

Resource allocation algorithm for symmetrical services in OFDMA systems

Swapna P S¹, Sakuntala S Pillai², Sreeni K G³

^{1,2}Mar Baselios College of Engineering and Technology, India

³College of Engineering, India

Article Info

Article history:

Received Aug 9, 2019

Revised Nov 10, 2019

Accepted Nov 23, 2019

Keywords:

Adaptive resource allocation

Genetic algorithm

Linear programming

Multiobjective optimization e

non dominance

OFDMA

ABSTRACT

The widespread acceptance of symmetrical services has urged for performance betterment techniques in wireless communication systems. In this paper, we propose an algorithm for resource allocation in MIMO-OFDMA system for applications that demand similar quality in uplink and downlink direction. The problem is formulated as multiobjective optimization problem with objectives to maximize the bidirectional data rates for individual users and to minimize the difference between the uplink and downlink data rate for each user. Fairness has been considered as a constraint in the optimization problem. The power allocation for each subcarrier in the OFDMA system is carried out using Linear Programming (LP) techniques, while the subcarrier allocation problem has been undertaken using an innovative multiobjective optimization technique that employs the concept of non-dominance in evolutionary algorithms. The results are extremely encouraging as they outperform the algorithms reported in literature using linear programming techniques or evolutionary algorithms solely.

*Copyright © 2020 Institute of Advanced Engineering and Science.
All rights reserved.*

Corresponding Author:

Swapna. P. S,

Department of Electronics and Communication Engineering,

Mar Baselios College of Engineering and Technology,

Trivandrum, Kerala, India.

Email: swapna.ps@mbcet.ac.in

1. INTRODUCTION

The ubiquitous application of smart devices has impelled for radical change in the telecommunication industry to meet the requirements of services that demand higher spectral efficiency and data rate. Smart devices have been constantly on the rise and studies reveal that the number of smart phone users in India grew to 239 million by the end of 2015 and is expected to be 702 million by 2020 [1]. The tremendous increase in the need for high data rate turns up against the constraints of radio spectrum availability and the telecommunication infrastructure. Hence, the techniques deployed need to be extremely efficient and judicious in terms of the usage of the available spectrum and infrastructure.

Nowadays, symmetrical services have found wide popularity and the demand to ameliorate the performance of such services is at its peak. The attribute of symmetrical services, however, does not adhere to the framework of the existing wireless infrastructure [2]. The existing framework cannot support symmetrical services efficiently since the resources are non-intersecting in uplink and downlink direction and therefore cannot guarantee the flow availability in both directions.

Orthogonal Frequency Division Multiple Access (OFDMA) is a multi-user version of the popular OFDM digital modulation scheme, which splits the available system bandwidth into orthogonal subcarriers. Further, Multiple-input-multiple-output (MIMO) OFDMA system helps to improve the system capacity, transmission range reliability and suppress interfering signals. The channel throughput increases linearly with

every pair of antennas added [3] at the cost of hardware complexity. It demands careful design of the resource allocation algorithm in MIMO OFDMA systems when employed for symmetrical services.

With vehement expansion of the telecommunication industry, customers demand high Quality of Service (QoS) which includes high data rate and roaming facilities. In such a scenario the formulation of the resource allocation problem results in a constrained multiobjective optimization problem. Quite a large number of resource allocation problems in OFDMA systems have been investigated in literature [4-22]. The problems have been addressed using optimization theory, graph theory and game theory [7-8]. The works in which the resource allocation problem was addressed using optimization with Linear Programming (LP) techniques resulted in suboptimal solutions or optimal solution with high complexity [9-10]. In such cases, optimization of resource allocation is mostly a mixed binary integer programming problem which is non-convex in nature, thereby resulting in highly complex solutions, which may not be feasible always. The authors in [21] employ an evolutionary approach for optimization of routing in optical OFDM systems while in [22], this approach is used successfully for resource allocation in a single direction OFDM system. In [23], inverse water filling algorithm is proposed for power allocation in wireless systems, while the authors in [24] propose a genetic algorithm for resource allocation in IPTV applications. In [25], a Composite Genetic and Ordered Subcarrier Pairing algorithm is proposed to solve the problem of resource allocation in an OFDM based Cognitive radio system.

Since the resource allocation problem for improving the performance of the system with symmetrical services is a constrained multiobjective optimization problem, the exclusive use of linear programming techniques solely results in high order of complexity [6]. Therefore attaining optimal solution becomes difficult and pressurizes to compromise with suboptimal solutions.

