Research Article

Research on Evaluating Algorithms for the Service Quality of Wireless Sensor Networks Based on Interval-Valued Intuitionistic Fuzzy EDAS and CRITIC Methods

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Wireless sensor networks play an important role in economic production and social life. However, in recent years, the number of wireless sensor network vulnerabilities has been increasing rapidly, which makes wireless sensor networks face more and more severe challenges. It is of great significance to realize the quantitative evaluation of wireless sensor networks in order to maintain the service quality of wireless sensor networks more effectively. The evaluating problem of the service quality of wireless sensor networks is a kind of multiple attribute group decision-making (MAGDM) problem. In this paper, depending on the classical EDAS method, the EDAS method will be extended to interval-valued intuitionistic fuzzy sets (IVIFSs) to address some MAGDM issues. At first, some essential concepts of IVIFSs are briefly reviewed. Subsequently, relying on the CRITIC method, the attributes' weights are decided. Furthermore, integrating the EDAS method with IVIFSs, IVIF-EDAS method is established, and all calculating procedures are depicted. Finally, an empirical application for evaluating the service quality of wireless sensor networks is given to demonstrate this novel algorithm, and some comparative analyses are made to confirm the merits of the designed method.

1. Introduction

In order to improve the accuracy of real-life decision-making, Zadeh [1] initially designed the fuzzy sets (FSs). Atanassov [2] designed the intuitionistic fuzzy sets (IFSs), which could be a generalization of FSs. In IFSs, there are three mathematical functions expressing the degrees of membership, nonmembership, and hesitancy. And they must satisfy the only condition that their sum of three degrees cannot exceed one. Gou et al. [3] pointed out a novel exponential operational law about IFNs and offered a method which was utilized to aggregate intuitionistic fuzzy information. He et al. [4] integrated the power averaging operators with IFSs and defined several intuitionistic fuzzy power interaction aggregation operators. Zhang and He [5] defined the extensions of intuitionistic fuzzy geometric interaction operators by using the t -norm and the corresponding t -conorm means. Li and Wu [6] presented the

intuitionistic fuzzy cross-entropy distance and the GRA. Liang et al. [7] extended the MABAC method to IFSs by utilizing the novel distance measures. Khan and Lohani [8] put forward a novel similarity measure about IFNs depending on the distance measure of the double sequence of bounded variation. Chen et al. [9] developed the novel MCDM method based on the TOPSIS method and similarity measures in the context of IFSs. Li et al. [10] developed a grey target decision-making method in the form of IFNs on the basis of grey relational analysis [11]. Garg [12] developed some intuitionistic fuzzy averaging operators by taking the degrees of hesitation between the membership mathematical functions into consideration. Gupta et al. [13] extended the fuzzy entropy [14] to IFSs with axiomatic justification and proposed the importance of parameter alpha. Bao et al. [15] put forward the prospect theory and the evidential reasoning method under IFSs. Gan and Luo [16] employed a hybrid method on the basis of DEMATEL and IFSs. Gupta et al. [17]

modified the superiority and inferiority ranking (SIR) method and combined it under IFSs. Krishankumar et al. [18] developed IFSP (intuitionistic fuzzy set-based PROMETHEE) which was a novel ranking method. Luo and Wang [19] combined IFSs with the VIKOR method relying on a novel distance measure by taking the IFSs into consideration. Hao et al. [20] presented the novel intuitionistic fuzzy MADM method depending on the decision theory. Zhang et al. [21] defined the intuitionistic fuzzy TOPSIS method based on CVPIFRS models with an application to biomedical problems. Garg [22] developed the generalized intuitionistic fuzzy entropy-based approach for solving multiattribute decision-making problems with unknown attribute weights. Liu et al. [23] presented some novel intuitionistic fuzzy operators by extending the BM operator on the basis of the Dombi operations [24] and designed some MAGDM methods. Jin et al. [25] developed two group decision-making (GDM) methods which could obtain the normalized intuitionistic fuzzy priority weights from the designed IFPRs on the basis of the order consistency and the multiplicative consistency. Wu et al. [26] gave VIKOR algorithms for assessing the financing risk about rural tourism projects under IVIFSs. Wu et al. [27] designed the algorithms for evaluating the competitiveness of tourist destination with some IVIF Hamy mean operators. Wu et al. [28] proposed some IVIF Dombi Heronian mean operators for evaluating the ecological tourism value. Chen and Kuo [29] presented the novel MADM method using the nonlinear programming (NLP) model with hyperbolic tangent function and IVIFSs. Lu and Wei [30] proposed the TODIM method for social-integration-based rural performance appraisal under IVIFSs and integrated the ELECTRE method with IFSs to tackle some MCDM issues. Garg and Kumar [31] defined the group decision-making approach based on possibility degree measures and the linguistic intuitionistic fuzzy aggregation operators using Einstein norm operations. Garg and Arora [32] proposed the generalized intuitionistic fuzzy soft power aggregation operator based on the t -norm and its application in multicriteria decision-making.

