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A New Fuzzy MCDM Model to Select Wireless Network Types in Healthcare Facilities

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ABSTRACT

In recent years, there has been a noticeable rise in the need for wireless network connection in healthcare facilities. This is a result of the requirement for immediate access to patient data as well as the growing number of medical devices that are internet-connected. To guarantee dependable and secure communication as well as support for diverse healthcare applications and services, it is essential to choose the right wireless network type. However, the selection procedure can be difficult because it includes a number of variables that are frequently arbitrary and subjective. The difficulties of choosing the best wireless network type to be used in healthcare facilities are addressed in this research by the introduction of a new fuzzy model for multi-criteria decision-making (MCDM). The approach considers several evaluation factors, including patient cost, patient privacy, patient safety, and patient comfort and convenience. The model uses a fuzzy analytic hierarchy process (FAHP) to compute the weights of these criteria. In addition, the model uses fuzzy methods like fuzzy ARAS, fuzzy EDAS, and fuzzy TOPSIS to rank the different kinds of wireless networks according to their performance. It is clear from the results that the suggested model can effectively and dependably assess different alternatives. Additionally, it provides useful and practical advice on how to choose the right wireless network types for medical facilities. The best feature is that this approach is easily adaptable to other healthcare industry decision-making procedures.

Keywords: FMCDM; wireless network; ARAS; EDAS; TOPSIS; healthcare

INTRODUCTION

Healthcare facilities now cannot function without wireless networks that are crucial for real-time data collection, patient monitoring, and inter professional communication. Healthcare facilities now face the difficulty of choosing the best network type that balances patient privacy, safety, convenience, and cost due to the quick advancements in wireless technology. Healthcare environments increasingly rely on wireless networks to serve a variety of applications, including telemedicine, medical imaging, and patient monitoring. Multi-criteria decision-making (MCDM) models have been demonstrated to be effective in choosing the best option from a group of options based on many criteria in the field of medical decision-making. Healthcare facilities have special demands and requirements; thus, patient privacy, safety, comfort, and cost criteria are carefully chosen to fulfill those needs and requirements. A thorough set of sub-criteria and related weights are constructed by a thorough assessment of the available literature in order to objectively evaluate the various types of wireless networks. To account for the inherent uncertainties and errors linked to decision-making processes in healthcare settings, the MCDM model uses fuzzy group theory. The model enables decision-makers to express their individual thoughts and preferences through the use of language variables and membership functions, providing a more thorough and precise evaluation of the many forms of wireless networks. This research is significant since it led to the creation of a novel fuzzy MCDM model that aids in decision-making when choosing wireless network types for healthcare institutions. Fuzzy set theory integration enables decision-makers to incorporate subjectivity and uncertainty into the decision-making process, producing more trustworthy and realistic results. Several wireless network types in healthcare institutions were analyzed with an emphasis on patient satisfaction, taking into account Wi-Fi, Bluetooth, ZigBee, and WBAN as alternative possibilities due to their inherent uncertainty and imprecision. Fuzzy ARAS, fuzzy EDAS, and fuzzy TOPSIS techniques were used within a MCDM framework to evaluate these possibilities.

When making crucial choices about the deployment of wireless networks in hospital settings, healthcare administrators, IT specialists, and legislators can benefit greatly from the insights and direction provided by the suggested model. The proposed model is anticipated to improve healthcare facility management by offering a systematic approach to evaluate different wireless network types and choose the most promising one according to the proposed MCDM framework.

RELATED WORKS

Wi-Fi (Wireless Fidelity): Wi-Fi technology is extensively used in healthcare settings for a range of purposes. It provides wireless internet connectivity, allowing healthcare professionals to access patient records, research information, and communicate efficiently (Bensky 2019b and 2019a). Wi-Fi also facilitates the use of mobile devices, such as tablets and smartphones, for tasks like data entry, remote monitoring, and telemedicine. Bluetooth technology is commonly utilized in healthcare for short-range wireless communication between devices. It enables connectivity between medical devices, such as heart rate monitors, glucose meters, and blood pressure monitors, and data collection systems like smartphones or tablets. Bluetooth can also support wearable devices for activity tracking and remote monitoring of patients' vital signs (Haataja et al. 2013a, 2013b) (Di Marco et al. 2015; Bensky 2019b).

ZigBee is a low-power wireless communication protocol that finds applications in healthcare, particularly for remote patient monitoring and home healthcare systems (Gislason 2008). ZigBee allows devices to form networks and communicate wirelessly over higher distances than Bluetooth. It is used for monitoring patients' health parameters, tracking movement, and managing sensor networks in healthcare facilities. WBAN (Wireless Body Area Network): WBAN refers to a network of interconnected medical devices, typically worn on the body or implanted, for continuous monitoring of a patient's vital signs (Muthuvel, Rajagopal and Subramaniam, 2022) (Movassaghi et al. 2014) (Hernandez and Mucchi, 2014). WBAN devices can wirelessly collect and transmit data, such as heart rate, temperature, blood pressure, and ECG readings, to a central monitoring system. This technology facilitates real-time patient monitoring, early detection of abnormalities, and timely intervention. These criteria can be used to evaluate and compare alternatives (Wi-Fi, Bluetooth, ZigBee, and WBAN) in order to select the most appropriate wireless network type for a specific healthcare facility and patient circumstances. The data for each criterion is uncertain or imprecise, so fuzzy sets can be used to represent the data.