The proposed work sets its goal to maximize the data rate and minimize the difference in the bidirectional rates for individual user in the MIMO OFDMA system. Works of similar nature have been reported, wherein the authors have tried to maximize the overall data rate of the system rather than considering each individual user case. Genetic algorithm (GA) has been adopted in this paper for subcarrier allocation and weighted sum method for power allocation. The inspiration for adopting genetic algorithm comes from the fact that GAs are ideal for optimization problems with a large feasible solution space where a quick sub-optimal solution will suffice. Non-dominance Sorting Genetic Algorithm II (NSGA-II) is a multiobjective optimization algorithm belonging to the category of evolutionary algorithms and is being employed here for subcarrier allocation.

To this end, our main contributions in this paper are consolidated as given below:

We consider maximizing the data rates and minimizing the difference in uplink and downlink data rates for each individual user in the system, under the assumption that all the users in the system demand symmetrical quality.

We have combined weighted sum method and NSGA-II for power allocation and subcarrier allocation respectively. The combination of these two techniques for resource allocation in MIMO OFDMA system has resulted in better system performance in terms of data rates and computational complexity.

While implementing NSGA II, we have redefined the chromosomes in a novel manner which helped in further reducing the complexity of the solution.

2. RESEARCH METHOD

The algorithm is applied at the MIMO OFDMA transmitter of both uplink and downlink directions, to allocate power and subcarriers to the users in a manner that the user attains almost similar quality in both uplink and downlink directions. The power allocation is performed using conventional linear programming techniques. The objective of the multiobjective optimization problem is to maximize the data rate in both the uplink and downlink direction and minimize the difference in the data rates between the two for each individual user. The base station and user equipment is updated every time the sub-channel information changes.

A single cell MIMO OFDMA system for downlink and uplink is considered. The cell spectrum of B Hz is divided into a set of M subcarriers and shared by a set of K users. It is assumed that no two users share the same subcarrier. The base station and user equipment have perfect information about channel states (CSI) through feedback channels. To support this assumption the wireless channel is considered to be slowly time-varying, frequency-selective Rayleigh faded.

The transmission process comprises of two phases:

a. Uplink Phase

In the uplink phase the data from the user i is sent through an OFDMA system to the base station. The signal-to-noise-ratio γ_{j2} is $\frac{h_{j2}^2}{N_o.B/N}$. ω_{ij2} takes the value 1 if j^{th} subcarrier is allocated to the i^{th} user or else it is set to 0.

b. Downlink Phase

In the downlink phase, the data from the base station is passed through an OFDMA system to the user. The signal-to-noise-ratio γ_{j1} is $\frac{h_{j1}^2}{N_o.B/N}$. ω_{ij1} takes the value 1 if j^{th} subcarrier is allocated to the i^{th} user, else it is set to 0. Notations as shown in Table 1.

Table 1. Notations

Symbol	Description
B Hz	Total Bandwidth
M	Number of subcarriers
K	Number of users
P_T	Total Uplink Power
P_{BS}	Total Downlink Power
i	User
j	subcarrier
h_{j2}	Uplink channel gain in the subcarrier j
N_o	Noise power spectral density
N	Noise power
R_{i2}	Data rate of user i in uplink
ω_{ij2}	Uplink Subcarrier allocation metric
γ_{j2}	Uplink signal-to-noise-ratio
h_{j1}	Downlink channel gain in the subcarrier j
R_{i1}	Data rate of user i in downlink
ω_{ij1}	Subcarrier allocation metric in downlink
γ_{j1}	Downlink signal-to-noise-ratio

The objectives of the problem are to:

Maximize R_{i1}

Maximize R_{i2}

Minimize the difference in the magnitudes of the two rates of user i i.e. $\|R_{i1} - R_{i2}\|$

The expression for R_{i1} is given as,

$$\sum_{j=1}^M \omega_{ij1} \cdot \log \left[1 + \frac{p_{j1} \cdot h_{j1}^2}{N_o \cdot B / N} \right] \tag{1}$$

Similarly the expression for R_{i2} is,

$$\sum_{j=1}^M \omega_{ij2} \cdot \log \left[1 + \frac{p_{j2} \cdot h_{j2}^2}{N_o \cdot B / N} \right] \tag{2}$$

