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Selection of Wireless Communication Technologies for Embedded Devices using Multi-criteria Approach and Expert Opinion

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Research Article

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ABSTRACT: Recent research has shown the significance of communication technologies in the development of embedded systems and devices. Decision makers may be impacted by several factors while selecting the best solution since different communication technologies in embedded systems have varying advantages and disadvantages. As a result, selecting the optimal wireless communication technology is a multifaceted task. In order to rank the prevalent wireless communication technologies relevant to the development of embedded systems, this research suggests a multi-criteria decision making (MCDM) approach for analyzing experts' perspectives on the most desirable wireless communication technologies for embedded devices. To take into consideration the subjective nature of expert opinions, a Fuzzy-TOPSIS MCDM approach is proposed for the ranking of wireless communication technologies that may be applied in the creation of embedded systems. According to the total of expert responses, Wi-Fi is the most preferred wireless communication option for embedded applications, with a closeness coefficient (CCi) of 0.52, while Long-Term Evolution (LTE) is the least preferred alternative, with a (CCi) of 0.32.

KEYWORDS: Wireless communication, Embedded systems, Internet of Things, Long-Term Evolution, Fuzzy-TOPSIS

INTRODUCTION

The idea of smart devices and the Internet of Things has advanced significantly toward a level that is realistically attainable because to the widespread use of communication technologies (both wired and wireless) in embedded system architecture. The concept of embedded systems, which first surfaced many years ago, started to take form when significant advancements in a variety of fields started using wireless communication technologies, such as electricity, electrical equipment, and household appliances, to name a few. Through the employment of smart devices powered by embedded system upgraded tools and technologies, almost every aspect of life, including agriculture, education, textiles, health, and energy, is advancing toward achieving the sustainable development objectives today (Adetunji, et al., 2022). The topic of communication is a rapidly evolving and fascinating area of technology. The transfer of data and information from one location to another without the need of physical media like cables and wires is known as wireless communication (Teja and Mishra, 2021). A communication system is often defined by the conveyance of information from a transmitter to a receiver across a finite distance. Similar to a television remote control or a few thousand miles of satellite communication, a transmitter and receiver may be placed anywhere within a few meters.

Since embedded devices and wireless communication have been around for decades, the former's incorporation in the

Interoperable and bidirectional communication has been made possible by the latter's functions. Wireless technologies are driving important aspects like energy optimization and efficiency, security, automation, and integration of smart and intelligent devices provided to end users. In the end, this leads to a variety of applications that improve the world. The issues of choosing the optimum wireless technology for exceptional distribution of embedded devices via real-world applications are addressed in this paper. The ease of use of inexpensive embedded devices and advancements in wired and wireless communication have led to the proliferation of several application areas, including remote internet of things in central heating systems. Global Positioning Systems (GPS), home appliances (dishwashers, TVs, digital phones and accessories, digital watches), electronic calculators, fitness trackers, and automobile engine management systems are all examples of this. Unlike integrated components, which offer a broad variety of automation applications and good security features, existing appliances are based on separate functions with limited remote, interoperable, and smart capabilities.

When new wireless communication technologies are suggested for embedded systems, engineers often have to decide which is the best option since each has advantages and disadvantages. In addition to their technological advantages and disadvantages, engineers take into account a variety of characteristics pertaining to cost and usability. The aforementioned makes it clear that engineers must consider competing factors when selecting wireless communication methods for embedded systems; these situations give rise to what is referred to as a multi-criteria decision making dilemma. This paper's main goal is to provide engineers and other stakeholders a framework for choosing the best wireless communication technologies based on several criteria in order to build a top-notch embedded device design. Bluetooth, Long-Term Evolution (LTE), Z-wave, Classic WaveLAN, Wi-Fi, and Zigbee are a few of the technologies examined in this book. These technologies are chosen according to their applicability and embedded device design characteristics, including Transmission Speed (TS), Security, Transmission Range (TR), Power Usage (PU), Development Cost (DC), and Development Complexity (DCOP). This article provides a thorough discussion of the multi-criteria process used in the selection of wireless communication technology, along with illustrative examples and future study.