METHODOLOGY

Triangular fuzzy membership functions in fuzzy logic, a membership function is a way to represent the degree to which an element belongs to a specific fuzzy set. It has been used in various fields as a decision-making tool (It assigns a membership value between 0 and 1 to elements within a defined universe of discourse. A triangular membership function is a specific type of membership function characterized by a triangular shape (Al-Hubaishi, Çeken and Al-Shaikhli, 2019), with three key parameters:

1. Lower Limit (a): This is the minimum value within the universe of discourse where the membership function starts increasing from 0.
2. Upper Limit (c): This is the maximum value within the universe of discourse where the membership function starts decreasing to 0.
3. Peak (b): This is the point within the universe of discourse where the membership function reaches its maximum value of 1. As illustrated in Figure 1.

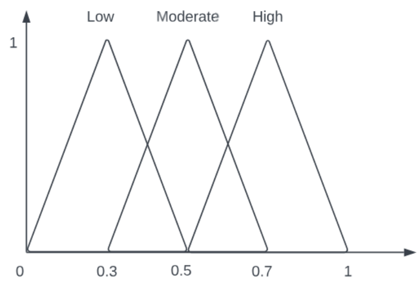

FIGURE 1. Triangular fuzzy membership functions

Next, specify the criteria used to assess various types of networks in this study. All criteria in Figure 2 within the matrix should be expressed as triangular fuzzy functions (Al-Hubaishi, Çeken and Al-Shaikhli 2019) (Alsaqour et al. 2015).

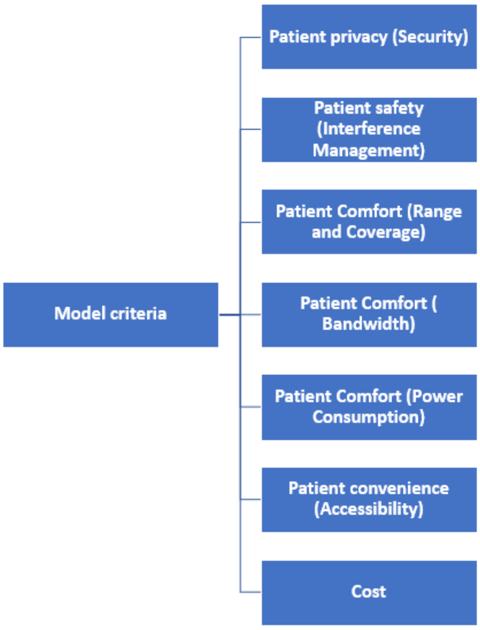

FIGURE 2. Proposed model criteria

Figure 2 shows the proposed model criteria, each with a triangular fuzzy membership function. Table 1 lists the range of values for each membership function.

TABLE 1. Membership function with the values of the Model

Membership Function	Rage Value of The Membership Function
Low	[0, 0.3, 0.5]
Moderate	[0.3, 0.5, 0.7]
High	[0.5, 0.7, 1]

PATIENT PRIVACY (SECURITY)

The security of a wireless network determines how protected the patient's data is from unauthorized access. A more secure network is more important for patients who are sharing sensitive medical information. Tyler (Wrightson 2012) explains the specifics of Wi-Fi security, covering topics such as different encryption protocols (WEP, WPA, WPA2), securing wireless routers, and protecting against common attacks like eavesdropping and unauthorized access. Moving on to Bluetooth security, Tyler discusses pairing mechanisms, Bluetooth security modes, and potential risks like Bluejacking and Bluesnarfing. Security also provides guidance on securing Bluetooth devices and mitigating the associated risks. Moreover, the same author discussed security features provided by Zigbee and explored potential vulnerabilities and attacks. Lastly, unique security challenges of WBANs include confidentiality, integrity, and availability of sensitive medical information. WBAN provides an overview of security mechanisms and protocols, with practical recommendations for protecting personal health data (Wrightson, 2012).

PATIENT SAFETY (INTERFERENCE)

The interference from a wireless network determines how likely it is that the signal will be interrupted by other devices or signals. A lower interference is more important for patients who are using medical devices that require a reliable signal. The level of interference management can depend on various factors such as the operating frequency, signal propagation characteristics, and the presence of other wireless devices in the environment. An analytical investigation of the interference issues that develop when ZigBee and Wi-Fi devices coexist in the same environment is conducted (Singh, Sharma and Tomar 2013). The study draws attention to the fact that both technologies use the 2.4 GHz ISM band, which can lead to interference because of frequency range overlap. Interestingly, the study reveals that Wi-Fi experiences less interference compared to ZigBee.

