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**Research article**

# TOWARDS SMART SYSTEM ARCHITECTURES: A FUZZY MCDM-BASED EVALUATION OF APPLICATION MAPPING STRATEGIES

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**Abstract**: Application mapping strategies in Network-on-Chip (NoC)-based Multiprocessor System-on-Chip (MPSoC) are critical for achieving efficient

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communication and reduced energy consumption. Therefore, choosing the optimal mapping strategy is of significant importance. However, due to the numerous evaluation criteria, trade-offs, conflict, and criteria importance, the assessment and selection of mapping strategies remain a complex challenge. Despite the importance of this issue, current literature reveals a significant research gap in comprehensive comparative evaluations of these strategies using systematic and quantitative methods. Previous researchers recommended multi-criteria decision-making (MCDM) to address the issue of identity best mapping strategy. Remarkably, the literature has reported a paucity of evaluations of the optimal mapping strategies. The present study aims to determine the most effective application mapping strategies in certain situations by using fuzzy MCDM methods. The design and methods of this study involve two phases. The first phase involves the evaluation decision matrix, which is derived through the intersection of the evaluation criteria and the mapping strategies list. The second phase includes the proposed MCDM methods, namely the Weight Fuzzy Judgment Method with Triangular Fuzzy (Tr-WFJM) for determining the weights for the criteria of mapping strategies and Multi-Attributive Border Approximation Area Comparison (MABAC) to rank the mapping strategies based on the weight assigned. The findings of Tr-WFJM revealed that PIP Cost has the highest final weight (0.2326) and MPEG-4 Cost has the lowest weight (0.0887), respectively. In terms of the MABAC method, the Integer Linear Programming (ILP) is the most efficient mapping strategy. This study is exceptional because it provides academics and practitioners insight into reducing resources and energy consumption.

**Keywords**: Network-on-Chip, smart system, MCDM, application mapping, mapping strategies, fuzzy set.

**MSC:** 68M07.

**List of Abbreviations**

| Abbreviation | Definition |
|---|---|
| **NoC** | Network-on-Chip |
| **MPSoC** | Multiprocessor System-on-Chip |
| **IoT** | Internet of Things |
| **ILP** | Integer Linear Programming |
| **MILP** | Mixed Integer Linear Programming |
| **PBIL** | Population-Based Incremental Learning |
| **PSO** | Particle Swarm Optimization |
| **GA** | Genetic Algorithm |
| **Ihpsa** | Improved Hybrid PSO and GA |
| **SA** | Simulated Annealing |
| **ACO** | Ant Colony Optimization |
| **MCDM** | Multi-Criteria Decision Making |
| **WFJM** | Weight Fuzzy Judgment Method |
| **Tr-WFJM** | Triangular Fuzzy Weight Fuzzy Judgment Method |
| **Tr-FN** | Triangular Fuzzy Number |
| **MABAC** | Multi-Attributive Border Approximation Area Comparison |
| **DNN** | Deep Neural Network |
| **CTH** | Cube-Tree-Hybrid |
| **LBC/LBL** | Lifetime-Based Core/Link Balancing |
| **SMAP** | Static Mapping Algorithm |
| **LMAP** | Load-Balancing Mapping Algorithm |
| **CHMAP** | Cluster-Based Hierarchical Mapping |

| | |
|---|---|
| **CMAP** | Communication-Aware Mapping |
| **BMAP** | Bandwidth-Aware Mapping |
| **NMAP** | Neighbor-Based Mapping |
| **Onyx** | Online Heuristic Mapping Strategy |
| **DVDPD** | Digital Video Disk Player Decoder (Benchmark) |
| **MPEG-4** | Moving Picture Experts Group Layer 4 (Benchmark) |
| **PIP** | Picture-in-Picture (Benchmark) |
| **MWD** | Multi-Window Display (Benchmark) |
| **263dec** | H.263 Decoder (Benchmark) |
| **mp3dec** | MP3 Decoder (Benchmark) |

## 1. INTRODUCTION

The rapid advancement of Internet of Things (IoT) technologies has revolutionized the way devices interact, communicate, and process data. This leading to an increased demand for efficient and high-performance embedded systems [1]. Multiprocessor System-on-Chip (MPSoC) integrated with Network-on-Chip (NoC) architectures (see Figure 1), offer scalable and efficient communication among multiple processing elements [2]. The process of assigning tasks to processing elements in NoC architecture plays a central role in determining overall system efficiency, communication latency, and energy consumption. Recent studies highlight the effectiveness of NoCs in handling the diverse and dynamic nature of IoT applications. The NoCs often involve real-time constraints, high energy efficiency requirements, and variable workloads. For example, Waqar Amin et al. (2019) proposed a Population-based Incriminate Learning (PBIL) approach to improve latency and throughput for task mapping in large scale NoC systems [3]. In addition, Barros et al. (2019) developed an adaptive task-to-core mapping technique that dynamically fits application demands to core resources, enhancing scalability and real-time adaptability [4]. Moreover, another study introduced iHPSA a hybrid of Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) to co-optimize task-resource allocation, reducing energy and execution time in NoC-based MPSoC architectures [5]. Furthermore, Zhang et al. introduced neuron-aware ILP+Simulated Annealing mapping strategy to minimize inter-neuron communication cost in 2D NoC with mesh for DNN workloads.

Therefore, identifying the optimal mapping strategy is a vial step towered enabling the development of energy efficient and scalable IoT systems [6].

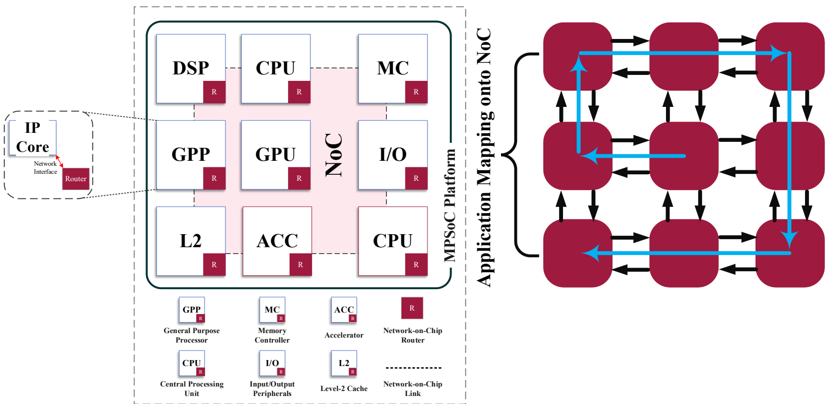


**Figure 1:** NoC-based MPSoC architecture with schematic diagram for mapping applications per IP Core

Despite numerous mapping strategies proposed in the literature, many focused on optimizing only a single metric – such as latency or energy while neglecting the boarder trad-offs that emerge in realistic IoT envelopments. The decision-making process for application mapping becomes more complex. Moreover, decision-making in this context often involves subjective judgments and uncertainty in expert assessment which traditional optimization methods fail to address [7, 8, 9, 10].

A critical gap in the current of body of knowledge is the lack of a robust, systematic evaluation framework that can handle multiple criteria and account uncertainty in expert opinions. Although MCDM methods have been suggested to support such evaluations, traditional MCDM approaches often fall short when faced with vagueness and imprecision in the decision-making process. Existing studies seldom integrate fuzzy login into both the criteria weighing and strategy ranking stages. Furthermore, there is limited research that applies these techniques specifically to application mapping in NoC-based MPSoCs, leaving room for advancement in this area [11, 12, 13, 14, 15]. The significance of this study lies in its systematic evaluation and ranking of application strategies for NoC-based MPSoC using fuzzy MCDM methods. By addressing conflicting criteria such as energy, latency, scalability, the study provides a structured decision-support framework for designers. It reduces uncertainty in strategy selection through Tr-WFJM and offers robust ranking using MABAC. Ultimately, this study contributes to more efficient, reliable, and scalable MPSoC designs for emerging IoT applications.

This study proposes a comprehensive fuzzy MCDM-based farmwork to evaluate and rank application mapping strategies in NoC-based MPSoC. The key contributions are:

a. Formulation of decision matrix combining 7 critical evaluation criteria and 10 mapping strategies.

b. Integrating Tringle Fuzzy Number (Tr-FN) into WFJM to effectively assign weights while managing uncertainty.

c. Application of MABAC method for robust rankling of mapping strategies, identifying integer Linear Programming (ILP) as the most effective solution

d. Provisions of practical Insights to designers and practitioners for improving energy efficiency, performance and scalability in IoT-driven MPSoC systems.

The remainder of the paper is organized as follows: Section 2 explains the related and current state of the work. In addition, Section 3 shows the preliminaries related to the NoC-based application mapping aspects formulation. Section 4 presents the research methodology in detail. Moreover, Section 5 shows the result and discussion of criteria weighting and alternatives ranking using MCDM methods. Finally, Section 6 concludes this paper.

## 2. RELATED WORK

NoC architecture has become foundational in designing scalable and energy-efficient MPSoC platforms, particularly for real-time and resource-constrained environments such as IoT. NoC facilitate parallel processing by providing high-throughput, low latency interconnection among cores, overcoming the bandwidth and congestion limitations of tractional bus-based systems [16]. A core challenging in NoC-based MPSoC design is the application mapping problem, where tasks or applications are assigned to processing elements in a way that minimizes communication cost, energy computation, and execution delay [17]. Over the past decade, a wide range of strategies have been proposed to tackle this problem. These can be broadly categorized into metaheuristics and ML-based approaches.

### 2.1. Metahusrsics-based mapping approaches

Techniques such as Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Grey Wolf Optimization (GWO) have been extensively utilized to find optimal mapping solutions [18, 19, 20]. These algorithms are effective in exploring large solution spaces and providing near-optimal solutions with relatively lower computational overhead.