I. BRIEF OVERVIEW OF WIRELESS COMMUNICATION TECHNOLOGIES

Wireless communication and embedded systems are becoming more and more common. Wireless communication networks are used for a variety of reasons, such as internet browsing on personal computers and mobile devices, as well as general-purpose portable devices that are reasonably priced in different parts of the globe (Gäwerth, 2017). Furthermore, the capacity to link and integrate several services at affordable costs is one of the main advantages of wireless networks (Silva-Pedroza et al, 2017). Similar fields of embedded devices and wireless technologies have been studied by a number of researchers. Numerous factors may be taken into consideration while choosing the best communication method for embedded device design. Making this selection is difficult, particularly when it comes to the technology's TS, Security, TR, PU, DC, and DCOP (Gore and Valsan, 2018). This goal is important for embedded device engineers, programmers, and developers because it helps them make an informed decision by comparing different technologies rather than making a decision without considering different factors that could improve the device in question (Adebisi and Abdulsalam, 2021). This is a fantastic improvement for making various decisions that will be very beneficial not only during the design and development phases but also lead to ongoing product growth, compatibility issues being fixed, ease of maintenance and repairs, upgrading when necessary, enhanced security, and scaling up of developed embedded devices. Making a poor decision on the technology that powers embedded devices might have devastating consequences.

Ghamari et al. (2015) studied wireless communications in embedded solutions and Micro-Electro-Mechanical Systems (MEMS). Blood pressure, heart rate, and glucose levels were measured using embedded health monitoring devices such Body Area Networks (BANs) that are implanted in the body. Wireless connection was used to convey data for every parameter. The authors demonstrated that choosing wireless communication involves a number of factors, including data transmission energy usage. The effort related to existing and developing minimum-power communication protocols that are suitable for BAN implementation. Similar to this, the Institute of Electrical and Electronics Engineers (IEEE) listed Local Area Network-LAN (Wi-Fi), WiMAX, the Global System for Mobile Communications (GSM) 3G/4G cellular, Power Line Communications (PLC), and Zigbee were among the major communication technologies discussed in (Usman & Shami, 2013), though there was no focus on the best option.

However, in order to support contemporary progress, these communications technologies concentrated on the implementation of smart grid realisation. In embedded device-driven technologies including metering, home area, substation, and infrastructure automation, among others, it focused on the use of both wired and wireless technology. Choosing the best communication technology to support the many potential in recognised smart grid technologies is one of the difficulties mentioned in the study of Usman and Shami (2013). Kos et al. (2019) investigated the use of wearable technology, wireless networks, sensors, and the internet of things in a biofeedback solution tailored to sports. A person's use of feedback information is influenced by the biofeedback. The authors highlighted a number of wireless technologies (actuators and sensors) that are often used in the design of embedded sport-related devices. The key designs of a typical biofeedback system were used to highlight the most significant limitations in the choice of pertinent technology. In order to match appropriate and scalable wireless technologies that may provide higher data rates over an extended period of time, the researchers took into consideration illustrative cases with particular sporting events. Based on the scenarios, the work's outcome showed that the selected wireless technologies do not meet the requirements of biofeedback solutions.

Additionally evaluated were studies on embedded devices such as intelligent transport systems and modelling analysis for heart attacks (life-threatening cardiac illnesses) (Dar et al., 2010). With a focus on the most effective communication interface for the intended solutions, the authors investigated current wireless communication technologies and their potential for future applications. The unique characteristics of embedded electrocardiogram (ECG) devices need clever algorithms that are powered by low energy consumption and ongoing signal monitoring for useful applications. Three potential models of data transmission for energy consumption in a simulated environment were investigated by Kim et al. (2021) and Ma et al. (2015), and their computational efficiency reached up to 84.67% every 508 s of data segment. When combined with unique features, wireless communications and sensors are often used in e-commerce, security, and healthcare.

confronted with several obstacles in terms of decision-making. Furthermore, Lin et al. (2004) noted that some of the strict requirements in the selection of wireless technologies utilised for embedded device design and packaging include restricted energy supply, data transmission rate, creative design approaches, and certain operational characteristics.

According to the research, choosing the best wireless communication technology for embedded system architecture has long been a difficult task. These days, poor wireless technology selection might result in worse Quality of Service (Qos) when sensitive applications like robotic and critical control systems are deployed (Calvo et al., 2021). As highlighted in Kavnuch et al. (2020), the suggested multi-criteria selection technique in this study can help improve understanding of wireless technology choice based on important criteria with consideration of defined rules, particularly when it comes to real-life solutions.