Zhang et al. (He et al. 2021) used an over-the-air (OTA) measurement system to assess the interference between Wi-Fi and Bluetooth. The authors concentrated on two 2.4 GHz ISM-frequency band mobile phones. Results show that when Bluetooth frequency hopping is disabled, Wi-Fi performs better than Bluetooth in terms of interference. This is due to the fact that when Bluetooth frequency hopping is turned on, Bluetooth's sensitivity to Wi-Fi interference rises. Hayajneh et al. (Hayajneh et al. 2014) applied depth to examine many highly used wireless technologies in WBANs, including Bluetooth, ZigBee, Wi-Fi, and cellular networks. The authors carefully considered the special qualities, benefits, and drawbacks of each technology, giving close attention to any potential interference problems. According to the study's findings, ZigBee and Bluetooth operate at lower power levels and have a shorter range than Wi-Fi and cellular networks. The study took into account a variety of scenarios, including WBAN-Alone, with1APx20, and with3APx5. Due to these variables, ZigBee and Bluetooth may show greater vulnerability to interference in circumstances (Hayajneh et al. 2014). Mahapatro et al. (Mahapatro et al. 2012) a radio frequency based wireless device suffers from interference due to the existence of other wireless devices operating in the same frequency band. In this paper we address the problem of interference when multiple WBANs come in the proximity of one another. In this paper propose a TDMA-based solution that creates a common schedule between these WBANs, so that there is seamless communication with their sensors without interference among them, while increasing the cost of latency per node. Sarra used the MiXiM framework and the MoBAN mobility model to evaluate the coexistence of WBAN and Wi-Fi networks. Their results showed that Wi-Fi nodes can have a significant impact on the DIPR (delivery ratio), EPR (error rate), packet reception, and packet transmission of WBANs (Sarra and Ezzedine 2016).

PATIENT COMFORT (RANGE AND COVERAGE)

The range of a wireless network determines how far away a patient can be from the device or access point without losing signal. A Higher range is more comfortable for patients who need to move around freely, while a shorter range may be more appropriate for patients who are bedridden. The range and coverage of wireless networks can vary depending on environmental factors, device capabilities, and specific implementations. For example, a hospital may need a wireless network that can support a large number of devices and users, while a clinic may need a network that is more focused on patient privacy and safety. Bensky (Bensky, 2019b) provides an overview of the Bluetooth protocol stack, which consists of multiple layers, including the physical layer, link layer, and higher-level protocols. The book focuses on short-range wireless communication systems, which typically have a range of up to 100 meters or less.

The coverage area of these systems is typically Low to a specific geographic region, such as a building or a small outdoor area. The book also discusses the use of various protocols and standards for short-range wireless communication, including Bluetooth, ZigBee, Wi-Fi, and RFID. These protocols enable reliable and efficient communication between wireless devices in a short-range environment. Di Marco (Di Marco et al. 2015), Bluetooth Low Energy (BLE) is suitable for short-range applications within an office environment, while IEEE 802.11ah (Wi-Fi HaLow) can provide extended coverage and better penetration through obstacles. The choice between the two technologies depends on the specific requirements of the application, such as data rate, range, and power consumption. Movassaghi (Movassaghi et al. 2014) defines WBAN as a network of wearable or implantable sensors that collect, process, and transmit data from the human body to a remote location. Also, Movassaghi explores the various applications of WBANs, such as remote monitoring of health conditions and fitness tracking. They also discuss the challenges in designing and implementing WBANs, including power consumption and network reliability. The authors suggest that future research should focus on developing efficient energy harvesting techniques and improving data transmission reliability. Finally, the article concludes that WBANs have the potential to revolutionize healthcare by providing real-time monitoring of vital signs and early detection of health problems. Hernandez (Hernandez and Mucchi, 2014) focuses on the IEEE 802.15.6 standard, which is designed for wireless personal area networks (WPANs) that support bidirectional communication between a human body and electronic devices. The book covers topics such as sensor design, data transmission methods, security, and energy efficiency. It also provides case studies and practical examples of using this technology for various healthcare applications.

PATIENT COMFORT (BANDWIDTH)

The bandwidth of a wireless network determines how much data can be transmitted at once. A higher bandwidth is important for patients who are using multiple devices or applications on the same network. The actual bandwidth and data transfer rates can vary based on specific implementations, network configurations, and device capabilities within each wireless network.

PATIENT COMFORT (POWER CONSUMPTION)

The frequency of device or access point recharging is directly impacted by a wireless network's power consumption, which is crucial for patients with limited mobility. In these circumstances, lower power usage is more practical. Due to variables including transmission power, data transfer rates, network activity, and the incorporation of power-saving technologies in the devices, wireless networks' power consumption can change. Hayajneh (Hayajneh et al. 2014), ZigBee consumes about half to one-third as much power as Bluetooth. Additionally, Wi-Fi uses the highest transmission power of the three technologies, and it operates in the same frequency band as WBANs. This can lead to higher interference with WBAN performance. The seamless integration of many networks presents significant obstacles and potential interference issues, particularly when other wireless technologies (such Wi-Fi, ZigBee, and Bluetooth) are present and share the same frequency range. Differences in MAC protocols and packet sizes make these problems worse since Wi-Fi networks, which use larger packets, can monopolize the medium for longer periods of time than WBAN, Bluetooth, and ZigBee networks, which use smaller packets. Additionally, fluctuations in transmission power levels contribute to making interference problems worse. The table 2 below summarizes as explained in the articles (Sarra and Ezzedine 2016) (Danbatta and Varol 2019) (Yaghoubi, Ahmed and Miao 2022).

