} \times P_{mi})} \tag{10}$$

where P_{ma} is the transmit power of the microcell base station, $G_{ma,ma}$ is the channel gain between a microcell user and the macrocell base station and σ^2 is the power of the AWGN. Furthermore, the γ_{mi} for the microcell network when considering the interference caused by neighboring cells as follows:

$$\gamma_{mi} = \frac{G_{mi,mi} \times P_{mi}}{\sigma^2 + (\sum_{neig(mi)} G_{mi,mi} \times P_{mi}) + (G_{mi,ma} \times P_{ma})} \tag{11}$$

Then, before calculating the throughput, the total capacity of users is formulated as follows:

$$C = \Delta f \times \log_2(1 + \alpha\gamma) \tag{12}$$

where Δf is the subcarrier spacing and α = -1.5*ln(5ε) relates to the bit error rate (BER), ε. The T-BER expression used for OFDM modulation in this paper was taken from Nissel and Rupp [38]. For the same bandwidth, Mestoui

DOI: 10.5614/j.eng.technol.sci.2023.55.1.5

and El Ghzaoui [39] implied that the SINR of OFDM is $\gamma_{OFDM} = \frac{1}{2}(\gamma_{FBMC})$, because FBMC only experiences half the noise power. Thus, the BER expression of FBMC becomes the following expression:

$$\varepsilon_{FBMC} = \frac{1}{2}\left(1 - \frac{1}{\sqrt{1+\frac{1}{\gamma}}}\right) \tag{13}$$

Finally, for a typical 5G FBMC configuration without E-DSA implementation, the throughput of a serving macrocell is formulated as follows,

$$TP_{typ} = \sum(\beta \times C) \tag{14}$$

where β is the subcarrier assignment and is set to 1.

Result Analysis

Validity of E-DSA: Effect of SUs' Price Weight Factors on Spectrum Allocation

Figure 7 depicts the effect of SUs' price weight factors on spectrum allocation for the first and second SUs for both S-BER and T-BER bit error rates. The bandwidths obtained by the first SUs for all conditions are always higher than those of the second SUs, that is, when the price factor is set to 1 for the first SU and 2 for the second SU. This is because the higher the price weight factor, the higher the unit spectrum price, which may lead to overpayment of costs for the same bandwidth. For these conditions, their own bandwidths will be reduced accordingly. Thus, when there is a sudden increment in the SU's bandwidth request, the SU's price weight factor is increased by the PU to prevent from the SU gaining an excessive spectrum. Besides that, the S-BER with E-DSA implementation has the highest spectrum requests followed by the T-BER with E-DSA implementation and lastly the T-BER without E-DSA implementation.

