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Architecture selection for 5G-radio access network using type-2 neutrosophic numbers based decision making model

Iman Mohamad Sharaf [a], A.H. Alamoodi [b m], O.S. Albahri [c d], Muhammet Deveci [e f], Mohammed Talal [g], A.S. Albahri [h n], Dursun Delen [i k], Witold Pedrycz [j l]

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Abstract

Fifth-generation (5G) technology provides new possibilities for a variety of applications, but it also comes with challenges influenced by distinct aspects, such as the size of organizations that use such technology. Therefore, it is important to understand which architecture of 5G-radio access networks (RANs) is best for a given purpose; this requires an evaluation platform for assessment. This paper tackles this problem by presenting a novel multi-criteria decision-making (MCDM) solution based on a new integrated fuzzy set. The proposed integrated approach, which is based on a Type-2 neutrosophic fuzzy environment, is developed to address the application challenges of 5G-RANs architecture evaluation, as also to face the MCDM theoretical challenge represented by ambiguities and inconsistencies among decision makers within the decision making context of the presented case study. Many MCDM techniques for weighting and selection were presented from the literature, yet many of them still suffer from inconsistencies and uncertainty. Therefore, the chosen methods in this research are unique in a way that previous issues are addressed, making them suitable for integration with Type-2 neutrosophic fuzzy environment, and therefore creating a more robust decision platform for the presented challenge in this research, as a theoretical contribution. First, a new "Type-2 Neutrosophic Fuzzy-Weighted Zero-Inconsistency" (T2NN-FWZIC) technique is formulated for weighting the evaluation criteria of RAN architectures. Second, another new method, namely, "Type-2 Neutrosophic Fuzzy Decision by Opinion Score Method" (T2NN-FDOSM), was formulated to select the optimal RAN architecture using the obtained weights. The weighting results by T2NN-FWZIC for the (*n=25*) evaluation criteria revealed that ($\mathbf{C_{21}}$ *latency* and $\mathbf{C_{22}}$ *reliability*) as the most important criteria, with *0.06* value for each as opposed to ($\mathbf{C_{15}}$ *Data Processing*) as the lowest weighted criteria with 0.0186 value. As for T2NN-FDOSM, a total of four 5G-RAN architectures were evaluated, including "virtualized cloud RAN" coming as the optimal one, followed by "fog RAN," "cloud RAN," and finally "heterogeneous cloud RAN." The results were confirmed by carrying out a sensitivity analysis. The outcome of this study can be used to assist future 5G-RAN developments according to business needs and to establish an assessment platform for 5G technology in different domains and applications.

Introduction

Fifth-generation (5G) wireless networking technology is a novel system with the potential to enhance user experience and open up exciting new avenues in numerous fields as diverse as transportation (Le & Moh, 2021), device-to-device communication (Ansari et al., 2017), agriculture (Tang et al., 2021), and industrial production (Cheng et al., 2018). Numerous new use cases and applications, including virtual/augmented reality, autonomous vehicles, the Internet of Things (IoT), and tactile Internet use cases, are expected with the advent of 5G (Pham et al., 2020). These new use cases significantly increase the number of users, volume of traffic, throughput, and latency (Pana et al., 2022). Each 5G technology has a unique effect on a mobile operator's capital expenditures (CAPEX) and operational expenditures (OPEX), which could decrease the performance and implementation of the 5G network if not accurately managed (Wu et al., 2021). Some technologies save expenses by a projected 30%, such as network function virtualization, but others, such as the high-frequency spectrum's unpredictable propagation properties, will increase expenses. Compared to earlier mobile network generations (2G, 3G, and LTE), 5G will enable capabilities, including data computing for diverse applications, control, and content delivery. Despite its significance and potential, 5G technology is prone to challenges encountered in other technological advances. For 5G, the challenges include end-to-end latency, number of connections, computing cost, and constraints, including end-device battery life, computational power, and memory limitations (Pana et al., 2022). Various technology approaches for 5G have been proposed in the areas of radio access to manage network resources to respond to radio access network (RAN) bottleneck issues or poor performance (Khumalo et al., 2021).

Network performance depends not only on resource management strategies but also on the RAN architecture itself (Khumalo et al., 2021). For instance, multi-perspective/criteria are neglected when implementing network optimization strategies, as most proposed approaches only consider one side (user or network) with no multi-concept/criteria diversity, resulting in the degradation of network performance (Ma et al., 2021). The essence is that mobile network capacity must be increased to meet the traffic demand, which can ensure the suitability/adaptability of RAN architecture to the user traffic load in certain geographical locations or times of the day, which vary in terms of network traffic, capacity, and latency (multi perspective consideration/criteria). Current technologies clearly lack the ability to support such crucial requirements. Therefore, industries and researchers need to bring some adaptive and/or multi-perspective solutions to 5G networks, both in technologies and architectures core network (CN) or RAN (Ma et al., 2021). In the literature, different types of RANs architectures have been proposed to overcome the problem of network capacity. These architectures are as follows: cloud-RAN (C-RAN), heterogeneous Cloud RAN (H-CRAN), virtualized cloud RAN (V-CRAN), and Fog RAN (F-RAN) (Habibi et al., 2022).