Keshavarz Ghorabae et al. [33] designed the evaluation based on distance from average solution (EDAS) to solve multicriteria inventory classification (MCIC) issues. In recent years, this method was enriched by the related extensions. For example, Ghorabae et al. [34] modified such an EDAS method to tackle supplier selection issues. Keshavarz Ghorabae et al. [35] presented the EDAS method with normal distribution to tackle stochastic issues. Peng and Liu [36] designed the neutrosophic soft MADM algorithms on the basis of EDAS and defined the similarity measure. Kahraman et al. [37] integrated the EDAS method with IFSs to select the solid waste disposal site. He et al. [38] designed the EDAS model for MAGDM with PULTSs. Keshavarz Ghorabae et al. [39] made some comparative analyses about the phenomenon of order reversal depending on EDAS and TOPSIS. Wang et al. [40] proposed the EDAS model for MAGDM under the 2-tuple linguistic neutrosophic environment. Li et al. [41] defined the EDAS for MAGDM issues under the q-rung

orthopair fuzzy environment. Feng et al. [42] integrated the EDAS with the extended hesitant fuzzy linguistic environment. Karasan and Kahraman [43] designed the interval-valued neutrosophic EDAS to decision-making issues.

Unfortunately, we failed to find the work of the EDAS method based on the CRITIC method with IVIFSs in the existing literature. So, investigating the EDAS method with IVIFSs is essential. The fundamental objective of our research is to develop an original method which can be more effectively to address some MAGDM issues in the context of the EDAS method and IVIFSs. Hence, the highlights of this work are illustrated subsequently. Above all, the EDAS method is extended to the IVIFSs. In addition, because the DMs are restrained by their knowledge, it is tricky to assign the criteria weights directly. Hence, the CRITIC method is utilized to decide each attribute's weight. Last but not the least, an empirical application is offered to demonstrate this novel approach, and several comparative analyses are offered to demonstrate some merits of the novel approach.

However, there are no studies on the EDAS method for MAGDM under IVIFSs in the existing literature. Therefore, it is necessary to pay attention to this issue. The innovativeness of the paper can be summarized as follows: (1) the EDAS method is modified by IVIFSs; (2) the interval-valued intuitionistic fuzzy EDAS (IVIF-EDAS) method is designed to solve the MAGDM issues with IVIFSs; (3) a case study for evaluating the service quality of wireless sensor networks is designed to prove the developed method; and (4) some comparative studies are given to verify the rationality of the IVIF-EDAS method.

The reminder of our essay proceeds as follows. Some fundamental knowledge of IVIFSs is concisely reviewed in Section 2. The extended EDAS method is integrated with IVIFSs, and the calculating procedures are simply depicted in Section 3. An empirical application for assessing the service quality of wireless sensor networks is given to show the superiority of this approach, and some comparative analyses are offered to prove some merits of such a method in Section 4. At last, we make an overall conclusion of such a work in Section 5.

2. Preliminaries

Definition 1 (see [2]). The interval-valued IFSs (IVIFSs) on X are the object of the form

$$I = \{ \langle x, \tilde{\mu}_I(x), \tilde{\nu}_I(x) \rangle \mid x \in X \}, \quad (1)$$

where $\tilde{\mu}_I(x) \subset [0, 1]$ is the “membership degree of I ” and $\tilde{\nu}_I(x) \subset [0, 1]$ is named the “nonmembership degree of I ,” and $\tilde{\mu}_I(x)$ and $\tilde{\nu}_I(x)$ meet the mathematical condition: $0 \leq \sup \tilde{\mu}_I(x) + \sup \tilde{\nu}_I(x) \leq 1, \forall x \in X$. For convenience, we call $I = ([\mu^L, \mu^R], [\nu^L, \nu^R])$ as an IVIFN.