### 2.2. ML-based approaches

The use of ML, particularly reinforcement learning and neural networks, has gained traction for application mapping in NoC-based MPSoC systems [21]. For supervised ML techniques, artificial neural networks have been utilized to predicted the core vulnerability for reliability aware-mapping in NoC-based MPSoC systems [22]. In addition, unsupervised ML also used in this domain by using K-means clustering ML approach to cluster tasks for a specific pattern grouping them for easy manner scheduling for MPSoC cores as in [23]. Moreover, refomented learning also used by employing Actor-critic, Q-learning in adaptive task-to-core mapping and scenario aware mapping for NoC-based MPSoC as in [24, 25, 26]. For additional details and information about proposed application mapping strategies onto NoC-based MPSoC platforms, refer to Table 1.

**Table 1:** Summary of prior studies and proposed approaches for application mapping on NoC-based MPSoC

| Article | Approach | Optimization Technique | Key Metrics | Key Findings |
|---|---|---|---|---|
| [27] | NoC Mapping | Whale Optimization Algorithm (WOA), GA | Energy Consumption, Stability | Achieved low energy consumption and stability |
| [28] | 2D NoC Mapping | ILP | Communication Costs | Reduced communication costs through exact mapping |
| [29] | Task Mapping | Chaotic Genetic Algorithm | Mapping Efficiency | Improved mapping using chaotic architecture |
| [30] | Mesh-of-Tree Networks | Discrete Particle Swarm Optimization (DPSO) | Execution Time, Mapping Quality | Enhanced mapping quality and execution time |
| [19] | Task Mapping | Self-Adapting Chicken Swarm Optimization (SCSO) | Clustering Efficiency, Mapping Speed | Efficient task clustering and mapping |
| [31] | Application Mapping | Tabu-Search Based Hybrid Algorithm | Search Efficiency, Mapping Quality | Marked search points for efficient solution space exploration |
| [20] | Application Mapping | Cuckoo Search with Levy Fly | Energy Consumption, Mapping Quality | Reduced energy consumption with improved mapping |
| [32] | Latency Estimation | Neural Network, Transfer Learning | Latency Prediction Accuracy | Accurate latency estimation with transfer learning |
| [21] | Application Mapping | Reinforcement Learning (RL) | Mapping Adaptability, Efficiency | Adaptive mapping with RL models |
| [3] | NoC Mapping | Hybrid PSO and SA (iHPSA) | Energy Efficiency, Communication Bandwidth | Improved energy efficiency with K-means clustering |
| [33] | Multi-Objective Mapping | PSO with Crowding Distance | Mapping Quality, Energy Efficiency | Enhanced multi-objective optimization |
| [34] | Application Mapping | Graph Neural Network (GNN), RL | Decision-Making Efficiency | Improved decision-making with GNN and RL framework |

These approaches can dynamically adapt to varying workloads and system states, offering robust and scalable solutions. (iii) Combining different optimization techniques has also proven beneficial. For instance, the integration of GA with other methods, such as Simulated Annealing (SA) or Differential Evolution (DE), has shown promising results in improving the efficiency of application mapping [3]. (iv) Approaches focusing on energy efficiency and contention reduction are critical for IoT applications, where power consumption and real-time performance are paramount [31]. Table 1 lists the prior studies, and Table 2 lists the compression between this study's MCDM approach and the proposed approaches in the literature on the NoC-based MPSoC domain.

**Table 2:** Comparison of previous studies with the proposed study

| Aspect | Existing Studies | My Study |
|---|---|---|
| **Focus** | Various optimization techniques for application mapping | MCDM approach for strategy selection |
| **Optimization Techniques** | Metaheuristics, Machine Learning, Hybrid Strategies | Integration of MCDM with existing mapping strategies. |
| **Key Metrics** | Energy consumption, latency, communication costs | Comprehensive criteria including performance, energy, and latency. |
| **Scalability** | Addressed through heuristic and metaheuristic approaches | Enhanced through MCDM framework. |
| **Adaptability** | Dynamic mapping using RL and adaptive algorithms | Flexible selection of mapping strategies based on multiple criteria. |
| **Efficiency** | Improved through specialized algorithms like GA, PSO, etc. | Further enhanced by combining MCDM with these algorithms. |
| **Innovation** | Focused on specific optimization goals | Holistic approach integrating multiple criteria for strategy selection. |

Although these contributions are valuable, there remains a significant research gap, that there is no existing study has proposed an MCDM approach to systematically evaluate, rank, and select the most efficient mapping strategy among a set for alternatives multiple conflicting performance metrics. This gap is critical, as definers often face competing objectives (e.g., energy vs. latency), and need intertribal, justifiable to select the best strategy for a given context.

The proposed MCDM approach aims to provide a holistic solution for the efficient selection of application mapping strategies in NoC-based MPSoCs, particularly for IoT applications. By integrating multiple criteria into the decision-making process, the approach seeks to enhance overall system performance, energy efficiency, and adaptability, addressing the limitations of existing methodologies. The premiers and definition related to NoC-based MPSoC are detailed in Section 3.

In this section, this study provides an overview of key concepts and terminologies essential for understanding the subsequent discussions on application mapping strategies and performance comparisons for NoC-based MPSoCs. We begin with an introduction to NoC-based MPSoCs, followed by a discussion on various application mapping strategies. Next, we explain the criteria used for the performance comparison of these strategies. Moreover, these foundations support the development of MCDM for evaluating and electing the most efficient mapping strategies. Finally, this study highlights the necessity of an MCDM approach in optimizing application mapping for IoT environments [35, 26, 37].

### 2.1. NoC applications and performance

In NoC -based MPSoC, an application can be represented in the form of a core graph [38], defined as follows:

**Definition 1.** *The communication graph for an application is a directed graph that defines the interaction of different cores in terms of communication. Every node in this graph represents a core in the network, and the arrows connecting them illustrate the communication channels. Their cost depicts the bandwidth allowance [39, 40].*

- *Graph Representation:* $G(V, E)$
- *Vertices:* $v_i \in V$ *for each core*
- *Edges:* $e_{i,j} \in E$ *for communication between core* $v_i$ *and* $v_j$
- *Edge Weight:* $bw_{i,j}$ *for bandwidth requirements from* $v_i$ *to* $v_j$.

**Definition 2.** *The NoC topology graph is also a directed graph that we are going to create for mapping the topology of the network. Each vertex of this graph represents a node of the network while the edge represents direct communication. The edge weight symbolizes the amount of bandwidth available on such links. A mapping function determines how each core from the 'core graph' relates to a certain node in the above-described 'topology graph'; further to this, the number of the cores shall not be more than the number of nodes* [41].

- *Graph Representation:* $T(N, L)$
- *Vertices:* $n_i \in N$ *for each node in the topology*
- *Edges:* $l_{i,j} \in L$ *for direct communication between node* $n_i$ *and* $n_j$
- *Edge Weight:* $cap_{i,j}$ *for bandwidth capacity of the link* $l_{i,j}$
- *Mapping Function: assign:* $V \rightarrow N$, *where* $assign\ (v_i) = n_j$
  - *Commodity Flow:* $d_k$ *with* $k = 1,2, \ldots, |E|$, *where* $d_k$ *corresponds to* $bw_{i,j}$
  - *Conditions:* $|V| \leq |N|$ *for mapping to be defined.*

The value of a commodity $d_k$, corresponding to the communication between cores $v_i$ and $v_j$, is equal to $bw_{i,j}$, the bandwidth requirement. If $v_i$ is mapped to the router assign $(v_i)$ and $v_j$ is mapped to assign $(v_j)$, the set of all commodities $D = \{d_k\}$ is defined as follows Eq (1) and Eq (2):

$$D = \left\{d_k \mid value\ (d_k) = bw_{i,j}, for\ k = 1,2, \ldots, |E|\ and\ e_{i,j} \in E\right\} \tag{1}$$

Also,

$$src\ (d_k) = assign\ (v_i)\ and\ dst\ (d_k) = assign\ (v_j) \tag{2}$$

The link between two individual routers $n_i$ and $n_j$ of the topology has a maximum bandwidth of $cap_{i,j}$. The total commodity flowing through such a link should not exceed this bandwidth. The quantity $x_{i,j}^k$ indicating the value of a commodity $d_k$ flowing through the link $(n_i, n_j)$ is given by Eq. (3):

$$\begin{cases} value\ (d_k) & if\ link\ (n_i, n_j) \in Route\ (src\ (d_k), dst\ (d_k)) \\ 0 & otherwise \end{cases} \tag{3}$$

where Route $(a, b)$ defines the definite pattern for passing through the mesh nodes in the topology. That is why satisfaction of the bandwidth limitations of individual links must be provided. In other words, all mapping solutions should be such that the following relation is given by Eq. (4) and Eq. (5).

$$\sum_{k=1}^{|E|} x_{i,j}^{k} \leq cap_{i,j} \text{ , for all } i,j \in \{1,2,\dots,|N|\} \tag{4}$$

If all the bandwidth requisites are met, then the communication cost of a mapping solution is estimated by the following formula;

$$T = \sum_{k=1}^{|E|} value\ (d_k) \cdot hops\ \big(src\ (d_k), dst\ (d_k)\big). \tag{5}$$

In this case, hops refer to the division in the topology nodes. If the shortest path routing is deterministic, then the hops refer to the minimum number of links/intermediate nodes between the constituent nodes. However, the communication cost depends on the given solution for mapping; thus, the mapping problem, in turn, is about minimizing the said cost yet taking into account the required bandwidth required link. The communication cost is discussed to discover its correlation to the performance of the system and the consumed power, as the number of hops has a positive correlation with both. It is the agreed percentage that results from an application mapping activity and is usually quantified against the following indicators. In most cases, the implementation of MPSoCa aimed at different types of benchmarks to justify or prove the efficiency or inefficiency of NoC design speoicnations as depicted in Figure 2 and Table 3, respectively. Existing tools have reported results on three benchmarks: VOPD [42], MPEG-4 [43], and PIP [17].