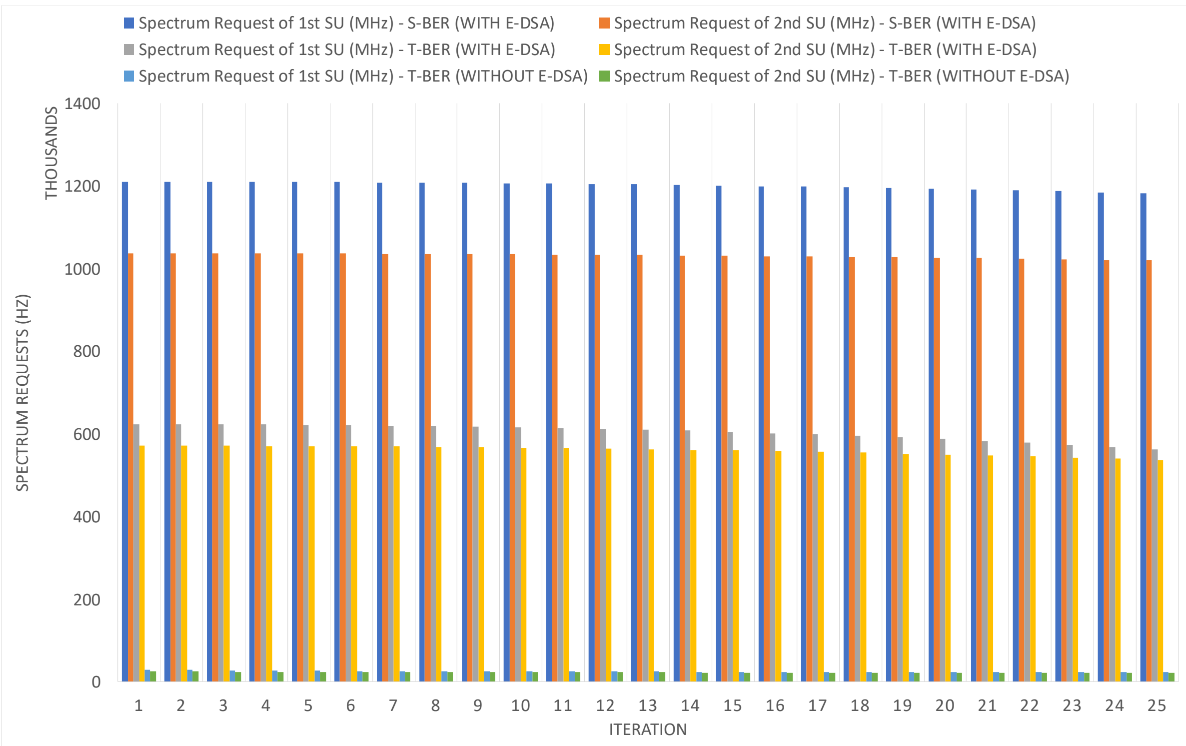

Figure 7 Spectrum requests from the first and the second SU.

Throughput Analysis

Figure 8 shows the throughputs calculated from the S-BERs and T-BERs for 5G FBMC configurations with and without E-DSA implementation. By comparing the average throughput increments between the typical 5G FBMC and E-DSA 5G FBMC configurations, it is proven that the E-DSA for 5G FBMC produces higher improvements than that of the typical 5G FBMC configuration, i.e., by 114%. When implementing the simulated BER values, the throughput was found to be 4% higher than that when using the theoretical BER values. This shows that the throughput of the 5G configurations can be improved by combining the proposed 5G FBMC design using the software with the proposed E-DSA algorithm. Table 6 summarizes the average percentage of throughput enhancement for the configurations.

