Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 46 No. 11
November 2025

Evaluating spectrum allocation strategies for 5G network in bipolar fuzzy environment

S. Anita Shanthi and N. Keerthana,

[1, 2] Departmentof Mathematics, Annamalai University,
Annamalai Nagar-608 002, India.
E-mail: Shanthi.anita@yahoo .com[1]
Keerthananm99@gmail.com[2]

Abstract
In The rapid evolution of wireless communication technologies has placed significant pressure on efficient spectrum utilization, particularly in the context of 5G networks. The growing need for faster data transmission, minimal latency and large-scale device connectivity has made efficient spectrum allocation an essential yet challenging task. This paper involves four prominent spectrum allocation strategies, AI – based spectrum management, cognitive radio allocation, Dynamic spectrum allocation and fixed spectrum allocation. Each alternative is evaluated based on key performance criteria including, Spectrum utilization, interference management, Adaptability and computational complexity. This paper discusses the use of bipolar picture fuzzy soft TODIM and MAUT methods to identify the best spectrum allocation strategies for 5G network/
Keywords: BPFS Dominance measure value, BPFS aggregated utility function value, BPFS global value.

1. Introduction

Zadeh [1] introduced the groundbreaking concept of fuzzy sets, which use degrees of membership to represent imprecision in decision-making processes. Atanassov [2] extended this concept with intuitionistic fuzzy sets (IFS), incorporating both membership and non-membership degrees to offer more detailed representation of uncertainty. Molodstov [3] proposed the concept of soft sets, offering a unique framework for dealing with uncertainty and decision making challenges. Maji et al. [4] expanded this by integrating fuzzy logic with soft sets, resulting in the formulation of fuzzy soft sets, resulting in the formulation of fuzzy soft sets. Cuong et al. [7] enhanced this field further by developing picture fuzzy sets, an extension of IFS that incorporates an additional degree of neutrality. Zhang [8] introduced bipolar fuzzy sets a novel framework for modeling bipolarity in fuzzy environments. Roy [9] advanced this idea by formulating bipolar fuzzy soft sets (BPFS) and proposing a systematic algorithm for multi-criteria decision making (MCDM) applications. Saleem et al. [10] explored MCDM within the BPFS context, while Alghamdi et al. [11] developed innovative technique for handing bipolar fuzzy environments in MCDM scenarios. Zavadaskas et al. [12] developed the CODAS method for multi – criteria decision making (MCDM) in the fuzzy domain. K.Mania et al. [13] proposed the preference selection index method. Mohini et al. [14] defined MEMS piezoelectric sensor for self powered devices. Majid et al. [15] introduced n approach for aggregating rankings generated by multi criteria decision making methods. Anita Shanthi et al. [16] extended the TODIM method to the intuitionistic fuzzy soft TODIM method, demonstrating its applicability through various practical applications. Based on these concepts BPFS TODIM and BPFS MAUT methods have been introduced to enhance decision-making frameworks.

.

2. TODIM and MAUT method on BPFS sets

Definitions of BPFS set and BPFS matrix are given in [17]

Definition: 2.1 Score function with refusal degree is defined as,

$$SD(BPF,Z) = \left| \begin{matrix} \mu_{ab}^{-} + \mu_{ab}^{-}(-1 - \mu_{ab}^{-} - \eta_{ab}^{-} - \gamma_{ab}^{-}) + \\ \mu_{ab}^{+} + \mu_{ab}^{+}(1 - \mu_{ab}^{+} - \eta_{ab}^{+} - \gamma_{ab}^{+}) \end{matrix} \right| / 3,$$

$a = 1,2,\cdots g, b = 1,2,\ldots,h..$

Applying this score function, the score matrix denoted by $SDM(BPF,Z)$ is constructed.

Definition: 2.2 The BPFS relative weight for each criteria are calculated as, $y_{bk} = \frac{y_b}{y_k}$. y_k is the maximum of the weights.

Definition: 2.3 The BPFS dominance measure of alternative Z_a over Z_t for each criteria $\in_b$ is assessed using a comparative analysis of their BPFS weights and BPFS weighted score values.

Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 46 No. 11
November 2025

$$BP\phi(Z_a,Z_t)=\begin{cases} 0 & if\ SDM_{ab}=SDM_{tb} \\ \sqrt{\dfrac{y_{bk}(SDM_{ab}-SDM_{tb})}{\sum_{b=1}^{h} y_{bk}}} & if\ SDM_{ab}\geq SDM_{tb} \\ \dfrac{-1}{BP\theta}\sqrt{\dfrac{\sum_{b=1}^{h} y_{bk}(SDM_{ab}-SDM_{tb})}{y_{bk}}} & if\ SDM_{ab}\leq SDM_{tb} \end{cases}$$

Moreover the dominance value is further through the lens of respect theory by distinguishing between perceived gains and losses. $BP\theta$ represents the loss of sensitivity coefficient such that $BP\theta \succ 0, S_{ab} \succ S_{tb}$, then the function $BP\phi(Z_a,Z_t)$ represents gain. Conversely $S_{ab} \succ S_{tb}$, $BP\phi(Z_a,Z_t)$ represents a loss. The BPFS dominance matrix is constructed by all such gain – loss comparisons across all alternatives and criteria.

$$BP\phi(Z_a,Z_t)=\begin{pmatrix} 0 & BP\phi(Z_1,Z_2) & \cdots & BP\phi(Z_1,Z_h) \\ BP\phi(Z_2,Z_1) & 0 & \cdots & BP\phi(Z_2,Z_h) \\ \vdots & \vdots & \vdots & \vdots \\ BP\phi(Z_g,Z_1) & BP\phi(Z_g,Z_2) & \cdots & 0 \end{pmatrix}$$

Definition: 2.4 The BPFS overall dominance degree among the alternatives is formulated as, $BP\delta(Z_a,Z_t)=\sum_{b=1}^{h} BP\phi_b(Z_a,Z_t).$

$BP\delta(Z_a,Z_t)$ represents the BPFS measurement of dominance degree using BPFS.

Definition: 2.5 The BPFS global alternative's value Z_a is,

$$BP\xi(Z_a)=\frac{\sum_{b=1}^{h} BP\phi_b(Z_a,Z_t)-\min_a BP\phi(Z_a,Z_t)}{\max_b BP\phi_b(Z_a,Z_t)-\min_a BP\phi_b(Z_a,Z_t)}$$

Ranking the global values, the maximum value is the best alternative.

MAUT on BPFS sets:

Definition: 2.6 BPFS aggregated utility function value for each alternative Z_a is,

$$BPU(Z_a)=\sum_{b=1}^{h} y_b S_{ab}\ .$$

The highest BPFS aggregated utility function value of respective alternative is considered as best alternative.

3. Procedure

The procedure for BPFS TODIM and BPFS MAUT methods to solve MCDM problem is,

Step: 2 BPFS score matrix $(SDM_{ab})_{s\times t}$ corresponding to the criteria $\in_b$ is determined using Definition 2.1.

Step: 3 Apply TODIM method, then by using Definition 2.2 to identify the BPFS relative weight values.

Step: 4 BPFS dominance measure value of each alternative Z_a over another alternative Z_t for each criteria $\in_b$ is calculated by using Definition 2.3.

Step: 5 BPFS overall dominance degree among the alternatives are computed by using Definition 2.4.

Step: 6 BPFS global value of the alternative are estimated using Definition 2.5. The alternatives are then ranked in order of their global values. The maximum global value is regarded as the best.

Step: 7 Apply MAUT methods, BPFS aggregated utility function value for each alternative is calculated by using Definition 2.6. Rank the alternatives using the BPFS utility scores, the higher value is the best.

4. Application

In 5G wireless communication systems spectrum is a critical and limited resource that must be efficiently allocated to ensure high-speed, low-latency and reliable connectivity. Various spectrum allocation strategies have been developed to manage this resource effectively. Efficient spectrum allocation is essential to ensure optimal utilization of limited frequency resources while maintaining service quality.

Illustrative Example: Various spectrum allocation strategies for 5G wireless communications systems such as, AI – based spectrum management fixed spectrum allocation Z_1, dynamic spectrum allocation Z_2, dynamic spectrum allocation x Z_3 and fixed spectrum allocation Z_4 are considered as alternatives which are investigated on criteria such as spectrum utilization $\in_1$, interference management $\in_2$, adaptability $\in_3$, computational complexity $\in_4$. The most effective spectrum allocation strategy for 5G communication systems is determined under BPFS TODIM and MAUT method.