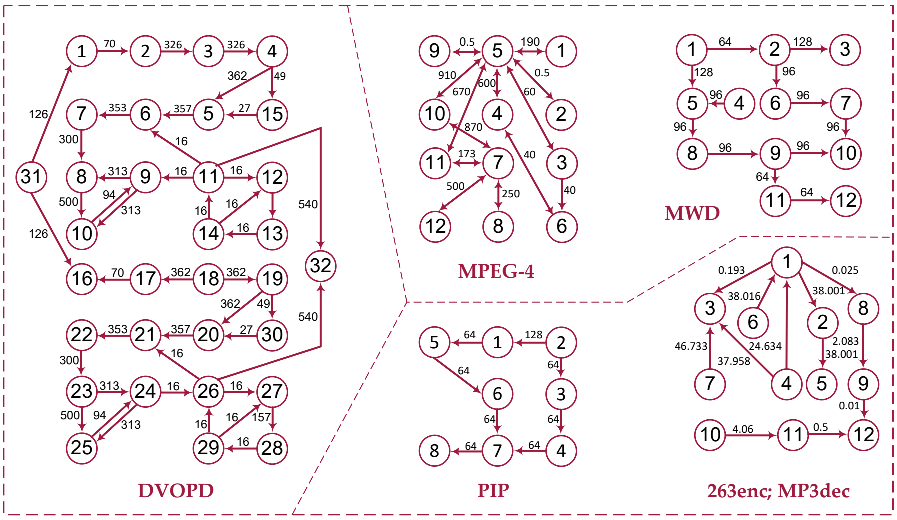


**Figure 2:** Graphs of applications core performance with communication bandwidth (MBps)

**Table 3:** Applications and benchmarks of NoC-based MPSoC

| Label | Explanation |
|---|---|
| **DVDPD** | Displays a hierarchical tree for data flow in DVDPD protocol. Nodes are interconnected, suggesting complex dependencies or sequences of operations. |
| **MPEG-4** | Depicts task mappings for MPEG-4 processing with nodes representing tasks like encoding, decoding, or buffering, focusing on multimedia data handling. |
| **PIP** | Illustrates a smaller, simpler structure, showing the task breakdown for Picture-in-Picture processing where fewer operations are involved. |
| **MWD** | It represents a broad and complex mapping, indicative of tasks in molecular weight distribution analysis in polymers, with various processing stages. |
| **263dec mp3dec** | Represents two separate decoding tasks (H.263 and MP3), with each node representing a stage in the decoding of video and audio streams, respectively. |

### 2.2. Application mapping

Application mapping refers to the process of assigning various tasks of an application to the cores in a NoC-based MPSoC. This process can be represented using Core Graph: Which represents the application, where each vertex signifies a core and each directed edge indicates communication between cores. Topology Graph: This represents the NoC, where each vertex represents a router/node, and each directed edge indicates a direct communication link between routers [21]. Efficient application mapping aims to minimize communication costs, balance load among cores, and optimize overall system performance. Various strategies have been developed to achieve this, including Heuristic Methods: which provide suboptimal solutions quickly but may not be the best in all scenarios. Metaheuristic Methods: Include algorithms like Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Simulated Annealing (SA), which aim to find near-optimal solutions by exploring a large solution space. Exact Methods: such as Integer Linear Programming (ILP), offer optimal solutions but with high computational complexity, making them impractical for large applications [44]. For the Application-Specific NoC Design Flow, this figure illustrates the step-by-step process involved in designing a NoC tailored for a specific application, as shown in Figure 3.

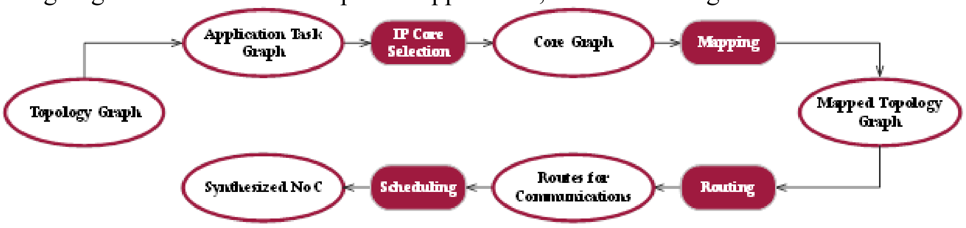


**Figure 3:** Design flow of a specific application for NoC-based MPSoC

The design flow includes the following stages:

- **Application Task Graph:** This represents the tasks and their dependencies within the application.
- **Core Selection:** In this stage, suitable processing cores are selected based on the application's requirements.
- **Core Graph:** The selected cores and their communication requirements are represented in a core graph.
- **Topology Graph:** The NoC's physical structure, including its routers and links, is depicted in the topology graph.
- **Mapping:** The core graph is mapped onto the topology graph, aligning the application's tasks with the NoC's physical nodes.
- **Mapped Topology Graph:** The result of the mapping process, showing the application tasks assigned to specific nodes in the NoC.
- **Routing:** This step determines the routes for communication between the cores in the NoC.
- **Routes for Communication:** Specifies the communication paths for data transfer between cores.
- **Scheduling:** Determines the execution order of tasks to optimize performance and meet timing constraints.

- **Synthesized NoC:** The final implementation of the NoC is ready for use in executing the application.

This flow (in Figure 2) ensures that the NoC is optimized for the specific requirements of the application, balancing performance, energy efficiency, and other critical metrics. Furthermore, Figure 4 categorizes various application mapping algorithms used in NoC-based MPSoCs into two main types: Dynamic Mapping and Static Mapping. Each type is further divided based on the approach used:

(i) **Programming-Based Mapping.** Formal mathematical methods such as ILP and MILP are used to find exact solutions.

(ii) **Branch and Bound (BB).** A methodical search approach to find optimal solutions by systematically exploring branches of possible solutions.

(iii) **Transformative Heuristic.** Methods such as PSO, GA, and ACO iteratively transform solutions to improve them.

(iv) **Constructive Heuristic.** Algorithms that construct a solution directly without iterative refinement, such as BMAP, CMAP, CHMAP, and SMAP.

(v) **Iterative Improvement.** Algorithms that start with an initial solution and iteratively refine it for better performance, such as NMAP, LMAP, SA, and Onyx.

This classification helps in understanding the variety of methods available for application mapping and their respective strengths and weaknesses. It highlights the broad spectrum of approaches, from exact mathematical solutions to heuristic and metaheuristic methods, catering to different levels of complexity and optimization needs.

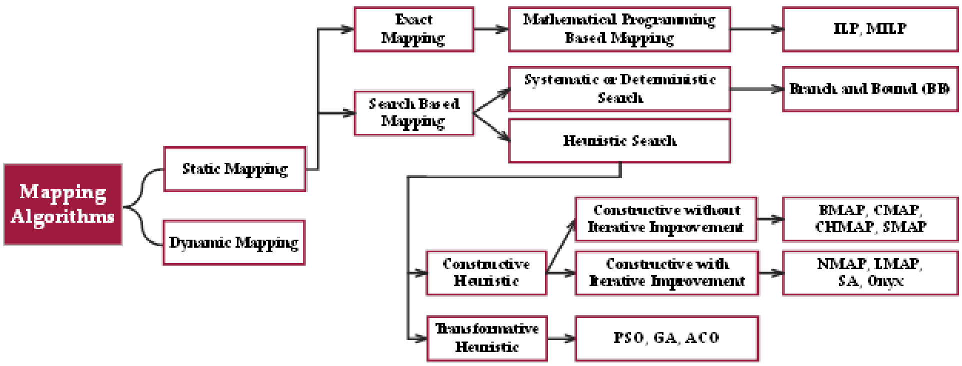


**Figure 4:** Taxonomy of mapping algorithms and approaches in the domain of NoC-based MPSoC

### 2.3. Performance comparison

The quality of an application mapping strategy is evaluated based on several performance metrics, including

- **Communication Cost:** The total cost incurred from the communication between cores, often measured in terms of bandwidth usage and hop count (number of routers a data packet traverses).
- **Energy Consumption.** Both computational and communication energy consumption are considered to ensure energy efficiency, which is crucial for IoT applications.
- **Latency.** The time delay from task initiation to completion impacts real-time application performance. Performance comparison involves running different

mapping algorithms on benchmark applications and evaluating them against these metrics.

For instance, exact methods such as ILP often achieve the best results but are computationally expensive, while heuristic and metaheuristic methods provide good results with less computational overhead [33].

## 3. METHODOLOGY

The methodology (see Figure 5) for this paper is a structured three-phase process for decision-making in the context of NoC-based MPSoCs, described in the 'Methodology' section. The first step, in this case, is to build the Decision Matrix (DM) that arranges and displays data of different mapping approaches and their performance indicators. The second phase deals with the criteria weighting phase, which is based on an enhanced MCDM framework. This framework integrates two robust decision-making techniques: two evaluation methods, namely, the WFJM and the MABAC.

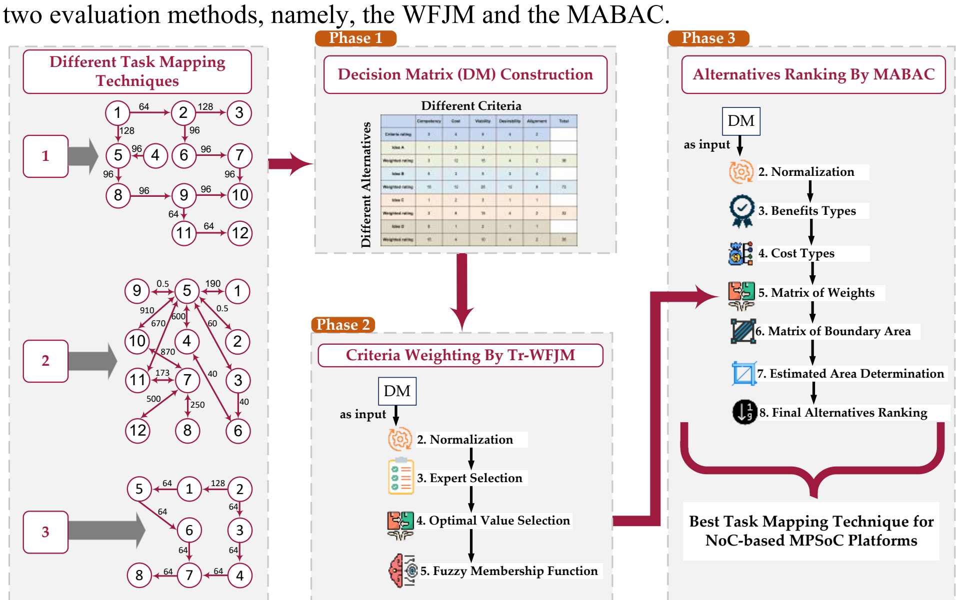


**Figure 5:** Research methodology

These methods are used to impose a systematic process of assessing and comparing different mapping techniques, basing the analysis mainly on noted effective parameters like communication cost and power consumption.