The third objective is to minimize the difference in the rates of the i^{th} user i.e., Minimize $\|R_{i1} - R_{i2}\|$. with the following constraints,

$$\begin{aligned} C1: & \omega_{ij1}, \omega_{ij2} \in [0,1] \\ C2: & \sum_{i=1}^K \omega_{ij1} \leq 1 \\ C3: & \sum_{i=1}^K \omega_{ij2} \leq 1 \\ C4: & \sum_{j=1}^M p_{j2} \leq P_T, \\ C5: & \sum_{j=1}^M p_{j1} \leq P_{BS}, \end{aligned} \tag{3}$$

The constraint C1 is introduced for relaxing the optimization problem to binary values. C2 and C3 ensure that a particular subcarrier will be allocated to a single user in each direction. The constraint C4 and

C5 shows that the sum of all power allocated to all subcarriers in the uplink and downlink respectively is limited to the total power. The constraints C6 and C7 ensure that the rate of each user i in the uplink and downlink will be at least R_{\min} , to ensure fairness among the users. Employing linear programming techniques solely leads to a solution which is highly complex and this has motivated us to combine evolutionary techniques with LPP and thereby arriving at better solutions.

GA belongs to the category of global search heuristics that facilitate to find solutions to optimization problems. It is a class of evolutionary algorithms that uses techniques inspired from biology such as inheritance, mutation, selection, and crossover. During the initial phase of implementation of GA, a set of chromosomes are assumed. The assumed chromosomes are random possible solutions to the optimization problem. Representation of these chromosomes plays a major role in determining the complexity of the solution to the optimization problem. Generally in literature, the chromosomes are represented as binary strings [22], non-binary strings, matrices etc. The fitness value is computed for each assumed chromosome in the first generation. It is then made to undergo crossover and mutation. The new chromosomes so formed are selected for the next generation population. These are further made to undergo mutation, selection and crossover. The algorithm terminates when either the maximum number of generations are reached or if a satisfactory fitness value is obtained. If the algorithm terminates due to maximum number of generations, a satisfactory result may or may not have been reached.

NSGA II is allied to the category of GAs, primarily for solving multiobjective optimization problems. NSGA II uses the concept of non-dominance in its search for the computed fitness function in each generation. Solutions are compared for non-dominance and sets of non-dominated solutions are categorized into different fronts. The new offspring's are created using a selection process followed by crossover and mutation. There are different types of selection process to select the offspring, most popular being the tournament selection. Number of techniques to carry out mutation and crossover is presented in literature. This offspring is used as the solution/ chromosome for the next iteration. As in GA, the algorithm terminates when either a maximum number of generations has been produced, or a satisfactory fitness level has been reached for the population.

In this work, NSGA II is utilized to allocate the subcarriers and weighted sum method for power allocation in a MIMO OFDMA system for symmetrical services.

Since the resource allocation problem formulated is multiobjective in nature, the fitness functions are multiple, namely the data rates in uplink and downlink and the difference between the two for each individual user. The steps followed for subcarrier allocation is as follows:

Step 1: Input number of generations (G), Size of population, Channel gain h_{j1} and h_{j2} for each user in each subcarrier, Total Power (P_T and P_{BS}), B , M and K .

Step 2: Create initial population of chromosomes and calculate their data rates using (1) and (2) and the difference in data rates. For the initial iteration, the power is equally allocated to all the users in both directions. As mentioned earlier representation of the chromosome plays an important role. Here the chromosomes are the subcarriers that are allocated to the users. Therefore basically, each solution is a matrix of size $K \times M$. If the size of the population is 20, means 20 $K \times M$ matrices, which makes the problem solving very tedious and complicated. E.g: For a 4 subcarrier 2 user system, a sample solution looks like,

$$\begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix}$$

Handling 20 such matrices in a single iteration itself makes the solution very complex and time consuming. This is overcome by defining the chromosomes in a novel manner. Instead of the matrices, the chromosomes are represented as a non-binary string where the position and the value of the data indicate which subcarrier is allocated to a user. The representation for the chromosomes in the above example is given as 1122. Since the first position is a '1', it means that the first subcarrier is allocated to user 1. Similarly, the value in the next position is also '1', indicating that the second subcarrier is allocated to user 1. The third and fourth position has a value '2' which means that the third and fourth subcarrier is allocated to user 2. This type of design reduces the complexity of the solution to large extent.

Step 3: Compute the fitness function for each chromosome. i.e., value of R_{i1} and R_{i2} and the difference in data rates.