Step 1. BPFS decision matrix is as follows:

$$BPFSM=\begin{pmatrix} & \in_1 & \in_2 \\ Z_1 & ((-0.11,0.25),(-0.03,0.05),(-0.06,0.31)) & ((-0.23,0.31),(-0.25,0.014),(-0.04,0.13)) \\ Z_2 & ((-0.49,0.14),(-0.07,0.003),(-0.007,0.3)) & ((-0.010,0.023),(-0.017,0.14),(-0.02,0.15)) \\ Z_3 & ((-0.15,0.03),(-0.005,0.15),(-0.16,0.25)) & ((-0.14,0.25),(-0.07,0.015),(-0.08,0.43)) \\ Z_4 & ((-0.02,0.013),(-0.35,0.017),(-0.16,0.03)) & ((-0.011,0.153),(-0.06,0.167),(-0.151,0.251)) \\ & \in_3 & \in_4 \\ Z_1 & ((-0.19,0.04),(-0.03,0.13),(-0.34,0.15)) & ((-0..053,0.151),(-0.04,0.16),(-0.135,0.159)) \\ Z_2 & ((-0.32,0.35),(-0.15,0.06),(-0.42,0.11)) & ((-0.43,0.167),(-0.08,0.181),(-0.371,0.165)) \\ Z_3 & ((-0.03,0.42),(-0.015,0.15),(-0.027,0.032)) & ((-0.28,0.291),(-0.31,0.28),(-0.17,0.31)) \\ Z_4 & ((-0.011,0.032),(-0.027,0.5),(-0.48,0.06)) & ((-0.4,0.33),(-0.169,0.312),(-0.171,0.41)) \end{pmatrix}$$

Step 2. BPFS score matrix is as follows:

$$SDM_{ab} = \begin{pmatrix} 0.1085 & 0.1199 & 0.0131 & 0.007298 \\ 0.01995 & 0.01278 & 0.0777 & 0.04351 \\ 0.00715 & 0.09522 & 0.195 & 0.0376 \\ 0.00487 & 0.0720 & 0.01313 & 0.00561 \end{pmatrix}$$

Step 3. Apply TODIM method to identify the BPFS relative weight values for each criteria is,

$y_{1k} = 1, y_{2k} = 0.0928, y_{3k} = 0.5192, y_{4k} = 0.0509$.

Step 4. BPFS dominance measure value of each alternative Z_a over other alternative Z_t for each criteria $\in_b$ are,

Here $BP\theta = 1$,

$$BP\phi_1 = \begin{pmatrix} 0 & 0.204 & 0.2186 & 0.221 \\ -0.443 & 0 & 0.0777 & 0.0843 \\ -0.464 & -0.165 & 0 & 0.0328 \\ -0.469 & -0.179 & -0.07 & 0 \end{pmatrix}$$

$$BP\phi_2 = \begin{pmatrix} 0 & 0.0684 & 0.0328 & 0.0458 \\ -1.565 & 0 & -1.373 & -1.164 \\ -0.751 & 0.06. & 0 & 0.0319 \\ -1.047 & 0.0509 & -0.729 & 0 \end{pmatrix}$$

$$BP\phi_3 = \begin{pmatrix} 0 & -0.514 & -0.862 & -0.011 \\ 0.1257 & 0 & -0.692 & 0.1257 \\ 0.211 & 01694. & 0 & 0.211 \\ 0.0024 & -0.514 & -0.862 & 0 \end{pmatrix}$$

$$BP\phi_4 = \begin{pmatrix} 0 & 0.0842 & 0.0922 & 0.01272 \\ -0.3502 & 0 & 0.0377 & 0.0954 \\ -0.3837 & -0.1568 & 0 & 0.0877 \\ -0.5295 & -0.3971 & -0.3649 & 0 \end{pmatrix}$$

Similarly the other values of $BP\theta = 2,3,4,5$ are calculated.