### 3.1. DM Construction

In this section, we explore the construction of the DM (see Table 4), where the intersection of different criteria and alternatives leads to the development of the decision matrix. The following section describes the alternatives and criteria.

### 3.2. DM Criteria

In this section, we will discuss the decision criteria and sub-criteria for the decision matrix created in order to select the most appropriate protocol for comparing the communication costs of VOPD, MPEG-4, and PIP, in relation to the chosen standard, NMAP. This matrix is important for determining the effect of each protocol on the resource utilization of the NoC-based MPSoC at various times.

- **VOPD Absolute Communication Cost (hops x BW):** VOPD Absolute Communication Cost (hops x BW): This quantifies the total reachability cost defined in terms of the quantity of information exchanged through the NoC intermediaries and computed as the product of the number of intermediaries (denoted as H) and the bandwidth (BW). This is an inevitable direct measure of the amount of load in the NoC with the VOPD protocol.
- **VOPD Cost (Normalized) to NMAP:** VOPD Cost (Normalized) to NMAP: This is VOPD denominated in units of ‘standard’ or ‘benchmark’ which is NMAP in this case; the value reflects the cost of communication incurred by the organization. Normalization might be employed with reference to the size of NoC or the topology or any other difference that could make the comparisons direct where they are being made across different networks or over different protocols.
- MPEG-4 Cost (Normalized) to NMAP: MPEG-4 Cost (Normalized) to NMAP: Analogue to the VOPD normalized cost; this is the criterion that measures the communication cost of MPEG-4 normalized to the standard. This is particularly important when wanting to make comparisons about the MPEG-4 efficiency or its load compared to the NMAP.
- **PIP Absolute Communication Cost (hops x BW): PIP Absolute Communication Cost (hops x BW):** Within this criterion, the overall cost of all communication activities in support of the PIP protocol is computed in the same way as with the VOPD absolute cost. It is a direct indicator of the number of resources throughout the NoC that is utilized by PIP.
- **PIP Cost (Normalized) to NMAP: PIP Cost (Normalized) to NMAP:** These measures show how the communication cost for PIP is when it is normalized to that of NMAP. It enables one to determine the performance or congestion degree of PIP’s network as compared to the typical standard NMAP. Average communication cost relative to NMAP: Average communication cost relative to NMAP: These numbers most likely refer to the average of the costs relative to NMAP of the communication costs of all protocols stated here – VOPD, MPEG-4, and PIP. This is used as an assessment of the relative values of each protocol’s communication overhead to a base of reference and offers a complete understanding of the NoC status concerning the various protocols.
- **PIP C3 Cost (Normalized) to NMAP**: a particular cell address of a spreadsheet which may be a formula or a value denoting PIP’s cost when benchmarked. It’s just another specific entry to analyze PIP’s cost effectivity against NMAP, and it could be a specific case or setting in your dataset.

Thus, the provided DM aims at analyzing and ranking the costs of NoC-based MPSoC platform communication application mapping techniques and stratifies absolutely and relatively to a certain standard, specifically NMAP. Normalized costs make it possible to compare these protocols under different network conditions or network settings since such comparison is affected by parameters such as offered load that contorts a direct comparison. This matrix is used to determine which protocol may be more beneficial or has less of a negative on network usage and critical information when designing and managing a network.

### 3.3. DM Alternatives

This section provides information on the decision matrix alternatives, elaborating on the various mapping approaches adopted in NoC-based MPSoCs. They quantify each technique considering optimality in the treatment of some applications such as VOPD, MPEG-4, and PIP.

(i) **Integer Linear Programming (ILP):** Optimization models that are employed are usually to solve the decision Problems where all the variable quantities will comprise integer values. It is very accurate but requires a significant number of calculations, which is recommended for choosing communication links and processors in MPSoCs.

**(ii) Cluster + ILP**: A joins clustering algorithms with ILP to group tasks and data before using ILP optimization. This technique is used to try to simplify the optimization problem by pre-grouping related tasks.

**(iii) Generic Mapping (GMAP):** A generic mapping algorithm of process onto the processor element in NoCs, which reduces the communication cost and load balancing.

**(iv) Partitioned Branch and Bound (PBB):** An optimization algorithm that partitions a problem into two parts one that can be solved effectively and the second for which the end solution is known; the algorithm employs branch and bound techniques, which are used for systematically generating candidate solutions.

**(v) Elixir:** a task mapping approach that works well pertaining to specific features of communication and processing, to be developed by experts not exposed to publicity.

**(vi) Clustered Generic Mapping Algorithm (CGMAP)**: A substitute version of GMAP that clusters a set of tasks together in order to increase GMAP accuracy and decrease communication costs.

**(vii) Greedy Best-fit Mapping Algorithm (GBMAP)**: It employs a greedy method to assign demands to the optimal processor using a best-fit technique; it gets a local optimum that is not always the global optimum.

**(viii) Greedy Adaptive Mapping Routine (GAMR):** A mapping approach that can alter the strategy as the feedback or system status is being received during the execution of a task, which may cause changes to occur to the task placements in order to improve efficiency.

**(ix) Advanced Adaptive Algorithm Mapping using Genetic Algorithms (A3MAP-GA):** Use genetic algorithms that make use of generations to revise solutions in an evolutionary way to discover the best and near-best mappings.

**(x) Particle Swarm Mapping Algorithm (PSMAP):** This relies on the PSO technique, which involves the use of particles, all of which act in a swarm and improve the solution iteratively.

This kind of matrix is an essential instrument for comparing the efficiency of various mapping approaches implemented within NoC-based MPSoCs and analyzing their results in terms of several applications and various measurements of the communication cost. Table 4 shows the decision matrix.

**Table 4:** DM based on different task mapping approaches in the domain of NoC-based MPSoC platforms

| Application Mapping Techniques | | VOPD | | MPEG-4 | | PIP | | Average communication cost relative to NMAP |
|---|---|---|---|---|---|---|---|---|
| | | Absolute Comm. Cost (hops x BW) | Cost (Normalized) to NMAP | Absolute Comm. Cost (hops x BW) | Cost (Normalized) to NMAP | Absolute Comm. Cost (hops x BW) | Cost (Normalized) to NMAP | |
| 1 | ILP [28] | 4119 | 0.966 | 3567 | 0.971 | 704 | 1.1 | 0.972 |
| 2 | Cluster + ILP [45] | 4205 | 0.986 | 3567 | 0.971 | 704 | 1.1 | 0.979 |
| 3 | GMAP [46] | 5553 | 1.302 | 7849 | 2.137 | 704 | 1.1 | 1.513 |
| 4 | PBB [47] | 4317 | 1.012 | 3763 | 1.025 | 704 | 1.1 | 1.012 |
| 5 | Elixir [48] | 4249 | 0.996 | 3640 | 0.991 | 704 | 1.1 | 0.994 |
| 6 | CGMAP [49] | 4300 | 1.008 | 3600 | 0.98 | 704 | 1.1 | 0.994 |
| 7 | GBMAP [50] | 4217 | 0.989 | 3572 | 0.973 | 704 | 1.1 | 0.981 |
| 8 | GAMR [51] | 4217 | 0.989 | 3772 | 1.027 | 704 | 1.1 | 1.027 |
| 9 | A3MAP-GA [52] | 4141 | 0.971 | 3772 | 1.027 | 704 | 1.1 | 0.971 |
| 10 | PSMAP [53] | 4119 | 0.966 | 3567 | 0.971 | 640 | 0.994 | 0.94 |

### 3.4. DM Criteria Weighting

The second phase of the methodology is weighting criteria. WFJM is one of the most recent and highly effective approaches to meeting the weight set by Yousif et al. [54]. The WFJM distinguishes itself from others by reducing the number of comparisons, providing constructive comparisons, eliminating the problem of consistency, and avoiding all forms of ambiguity. The initial application of WFJM was to rank nine assessment criteria of oil and gas companies' [54]. However, the WFJM has a weakness. It should extend to a fuzzy environment to address MCDM problems under conditions of uncertainty [13], [14]. Thus, we expand it to a triangular fuzzy number given the fact that it is capable of capturing uncertainties and imprecision. Using Tr-WFJM for determining the weights for the criteria of mapping strategies. The following are detailed stages of the Tr-WFJM.

- **First Stage: Decision matrix**

In line with other MCDM methods, the input unit consists of sets of options (O1, O2, ……, Om) and sets of decision criteria (C1, C2, ……..Cn). The decision matrix is the cross-product of the alternatives with the criterion.

- **Second Stage: Normalization**

Identity of the benefits and costs criteria based, then, the criteria values are normalized by applying the compromise normalization formula, which is presented in the following Eq. (6) and Eq. (7):

$$c_{ij} = \frac{c_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}; \text{ for benefit criterion} \tag{6}$$

$$c_{ij} = \frac{\max_i x_{ij} - c_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \text{ for cost criterion} \tag{7}$$

- **Third Stage: Expert selection and evaluation form steps**

(i) **Step1:** The process of finding recognized experts in the field of study and identifying their expertise is a systematic process. First of all, the authors have gathered the list of potential participants based on the analysis of academic publications, professional activities, and participation in key industry events. In addition, we sought opinions from other people in the same field to establish who is recognized in the field by others. This way, the selected experts are really the best in their field and are known throughout the academic community.

(ii) **Step2:** The process of selecting a specialist and the first appointment includes a number of important stages to provide a proper approach and minimize the chance of mistakes. The candidate should be someone who has achieve a lot and is an active participant in current research or other professional activities.

**The evaluation form steps**

(i) **Step 1:** Proposal on the creation of an assessment questionnaire for the identification of expert opinion.

(ii) **Step 2:** Confirm that the evaluation form undergoes validity and reliability tests.