Step 4: Sort all chromosomes in a manner that all solutions that are not dominated by any other into front 1, and dominated by any one into front 2 and so on.

Step 5: Generate probability levels for each chromosome based on fronts allotted, such that the chromosome in front 1 has highest probability of selection for crossover.

Step 6: Based on fitness value select two chromosomes from the entire population and two points randomly on the parent chromosome for crossover. Two point crossover is opted in this solution. If the

chromosomes selected are 1112 and 2221, then in two point crossover, two points are randomly selected. For example, if 1 and 3 are selected, then after the first crossover the resultant is 2112 and 1221. When the crossover is carried out in position 3, it becomes 2111 and 1222. So obtained is the child chromosome after crossover.

Step 7: Replace the two chromosomes of lowest fronts with the two new child chromosomes.

Step 8: Select a chromosome from the entire population for mutation.

Step 9: Flip the channels allocated to users in the selected chromosome.

Step 10: If a particular user has more channels than he should, corresponding channel is allocated to the user with less number of channels.

Step 11: If any user has less number of channels, unallocated channel with highest channel gain is allocated to that user.

Step 12: Compute the power for each subcarrier using LP technique.

The lagrangian of the objective function in (1) to (3) is written as,

$$L(.) = \alpha_{i1} R_{i1} + \alpha_{i2} R_{i2} - \lambda_{i1} [\sum_{j=1}^K \omega_{ij1} - 1] - \lambda_{i2} [\sum_{j=1}^K \omega_{ij2} - 1] - \lambda_{i3} [\sum_{j=1}^K \omega_{ij2} p_{j2}] - P_T - \lambda_{i4} [\sum_{j=1}^K \omega_{ij1} p_{j1}] - P_{BS} \tag{4}$$

The lagrangian is modified as,

$$L(.) = \sum_{j=1}^M \omega_{ij1} (\widetilde{f}(p_{j1})) + \sum_{j=1}^M \widetilde{\omega}_{ij2} (f(p_{j2})) + \lambda_{i1} [\sum_{i=1}^K \omega_{ij2} - 1] - \lambda_{i2} [\sum_{i=1}^K \omega_{ij1} - 1] + \lambda_{i3} P_T + \lambda_{i4} P_{BS}$$

where $\widetilde{f}(p_{j1}) = \log_2[1 + \gamma_{j2} \widetilde{p}_{j2}] (\alpha_{i2}) - \lambda_{i4} [\sum_{j=1}^K p_{j1}]$ and $\widetilde{f}(p_{j2}) = \log_2[1 + \gamma_{j2} \widetilde{p}_{j2}] (\alpha_{i1}) - \lambda_{i3} [\sum_{j=1}^K p_{j2}]$

The variables are now distinct and therefore maximization over them can be carried out by taking the derivatives of $\widetilde{f}(p_{j1})$ and $\widetilde{f}(p_{j2})$ and setting it to zero, yields,

$$\frac{d\widetilde{f}(p_{j1})}{dp_{j1}} = (\alpha_{i2} + \lambda_{i6} - \lambda_{i7}) \left[\frac{\gamma_{j1}}{\log_2(1 + \gamma_{j1} p_{j1})} \right] + \lambda_{i4}$$

$$(\alpha_{i2} + \lambda_{i6} - \lambda_{i7}) \left[\frac{\gamma_{j1}}{\log_2(1 + \gamma_{j1} p_{j1})} \right] - \lambda_{i4} = 0$$

$$(\alpha_{i2} + \lambda_{i6} - \lambda_{i7}) \left[\frac{\gamma_{j1}}{\log_2(1 + \gamma_{j1} p_{j1})} \right] = \lambda_{i4}$$

$$\widetilde{p}_{j1}^* = \left[\frac{(\alpha_{i2})}{\lambda_{i4} \log_2} - \frac{1}{\gamma_{j1}} \right]^+$$

$$\text{Similarly, } \widetilde{p}_{j2}^* = \left[-\frac{(\alpha_{i1})}{\lambda_{i3} \log_2} - \frac{1}{\gamma_{j2}} \right]^+$$

Step 13: Calculate rates for each chromosome using (1) & (2).

Step 14: Iterate till the number of generations is reached.

Here the convergence of the algorithm is considered as the point where there is no significant change in the fitness function over generations.