The appropriate selection of communication technology is necessary given the speed at which technological advancements are occurring. The majority of tools are similar in terms of their impact and behaviour when used. Even if new technologies have emerged, the old ones are still very much in use; they are not replaced but rather provide for more options and enhanced features. However, depending on the preferences and standards of product designers, new communication technologies provide a certain amount of competition to the current tools. A number of wireless communication technologies, such as General Packet Radio Services (GPRS), Edge, 3G, and 4G, are extensively used in embedded sensor devices for real-time applications in sports, e-commerce, health, agriculture, and education. Based on the necessary requirements, the following widely used wireless technologies were investigated in this study to determine the optimal choice.

A. Bluetooth

This is a wireless communication technology (packet-based protocol) used for short distance communication. They are popularly deployed in Personal Area Networks (PAN). It is a standard IEEE 802.15.1 and it is commonly found in mobile devices and headsets, with the operation range of 2.4 GHz allowable for data exchange within 100 m. It enables data transmission in a strong manner using a frequency-hopping spread spectrum. Bluetooth uses the same hopping arrangement in the assignment of address spaces. With the presence of profile and core specification, it manages required functions to acclimatize new technology and applications. The interpretation of individual Bluetooth profile is very germane to the usage of Bluetooth wireless technology. Certain behaviour needs to be enabled for devices to communicate through settings and parameters. Many different applications described different cases of Bluetooth profiles. This technology is largely compactible, simple and one of the most common wireless technologies.

B. LTE

Sometimes referred to as fourth generation Long Term Evolution (4G LTE). Allows data transmission and download of contents especially media in very fast and standard mode than previous technologies. It is specifically designed to increase speed capacity on mobile networks (Figure 1). Extremely characterized with very high performance for cellular communication devices, LTE comes at relatively reduced cost, offers flexibility, simplified architecture, and realistic power consumption with more services. The incorporation of Orthogonal Frequency Division Multiplex (OFDM) into LTE strengthens the bandwidth to be conveyed proficiently. Most of the main challenges of previous technologies which arose from multiple signals are addressed in LTE. It essentially provides increased throughput coupled with very high resilience to reflections and interference while routing data directly to its destination.

C. Z-wave

This is a wireless communication technology that supports interoperability especially at the application layer of the OSI model. Since embedded devices share information between hardware and software, the place of z-wave cannot be over emphasized in allowing hardware to interoperate with software. It has the capability of achieving data rate of 40 and 100 kbit/s providing cloud access through gateway (Z-wave bridge). They are embedded device protocols that are implemented on chips with frequency specification of sub-1 GHz band between 865 to 926 MHz routed through network architecture while the physical range covers up to 100 m. It functions more within low-power Radio Frequency Identification (RFID) communication with a reasonable support for home automation.

D. Classic WaveLAN

This is a wireless communication technology that uses 64-bit and 128-bit data encryption technology. It is used in different families of wireless communication, it was a proprietary protocol before the advent of 802.11. It is one of the technologies that led to the creation of Wi-Fi, and it is established with a goal to provide more security and confidentiality when compared to wired technologies. The first application was named Wired Equivalent Privacy (WEP). It is well matched with other monitoring and communication management wireless technologies, it is good for domestic and commercial areas. The major advantage is the provision of reliable transmission for not too long messages from one unit to other nodes on the network. It gives room for full-type topology without a coordinator (Krapivina *et al*., 2019).

E. Wifi

This is a technology that translates radio signals from wireless router to devices that are not too far from each other into meaningful data. It is simply an internet connection medium shared with many devices within a home or commercial areas. Wi-Fi enabled devices receive internet connections directly from router or MODEM during broadcast. As long as users are within the network range, Wi-Fi gives network constant connectivity known as IEEE 802.11 which uses radio waves for transmission. The

application can be found in various devices (embedded and non-embedded) such as smartphone and other mobile devices, computers, televisions among others. Since communication occurs over airwaves, the devices and other information can be at security