PATIENT CONVENIENCE (ACCESSIBILITY)

For patients with restricted mobility or dexterity, user-friendliness of a wireless network has a substantial impact on how readily they can set up and utilize the device or access point. The usability of wireless networks can be impacted by elements such as signal propagation characteristics, interference, physical barriers, and ambient factors.

TABLE 2. Summary of articles for network types

Wireless Network Type	Standard IEEE	Range meters	Bandwidth	Power Consumption	Cost
Wi-Fi	802.11	1000	1000 Mbps	High	Medium
Bluetooth	802.15.1	10	3 Mbps	Low	Very Low
ZigBee	802.15.4	100	250 kbps	Very low	Low
WBAN	802.15.6	10	2 Mbps	Very low	High

COST

A wireless network's price is a major factor in whether patients can afford it, especially those with limited resources. Wi-Fi typically costs more than Bluetooth and ZigBee because it requires stronger antennas and uses more power. Wireless Body Area Networks (WBANs) are more cost-effective since they are designed for low-power, low-cost devices worn on the body. Both Bluetooth and ZigBee are intended to be reasonably priced and low-power, however ZigBee is frequently less expensive because of its less complicated protocol and slower communication speeds. The price of wireless networks can vary depending on things like the size of the deployment, the gear needed, the license costs, and maintenance costs. A profiling-policing framework for WBAN against Wi-Fi interference (Wang, 2013) is one step toward ensuring the safe use of costs wireless devices in medical contexts. The difficulties of coexisting with Wi-Fi and medical wireless body area networks (WBANs) in the 2.4GHz ISM band are discussed in this thesis. It notes that Wi-Fi poses a danger to WBANs and suggests a remedy dubbed WiCop that improves WBAN performance in the presence of Wi-Fi interference without changing current standards. The wireless body area networks (WBANs) are the subject of this article (Yaghoubi, Ahmed and Miao, 2022). It talks about the obstacles and implementation issues, as well as the architecture and purpose of WBANs. The paper also discusses emerging WBAN technologies, such as security and energy consumption reduction. WBANs can provide continuous vital sign monitoring, which has the potential to change healthcare. Before WBANs may be widely used, there are still a few issues that need to be resolved.

TABLE 3. Summary of all model criteria

Criteria	Security	Range and Coverage	Bandwidth	Interference Management	Power Consumption	Accessibility	Cost
Wi-Fi	Moderate (Wrightson 2012)	High (Bensky 2019b) (Bensky 2019b, 2019a)	High (Danbatta and Varol 2019)	High (Singh, Sharma and Tomar 2013) (He et al. 2021) (Hayajneh et al. 2014) (Mahapatro et al. 2012)	High (Danbatta and Varol 2019)	High (Yaghoubi, Ahmed, and Miao 2022)	Moderate (Wang 2013)
Bluetooth	Low (Haataja et al. 2013a, 2013b)	Low (Bensky, 2019b) (Di Marco et al. 2015)	Low (Danbatta and Varol 2019)	Low (Singh, Sharma and Tomar, 2013) (He et al. 2021) (Hayajneh et al. 2014) (Mahapatro et al. 2012)	Low (Danbatta and Varol, 2019)	Moderate (Yaghoubi, Ahmed and Miao, 2022)	Low (Wang 2013)

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ZigBee	Moderate (Gislason, 2008)	Moderate (Mahapatro et al. 2012)	Moderate (Danbatta and Varol, 2019)	Moderate (Singh, Sharma and Tomar 2013) (He et al. 2021) (Hayajneh et al. 2014)(Mahapatro et al. 2012)	Moderate (Danbatta and Varol, 2019)	Low (Yaghoubi, Ahmed and Miao, 2022)	Moderate (Wang 2013)
WBAN	Low (Muthuvel, Rajagopal and Subramaniam 2022) (Yaghoubi, Ahmed and Miao 2022)	Low (Movassaghi et al. 2014) (Yaghoubi, Ahmed and Miao 2022)	Low (Hayajneh et al. 2014)	Moderate (Singh, Sharma and Tomar 2013) (He et al. 2021) (Hayajneh et al. 2014)(Mahapatro et al. 2012)	Low (Yaghoubi, Ahmed and Miao 2022)	Low (Yaghoubi, Ahmed and Miao 2022)	Moderate (Yaghoubi, Ahmed and Miao 2022)

FUZZY METHODS

This paper used THREE types of method for making decisions as the following:

1. Fuzzy ARAS

Fuzzy ARAS, also known as Fuzzy Analytic Hierarchy Process (AHP) (Więckowski, Kizielewicz and Sałabun, 2022) (Karagöz et al. 2021) and Ratio Analysis System, is a method for making decisions that involves weighing multiple criteria. It is a development of the conventional AHP that uses fuzzy logic to deal with ambiguous or inaccurate information when making decisions. Fuzzy logic enables the representation of ambiguous, qualitative, or subjective data, which is frequently found in situations requiring decision-making in the real world. Various normalization methods, such as the default sum normalization, are used in the FARAS procedure. Different preferences are noticed depending on the normalization method employed while evaluating alternatives using each normalization approach. A particular strategy is used for this to guarantee consistency in alternative ranks across various normalization techniques.