Step 5. BPFS overall dominance degree matrix among the alternatives is,

For $BP\theta = 1$ is,

$$BP\delta_1 = \begin{pmatrix} 0 & -0.157 & -0.519 & 0.382 \\ -2.223 & 0 & -1.195 & -0.8585 \\ -1.3879 & -0.0922 & 0 & 0.3633 \\ -2.0425 & -1.0388 & -2.0254 & 0 \end{pmatrix}$$

For $BP\theta = 2$ is,

$$BP\delta_2 = \begin{pmatrix} 0 & 0.1 & -0.087 & 0.3885 \\ -1.049 & 0 & -0.917 & -0.277 \\ -0.588 & 0.0686 & 0 & 0.3633 \\ -1.02 & -0.494 & -1.013 & 0 \end{pmatrix}$$

For $BP\theta = 3$ is

$$BP\delta_3 = \begin{pmatrix} 0 & 0.1856 & 0.05621 & 0.3903 \\ -0.6573 & 0 & -0.5723 & -0.0825 \\ -0.322 & 0.12224 & 0 & 0.3633 \\ -0.679 & -0.3124 & -0.6751 & 0 \end{pmatrix}$$

For $BP\theta = 4$ is

$$BP\delta_4 = \begin{pmatrix} 0 & -0.157 & -0.519 & 0.382 \\ -2.223 & 0 & -1.195 & -0.8585 \\ -1.3879 & -0.0922 & 0 & 0.3633 \\ -2.0425 & -1.0388 & -2.0254 & 0 \end{pmatrix}$$

Step 6. The ranking order of the alternatives are Z_1, Z_3, Z_2, Z_4. The alternative Z_1 which is AI based spectrum management has the greater global value $BP\xi(Z_a)$ as compared with other alternatives shown in Table 1 and in Figure 1, the graphical representation of these values are depicted.

Table 1: BPFS global value using TODIM method

	$BP\theta = 1$	$BP\theta = 2$	$BP\theta = 3$	$BP\theta = 4$	$BP\theta = 5$
Z_1	1	1	1	1	1
Z_2	0.015	0.0969	0.1538	0.1957	0.2279
Z_3	0.829	0.8096	0.7962	0.7863	0.7787
Z_4	0	0	0	0	0

Step 7. Apply MAUT method, BPFS weighted score matrix is,

$$WSDM_{ab} = \begin{pmatrix} 0.0511 & 0.0052 & 0.0032 & 0.0175 \\ 0.0095 & 0.0006 & 0.01901 & 0.0105 \\ 0.0034 & 0.0042 & 0.0477 & 0.009 \\ 0.0023 & 0.0031 & 0.0032 & 0.0013 \end{pmatrix}$$

Step 8. BPFS aggregated utility function value for each alternative is,

$BPU(Z_1) = 0.0771, BPU(Z_2) = 0.0394$

$BPU(Z_3) = 0.0643, BPU(Z_4) = 0.010004.$

Based on the above utility function value, the ranking of the alternatives is Z_1, Z_3, Z_2, Z_4. Hence the AI based spectrum management is the best one and it shown in Figure 2.

Finally Z_1 consistently secures the first rank across both BPFS TODIM and BPFS MAUT methods.