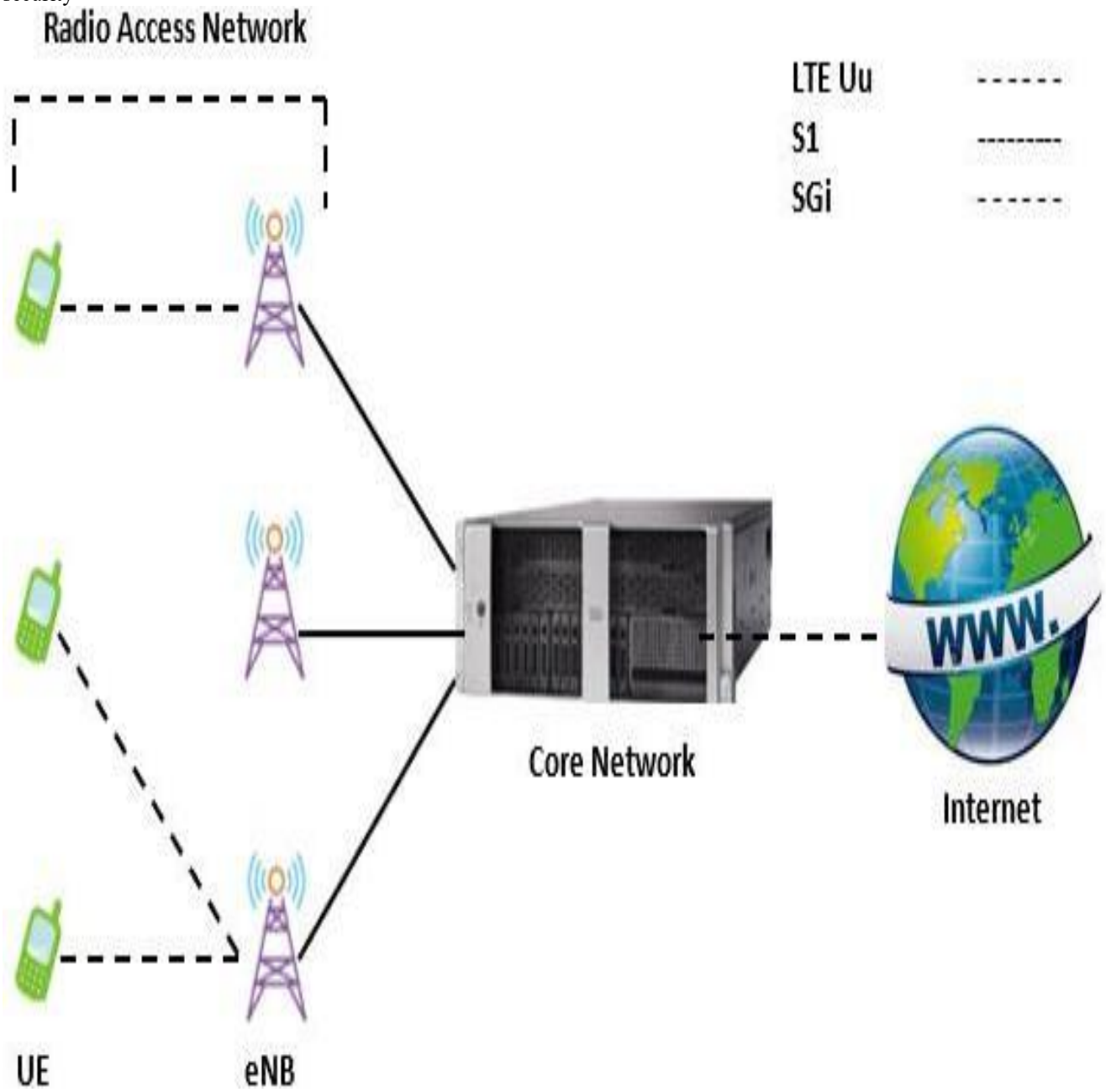


Figure 1: LTE Network Diagram Source: Adapted from (Stiller *et al*., 2020).

II. METHODOLOGY

risk, exposed to hackers (cyber-attacks) among other threats. This become very challenging when using devices with free or public channels that are not password protected. Implemented with a security feature, Wi-Fi performances are very good in collective spectrum and noisy RF channel atmosphere. In Wi-Fi communication technology, IP based protocols are used (point-to-point and point-to-multipoint). Table 1 provides a summary of the wireless communication technology alternatives and their additional features.

The methodology developed to implement the aim of this research is presented in this section. Shown in Figure 2 is the proposed framework for the selection of wireless communication technologies for embedded devices. This proposed framework deploys the distinctive features of Fuzzy-TOPSIS techniques. The aggregation method was used to evaluate the significance/weight of evaluation criteria based on expert opinion. Ranks for the wireless communication technologies are calculated using the fuzzy-TOPSIS method. In the proposed framework, experts' viewpoints generate the information used for the proposed model appraisal.