2. Fuzzy EDAS

The flexibility of the defuzzification procedure using the fuzzy EDAS (Evaluation based on Distance from Average Solution) method (Cakmak and Guney, 2023) (Więckowski, Kizielewicz and Sałabun, 2022). The mean defuzzification method is what the FEDAS function uses by default. Similar to EDAS, this method is intended to rank and evaluate alternatives, offering higher preferences to alternatives that perform better.

3. Fuzzy TOPSIS

The Fuzzy TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) method (Więckowski, Kizielewicz and Sałabun, 2022) (Tüysüz and Kahraman, 2023), which allows for the flexible adjustment of normalization and distance computation parameters. Vertex_distance and linear normalization are included in the default settings. TOPSIS is a valuable tool for assessing and ranking options based on predetermined criteria because it is meant to ensure that superior alternatives obtain higher preference ratings.

HEALTHCARE APPLICATIONS

Healthcare applications used in Table 4 for the wireless networks are summarized.

EVALUATION AND RESULTS

As can be seen in Table 4, monitoring and real time applications can determine criteria weights as shown in Table 5.

TABLE 4. Healthcare applications used the wireless networks represented.

Network Type	Applications in Healthcare	References
WBAN	Continuous monitoring of vital signs, remote patient monitoring, and drug delivery	(Bhatti et al. 2022) (Arefin et al. 2017) (Tavera et al. 2021)
ZigBee	Wireless medical telemetry systems, remote patient monitoring, and asset tracking	(Dobrilovic, Stojanov and Odadzic, 2014; Jasmine Hephzipah et al. 2023) (Zhang, Sun and Cui, 2010)
Bluetooth	Wireless medical devices, such as glucose meters and blood pressure monitors, and telemedicine	(Decuir, 2015; Goh and Hau, 2019) (Shanthi et al. 2018)
Wi-Fi	Telemedicine, patient portals, and electronic health records (EHRs)	(Purat et al. 2022) (Ge et al. 2023) (Manzoor et al. 2019)

TABLE 5. Criteria's weights of real time application

Security	Range and Coverage	Bandwidth	Interference	Power Consumption	Accessibility	Cost
High	Moderate	Moderate	High	Moderate	High	High
[0.5, 0.7, 1]	[0.3, 0.5, 0.7]	[0.3, 0.5, 0.7]	[0.5, 0.7, 1]	[0.3, 0.5, 0.7]	[0.5, 0.7, 1]	[0.5, 0.7, 1]