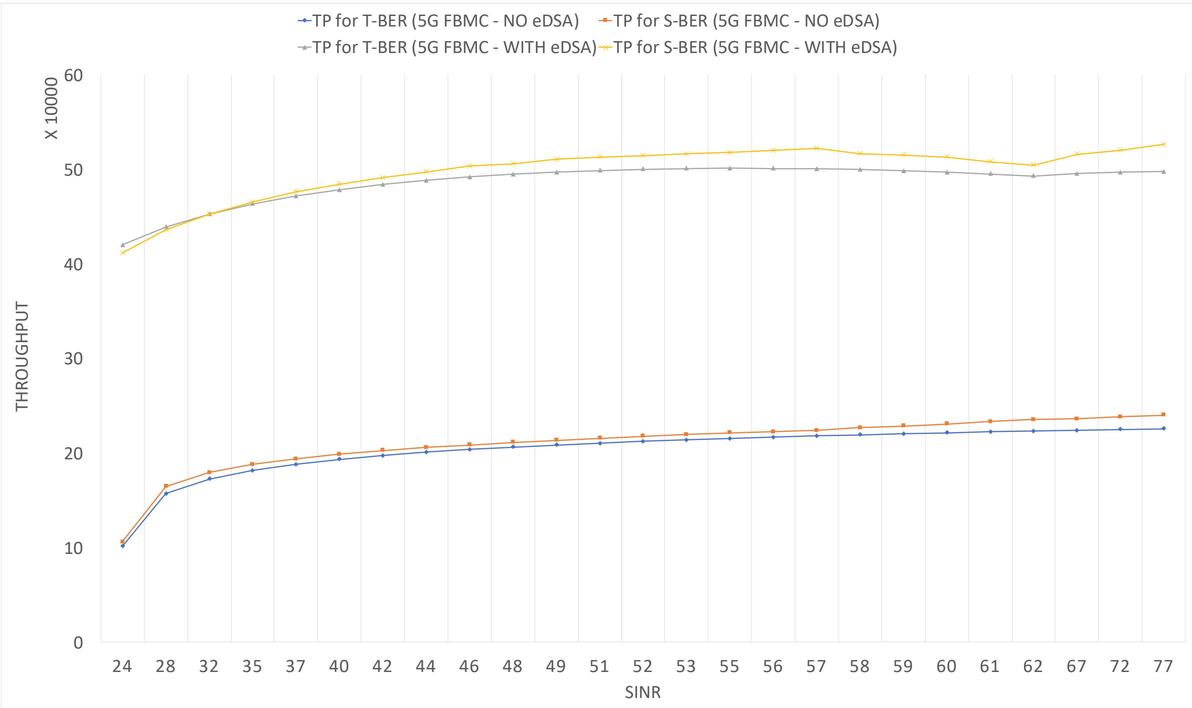

Figure 8 Throughput analysis for T-BER and S-BER 5G FBMC configuration with and without E-DSA implementation.

Table 6 Average percentage of throughput enhancement when implementing E-DSA for 5G FBMC.

Item	Theoretical BER (T-BER)	Simulated BER (S-BER)
Average throughput enhancement for 5G FBMC with E-DSA	140%	144%

Conclusion

In this paper, an enhanced dynamic spectrum allocation (E-DSA) was developed by combining the FBMC 5G configuration with the cooperative game theory called the Nash bargaining solution (NBS) for spectrum allocation in order to improve 5G network throughput performance. The FBMC transceiver was designed and simulated using the Labview communication software to obtain the BER values. The S-BER values were then incorporated into the E-DSA algorithm to maximize the system's throughput. The first result showed that the E-DSA algorithm successfully helped in spectrum allocation among the primary user (PU) and the secondary users (SUs) where the bandwidth requests by the secondary users were supported by the bandwidth's availability of the primary user.

DOI: 10.5614/j.eng.technol.sci.2023.55.1.5

The price weight factors were used to control and prevent the overpayment of costs of SUs' bandwidth's requests. Secondly, for throughput maximization, it was proven that the throughputs for 5G can be improved tremendously with the implementation of E-DSA, where an increment of 140% of throughput was calculated theoretically and an increment of 144% was recorded from the simulation design. The E-DSA results in this study were solely derived from simulations run on the Labview Communication software platform. Future comparisons between the simulation findings and a real-time configuration should take into account the hardware implementation. Adaptive characteristics, including the allotted subcarrier per channel quality need and the transform scheme, such as the wavelet transform, could also be examined.

Acknowledgement

The authors acknowledge the Research Management Centre (RMC) of the International Islamic University Malaysia (IIUM) and the Malaysian Ministry of Education (MOHE) for the financial support for this research. The research output is part of the deliverables for the research funded under IIUM's Research University Initiatives. The Fundamental Research Grant Scheme (FRGS) Research Project by the Malaysian Ministry of Education sponsors this research in the creation of novel theories and concepts.

References

[1] Siddiqui, M.U.A., Qamar, F., Ahmed, F., Nguyen, Q.N. & Hassan, R., *Interference Management in 5G and Beyond Network: Requirements, Challenges and Future Directions*, IEEE Access, **9**, pp.68932-68965, 2021,

[2] Pirinen, P.A., *Brief Overview of 5G Research Activities*, Proceedings 1st International Conference 5G Ubiquitous Connectivity, pp. 17-22, 2014.

[3] Haroon, M.S., Abbas, Z.H., Muhammad, F. & Abbas, G., *Analysis of Coverage-Oriented Small base Station Deployment in Heterogeneous Cellular Networks*, Physical Communication, **38**(C), Feb. 2020. doi: 10.1016/j.phycom.2019.100908.

[4] Hossain, E., Rasti, M., Tabassum, H. & Abdelnasser, A., *Evolution Towards 5G Multi-Tier Cellular Wireless Networks: An Interference Management Perspective*, IEEE Wireless Communications, **21**(3), pp. 118-127, June 2014. doi: 10.1109/MWC.2014.6845056.

[5] Fooladivanda, D. & Rosenberg, C., *Joint Resource Allocation and User Association for Heterogeneous Wireless Cellular Networks*, IEEE Transactions on Wireless Communications, **12**(1), pp. 248-257, 2013.

[6] Han, T., *Interference Minimization in 5G Heterogeneous Networks*, Mobile Network Applications, **20**, pp.756-762, 2015. doi: 10.1007/s11036-014-0564-1.