Table 1: Standardized wireless technologies with details.

Technology	Frequency	Range	Bit rate	TX Power
Bluetooth	2.4GHz	10-100m	1-3Mbits/s	2.5-100mW
Zigbee	867MHz and 2.4GHz	10-100m	20-250kbits/s	1-100mW
Wifi	2.4GHz	70m	600Mbits/s	100mW
Classic WaveLAN	2.4GHz	45	600Mbits/s	32mW
Z-wave	800-900MHz	100m	100kbits/s	1mW
LTE	20MHz	1732m	299.6Mbits/s	200mW
Criteria Used in this study				
Transmission Speed (C_1), Security (C_2), Transmission Range (C_3), Power Usage (C_4), Development Cost (C_5), and Development Complexity (C_6)				

F. *Zigbee*

Zigbee is a wireless communication technology with applications in monitoring and control of various equipment. It has the capacity to monitor online parameters working with different factors with absolute security. Its strong authentication process (128-bit AES Encryption) between communicating devices is amazing. In addition to embedded devices and consumer electronics; other usage of Zigbee found its place in healthcare, building automation, energy

A. *Fuzzy TOPSIS*

TOPSIS Multiple-criteria Decision Making (MCDM) approach is based on the ideology that the most suitable or best alternative must have the shortest distance to Positive Ideal Solution (PIS) while the least preferred alternative usually have the farthest distance to Negative Ideal Solution (NIS). As an extension of the TOPSIS method, Chen, (2000) implemented a vertex approach to estimate the distance between two triangular fuzzy numbers as defined in Eqn. (1).

management and efficiency, industrial control and telecommunication services. Most often Zigbee appears as a

$$d(\tilde{x},\tilde{y}) := \sqrt{\frac{1}{3}\left[(a_1-a_2)^2+(b_1-b_2)^2+(c_1-c_2)^2\right]} \quad (1)$$

choice when it comes to Home Area Network (HAN) at the domestic level. It is a platform for communication with low power consumption though within a little range/small data rate. The communication technology can connect up to two hundred and fifty-four devices. It is flexible, scalable and maintainable.

$\tilde{x} = (a_1, b_1, c_1), \tilde{y} = (a_2, b_2, c_2)$ is specified as two triangular fuzzy numbers.

According to Chen (2000) The procedures in the realization of the Fuzzy-TOPSIS technique includes:

Step 1: Allocate ratings to the relationship between the alternatives and their criteria. Suppose opinion is taken from *P*