- **Fourth Stage: This stage has two steps**

(i) **Step1:** is to seek and choose the optimal value for each criterion. The optimal value is sometimes the maximum value, minimum value, or not minimum and not maximum, such as the blood pressure value in order to choose the optimal value, see Eq. (8).

$$x_i^* = \begin{cases} \max\limits_{x} f_i(x) & \text{If the maximum is the optimal value} \\ \min\limits_{x} f_i(x) & \text{If the minimum is the optimal value} \\ x \text{ between } [\max, min] & \text{If the optimal value is between max and min} \end{cases} \tag{8}$$

Where $x_i^*$ is the optimal value and $f_i(x)$ represent the criterion.

The second step requires comparing the optimal choice with other values. For every criterion, the best option is compared with other possible values for the same criteria. The linguistic words are compared in terms of huge difference, big difference, difference, slight difference, and no difference. Eq. (9) presents the process.

$$judgment\ matrix = \Big\{\Big(\big(\text{optimal V} \otimes v_{ij} \,\big|\, j \in J\big).\ \Big|\, i = 1.2.3.\dots.m\Big)\Big\} \tag{9}$$

where ⊗ reference comparison. The judgment matrix is prepared based on comparing the ideal value with other values belonging to the same criterion. Our method has zero inconsistency because it is formulated based on the judgment matrix and comparison made within each criterion value.

- **Fifth Stage**: **Fuzzy membership function**

The judgment matrix, which is a significant part of the MCDM techniques, can be altered with the help of the fuzzy membership function. This function helps to introduce flexibility and more subtle distinctions since it allows for the use of fuzzy values rather than definite ones. Fuzzy logic helps in the modeling of uncertainty that is normally experienced in decision-making since the values involved are not always certain or precise:

For this reason, triangular fuzzy information is used to develop a fuzzy judgment matrix after subjecting the judgment matrix through the process of fuzzification (see Table 5). Triangular fuzzy sets are described by their membership function.

**Table 5:** Linguistic terms

| Linguistic terms | Fuzzy Likert | | |
|---|---|---|---|
| | l | m | r |
| **No difference** | 0 | 0.1 | 0.3 |
| **Slight difference** | 0.1 | 0.3 | 0.5 |
| **Difference** | 0.3 | 0.5 | 0.75 |
| **Big difference** | 0.5 | 0.75 | 0.9 |
| **Huge difference** | 0.75 | 0.9 | 1 |

The arithmetic operations are well-defined based on the allowance notion in the following Eq. (10).

$$\mu A(x) = \begin{cases} 0 \; if\, x < a \\ \dfrac{x-a}{b-a} \; if\, a \le x \le b \\ \dfrac{c-x}{c-b} \; if\, b \le x \le x \\ 0 \; if\, x > c \end{cases} \quad \text{where } a \le b \le c. \tag{10}$$

- $\grave{x} + \grave{y} = (a_1 + a_2, b_1 + b_2, c_1 + c_2)$,
- $\grave{x} - \grave{y} = (a_1 - c_2, b_1 - b_2, c_1 - a_2)$,
- $\grave{x} \times \grave{y} \cong (a_1 a_2, b_1 b_2, c_1 c_2)$,
- $\grave{x} / \grave{y} \cong (a_1/c_2, b_1/b_2, c_1/a_2)$.

The following procedures are performed in order to obtain the final weight coefficients of the assessment criteria ($w_1, w_2, \ldots, w_n$); see Eq. (11).

$$W = \left( \sum_{i=1}^{m} \frac{\overline{(A_{tj})}}{\sum_{j=1}^{n} (A_{tj})} \right) / m \Big), \text{ for } i = 1,2,3, \ldots m \tag{11}$$

### 3.5. DM Alternatives Ranking

MABAC can be useful in solving intelligent decision-making systems. To address decision-making problems with multiple criteria, the MABAC method is chosen due to its effectiveness in establishing a sound decision-making model. It has been applied in Business and Economics, Engineering, Environmental, Healthcare, and many others [55, 56, 57]. By overcoming these challenges, the researchers will be able to enhance the development of NoC-based MPSoC architecture. It compares the different aspects of several choices with the aim of making the right decision. This section outlines the steps of the MABAC procedure for ranking.

**Stage 1:** Create an initial decision matrix (Y).

$$Y = \begin{matrix} A_1 \\ A_2 \\ \ldots \\ A_m \end{matrix} \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix} \tag{12}$$

Where A refers to alternatives and Y refers to the criteria as in the formula of Eq. (12).

**Stage 2:** Normalizations of the elements of the original matrix is done at this stage using the following equations (13) and (14).

$$M = \begin{matrix} A_1 \\ A_2 \\ \dots \\ A_m \end{matrix} \begin{bmatrix} m_{11} & m_{12} & \dots & m_{1n} \\ m_{21} & m_{22} & \dots & m_{2n} \\ \dots & \dots & \dots & \dots \\ m_{m1} & m_{m2} & \dots & m_{mn} \end{bmatrix} \tag{13}$$

a) Criteria for Benefit Types (a higher criterion value is optimal).

$$m_{ij} = \frac{y_{ij} - y_i^-}{y_i^+ - y_i^-} \tag{14}$$

b) Criteria of the Cost type (a lower criterion value is optimal).

$$m_{ij} = \frac{y_{ij} - y_i^+}{y_i^- - y_i^-} \tag{15}$$

where $y_i^+ = \max(y_1, y_2, \dots, y_m)$ $and$ $y_i^- = \max(y_1, y_2, \dots, y_m)$.

**Stage 3:** Weighted matrix elements are computed. To find the elements of the matrix the following equation is used.

$$v_{\text{ij}} = w_{\text{i}} * (m_{\text{i}j} + w_{\text{i}}) \tag{16}$$

where $n_{\text{i}j}$ are components of the normalised matrix, and $w_{\text{i}}$ is the weight obtained from the FWFJM. The weighted matrix V is found by applying Eq. (16).

**Stage 4:** The fourth stage is to identify the boundary area matrix (G). Relative to this, in order to calculate the estimated boundary area for each criterion, we use the continuity as in Eq. (17).

$$g_i = \left(\prod_{j=1}^{m} v_{ij}\right)^{1/m} \tag{17}$$

Here m is the total number of alternatives and $v_{ij}$ are the elements of weighted matrix.

**Stage 5:** determine the estimated area of the border based on the distances of the components of the alternate matrices from the border (Q) by applying Eq 18.

$$\text{Q} = \text{V} - \text{G} \tag{18}$$

Alternative Ai could be classified in the border approximation area. Upper approximation area (G+) or lower approximation area (G-). G+ is the area that encompasses the ideal alternative (A+), while G- is the area that embraces the anti-ideal alternative (A-).

**Stage 6:** Evaluation and ordering of the current alternatives. Final values of alternative criterion functions are calculated by adding together rows of the matrix Q:

$$S_i = \sum_{j=1}^{n} q_{ij},\ j = 1,2,\dots,n,\ i = 1,2,\dots,m \tag{19}$$

## 4. RESULTS AND DISCUSSION

In this section, the findings of the study on the application of mapping strategies with the aim of enhancing the performance in the case of NoC-based MPSoC with regard to the weighting and ranking of results are discussed. This part is further divided into two categories. The section named “Criteria Weighting Results” describes the results of the Tr-FWFJM in the aspect of criteria weighting. Moreover, the “Ranking Results” section shows the ranking of application mapping strategies by using MABAC.

### 4.1. Weighting Result Discussion

The Tr-FWFJM helps to speed up the process of selecting the most appropriate weights for each of the evaluation criteria. All the phases of the Tr-FWFJM method were properly carried out in order to determine the weights of the application mapping strategies. This method does not necessitate a group of experts but can be used with the view of one expert providing the opinion. First of all, judgment responses for all criteria are gathered from an expert in the field of MPSoC work. This expert was selected with much care, given the fact that has working experience in this field. He/she was requested to rate the seven criteria on the basis of his judgment with the help of a five-point Likert scale, as presented in Table 6.

**Table 6:** Criteria weighting results.

| VOPD Absolute Comm. Cost (hops x BW) criteria 1 | VOPD Cost (Normalized) to NMAP criteria 2 | PIP C3:I10Cost (Normalized) to NMAP criteria 3 | MPEG-4 Cost (Normalized) to NMAP criteria 4 | PIP Absolute Comm. Cost Cost (hops x BW) criteria 5 | PIP Cost (Normalized) to NMAP criteria 6 | Average communication cost relative to NMAP riteria 7 |
|---|---|---|---|---|---|---|
| 0.1242 | 0.1362 | 0.1026 | 0.0887 | 0.2110 | 0.2326 | 0.1046 |

When considering the rating of the criteria based on the given values, it is possible to note that Criteria 5 and 6 are most important, having the values of 0. 2110 and 0. 2326, respectively. These values are substantially higher than the others, and this reveals their significance or perhaps their ranking in the decision-making process. The rationale for this ranking may be that some of these criteria may be considered as having higher priority than others due to their influence on the goals and outcomes. Criteria 1, 3, 4, and 7, with the values of 0.1242, 0.1026, 0. 0887, and 0.1045, seem to have a weaker impact than the previous ones. This does not mean that these criteria are unimportant or irrelevant at all, but they have a less or relatively minor bearing in this particular case. They may describe elements that are either less important in relation to the primary goals or have a lesser impact on the decision or the project as a whole.

Based on the above analysis, my suggestion would be to concentrate on the enhancement of Criteria 5 and 6 since a higher level of improvement in these areas will result in maximum gain. However, it is also important to set the minimum threshold of the other criteria to prevent neglecting the other aspects that may be equally important for obtaining the intended results. This strategy enables one to make the necessary adjustments in the right areas while not forgetting the general impact that may not affect the critical areas due to the neglect of other areas.

### 4.2. Ranking Result Discussion

MABAC is applied to rank the mapping strategies in this study. This section presents the results and discusses the findings of the study on MABAC. The evaluated values are presented in Table 7, which shows the scour of the aggregated assessment, calculated with the use of Eqs. (12)-(19).