[7] Bogale, T.E. & Le, L.B., *Massive MIMO and mmWave for 5G Wireless HetNet*, IEEE Vehicular Technology Magazine, **11**(1), pp. 64-75, 2016.

[8] Faizan, Q., Ahmed, M.U.S., Hindia, M., Rosilah, H. & Quang, N., *Issues, Challenges, and Research Trends in Spectrum Management: A Comprehensive Overview and New Vision for Designing 6G Networks*, Faculty of Engineering and Information Sciences - Papers: Part B. 4510, 2020.

[9] Prasad, R., Sridhar, V. & Bunel, A., *An Institutional Analysis of Spectrum Management in India*, Journal of Information Policy, **6**, pp. 252-293, 2016.

[10] Kumar, S. & Payal, *Performance Investigation of MIMO Based CO-OFDM FSO Communication Link for BPSK, QPSK and 16-QAM under the Influence of Reed Solomon Codes*, Journal of Engineering and Technological Sciences, **53**(5), 210508, 2021.

[11] Khudhair, S.A. & Singh, M.J., *Review in FBMC to Enhance the Performance of 5G Networks*, Journal of Communications **15**(5), pp. 415-426, May 2020.

[12] Nekovee, M., Wang, Y., Tesanovic, M., Wu, S., Qi, Y & Al-Imari, M., *Overview of 5G Modulation and Waveforms Candidates*, Journal of Communications and Information Networks, **1**(1), pp. 44-60, June 2016.

[13] Roessler, A., *5G Waveform Candidates*, Rohde & Schwarz GmbH & Co. KG, Application Note, 1MA271, Munich, Germany, pp.1-60, 2019.

[14] Anish, A.K., Yamini, P., Nevatha, J. A., Suthendran, K. & Raju, K. S., *GFDM-Based Device to Device Systems in 5G Cellular Networks*, Lecture Notes on Data Engineering and Communications Technologies, **63**, pp 653-660, Singapore: Springer, 2021.

[15] Baltar, L.G., Waldhauser, D.S. & Nossek, J.A., *Out-Of-Band Radiation in Multicarrier Systems: A Comparison*, in: Plass, S., Dammann, A., Kaiser, S., Fazel, K. (eds) Multi-Carrier Spread Spectrum 2007, Lecture Notes Electrical Engineering, 1, Dordrecht: Springer, 2007.

[16] Sangdeh, P.K. & Zeng, H., *Overview of Multiplexing Techniques in Wireless Networks*, IntechOpen, 2019.

[17] Kumar, A. & Bharti, S., *Design and Performance Analysis of OFDM and FBMC Modulation Techniques*, Scientific Bulletin of the Electrical Engineering Faculty, **2**(37) ISSN 2286-245, 2017.

[18] Franzin, R.P. & Lopes, P.B., *A Performance Comparison between OFDM and FBMC in PLC Applications*, IEEE Second Ecuador Technical Chapters Meeting (ETCM), 2017.

[19] Azari, A. & Masoudi, M., *Interference Management for Coexisting Internet of Things Networks Over Unlicensed Spectrum*, Ad Hoc Networks, **120**(1), 102539, 2021.

[20] Qmar, F., Nour Hindia, M.H.D., Dimyati, K., Noordin, K.A. & Amiri, I.S., *Interference Management Issues for the Future 5G Network: A Review*, Telecommunication Systems, **71**, pp. 627-643, 2019.

[21] Huang, J., Li, J., Chen, Z. & Pan, H., *HICIC: Hybrid Inter-Cell Interference Coordination for Two-Tier Heterogeneous Networks with Non-Uniform Topologies*, IEEE Access, **6**, pp. 34707–34723, 2018.

[22] Alzubaidi, O.T.H., Nour Hindia, M.H.D, Dimyati, K., Noordin, K.A., Wahab, A.N.A., Qamar, F. & Hassan, R., *Interference Challenges and Management in B5G Network Design: A Comprehensive Review*, Electronics, **11**, 2842, 2022.

[23] Yang, L., Lim, T.J., Zhao, J. & Motani, M., *Modeling and Analysis of HetNets with Interference Management Using Poisson Cluster Process*, IEEE Transactions on Vehicular Technology, **70**(11), pp. 12039-12054, November 2021.