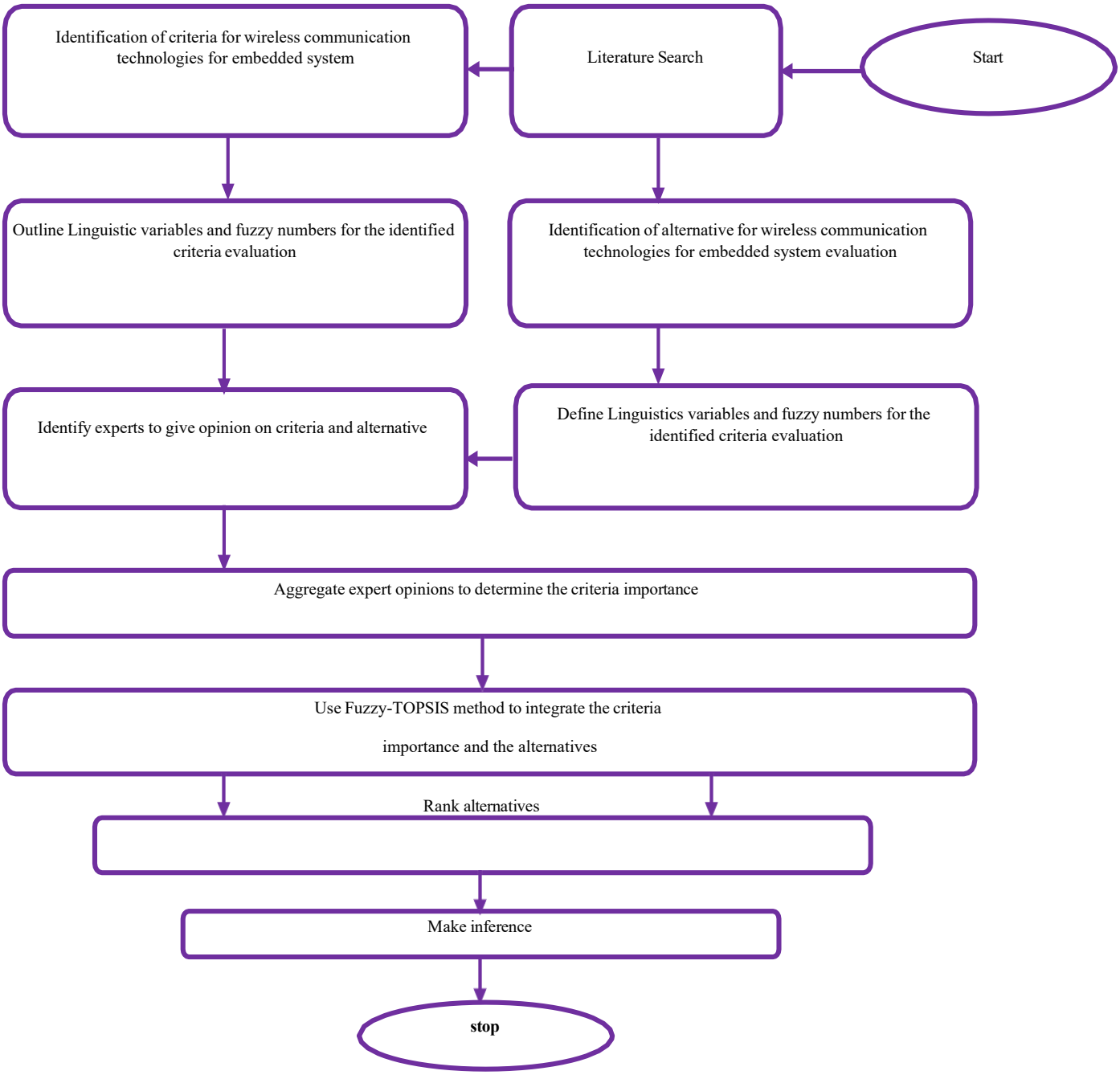


Figure 2: Proposed framework for the selection of wireless communication technologies for embedded devices

The criteria considered are Transmission Speed (C_1), Security (C_2), Transmission Range (C_3), Power Usage (C_4), Development Cost (C_5), and Development Complexity (C_6). Using the 10-point linguistic term presented in Figure 3, the expert were consulted to rank the relationship between the identified technologies and the selected criteria.

Figure 3: Ten-point fuzzy scale adopted in this study.

Legend

Not Important/Extremely Low -NI/EL
Very V.ery Less Important/ Low - VVLI/L
Very Very Less Important/ Low -VVLI/L
Very Less Important/ Below Average - VLI/BA
Less Important/ Average -LI/A
Important/Above Average - I/AA
More Important/ High - MI/H
Very More Important/Very High-VMI/VH
Very Very More Important/ Very Very High - VVMI/VVH
Extremely More Important/ Extremely High - EMI/EH

Table 2: Expert opinion on wireless technologies for embedded systems.

P1

	C_1	C_2	C_3	C_4	C_5	C_6
W_1	VVH	AA	VH	L	A	VH
W_2	L	EH	VH	A	H	H
W_3	H	H	AA	VL	A	H
W_4	VH	H	VH	A	H	AA
W_5	H	H	H	A	A	AA
W_6	VH	H	H	AA	AA	AA

P2

	C_1	C_2	C_3	C_4	C_5	C_6
W_1	VVH	EH	VH	EH	VVH	EH
W_2	H	H	VVH	VVH	VVH	EH
W_3	AA	H	EH	VVH	VVH	VVH
W_4	EH	VH	H	VH	AA	VH
W_5	VH	VVH	EH	EH	VH	VVH
W_6	H	H	VVH	AA	H	H

P3

	C_1	C_2	C_3	C_4	C_5	C_6
W_1	H	H	VH	H	A	VH
W_2	H	VH	VH	H	A	VH
W_3	EH	AA	L	BA	VH	AA
W_4	H	AA	H	H	AA	VH
W_5	H	EH	AA	H	AA	VVH
W_6	H	H	AA	H	AA	H