The C-RAN architecture minimizes OPEX, a mobile network operator (MNO), andCAPEX, uses less energy, boosts network scalability, simplifies network management and maintenance, increases spectrum efficiency and network throughput, and allows for load balancing (Maximidis et al., 2023). Recently, a new RAN architecture known as H-CRAN was designed to decouple both the control and user network planes to improve the functionality and performance of the C-RAN architecture, in which control plane operations are performed only at macrobase stations (BSs). In the next H-CRAN, the benefits of both heterogeneous networks and C-RANs have been fully exploited, resulting in improved spectrum and energy efficiency and increased data throughput (Maximidis et al., 2023). The H-CRAN can enhance the 5G network by an Enhanced-Cloud and Real-Time Virtualized Baseband Unit (BBU) Pool, Extremely Reliable Transport Network, High Number of Macro BSs, and small BSs and Remote Radio Head (RRH) (Goutham & Mishra, 2023). However, there are some differences between C-RAN and H-CRAN which need to be addressed like having all RRHs in the H-CRAN managed by the BBU pool, even in sleep mode, to save power when the traffic load is low (Lorincz et al., 2023). Additionally, MNOscan fully leverage the benefits of the next V-CRAN architecture, including lower power consumption, lower CAPEX/OPEX, service isolation via virtual networks, scalability throughout network upgrades, and responsiveness to non-uniform traffic. V-CRAN has several benefits for 5G systems; however, its implementation has drawbacks. Most of these problems are caused by C-RAN network function virtualization and software-defined networking, both of which affect V-CRAN implementation (Ejaz et al., 2020). However, CISCO coined the name "Fog Computing" to describe F-RAN, where "fog is a cloud close to the ground" and cloud computing extends to the periphery of the network. Computation, communication, control, and decision-making processes are selectively moved to the edge of the network in fog computing to act on data in milliseconds, assess time-sensitive data close to the IoT device, and send gathered information to the cloud data center for long-term storage or historical analysis (Dwivedi et al., 2023, Xiang et al., 2020). Fog computing places numerous tasks that are typically performed by central servers closer to the core of the network to its periphery. The BBU pool, the RRH, and the UEs themselves can all execute the collaborative radio signal processing (CRSP) in a fog computing environment (such as wearable smart UEs) (Jo et al., 2023). An F-RAN has several benefits for 5G mobile networks, but there are also many unanswered questions and obstacles. These include standard development, optimal resource allocation, backhaul load balancing, theoretical performance analysis, and spectrum/energy efficiency (Habibi et al., 2019, Mukherjee et al., 2018). Based on the discussed foundations, advantages, and challenges of each RAN, there is an essential need to investigate the current state of the evaluation mechanisms and their various criteria to be used in the RANs selection process for 5G mobile communication systems alongside the proposed evaluation approach in this research, as presented in Section 2.

In evaluating and selecting RAN architectures for 5G mobile communication systems, it is essential to keep in mind that this can provide the basis for serving users' needs, minimizing the number of handoffs, lowering anomaly ratios, and increasing the usage of network resources (Zhong et al., 2020). Thus, this study contributes to the body of knowledge in this area by developing a novel multi-criteria decision making MCDM-based selection approach for RAN architectures of 5G mobile communication systems, as follows:

1) To formulate a new evaluation decision matrix for 5G mobile communication systems considering the crisscrossing of all available RAN criteria and alternative lists of RAN architectures.

2) To evaluate the significance levels of RAN evaluation criteria based on a novel MCDM weighting method called T2NN-FWZIC ("Type-2 Neutrosophic Fuzzy-Weighted Zero-InConsistency").

3) Select the most optimum RAN architectures based on individual, internal, and external group MCDM contexts using a novel MCDM ranking method called

T2NN-FDOSM ("Type-2 Neutrosophic Fuzzy Decision by Opinion Score Method").

4) To evaluate the robustness of the proposed T2NNs-based MCDM approach using several scenario-based sensitivity analyses.