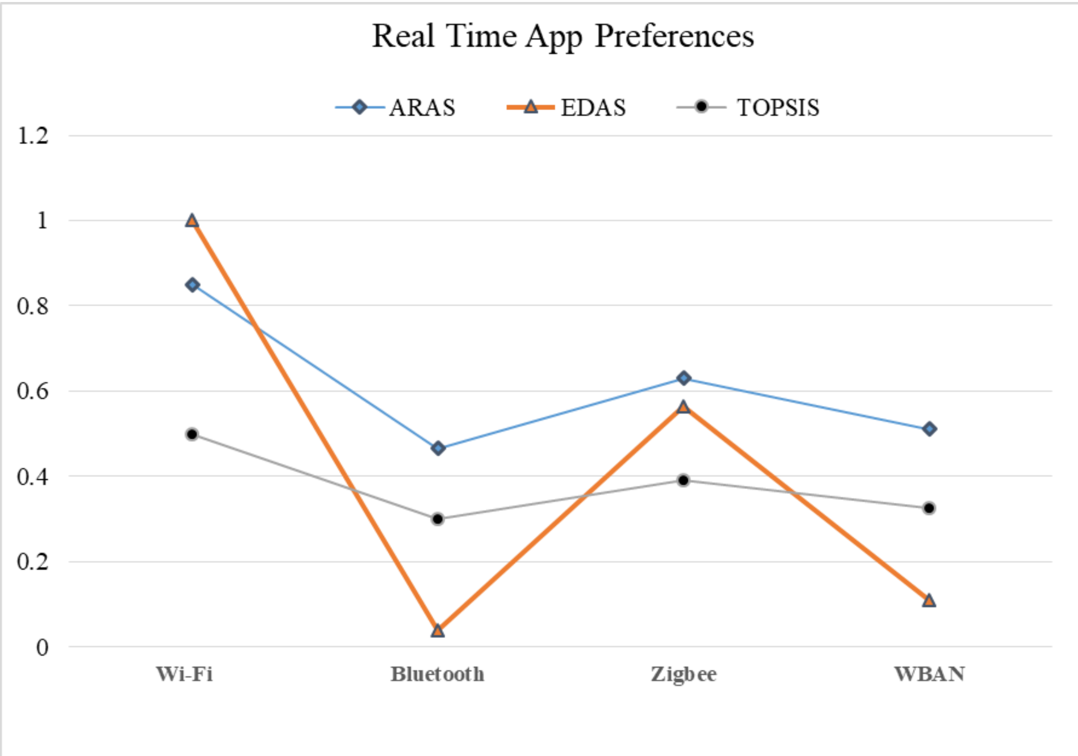

FIGURE 3. Real time application preferences results

Figure 3 presents preference results of Fuzzy ARAS, Fuzzy EDAS, and Fuzzy Topsis for real time applications on network types which determine criteria weights for each network type. The different normalizations are used for each approach to produce varied preferences, the ranking outcomes are the same across all networks.

TABLE 6. Ranking of fuzzy methods and network types

	Wi-Fi	Bluetooth	ZigBee	WBAN
ARAS	1	4	2	3
TOPSIS	1	4	2	3
EDAS	1	4	2	3

TABLE 7. Fuzzy ARAS normalization

Method	Wi-Fi	Bluetooth	ZigBee	WBAN
Sum	0.85	0.47	0.63	0.51
Max	0.79	0.41	0.59	0.46
Linear	0.79	0.41	0.59	0.46
MinMax	0.79	0.41	0.59	0.46
Vector	0.79	0.41	0.58	0.46
SAW	0.79	0.41	0.59	0.46

TABLE 8. Fuzzy EDAS normalization

Method	Wi-Fi	Bluetooth	ZigBee	WBAN
Mean	1	0.04	0.57	0.11
Mean Area	1	0.04	0.56	0.11
Graded Mean Average	1	0.03	0.55	0.12
Weighted Mean	1	0.04	0.56	0.11

TABLE 9. Fuzzy TOPSIS normalization

Method	Wi-Fi	Bluetooth	ZigBee	WBAN
Sum	0.45	0.29	0.36	0.31
Max	0.61	0.33	0.47	0.37
Linear	0.5	0.3	0.39	0.33
MinMax	0.5	0.3	0.39	0.33
Vector	0.28	0.16	0.21	0.17
SAW	0.5	0.3	0.39	0.33

Table 6 has three distinct fuzzy algorithms (ARAS, TOPSIS, and EDAS) as well as four distinct network types (Wi-Fi, Bluetooth, ZigBee, and WBAN). The numbers in the table show how each network type ranks for each fuzzy approach. With a score of 1, ARAS, TOPSIS, and EDAS all rank Wi-Fi as the best alternative. This means that all three fuzzy approaches agree that Wi-Fi is the best network type to use. Bluetooth is ranked as the weakest alternative by ARAS, TOPSIS, and EDAS, each with a score of 4. As a result, there is widespread agreement that Bluetooth is the least desirable option.

With a score of 2, ARAS, TOPSIS, and EDAS all rank ZigBee as the second-best choice. This means that all three approaches agree that ZigBee is a solid option, but not the best. WBAN is ranked third best by ARAS, TOPSIS, and EDAS, each with a score of 3. Like ZigBee, all three approaches conclude that WBAN is a viable option but not the best. Wi-Fi is the best option, according to the rankings in the table and the consensus among the fuzzy techniques, followed by ZigBee, WBAN, and Bluetooth, which is the least desirable option.

The mean defuzzification was chosen as the defuzzification setting using the FEDAS method. Better options with higher preferences are also evaluated by EDAS. The distance computation and normalization parameters can both be changed using the TOPSIS approach. Vertex distance and linear normalization are the TOPSIS algorithms that we are using. Better options have greater preference values, according to TOPSIS. Normalization results are shown in Table 7, Table 8, and Table 9.

CONCLUSION

Increasing demand for wireless network connectivity in healthcare facilities, driven by the need for immediate access to patient data and the proliferation of internet-connected medical devices, necessitates a careful selection of the appropriate wireless network type. This selection process is complex due to the subjectivity and arbitrariness of the factors involved. This research has addressed the challenges of choosing the optimal wireless network type for healthcare facilities by introducing a novel fuzzy model for multi-criteria decision-making (MCDM). The model considers a range of evaluation factors, including patient cost, patient privacy, patient safety, and patient comfort and convenience.

To determine the importance of these criteria, the model employs a fuzzy analytic hierarchy process (FAHP) to compute their weights. Furthermore, it employs fuzzy methodologies such as fuzzy ARAS, fuzzy EDAS, and fuzzy TOPSIS to rank various wireless network types based on their performance. Results obtained from this study demonstrate the effectiveness and reliability of the proposed model in assessing different alternatives. Additionally, it offers valuable and practical guidance on selecting the most suitable wireless network types for healthcare facilities. A significant advantage of this approach is its adaptability to other decision-making processes within the healthcare industry.