3. RESULTS AND ANALYSIS

A Rayleigh fading channel is assumed between the transmitter and the receiver. A maximum delay spread of 5µs and maximum Doppler frequency of 30 Hz has been assumed [6]. The channel information is updated every 1ms. These constants are used for the calculation of the data rates in uplink and downlink direction. Total uplink power is assumed to be 250mW and downlink power is assumed to be 30W. The system is simulated using Matlab Software R2018b.

Figure 1(a) clearly depicts that the data rates for both users in the uplink and downlink direction computed from the initial population is lower than the other generations. This is due to the fact that the initial population was randomly chosen and the data rates achieved may or may not be good ones with this population. Moreover, for the initial population the power is equally divided among all the subcarriers. Figure 1(b) shows that the data rates increase with generations and data rates exhibit almost similar values as

the number of generation's increases. This can be justified by the fact that after computing the fitness function in each generation, they are sorted according to non-dominance criteria. As the generations proceeds, all possible combination of chromosomes are tried out and the best values are attained. Since one of the objectives of the optimization problem was to minimize the difference in data rates, the difference is within limits irrespective of the number of generations. For higher value of generations the difference in data rates for both uplink and downlink direction are very small and consistent.

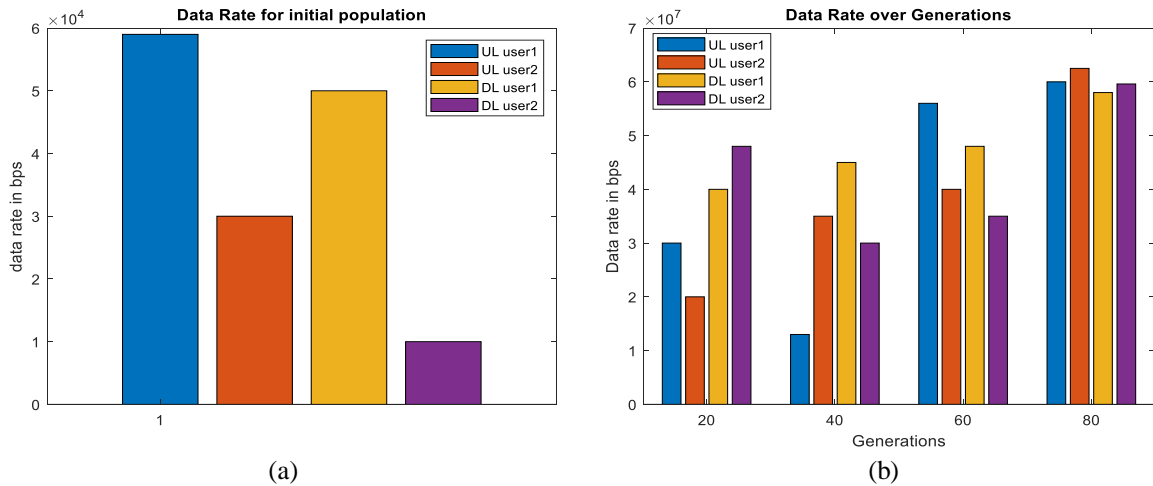


Figure 1. Simulation results for a 2 user system for various generations

Figure 2 depicts the system performance for 12 users and 64 subcarriers in the 80th generation with 12 db SNR. From the figure the difference in the data rates is seen to be reduced compared to that of the initial population and an increase in data rates as expected is seen.

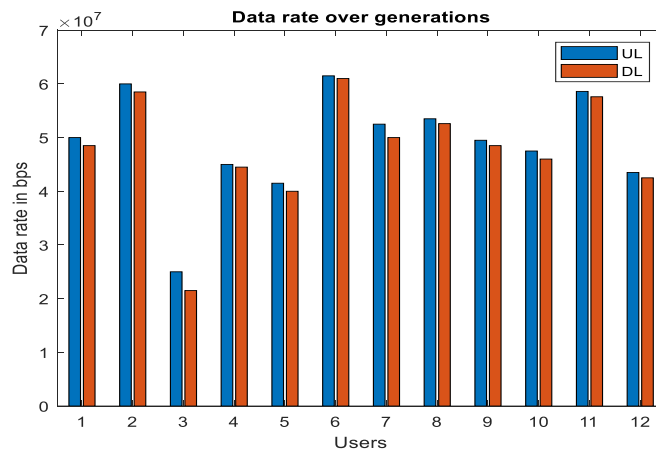


Figure 2. Simulation results for a 12 user system

4. CONCLUSION

In this paper, NSGA II is proposed as a solution for rate adaptive subcarrier allocation and linear programming approach for power allocation of symmetrical services in MIMO OFDMA system. To this end, a multiobjective optimization problem was formulated which involved the optimization of two objectives. Adoption of evolutionary techniques and representation of chromosomes in an innovative manner helped in the reduction of the problem's complexity as compared to linear programming techniques solely. The simulation results demonstrate that the proposed method not only helps in attaining high data rates in both