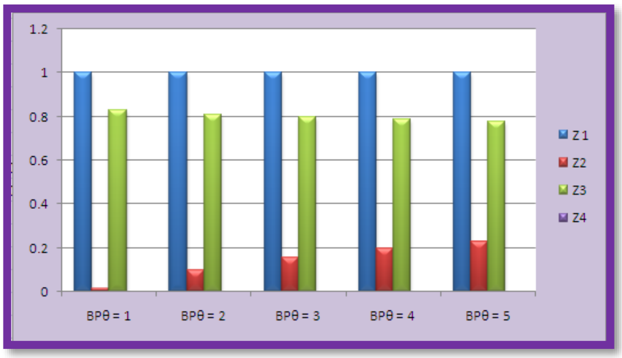

Figure 1: Graphical representation of BPFS TODIM method

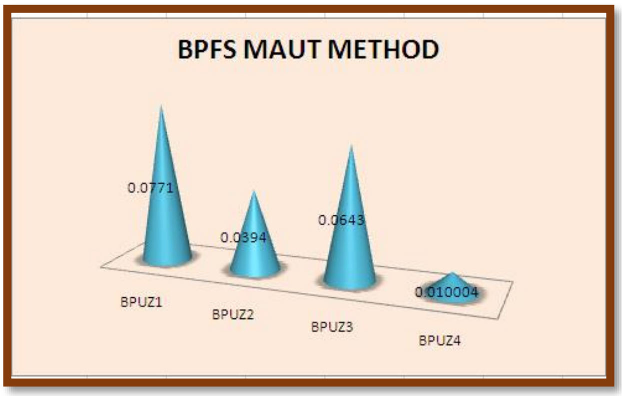

Figure 2: Graphical representation of BPFS MAUT method

5. Conclusion

In this paper, the best spectrum allocation strategy for 5G wireless communication systems is evaluated using BPFS TODIM and BPFS MAUT. BPFS sets are represented as a decision matrix. BPFS score function is defined and a score matrix is established. Applying TODIM method, BPFS relative weights values are calculated. BPFS dominance measure value and BPFS global value of alternatives are determined. After applying MAUT, BPFS aggregated utility function values are enumerated. After that, the ranking value of BPFS TODIM and BPFS MAUT. The maximum value of this comparison Z_1 corresponds to the best alternative.

Refrences

[1] L.A. Zadeh, 1965. Fuzzy sets, Information and control, Vol-8, 338-353.

[2] K.T. Atanassov, Intuitionistic fuzzy sets, Fuzzy sets and systems, Vol-20, issue-1, 87-96.

[3] D. Molodstav, 1999. Soft theory sets first results, Computer Science and mathematics with applications, Vol-37,19-31.

[4] P.K. Maji, A.R. Roy and R. Biswas, 2001. Fuzzy soft set, Journal of Fuzzy Mathematics Vol-9, issue-3, 589-602.

[5] B.C. Cuong and V. Kreinovich, 2013. Picture Fuzzy sets – a new concepts for computational intelligence, IEEE, 1-16.

[6] B.C. Cuong, 2014. Picture Fuzzy Sets, Journal of Computer Science and cybernetics, Vol-30, issue-4, 409-420.

[7] B.C. Cuong and V.H. Pham, 2015. Some fuzzy logic operators for picture fuzzy sets, Seventh International Conference on Knowledge and Systems engineering, 132-137.

[8] W.R. Zhang, 2008. Bipolar fuzzy sets, IEEE international conference on fuzzy sets, 305-309.

[9] A.R. Roy and P.K. Maji, 2007. A fuzzy soft set theoretic approach to decision making problems, Journal of computational and applied mathematics, Vol-203, 412-418.

[10] Saleem Abdulla, Muhammed Aslam and Kifayat Ullah, 2014. Bipolar fuzzy soft sets and its applications in decision making problem, J.Intell, Fuzzy Systems, Vol-27, 729-742.

[11] M.A. Alghmdi, N.O. Alshehri and M. Akram, 2018. Multi-criteria Decision making methods in Bipolar Fuzzy Environment, Internation Journal of Fuzzy Systems, Vol-20, 2057-2064.

[12] Mehdi Keshvarz-Ghorabee, Edmundas Kazimieras Zavadaskas, Zenonans Turkis, Jurgita Antuchevicience, 2016. A new combinative distance based assessment (CODAS) method for multi-criteria decision making, Economic computation and Economic cybernetics studies and Research, Vol-50, issue-3, 25-44.

[13] K. Mania and M.G. Bhatt, 2010. A selection of material using a novel type decision making method preference selection index method, Material and Designs, Vol-31, issue-4, 1785-1789.

[14] Mohini Sawane, Mahanath Prasad, 2023. MEMS piezoelectric sensor for self powered devices, Material Science in Semiconductor Processing, Vol-158, 107324.

[15] Majid Mohammadi, Jafar Rezaei, 2020. Ensemble Ranking: Aggregation of rankings produced by different multi-criteria decision making methods, Omega, Vol-96, issue-102254, 1-12.

[16] S. Anita Shanthi and Prathipa Jayapalan, 2021. TODIM method based on bipolar intuitionistic fuzzy soft set, Journal of Physics, Vol-1724, 012041.

[17] S. Anita Shanthi and N. Keerthana, 2023. Evaluating types of soil suitable for construction using radial basis function fuzzy neural network, E3S Web of Conference, Vol-404, issue-04030, 1-4.