This ranking table is particularly useful in identifying ranks and scores of the various options that are being compared with the view of identifying which is the best among the lot. ILP, thus occupying the first place with a score of 0. This means that ILP based on integer linear programming is highly effective in providing accurate and efficient solutions, and this is particularly relevant in the areas that demand proper mathematical optimization. To rank first, ILP not only has to perform the same as the other alternatives but probably does so even better; thus, it can be recommended for use in conditions where accuracy and the speed of calculations are the main concerns.

**Table 7:** Alternatives ranking results

| Alternatives | Score | Final rank |
|---|---|---|
| ILP | 0.0441 | 1 |
| Cluster + ILP | 0.0434 | 3 |
| GMAP | -0.0566 | 10 |
| PBB | 0.0377 | 7 |
| Elixir | 0.0407 | 6 |
| CGMAP | 0.0413 | 5 |
| GBMAP | 0.0433 | 4 |
| GAMR | 0.0342 | 8 |
| A3MAP-GA | 0.0437 | 2 |
| PSMAP | 0.0283 | 9 |

On the other hand, for options like GMAP, which is the least, with a score of -0.0566, critical aspects of the evaluated criteria can be described as impaired or ineffective. This result is negative for GMAP, which means that it does not accomplish the expected performance criteria. This underlines the fact that there is a need to take a lot of caution and refrain from coming up with solutions that may have negative impacts or, in one way or another, affect the objectives of the project. As such, in view of the above rankings, my recommendation is to build upon the positives of the highest-ranked options and manage the risks of the least favored ones. ILP's highest rank means that it should be used first and foremost in situations when the solution needs to be as accurate as possible, for example, in logistics planning, resource management, or scheduling. This reliability means that the ends are very likely to be achieved with the means efficiently. Likewise, A3MAP-GA, placed the second with a score of 0.0437. The adaptive mapping approach that is used together with the genetic algorithms makes it a very viable option. This approach is most effective in applications where change is constant and where there is a need to be as fluid and changing as the environment.

For the other alternatives that rank lower, for instance, GMAP and PSMAP, there is a need to conduct a critical analysis and possibly reform or even discard them. It may entail more work to repair comprehensible gaps that might have been observed or a combination of the most effective strategies that were unveiled in the assessment with a view to avoiding the weaknesses that were evident in other methods. In conclusion, it is possible to state that the ranking table is not only helpful in identifying the comparative effectiveness of the methodologies but also beneficial for strategic planning of resource distribution in favour of the most promising approaches. Thus, the proposed top-ranked alternatives, such as ILP and A3MAP-GA, may help organizations improve their operational performance, increase the effectiveness of resource usage, and attain better results supportive of strategic goals.

### 4.3. Validation Result Discussion

The sensitivity analysis revealed how adjusting the relative importance of different criteria would affect the systematic ranking of application mapping strategies [58, 59]. Before conducting a sensitivity analysis, it is crucial to determine which criteria are most important. Table 5 shows that, out of the total of 7 criteria, PIP Cost (Normalized) to NMAP was the most important (0.2326). Using Eq. 15, we developed 10 scenarios to analyse the impact of varying criterion weights. Figure 6 depicts 10 potential results based on the 0.3 rise and the 7 criteria utilized. The relative importance of each criterion was calculated using the following formula.

$$w_{n\beta} = (1 - w_{n\alpha})\frac{w_\beta}{(1-w_n)} \quad (20)$$

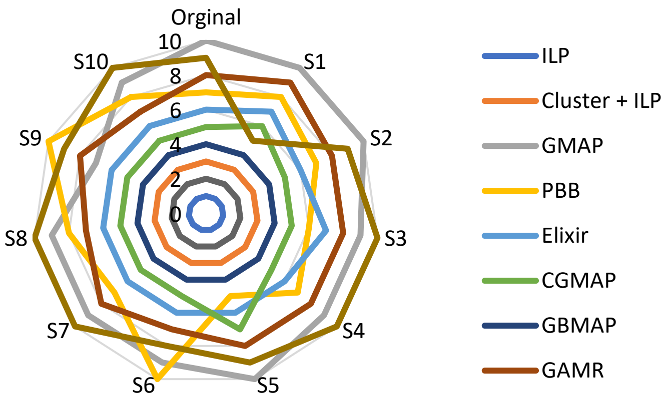


**Figure 6:** Sensitivity analysis

Figure 6 shows the comparison of different algorithms (ILP, Cluster + ILP, GMAP, PBB, Elixir, CGMAP, GBMAP, GAMR, A3MAP-GA, PSMAP) for each of the 10 scenarios (S1 to S10) and the original ranking. It was observed that ILP had outperformed all other approaches and remained at the first position in all cases. Cluster + ILP also had a fairly constant third place all through the trials. GMAP remained at the tenth rank in all the cases except in the scenarios S4, S5, S7, and S9 where it had slightly climbed up to the ninth and seventh ranks. PBB ranked from 7th to 10th depending on the scenarios; PBB got as high as 5th place in season 5 and as low as 10th in season 6 and season 9. Elixir remained sixth in all the cases except two scenarios. CGMAP remained mostly stable and fluctuated at the fifth position, except for S6, which was shifted to the seventh position. GBMAP remained in the fourth position as well. GAMR ranked slightly differently in each scenario; however, it remained near the eighth position. PSMAP ranked from fifth to tenth place, which points to its unstable position in the course of the scenarios. All the algorithms used in the comparison were evaluated based on the 7 criteria.

At the final stage of the evaluation, we used the Spearman correlation coefficient (SCC) to investigate the correlations of ten different options. Spearman's rank is a measure used in statistics to establish the extent of correlation between two variables and their direction based on the ranked data.

The results of the correlation analysis are presented in Figure 7, which points to the key implications for the overall relations between the ten scenarios. The lowest correlation value was 87%, and this indicates the strength and sobriety of the methods used for weights and ranking.

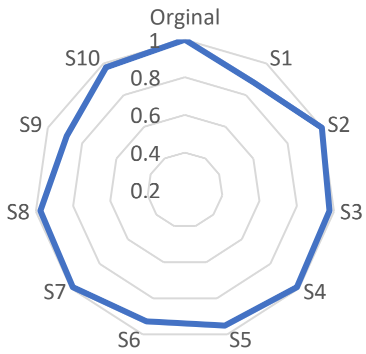


**Figure 7:** Correlation coefficient

## 5. PRACTICAL IMPLICATIONS

The findings of the research on the application mapping strategies for NoC-based MPSoC are as follows: It offers important implications for NoC designers, system architects, software developers, and policymakers. The results presented are valuable for enhancing performance, decreasing energy consumption, and increasing efficiency in NoC-based MPSoC systems. In terms of mapping strategies, NoC designers were found to obtain ILP as the best solution following the investigations carried out with the help of the MABAC approach. Analyzing the outcome of the Weights of Tr-WFJM, PIP Cost was ranked as the highest importance. From the analysis, it can be recommended that ILP should be taken as the leading mapping technique for designers because its approach and focus are more efficient than the others concerned with strategies that make PIP expenses in order to improve system efficiency. Implementation of the proposed guidelines will help increase the performance of systems and decrease their energy utilization, which is highly beneficial for developing power-aware NoC architectures.

Analyzing the weights of the evaluation criteria presented by Tr-WFJM, system architects can emphasize the prioritization of cost-related factors in mapping strategies. Thus, MPEG-4 Cost was identified to have the least importance weight, which implies that its impact is minimal during the decision-making stage. Cost-effective solutions like integration of ILP in the design of Systems should also be incorporated to minimize the use of resources while maximizing the functions of such Systems. When integrated with Tr-WFJM weightings, the goal allocation during the design phase will allow for better resource utilization, thus extending the scalability and containing costs towards lower rates to optimize resource management and perform the system under different load capacities. Mapping plays a crucial role in SDN where a delay in mapping strategy brought serious consequences such as high communication latency and power consumption in software developers. In this context, the proposed MCDM method of the study is a sound approach for assessing and ranking suitable strategies. It also means that the developers should correlate resources such as the timetable and the optimization procedures with the selected mapping strategies, especially with ILP, and integrate tools that can implement instant changes based on real-time assessments. These measures will enhance the rate at which software is able to complete its tasks and also eliminate points where communication becomes a problem, thus enhancing the throughput and performance of the system.

For policymakers, the perceived attributes indicate that the governmental policy focusing on cost efficiencies has a large impact on realizing sustainable NoC designs. Policymakers in charge of such decisions should ensure the formulation of policies that encourage the applicability of efficiency criteria in mapping endeavors and facilitate continued research through the development of enhanced best MCDM approaches for the evaluation and selection of efficient mapping strategies. Implementing these actions will strengthen NoC technology regulatory and compliance and increase its sustainability and efficiency. The realistic approaches that can be formulated and applied based on the results of this work will help the stakeholders receive actual advances in NoC-based MPSoC design and functionality. The detailed resources of MCDM methods, including Tr-WFJM and MABAC, would help the stakeholders make thorough decision-making of the application mapping strategies and reach the goal of minimizing the usage of resources and energy. Thus, these advancements would lead to improvement in the efficiency, reliability, and scalability of NoC systems, hence helping the generic field of embedded system design.

## 6. COMPARATIVE ANALYSIS

This section intends to put into comparison many of the traditional MCDM methods which operate within the framework of the triangular fuzzy set. As Tr-WFJM has been selected rather than other MCDM methods in this study, the comparison proves the efficiency of Tr-WFJM. Firstly, the BWM is one of the most versatile and widely applied MCDM methods in many fields [60, 61, 62]. Moreover, it occupies one of the first places in the list of MCDM methods. Although the BWM in its pure form is susceptible to vagueness, it has been enhanced, and the same triangular fuzzy set used in Tr-WFJM is used in the FBWM [64, 65]. The points of comparisons listed in Table 8.