uplink and downlink directions, but also minimizes the difference in the data rates. Almost stable results are achieved as the number of generations is increased to 80, irrespective of the number of users. The proposed algorithm achieves higher data rates than [4], and is computationally less expensive as compared to previous algorithms available in literature using exclusive linear programming techniques.

REFERENCES

- [1] Frost and Sullivan, "Industry Outlook for the Indian Telecom and Broadcast Industry", *Digital India Convergence 2017*.
- [2] Wee-Kiat New, Chee-Onn Chow and Maode Ma, "Performance Measurements for Symmetrical Services in Wireless Networks", 2014 *IEEE International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS)*, December 1-4, 2014.
- [3] A.R. Utami and Iskandar, "Optimization Subcarrier Allocation and Genetic Algorithm for Resource Allocation in MIMO-OFDMA", 2018 *International Symposium on Electronics and Smart Devices*.
- [4] Ahmad M. El-Hajj, Zaher Dawy, "On Probabilistic Queue Length based Joint Uplink/Downlink resource allocation in OFDMA networks", 19th International Conference on Telecommunications 2012.
- [5] Ahmad M El-Hajj, Zaher Dawy and Walid Saad, "A stable matching game for joint Uplink/Downlink resource allocation in OFDMA wireless networks", *IEEE ICC 2012-Wireless network Symposium*.
- [6] Ahmad M El-Hajji, Zaher Dawy, "On optimized joint uplink/downlink resource allocation in OFDMA networks", 2011 *IEEE Symposium on Computers and Communications*.
- [7] Ahmad M El-Hajji, Mariette Awad, Zaher Dawy, "SIRA: A socially inspired game theoretic uplink/downlink resource aware allocation in OFDMA systems", 2011 IEEE International Conference on Systems, Man and Cybernetics.
- [8] Zhao Hou, Dan Wu, Yueming Cai, "Subcarrier and power allocation in uplink multi-cell OFDMA systems based on game theory", 12th International Conference on Communication Technology, 2010 IEEE.
- [9] Hanjin Kim, Hoon Lee, Minki Ahn, Han Bae Kong and Inkyu Lee, "Joint Subcarrier and Power Allocation Methods in Full Duplex Wireless Powered Communication Networks for OFDM Systems", *IEEE Transactions on Wireless Communications*, Vol.15, No.7, July 2016.
- [10] Roya Arab Loodaricheh, shankhanaad Mallick and Vijay K Bhargave, "Energy Efficient Resource Allocation for OFDMA Cellular Networks With User Cooperation and QoS Provisioning", *IEEE Transactions on Wireless Communications*, Vol.13, No.11, November 2014.
- [11] Lukai Xu, Guanding Yu and Yuhuan Jiang, "Energy Efficient Resource Allocation in Single Cell OFDMA Systems: Multi-Objective Approach", *IEEE Transactions on Wireless Communications*, 2015.
- [12] Shahid Mumtaz, Kazi Mohammed Saidul Huq, Ayman Rudwan, Jonathan Rodriguez, Rui L Aguiar, "Energy efficient Interference-aware resource allocation in LTE-D2D communication" 2014 IEEE International Conference on Communications (ICC).
- [13] Samaneh Bidabadi, Mohammad Javad Omid, Jafar Kazemi, "Energy Efficient Power Allocation in Downlink OFDMA Systems using SQP Method", 2016 24th Iranian Conference on Electrical Engineering.
- [14] Lukai Xu, Guanding Yu, Yuhuan Jiang and Qimei Chen, "Multi-Objective Bandwidth and Power Allocation for Energy-Efficient Uplink Communications", 2015 IEEE 26th Annual International Symposium on Personal, Indoor and Mobile Radio Communications.
- [15] Stefano Buzzi, Giulio Colavolpe, Daniela Saturnino, Alessio Zappone, "Potential games for energy efficient power control and subcarrier allocation in uplink multicell OFDMA systems", *IEEE journal of selected topics in signal processing*, Vol 6, No 2, April 2012.
- [16] Zhengyu Song, Qiang Ni, Keivan Navaie, Shujuan Hou and Siliang Wu, "Energy and Spectral Efficiency Tradeoff with α -Fairness in Downlink OFDMA Systems", *IEEE Communications Letters*, 2015.
- [17] Alessio Zappone, Stefano Buzzi, Eduard Jorwieck and Michela Meo, "A Survey on Game-Theoretic Approaches to Energy Efficient Relay Assisted Communications", 24th Tyrrhenian International Workshop on Digital Communications-Green ICT (TIWDC), 2013.
- [18] U. Akgul, B. Canberk, "Self-Organized Things (SoT): An Energy Efficient Next Generation Network Management", *Computer Communications (Elsevier)*, vol. 74, pp. 52-62, January 2016.
- [19] Liang Zhou, Olav Tirkkonen, Randal Berry, "Two-player D2D interference canceling games", 2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC).
- [20] Guopeng Zhang, Kun Yang, and Hsiao-Hwa Chen, "Resource Allocation for Wireless Cooperative Networks - A Unified Cooperative Bargaining Game Theoretic Framework", *IEEE Wireless Communications*, Volume: 19, Issue: 2, Page(s): 38-43, April 2012. (SCI).
- [21] Long Gong, Xiang Zhou, Wei Lu, Zuking Zhu, "A Two-Population Based Evolutionary Approach for Optimizing Routing, Modulation and Spectrum Assignments (RMSA) in O-OFDM Networks", *IEEE Communication Letters*, Vol 16, Issue 9, September 2012.
- [22] Nitin Sharma, K. R. Anupama "A Novel Genetic Algorithm for Adaptive Resource Allocation in MIMO-OFDM Systems with Proportional Rate Constraint", *Wireless Personal Communications (2011)*.
- [23] Vinsensius Sigit Widhi Prabowo, Arfianto Fahmi, Nachwan Mufti Adriansyah, Nur Andin, "Energy efficient resources allocations for wireless communication systems", *TELKOMNIKA (Telecommunication, Computing, Electronics and Control)*, Vol.17, No.4, August 2019, pp.1625-1634 ISSN: 1693-6930.