P4

	C_1	C_2	C_3	C_4	C_5	C_6
W_1	VH	AA	High	VH	H	VH
W_2	VVH	AA	VVH	VH	VH	VH
W_3	A	AA	A	A	A	A
W_4	EH	VH	EH	EH	EH	EH
W_5	VH	VH	VH	VH	VH	VH
W_6	H	H	H	H	H	H

P5

	C_1	C_2	C_3	C_4	C_5	C_6
W_1	VVH	AA	VVH	VH	H	VH
W_2	VH	VH	VH	VH	VH	VH
W_3	VH	VVH	VH	VVH	VH	VVH
W_4	VH	H	VH	VH	VH	VH
W_5	H	VVH	VH	VH	VH	VH
W_6	VVH	VH	VH	VH	VH	VH

The relationship between the alternatives and criteria is used to form the intuitionistic fuzzy decision matrix (Mahase *et al*., 2016). A total of five experts (P1-P5) in the area of wireless technologies were selected from both the industry and the academia to give their professional opinion on the subject. This was done through the use of a well-structured questionnaire where experts were encouraged to evaluate alternative solutions according to the indicated criteria using the 10-point rating scale. The 10-point fuzzy rating scale was adopted so has to accommodate the fuzzy nature of the responses that would be supplied by the experts.

With each expert allocated the same weight, the responses of the five experts with respect to the wireless network alternatives are given in Table 2. The responses of the experts were presented in linguistic terms and then converted to triangular intuitionistic fuzzy numbers. Basic fuzzy number operators were used to combine the responses of the experts on the relationship between the alternatives and the criteria and their opinion on the proper weights that should be allocated to the criteria.

The results of the aggregated opinion of the experts with respect to the technologies are presented in Table 3 while the aggregated responses on the weights of the criteria are presented in Table 4. To obtain the weighted normarlized decision matrix (Table 5), the results of the combined decision matrix is used to multiply (using the fuzzy operator) aggregated responses on the weights of the criteria.

To obtain the distance from each alternative to the fuzzy PIS and fuzzy NIS Eqns. 1 and 8-1 are combined and deployed. The result of this step is presented in Table 6. Furthermore, the closeness coefficient for each alternative is calculated and used in the ranking of the wireless alternatives. From Table 7, based on the experts' opinion, the most preferred wireless technology for embedded system application is the Wifi becuase; it has the highest closeness coefficient. The next most preferred wireless technology is the Z-wave with a closeness index of 0.5, followed by Bluetooth, classic Wave, LAN, and Zigbee respectively. The least preferred wireless technology for embedded system is the LTE with a closeness index of 0.26.

CONCLUSION

An assessment of some of the current wireless communication technologies that may be used to the creation, use, and application of embedded devices was provided in this article. Expert views and multi-criteria decision-making analysis have been used in prior research to rank different wireless communication technologies according to different criteria. varied stakeholders have varied goals to achieve in the development of embedded devices, which might be converted into requirements for acquiring the most favored wireless communication technologies (alternatives). Six wireless communication technologies—Bluetooth ($W1$), LTE ($W2$), Z-wave ($W3$), Classic

Table 3: Combined results of expert opinion.

	C_1	C_2	C_3	C_4	C_5	C_6
W_1	(4,6,9)	(4,6,10)	(1,3.6,8)	(2,5,8)	(1,4.8,8)	(1,6.6,10)
W_2	(5,7.8,are)	(6,8,10)	(2,8,10)	(6,8.6,10)	(4,7.4,10)	(5,8.2,10)
W_3	(4,6.8,10)	(5,7.4,10)	(4,6.8,9)	(1,6,10)	(3,6,9)	(6,8,10)
W_4	(2,7.4,10)	(3,7,10)	(4,7.2,9)	(1,6.6,10)	(5,7,10)	(4,7,10)
W_5	(7,8.8,10)	(6,8.6,10)	(6,8,10)	(2,7,10)	(2,6.6,10)	(3,7.2,10)
W_6	(4,6.8,9)	(5,7.2,10)	(2,5.4,10)	(3,5.6,10)	(2,5,8)	(2,5.6,8)

Table 4: Combined weights of criteria.