The remainder of this paper is organized as follows: Section 2 discusses related works on the current state of RAN architecture evaluation mechanisms and the MCDM-integrated approach. Section 3 outlines basic definitions and preliminaries. Section 4 describes the research methodology applied in this research, and Section 5 discusses a novel case study. Section 6 details the experimental and validation results, and section 7 concludes the study.

Section snippets

Related works

In this section, a brief and focused literature review is presented, covering topics such as RAN architecture evaluation mechanisms represented in previous academic works, followed by literature on the proposed MCDM approach and its theoretical background. …

Preliminaries

In this section, the basic concepts and operations of T2NNs are presented and the parameters used are described in Table 2.

Firstly, the concepts of NFSs and T2NNs are presented in Definition 1 and Definition 2.
Definition 1
(Deveci, Erdogan, et al., 2021). *An NFS* $\widetilde{N}$ *of the universe of discourse* X *is described by*. …

$$\widetilde{N} = \left\{ \left\langle x, \left(T_{\widetilde{N}}(x), I_{\widetilde{N}}(x), F_{\widetilde{N}}(x) \right) \middle| x \in X \right\rangle \right\},$$

where the functions T, I, and F: $X \to [0.1+]$ define the truth, indeterminacy, and falsity grades, respectively, of the element $x \in X$ to the set $\widetilde{N}$ under the condition $0^- \leq T_{\widetilde{N}}(x) + I_{\widetilde{N}}(x) + F$ …

Methodology

This section explains the proposed integrated fuzzy approach and the main and sub process steps of the T2NN-FWZIC method for criteria weighting in Section 4.1, followed by the T2NN-FDOSM method for the selection results of the 5G-RANs architectures in Section 4.2. The details of both the methods are described in the following subsections. …

MCDM case study of 5G-RAN architectures

In this section, the MCDM complex problem of evaluating and selecting 5G-RAN architectures is discussed. First, as discussed earlier, four alternatives of RAN architectures used in 5G mobile communication systems were evaluated and selected based on their similarities, working and implementation structures, and advantages and disadvantages. These four alternatives were C-RAN (A_1), H-CRAN (A_2), V-CRAN (A_3), and F-RAN (A_4). It should be noted that 25 criteria were used to evaluate those 5G-RANs …

Experimental results

This section presents the research results for criteria weighting using T2NN-FWZIC, followed by selecting the 5G-RANs architectures using T2NN-FDOSM. …

Conclusion

From a technological standpoint, 5G technologies are used in various applications in our daily lives. These applications have altered our perspectives on normal wireless communications used for chatting and basic Internet services, transforming them into essential tools that integrate into many domains, including medicine, transportation, manufacturing and many others. Despite their relevance, 5G technologies are not simple to adopt, especially when considering factors such as the type of …

CRediT authorship contribution statement

Iman Mohamad Sharaf: Conceptualization, Methodology. **Abdullah Alamoodi:** Conceptualization, Methodology. **Osamah Albahri:** Writing – original draft, Data curation. **Muhammet Deveci:** Writing – review & editing, Validation, Visualization. **Mohammed Talal:** Writing – review & editing, Validation, Visualization. **Ahmed Albahri:** Supervision. **Dursun Delen:** Writing – review & editing, Supervision. **Witold Pedrycz:** Writing – review & editing, Supervision. …

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

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> *Citation Excerpt :*
> …MCDM has significant potential in various areas (Hiba Mohammed et al., 2023). In order to fully understand its potential, it is essential to know about MCDM methods, which vary in their primary aim to either being used for weighting and assigning importance values for the criteria involved in the decisions or selecting the choices for decision makers (DMs), and other MCDM methods can perform both tasks simultaneously (Sharaf et al., 2024). Some of the most trending and well-known MCDM methods include “Fuzzy-Weighted with Zero-Inconsistency (FWZIC)” (Mohammed, Zaidan, et al., 2021), “Full Consistency Method” (Pamučar et al., 2018), Entropy (Banadkouki, 2023), and others.…

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> …A two stage transportation problem for breakable items was solved by Samanta et al. [49] using SVNSs. Sharaf et al. [50] demonstrated type-2 SVN approach for 5 G radio access network architecture selection. The presentdliterature review highlights a significant gap in current SVN decision-making procedures, specifically the inadequate emphasis on "consensus-reaching process."…

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>
> …There were many applications of MADM in different fuzzy frameworks discussed by mathematicians. For example, the 5-G radio network selection using the MADM method with neutrosophic information given by Sharaf et al. [22] and some divergence measures for MADM in the IFS framework were introduced by Umar and Saraswat [23]. Using the trigonometric value-based AOs for MADM was diagnosed by Deveci et al. [24], and the AOs based on the interval-valued Heronian mean for the MADM problem offered by Mishra et al. [24].…

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