- [24] Suliman M. Fati, Putra Sumari, Wou Onn Choo," Content-aware resource allocation model for IPTV delivery networks", *International Journal of Electrical and Computer Engineering (IJECE)* Vol. 9, No. 1, February 2019, pp. 369-385 ISSN: 2088-8708.
- [25] Pradip Varade, Akanksha Wabale, Ravinder Yerram, Rupesh Jaiswal," Throughput Maximization of Cognitive Radio Multi Relay Network with Interference Management", *International Journal of Electrical and Computer Engineering (IJECE)* Vol. 8, No. 4, August 2018, pp. 2230~2238,ISSN: 2088-8708.

BIOGRAPHIES OF AUTHORS



Swapna P.S. received her M.Tech degree in Microwave and TV Engineering from College of Engineering, Trivandrum, Kerala in the year 2007. She graduated in Electronics and Communication Engineering from RIT Government Engineering College, Kottayam in the year 2004. She is currently working as an Assistant Professor in the department of Electronics and Communication Engineering at Mar Baselios College of Engineering, Trivandrum, Kerala and pursuing her Ph. D in Resource Allocation in OFDMA Systems.



Dr. Sakuntala S. Pillai obtained Ph. D degree from University of Kerala 1989. She was the Head of the Department of Electronics & Communication, College of Engineering, Trivandrum from 1996-1998 and later worked as Director, LBS centre for Science and Technology, Trivandrum. She joined Mar Baselios College of Engineering & Technology, Trivandrum as Head the Department of Electronics & Communication in 2003 and was the former Dean (R&D) from 2009-2016. Her research interests include OFDM, OFDMA, MIMO wireless systems, Error Correction Coding etc. She is a Senior Member of IEEE, Fellow of IETE and Fellow of Institution of Engineers (India). Email: sakuntala.pillai@gmail.com



Dr. SreeniK G received his B. Tech (2000) in Electronics from College of Engineering, Adoor and M. Tech. (2003) in Power Electronics from NIT, Calicut. His Ph. D. is on Computational Haptics from IIT, Bombay in 2013. His area of interest includes Linear Algebra for Signal Processing. Email: sreenikg79@gmail.com.