Criteria	Importance of criteria					Combined weight
	P1	P2	P3	P4	P5	
C_1	VVMI	MI	I	MI	VMI	(5,8,10)
C_2	EMI	VVMI	I	EMI	VMI	(5,8.8,10)
C_3	VMI	EMI	I	VMI	VMI	(7,9.2,10)
C_4	VMI	EMI	VVMI	I	MI	(6,8.8,10)
C_5	VVMI	VMI	EMI	I	VMI	(4,7,10)
C_6	MI	VVMI	EMI	VMI	VMI	(4,6.2,8)

Table 5: weighted normalized fuzzy decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6
W_1	(2.00, 4.80, 9.00)	(2.00, 5.28, 10.00)	(0.70, 3.31, 8.00)	(0.75, 1.76, 5.00)	(0.50, 1.46, 10.00)	(0.40, 0.61, 8.00)
W_2	(2.50, 6.24, 10.00)	(3.00, 7.04, 10.00)	(1.40, 7.36, 10.00)	(0.60, 1.02, 1.67)	(0.40, 0.95, 2.50)	(0.40, 0.49, 1.60)
W_3	(2.00, 5.44, 10.00)	(2.50, 6.51, 10.00)	(2.80, 6.26, 10.00)	(0.60, 1.47, 10.00)	(0.44, 1.17, 3.33)	(0.40, 0.50, 1.33)
W_4	(1.00, 5.92, 10.00)	(1.50, 6.16, 10.00)	(2.80, 6.62, 9.00)	(0.60, 1.33, 10.00)	(0.40, 1.00, 2.00)	(0.40, 0.57, 2.00)
W_5	(3.50, 7.04, 10.00)	(3.00, 7.57, 10.00)	(4.20, 7.36, 10.00)	(0.60, 1.26, 5.00)	(0.40, 1.06, 5.00)	(0.40, 0.56, 2.67)
W_6	(2.00, 5.44, 9.00)	(2.50, 6.34, 10.00)	(1.40, 4.97, 10.00)	(0.60, 1.57, 3.33)	(0.50, 1.40, 5.00)	(0.50, 0.71, 4.00)
A*	(3.50, 7.04, 10.00)	(3.00, 7.57, 10.00)	(4.20, 7.36, 10.00)	(0.75, 1.76, 10.00)	(0.50, 1.46, 10.00)	(0.50, 0.71, 8.00)
A-	(1.00, 4.80, 9.00)	(1.50, 5.28, 10.00)	(0.70, 3.31, 8.00)	(0.60, 1.02, 1.67)	(0.40, 0.95, 2.00)	(0.40, 0.49, 1.33)

Distance from FPIS

	C_1	C_2	C_3	C_4	C_5	C_6
W_1	1.66	1.44	3.30	2.89	0.00	6.08
W_2	0.74	0.30	1.62	4.83	4.34	4.42
W_3	1.27	0.67	1.18	0.19	3.85	4.40
W_4	1.58	1.19	1.08	0.26	4.63	4.45
W_5	0.00	0.00	0.00	2.90	2.90	4.53
W_6	1.39	0.77	2.13	3.85	2.89	4.73

Distance from FNIS

	C_1	C_2	C_3	C_4	C_5	C6
W_1	0.58	0.29	0.00	1.97	4.63	3.85
W_2	1.33	1.34	2.64	0.00	0.29	0.15
W_3	0.90	0.92	2.17	4.82	0.78	0.01
W_4	0.87	0.51	2.34	4.81	0.03	0.39
W_5	2.02	1.58	3.30	1.93	1.73	0.77
W_6	0.69	0.84	1.55	1.01	1.75	1.55

Table 7: Final ranking.

Alternative	d_i^*	d_i^-	CC_i	Rank
W_5	10.33	11.33	0.52	1
W_3	11.57	9.58	0.45	2
W_1	15.37	11.32	0.42	3
W_4	13.19	8.95	0.40	4
W_6	15.75	7.39	0.32	5
W_2	16.25	5.75	0.26	6

(1) Transmission Speed; (2) Security; (3) Transmission Range; (4) Power Usage; (5) Development Cost; and (6) Development Complexity. Since each option has advantages and disadvantages, it was necessary for this research to examine how to choose and rate the best wireless communication option for embedded device development. The experts in this research were given equal weights. According to expert opinion, Wi-Fi, which has the highest closeness

coefficient of 0.52, is the most preferred wireless technology alternative for embedded systems, while LTE technology, which has the lowest closeness coefficient of 0.32, is the least preferred option.

Additional research is being conducted to rate the wireless communication technologies only according to the technical characteristics listed in the user's manual and compare the findings with the views of experts. This will include comparing how different MCDM tools are used to the same topic.