[24] Tarriba-Lezama, Y. & Valdez -Cervantes, L., *Approximation of Cross-tier interference in HETNET using Stochastic Geometry*, IOP Conf. Series: Materials Science and Engineering, **1154**, 012048, 2021.

[25] Hasan, M.K., Ismail, A.F., Islam, S., Hashim, W. & Pandey, B., *Dynamic Spectrum Allocation Scheme for Heterogeneous Network*, Wireless Personal Communications, **95**(2), pp.299-315, 2017.

[26] Othman, N.I., Ismail, A.F., Hasan, M.K., Badron. K. & Hashim, W., *Throughput Analysis on Dynamic Spectrum Al-location Technique to Mitigate Interference on LTE Heterogeneous Network*, **11**(4), pp.95-104, 2018.

[27] Rony, R.I., Lopez-Aguilera, E. & Garcia-Villegas, E., *Dynamic Spectrum Allocation Following Machine Learning-Based Traffic Predictions in 5G*, IEEE Access, **9**, pp. 143458-143472, 2021.

[28] Dong, W., Rallapalli, S., Qiu, L., Ramakrishnan, K.K. & Zhang, Y., *Double Auctions for Dynamic Spectrum Allocation*, IEEE INFOCOM IEEE Conference on Computer Communications, **24**(4), pp.709-717, 2014. doi: 10.1109/INFOCOM.2014.6847997.

[29] Koley, S., Bepari, D. & Mitra, D., *Predictive Multi-user Dynamic Spectrum Allocation Using Hidden Semi-Markov Model*, Journal of Communications Technology and Electronics, **63**(12), pp.1393-1405, 2019.

[30] Jaishanthi, B., Ganesh, E.N. & Sheela, D., *Priority-Based Reserved Spectrum Allocation by Multi-Agent Through Reinforcement Learning Incognitive Radio Network*, 2019 Automatika, **60**(5), pp. 564-569, 2019.

[31] Nair, V.G.R., Moorthy, Y.K. & Pillai, S.S., *A Novel Interference Reduction Technique in Game Theory Based Dynamic Spectrum Leasing Scheme*, International Conference on Emerging Technological Trends [ICETT], 2016.

[32] Han, P.L.B., Li, H., Hou, D., Liu, D. & Wang, G., *The Research of Dynamic Spectrum Allocation Based on Nash Bargaining Game*, IEEE 4th Information Technology and Mechatronics Engineering Conference, 2018.

[33] Anand, A., de Veciana, G. & Shakkottai, S., *Joint Scheduling of URLLC and eMBB Traffic in 5G Wireless Networks*, International Conference on Computer Communications, 2017.

[34] Handyarso, A. & Kadir, W.G. A., *Gravity Data Decomposition Based on Spectral Analysis and Halo Wavelet Transform, Case Study at Bird's Head Peninsula, West Papua*, Journal of Engineering and Technological Sciences, **49**(4), pp. 423-437, 2017.

[35] Susanti, H., Suprijanto & Kurniadi, D., *New Reconstruction Method for Needle Contrast Optimization in B-Mode Ultrasound Image by Extracting RF Signal Parameters in Frequency Domain*, Journal of Engineering and Technological Sciences, **52**(4), pp. 514-533, 2020.

[36] Hmamou, A., El Ghzaoui, M., Foshi, J. & Mestoui, J., *Experimental and Theoretical Analysis of Throughput of MIMO PLC Network*, Journal of Engineering and Technological Sciences, **54**(3),220308, 2022.

[37] ETSI, 5G; *Study on Channel Model for Frequencies from 0.5 to 100 GHz*, 3GPP TR 38.901 version 14.3.0 Release 14, 2018.

DOI: 10.5614/j.eng.technol.sci.2023.55.1.5

[38] Nissel, R. & Rupp, M., *OFDM and FBMC-OQAM in Doubly-Selective Channels: Calculating the Bit Error Probability*, IEEE Communications Letters, **21**(6), pp. 1297-1300, June 2017.

[39] Mestoui, J. & El Ghzaoui, M., *Theoretical Analysis and Performance Comparison of Multicarrier Waveforms for 5G Wireless Applications*, International Journal of Integrated Engineering, **13**(6), pp. 202-219, 2021.

Manuscript Received: 24 June 2022
Revised Manuscript Received: 18 November 2022
Accepted Manuscript: 26 January 2023