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DECLARATION OF COMPETING INTEREST

None

REFERENCES

Al-Hubaishi, M., eken, C. and Al-Shaikhli, A. 2019. 'A novel energy-aware routing mechanism for SDN-enabled WSAN', International Journal of Communication Systems, 32(17). Available at: https://doi.org/10.1002/dac.3724.

Alsaqour, R. et al. 2015. 'Dynamic packet beaconing for GPSR mobile ad hoc position-based routing protocol using fuzzy logic', Journal of Network and Computer Applications, 47, pp. 32–46. Available at: https://doi.org/10.1016/J.JNCA.2014.08.008

Arefin, Md.T. et al. 2017. 'Wireless Body Area Network: An Overview and Various Applications', Journal of Computer and Communications, 5(7), pp. 53–64. Available at: https://doi.org/10.4236/JCC.2017.57006.

Bensky, A. 2019a. 'Short-range Wireless Communication, 3rd Edition / Bensky, Alan.' Available at: https://ucl-new-primo.hosted.exlibrisgroup.com/primo-explore/fulldisplay?docid=UCL_LMS_DS51288659870004761&context=L&vid=UCL_VU2&lang=en_US&search_scope=CSCOP_UCL&adaptor=Local Search Engine&tab=local&query=any,contains,Short-range Wireless Communication& (Accessed: 20 May 2023).

Bensky, A. 2019b. 'Short-range Wireless Communication: Fundamentals of RF System Design and Application', Short-range Wireless Communication, pp. 1–445. Available at: https://doi.org/10.1016/B978-0-12-815405-2.09989-9.

Bhatti, D.S. et al. 2022. 'A Survey on Wireless Wearable Body Area Networks: A Perspective of Technology and Economy', Sensors 2022, Vol. 22, Page 7722, 22(20), p. 7722. Available at: https://doi.org/10.3390/S22207722.

Cakmak, E. and Guney, E. 2023. 'Spare parts inventory classification using Neutrosophic Fuzzy EDAS method in the aviation industry', Expert Systems with Applications, 224, p. 120008. Available at: https://doi.org/10.1016/J.ESWA.2023.120008.

Danbatta, S.J. and Varol, A. 2019. 'Comparison of Zigbee, Z-Wave, Wi-Fi, and bluetooth wireless technologies used in home automation', 7th International Symposium on Digital Forensics and Security, ISDFS 2019 [Preprint]. Available at: https://doi.org/10.1109/ISDFS.2019.8757472.

Decuir, J. 2015. 'Bluetooth Smart Support for 6LoBTLE: Applications and connection questions', IEEE Consumer Electronics Magazine, 4(2), pp. 67–70. Available at: https://doi.org/10.1109/MCE.2015.2392955.

Dobrilovic, D., Stojanov, Z. and Odadzic, B. 2014. 'Teaching application development for RFID/ZigBee networks using open source hardware', BIHTEL 2014 - 10th International Symposium on Telecommunications, Proceedings [Preprint]. Available at: https://doi.org/10.1109/BIHTEL.2014.6987641.

Ge, Y. et al. 2023. 'Contactless WiFi Sensing and Monitoring for Future Healthcare - Emerging Trends, Challenges, and Opportunities', IEEE Reviews in Biomedical Engineering, 16, pp. 171–191. Available at: https://doi.org/10.1109/RBME.2022.3156810.

Gislason, D. 2008. 'Zigbee Wireless Networking', Zigbee Wireless Networking [Preprint]. Available at: https://doi.org/10.1016/B978-0-7506-8597-9.X0001-8.

Goh, V.H. and Hau, Y.W. 2019. 'Android-based mobile application for home-based electrocardiogram monitoring device with google technology and bluetooth wireless communication', 2018 IEEE EMBS Conference on Biomedical Engineering and Sciences, IECBES 2018 - Proceedings, pp. 205–210. Available at: https://doi.org/10.1109/IECBES.2018.8626603.

Haataja, K. et al. 2013a. 'Bluetooth Security Attacks'. https://doi.org/10.1007/978-3-642-40646-1.

Haataja, K. et al. 2013b. 'Comparative Analysis of Bluetooth Security Attacks', SpringerBriefs in Computer Science, 0(9783642406454), pp. 23–60. Available at: https://doi.org/10.1007/978-3-642-40646-1_4.

Hayajneh, T. et al. 2014. 'A survey of wireless technologies coexistence in WBAN: analysis and open research issues', Wireless Networks, 20(8), pp. 2165–2199. Available at: https://doi.org/10.1007/S11276-014-0736-8/FIGURES/24.

He, S. et al. 2021. 'Research on coexistence and mutual interference of Wi-Fi and Bluetooth', 2021 International Conference on Microwave and Millimeter Wave Technology, ICMMT 2021 - Proceedings [Preprint]. https://doi.org/10.1109/ICMMT52847.2021.9617988.