**Table 8:** The comparison points

| | Comparison Points | | Present study | The study of [63] |
|---|---|---|---|---|
| Application Based comparison | Multiple attributes | | √ | √ |
| | The importance level | | √ | √ |
| | The data variations | | √ | √ |
| | Weighting method | Zero Inconsistency | √ | × |
| | | Nature of comparisons | √ | × |
| | | pairwise comparisons | √ | × |
| | | Vague and ambiguity | √ | √ |
| | | An ideal solution and distance measurement | √ | × |
| | | Apply fuzzy set | √ | √ |
| | Ranking method | The ranking method might calculate weighting | × | × |
| | | The matter vagueness in ranking was answered | × | √ |
| | | Normalization | √ | √ |
| | | Calculate the three judgment scores | √ | × |
| | Total score | | 11/13 | 7/13 |

The points that are discussed based comparison are 13 points as depicted in Table 8. The study by [43] and current study have been able to answer all the three questions (100%) in the application-based comparison. In contrast, the study of [60] selected only 4 out of the 10 factors for comparison of weighting and ranking methods, which is 40% while current study has encompassed 8 factors that is 80%.

In general, the research by [60] achieved only 53%. Only 7 of the criteria out of the 13 points were met in this research while the current study met 84%. Only 11 points out of the 13 points were met. It has been seen from the results that this research has developed an effective way of comparing and contrasting application mapping strategies so as to choose the right one.

## 6. CONCLUSION, LIMITATION, AND FUTURE DIRECTION

The mapping strategies in the NoC-based MPSoC are paramount in ensuring that there is proper communication with the least energy consumption. Hence, identifying the best mapping strategies is reasonable as it would ensure the system's optimal performance. The previous researchers suggested that the use of Fuzzy MCDM is best suited to help solve the problem of finding the best mapping strategy for identity. The approach of this study entails two phases. The first phase involves the generation of an evaluation decision matrix, which is obtained through the cross of the evaluation criteria and mapping strategies list. The second phase is the proposed MCDM techniques, where Tr-WFJM is used to determine the weights of the criteria of mapping strategies, and MABAC is used to rank the mapping strategies with the assigned weight. Tr-WFJM results indicated that the PIP Cost has the greatest final weight of 0. 2326 while the MPEG-4 Cost has the smallest weight of 0. 0887, respectively. Regarding the proposed MABAC method, the ILP is the most efficient mapping strategy. Ranking results reveal that the ILP method has the best performance and energy efficiency for mapping in NoC-based MPSoCs and guides the designer to map with this method more strongly. These two characteristics make it likely that the previously identified strategic preferences will lead to changes in the design, be it the layout of the chip or the choice of the processing units that improve the functionality of the system. Moreover, the ideas derived from the Tr-WFJM method, which underscores such criteria as the PIP Cost, will increase the resource-oriented approach among decision-makers by focusing on cost optimization while achieving the highest results. There are suggestions that as designers keep on benchmarking and optimizing against these results, MPSoC designs are expected to progress, especially in line with the best practices and in the development of the newest technology. While this work presents obvious advantages, this work has a few shortcomings. It does not consider the relative contribution or weight of each expert in their provision of knowledge or their opinion, which might affect the final weight of the criteria, and the alternative settled on. The exploration of other MCDM methods and weightings of some criteria can also give important insights into the usefulness and efficiency of various approaches. Possible future work on NoC-based MPSoC design includes improving the ILP algorithms and energy consumption under different loads. Also, it is possible to prioritize and weigh experts depending on the level of expertise. In addition, more fuzzy sets, such as Pythagorean, Rough number, Z number, and others, can be integrated with the WFJM to decrease uncertainty. Moreover, other MCDM methods may be integrated with WFJM. Finally, a Likert scale of 7, 9, or 11 could be employed.

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## REFERENCES

[1] G. Gonzalez-Martinez et al., "A Survey of MPSoC Management toward Self-Awareness," *Micromachines*, vol. 15, no. 5, p. 577, 2024.
[2] W. Amin, F. Hussain, S. Anjum, S. Saleem, W. Ahmad, and M. Hussain, "HyDra: Hybrid Task Mapping Application Framework for NOC-based MPSoCs," *IEEE Access*, 2023.
[3] W. Amin et al., "Performance evaluation of application mapping approaches for network-on-chip designs," *IEEE Access*, vol. 8, pp. 63607–63631, 2020.
[4] J. B. de Barros, R. C. Sampaio, and C. H. Llanos, "An adaptive discrete particle swarm optimization for mapping real-time applications onto network-on-a-chip based MPSoCs," in *Proceedings of the 32nd Symposium on Integrated Circuits and Systems Design*, 2019, pp. 1–6.
[5] W. Amin, F. Hussain, and S. Anjum, "iHPSA: An improved bio-inspired hybrid optimization algorithm for task mapping in Network on Chip," *Microprocessors and Microsystems*, vol. 90, p. 104493, 2022.
[6] A. Bose and P. Ghosal, "The CTH Network: An NoC Platform for Scalable and Energy Efficient Application Mapping Solution," *IEEE Transactions on Nanotechnology*, vol. 22, pp. 58–69, 2023.
[7] R. S. R. Raj, A. Joseph, and S. Kalady, "SpecMap: An efficient spectral partitioning based static application mapping algorithm for 2D mesh NoCs," *Concurrency and Computation: Practice and Experience*, vol. 35, no. 26, p. e7838, 2023.
[8] S. P. Kaur, M. Ghose, A. Pathak, and R. Patole, "A survey on mapping and scheduling techniques for 3D Network-on-chip," *Journal of Systems Architecture*, p. 103064, 2024.
[9] X. Weng et al., "A Machine Learning Mapping Algorithm for NoC Optimization," *Symmetry*, vol. 15, no. 3, p. 593, 2023.
[10] J. Fang, H. Cai, and X. Lv, "Hybrid optimization algorithm based on double particle swarm in 3D NoC mapping," *Micromachines*, vol. 14, no. 3, p. 628, 2023.
[11] Ž. Stević, M. Baydaş, M. Kavacık, E. Ayhan, and D. Marinković, "Selection of data conversion technique via sensitivity-performance matching: ranking of small e-vans with probid method," *Facta Universitatis, Series: Mechanical Engineering*, pp. 643–671, 2024.
[12] X. Chen, B. Zhou, A. Štilić, Ž. Stević, and A. Puška, "A fuzzy–rough MCDM approach for selecting green suppliers in the furniture manufacturing industry: a case study of eco-friendly material production," *Sustainability*, vol. 15, no. 13, p. 10745, 2023.
[13] A. H. Alamoodi et al., "Based on neutrosophic fuzzy environment: a new development of FWZIC and FDOSM for benchmarking smart e-tourism applications," *Complex & Intelligent Systems*, 2022, doi: 10.1007/s40747-022-00689-7.
[14] A. S. Albahri et al., "Integration of fuzzy-weighted zero-inconsistency and fuzzy decision by opinion score methods under a q-rung orthopair environment: A distribution case study of COVID-19 vaccine doses," *Computer Standards & Interfaces*, vol. 80, p. 103572, 2022, doi: 10.1016/j.csi.2021.103572.
[15] D. Božanić, I. Epler, A. Puška, S. Biswas, D. Marinković, and S. Koprivica, "Application of the DIBR II–rough MABAC decision-making model for ranking methods and techniques of lean organization systems management in the process of technical maintenance," *Facta Universitatis, Series: Mechanical Engineering*, vol. 22, no. 1, pp. 101–123, 2024.
[16] B. Guo, H. Liu, and L. Niu, "Network-on-Chip (NoC) applications for iot-enabled chip systems: latest designs and modern applications," *International Journal of High Speed Electronics and Systems*, vol. 34, no. 03, p. 2540027, 2025.

[17] S. Saleem, F. Hussain, and N. K. Baloch, "IWO-IGA—A Hybrid Whale Optimization Algorithm Featuring Improved Genetic Characteristics for Mapping Real-Time Applications onto 2D Network on Chip," *Algorithms*, vol. 17, no. 3, p. 115, 2024.

[18] X. Wang, Y. Sun, H. Gu, and Z. Liu, "WOAGA: A new metaheuristic mapping algorithm for large-scale mesh-based NoC," *IEICE Electronics Express*, vol. 15, no. 17, p. 20180738, 2018.

[19] A. Alagarsamy, L. Gopalakrishnan, S. Mahilmaran, and S.-B. Ko, "A self-adaptive mapping approach for network on chip with low power consumption," *IEEE Access*, vol. 7, pp. 84066–84081, 2019.

[20] M. J. Mohiz, N. K. Baloch, F. Hussain, S. Saleem, Y. Bin Zikria, and H. Yu, "Application mapping using cuckoo search optimization with Lévy flight for NoC-based system," *IEEE Access*, vol. 9, pp. 141778–141789, 2021.

[21] R. Sambangi, A. S. Pandey, K. Manna, S. Mahapatra, and S. Chattopadhyay, "Application Mapping Onto Manycore Processor Architectures Using Active Search Framework," *IEEE Transactions on Very Large Scale Integration (VLSI) Systems*, 2023.

[22] R. B. Tonetto, M. G. de A. Hiago, G. L. Nazar, and A. C. S. Beck, "A machine learning approach for reliability-aware application mapping for heterogeneous multicores," in *57th ACM/IEEE Design Automation Conference (DAC)*, 2020, pp. 1–6.

[23] S. G. Khawaja, M. U. Akram, S. A. Khan, A. Shaukat, and S. Rehman, "Network-on-Chip based MPSoC architecture for k-mean clustering algorithm," *Microprocessors and Microsystems*, vol. 46, pp. 1–10, 2016.

[24] I. I. Weber, V. B. Zanini, and F. G. Moraes, "Reinforcement learning for thermal and reliability management in manycore systems," *Design Automation for Embedded Systems,* vol. 29, no. 1, pp. 1–34, 2025.

[25] F. Niknia, V. Hakami, and K. Rezaee, "An SMDP-based approach to thermal-aware task scheduling in NoC-based MPSoC platforms," *Journal of Parallel and Distributed Computing*, vol. 165, pp. 79–106, 2022, doi: 10.1016/j.jpdc.2022.03.016.

[26] N. Kadri, A. Chenine, Z. Laib, and M. Koudil, "Reliability-aware intelligent mapping based on reinforcement learning for networks-on-chips," *Journal of Supercomputing*, vol. 78, no. 16, pp. 18153–18188, 2022.