Hernandez, M. and Mucchi, L. 2014. 'Body Area Networks using IEEE 802.15.6: Implementing the Ultra-Wide Band Physical Layer', Body Area Networks using IEEE 802.15.6: Implementing the Ultra-Wide Band Physical Layer, pp. 1–44. https://doi.org/10.1016/C2011-0-07212-5.

Jasmine Hephzipah, J. et al. 2023. 'A 2.4GHz Rectangular Shaped Patch Antenna for ZigBee Application', Proceedings of the 1st IEEE International Conference on Networking and Communications 2023, ICNWC 2023 [Preprint]. https://doi.org/10.1109/ICNWC57852.2023.10127535.

Karagöz, S. et al. 2021. 'Interval type-2 Fuzzy ARAS method for recycling facility location problems', Applied Soft Computing, 102, p. 107107. https://doi.org/10.1016/J.ASOC.2021.107107.

Mahapatro, J. et al. 2012. 'Interference mitigation between WBAN equipped patients', pp. 1–5. https://doi.org/10.1109/WOCN.2012.6331909.

Manzoor, S. et al. 2019. Understanding Traffic Load in Software Defined WiFi Networks for Healthcare', 2019 IEEE International Conference on Consumer Electronics - Taiwan, ICCE-TW 2019 [Preprint]. Available at: https://doi.org/10.1109/ICCE-TW46550.2019.8991777.

Di Marco, P. et al. 2015. Coverage analysis of Bluetooth low energy and IEEE 802.11ah for office scenario. IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC, 2015-December, pp. 2283–2287. https://doi.org/10.1109/PIMRC.2015.7343678.

Movassaghi, S. et al. 2014. Wireless body area networks: A survey. IEEE Communications Surveys and Tutorials, 16(3), pp. 1658–1686. Available at: https://doi.org/10.1109/SURV.2013.121313.00064.

Muthuvel, S., Rajagopal, S. and Subramaniam, S.K. 2022. 'Analysis of Security Issues in Wireless Body Area Networks in Heterogeneous Networks', Sensors. MDPI. https://doi.org/10.3390/s22197588.

Purat, J. et al. 2022. HaLowNet - A WiFi HaLow network-based information system for the provision of multi-sided applications for medical emergency scenarios. Proceedings - 2022 IEEE 10th International Conference on Healthcare Informatics, ICHI 2022, pp. 519–521. Available at: https://doi.org/10.1109/ICHI54592.2022.00095.

Sarra, E. and Ezzedine, T. 2016. Performance improvement of the wireless body area network (WBAN) under interferences. 2016 IEEE 18th International Conference on e-Health Networking, Applications and Services, Healthcom 2016 [Preprint]. Available at: https://doi.org/10.1109/HEALTHCOM.2016.7749507.

Shanthi, T. et al. 2018. DAC to monitor solar powered home appliances and usage control using bluetooth enabled mobile application and IoT. Proceedings of 2017 International Conference on Innovations in Information, Embedded and Communication Systems, ICIIECS 2017, 2018-January, pp. 1–4. Available at: https://doi.org/10.1109/ICIIECS.2017.8276036.

Singh, V., Sharma, R. and Tomar, M.S. 2013. An analytical study of interference problem between ZigBee and WI-FI. Proceedings - 2013 International Conference on Communication Systems and Network Technologies, CSNT 2013, pp. 257–261. Available at: https://doi.org/10.1109/CSNT.2013.61.

Tavera, C.A. et al. 2021. Wearable wireless body area networks for medical applications. Computational and Mathematical Methods in Medicine, 2021. https://doi.org/10.1155/2021/5574376.

Tüysüz, N. and Kahraman, C. 2023. An Integrated Picture Fuzzy Z-AHP & TOPSIS Methodology: Application to Solar Panel Selection. Applied Soft Computing, p. 110951. https://doi.org/10.1016/J.ASOC.2023.110951.

Wang, Y. 2013. Towards safe usage of COTS wireless devices in medical settings : a profiling - policing framework for WBAN against WiFi interference. https://theses.lib.polyu.edu.hk/handle/200/7262 (Accessed: 19 July 2023).

Więckowski, J., Kizielewicz, B. and Sałabun, W. 2022. pyFDM: A Python library for uncertainty decision analysis methods. SoftwareX, 20, p. 101271. Available at: https://doi.org/10.1016/J.SOFTX.2022.101271.

Wrightson, Tyler. 2012. Wireless network security: a beginner's guide.

Yaghoubi, M., Ahmed, K. and Miao, Y. 2022. Wireless Body Area Network (WBAN): A Survey on Architecture, Technologies, Energy Consumption, and Security Challenges. Journal of Sensor and Actuator Networks 2022, Vol. 11, Page 67, 11(4), p. 67. https://doi.org/10.3390/JSAN11040067.

Zhang, Q., Sun, Y. and Cui, Z. 2010. Application and analysis of ZigBee technology for Smart Grid. Proceedings of ICCIA 2010 - 2010 International Conference on Computer and Information Application, pp. 171–174. https://doi.org/10.1109/ICCIA.2010.6141563.