[27] X. Wang, Y. Sun, and H. Gu, "BMM: A binary metaheuristic mapping algorithm for mesh-based network-on-chip," *IEICE TRANSACTIONS on Information and Systems*, vol. 102, no. 3, pp. 628–631, 2019.

[28] S. Tosun, O. Ozturk, and M. Ozen, "An ILP formulation for application mapping onto network-on-chips," in *International conference on application of information and communication technologies*, 2009, pp. 1–5.

[29] F. Moein-Darbari, A. Khademzade, and G. Gharooni-Fard, "Cgmap: a new approach to network-on-chip mapping problem," *IEICE Electronics Express*, vol. 6, no. 1, pp. 27–34, 2009.

[30] P. K. Sahu, A. Sharma, and S. Chattopadhyay, "Application mapping onto mesh-of-tree based network-on-chip using discrete particle swarm optimization," in *International Symposium on Electronic System Design (ISED)*, 2012, pp. 172–176.

[31] M. Obaidullah and G. N. Khan, "Application mapping to mesh NoCs using a tabu-search based swarm optimization," *Microprocessors and Microsystems*, vol. 55, pp. 13–25, 2017.

[32] Y. Li and P. Zhou, "Fast and accurate NoC latency estimation for application-specific traffics via machine learning," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 70, no. 9, pp. 3569–3573, 2023.

[33] M. Darbandi, A. R. Ramtin, and O. K. Sharafi, "Tasks mapping in the network on a chip using an improved optimization algorithm," *International Journal of Pervasive Computing and Communications*, vol. 16, no. 2, pp. 165–182, 2020.

[34] J. Choudhary, C. S. Sudarsan, and J. Soumya, "A performance-centric ML-based multi-application mapping technique for regular Network-on-Chip," *Memories-Materials, Devices, Circuits and Systems,* vol. 4, p. 100059, 2023.

[35] A. A. J. Al-Hchaimi et al., "Prioritizing Network-On-Chip Routers for Countermeasure Techniques against Flooding Denial-of-Service Attacks: A Fuzzy Multi-Criteria Decision-

Making Approach," *Computer Modeling in Engineering & Sciences* , vol. 142, no. 3. 2025. doi: 10.32604/cmes.2025.061318.

[36] A. A. J. Al-Hchaimi, A. H. M. Alaidi, Y. R. Muhsen, M. F. Alomari, N. Bin Sulaiman, and M. U. Romdhini, "Optimizing Energy and QoS in VANETs through Approximate Computation on Heterogeneous MPSoC," in *4th International Conference on Emerging Smart Technologies and Applications (eSmarTA)*, 2024, pp. 1–6.

[37] D. Grover, T. Sharma, S. Agarwal, S. S. Rout, M. Kumar, and S. Deb, "NoCiPUF: NoC-Based Intrinsic PUF for MPSoC Authentication," *IEEE Transactions on Circuits and Systems I: Regular Papers*, 2025.

[38] T. Nagalaxmi, E. S. Rao, and P. Chandrasekhar, "Design and Performance Analysis of Low Latency Routing Algorithm based NoC for MPSoC," *International Journal of Communication Networks and Information Security*, vol. 14, no. 1s, pp. 37–53, 2022.

[39] R. Pop and S. Kumar, "A survey of techniques for mapping and scheduling applications to network on chip systems," *School of Engineering, Jonkoping University, Research Report*, vol. 4, no. 4, 2004.

[40] R. Dafali and J.-P. Diguet, "MPSoC architecture-aware automatic NoC topology design," in *Network and Parallel Computing: IFIP International Conference, NPC* 2010, Zhengzhou, China, September 13-15, 2010. Proceedings, 2010, pp. 470–480.

[41] P. Narayanasamy and S. Gopalakrishnan, "Novel fault tolerance topology using corvus seek algorithm for application specific NoC," *Integration*, vol. 89, pp. 146–154, 2023.

[42] Z. Li et al., "Hotspots reduction for GALS NoC using a low-latency multistage packet reordering approach," *Micromachines*, vol. 14, no. 2, p. 444, 2023.

[43] S. Ramesh, K. Manna, V. C. Gogineni, S. Chattopadhyay, and S. Mahapatra, "Congestion-Aware Vertical Link Placement and Application Mapping Onto Three-Dimensional Network-On-Chip Architectures," *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems.*, 2024.

[44] J. Soumya and S. Chattopadhyay, "Application-specific network-on-chip synthesis with flexible router placement," *Journal of Systems Architecture.*, vol. 59, no. 7, pp. 361–371, 2013.

[45] S. Tosun, "Cluster-based application mapping method for network-on-chip," *Advances in Engineering Software*, vol. 42, no. 10, pp. 868–874, 2011.

[46] J. Hu and R. Marculescu, "Energy-aware mapping for tile-based NoC architectures under performance constraints," in *Proceedings of the 2003 Asia and South Pacific Design Automation Conference*, vol. 2003-Janua, pp. 233–239, 2003, doi: 10.1109/ASPDAC.2003.1195022.

[47] J. Hu and R. Marculescu, "Energy-and performance-aware mapping for regular NoC architectures," *IEEE Transactions on computer-aided design of integrated circuits and systems*, vol. 24, no. 4, pp. 551–562, 2005.

[48] M. Reshadi, A. Khademzadeh, and A. Reza, "Elixir: a new bandwidth-constrained mapping for networks-on-chip," *IEICE Electronics Express*, vol. 7, no. 2, pp. 73–79, 2010.

[49] F. Moein-darbari, A. Khademzadeh, and G. Gharooni-fard, "Evaluating the performance of a chaos genetic algorithm for solving the network on chip mapping problem," in *International Conference on Computational Science and Engineering*, 2009, vol. 2, pp. 366–373.

[50] M. Tavanpour, A. Khademzadeh, S. Pourkiani, and M. Yaghobi, "GBMAP: an evolutionary approach to mapping cores onto a mesh-based NoC architecture," *Journal of Communication and Computer*, vol. 7, no. 3, pp. 1–7, 2010.

[51] G. E. Fen and W. U. Ning, "Genetic algorithm based mapping and routing approach for network on chip architectures," *Chinese Journal of Electronics*, vol. 19, no. 1, pp. 91–96, 2010.

[52] W. Jang and D. Z. Pan, "A3MAP: Architecture-aware analytic mapping for networks-on-chip," *ACM Transactions on Design Automation of Electronic Systems (TODAES)*, vol. 17, no. 3, pp. 1–22, 2012.

[53] P. K. Sahu, P. Venkatesh, S. Gollapalli, and S. Chattopadhyay, "Application mapping onto mesh structured network-on-chip using particle swarm optimization," in *IEEE computer society annual symposium on VLSI*, 2011, pp. 335–336.

[54] Y. R. Muhsen, S. L. Zubaidi, N. A. Husin, A. Alnoor, D. Božanić, and K. S. Hashim, "The weight fuzzy judgment method for the benchmarking sustainability of oil companies," *Applied Soft Computing*, vol. 161, p. 111765, 2024.

[55] H. Shi, L. Huang, K. Li, X.-H. Wang, and H.-C. Liu, "An extended multi-attributive Border Approximation Area comparison method for emergency decision making with complex linguistic information," *Mathematics*, vol. 10, no. 19, p. 3437, 2022.

[56] A. Puška, A. Štilić, M. Nedeljković, D. Božanić, and S. Biswas, "Integrating fuzzy rough sets with LMAW and MABAC for green supplier selection in agribusiness," *Axioms*, vol. 12, no. 8, p. 746, 2023.

[57] N. Rahim, L. Abdullah, and B. Yusoff, "A border approximation area approach considering bipolar neutrosophic linguistic variable for sustainable energy selection," *Sustainability*, vol. 12, no. 10, p. 3971, 2020.

[58] M. A. Alsalem et al., "Based on T-spherical fuzzy environment: A combination of FWZIC and FDOSM for prioritising COVID-19 vaccine dose recipients," *Journal of Infection and Public Health*, vol. 14, no. 10, pp. 1513–1559, 2021, doi: 10.1016/j.jiph.2021.08.026.

[59] A. Štilić and A. Puška, "Integrating multi-criteria decision-making methods with sustainable engineering: A comprehensive review of current practices," *Eng*, vol. 4, no. 2, pp. 1536–1549, 2023.

[60] N. Koohathongsumrit and W. Chankham, "Route selection in multimodal supply chains: A fuzzy risk assessment model-BWM-MARCOS framework," *Applied Soft Computing*, vol. 137, p. 110167, 2023.

[61] D. Božanić, M. Borota, A. Štilić, A. Puška, and A. Milić, "Fuzzy DIBR II-MABAC model for flood prevention: A case study of the river Veliki Rzav," *Journal of Decision Analytics and Intelligent Computing,* vol. 4, no. 1, pp. 285–298, 2024.

[62] D. Tešić and M. Khalilzadeh, "Development of the rough Defining Interrelationships Between Ranked criteria II method and its application in the MCDM model," *Journal of Decision Analytics and Intelligent Computing*, vol. 4, no. 1, pp. 153–164, 2024.

[63] A. Khodamipour, M. Askari Shahamabad, and F. Askari Shahamabad, "Fuzzy AHP-TOPSIS method for ranking the solutions of environmental taxes implementation to overcome its barriers under fuzzy environment," *Journal of Applied Accounting Research*, vol. 23, no. 3, pp. 541–569, 2022.

[64] A. Alnoor, S. Abbas, A. M. Sadaa, X. Chew, and G. E. Bayram, "Navigating the power of blockchain strategy: Analysis of technology-organization-environment (TOE) framework and innovation resistance theory using PLS-SEM and ANN insights," *Technological Forecasting and Social Change*, vol. 214, no. 5, pp. 1-16, 2025.

[65] A. Alnoor, M. Salah, A. Sammar, Y. R. Muhsen, A. M. Sadaa, X. Chew, and G. E. Bayram, "Determinants of retailers' trust in live-stream selling on social commerce platforms: Evidence using PLS-SEM and FsQCA," *International Journal of Human–Computer Interaction*, pp. 1–21, 2025.