Definition 2 (see [44]). Let $I_1 = ([\mu_1^L, \mu_1^R], [\nu_1^L, \nu_1^R])$ and $I_2 = ([\mu_2^L, \mu_2^R], [\nu_2^L, \nu_2^R])$ be two IVIFNs; the operation formula of them can be defined as follows:

$$I_1 \oplus I_2 = ([\mu_1^L + \mu_2^L - \mu_1^L \mu_2^L, \mu_1^R + \mu_2^R - \mu_1^R \mu_2^R], [\nu_1^L \nu_2^L, \nu_1^R \nu_2^R]), \quad (2)$$

$$I_1 \otimes I_2 = ([\mu_1^L \mu_2^L, \mu_1^R \mu_2^R], [\nu_1^L + \nu_2^L - \nu_1^L \nu_2^L, \nu_1^R + \nu_2^R - \nu_1^R \nu_2^R]), \quad (3)$$

$$\lambda I_1 = ([1 - (1 - \mu_1^L)^\lambda, 1 - (1 - \mu_1^R)^\lambda], [(\nu_1^L)^\lambda, (\nu_1^R)^\lambda]), \quad \lambda > 0, \quad (4)$$

$$I_1^\lambda = ([(\mu_1^L)^\lambda, (\mu_1^R)^\lambda], [1 - (1 - \lambda_1^L)^\lambda, 1 - (1 - \lambda_1^R)^\lambda]), \quad \lambda > 0. \quad (5)$$

Derived from Definition 2, the following properties of the operation laws can be obtained:

- (1) $I_1 \oplus I_2 = I_2 \oplus I_1$, $I_1 \otimes I_2 = I_2 \otimes I_1$, $((I_1)^{\lambda_1})^{\lambda_2} = (I_1)^{\lambda_1 \lambda_2}$
- (2) $\lambda(I_1 \oplus I_2) = \lambda I_1 \oplus \lambda I_2$, $(I_1 \otimes I_2)^\lambda = (I_1)^\lambda \otimes (I_2)^\lambda$
- (3) $\lambda_1 I_1 \otimes \lambda_2 I_1 = (\lambda_1 + \lambda_2) I_1$, $(I_1)^{\lambda_1} \otimes (I_1)^{\lambda_2} = (I_1)^{(\lambda_1 + \lambda_2)}$

Definition 3 (see [45]). Let $I_1 = ([\mu_1^L, \mu_1^R], [\nu_1^L, \nu_1^R])$ and $I_2 = ([\mu_2^L, \mu_2^R], [\nu_2^L, \nu_2^R])$ be IVIFNs; the score and accuracy values of I_1 and I_2 can be defined as follows:

$$S(I_1) = \frac{\mu_1^L + \mu_1^R(1 - \mu_1^L - \nu_1^L) + \mu_1^R + \mu_1^R(1 - \mu_1^R - \nu_1^R)}{2},$$

$$S(I_2) = \frac{\mu_2^L + \mu_2^R(1 - \mu_2^L - \nu_2^L) + \mu_2^R + \mu_2^R(1 - \mu_2^R - \nu_2^R)}{2}, \quad (6)$$

$$H(I_1) = \frac{\mu_1^L + \nu_1^L + \mu_1^R + \nu_1^R}{2},$$

$$H(I_2) = \frac{\mu_2^L + \nu_2^L + \mu_2^R + \nu_2^R}{2}. \quad (7)$$

For two IFNs I_1 and I_2 , regarding Definition 3,

- (1) If $s(I_1) < s(I_2)$, then $I_1 < I_2$
- (2) If $s(I_1) > s(I_2)$, then $I_1 > I_2$
- (3) If $s(I_1) = s(I_2)$ and $h(I_1) < h(I_2)$, then $I_1 < I_2$
- (4) If $s(I_1) = s(I_2)$ and $h(I_1) > h(I_2)$, then $I_1 > I_2$
- (5) If $s(I_1) = s(I_2)$ and $h(I_1) = h(I_2)$, then $I_1 = I_2$

Under the context of the IVIFNs, some aggregation operators will be introduced in this chapter, including the interval-valued intuitionistic fuzzy WA (IVIFWA) operator and the interval-valued intuitionistic fuzzy WG (IVIFWG) operator.

Definition 4 (see [44]). Let $I_j = (\mu_{I_j}, \nu_{I_j})$ ($j = 1, 2, \dots, n$) be a set of IVIFNs; the IVIFWA operator is defined as

$$\text{IVIFWA}_\omega(I_1, I_2, \dots, I_n) = \oplus_{j=1}^n (\omega_j I_j), \quad (8)$$

where $\omega = (\omega_1, \omega_2, \dots, \omega_n)^T$ is the weight vector of I_j ($j = 1, 2, \dots, n$) and $\omega_j > 0$, $\sum_{j=1}^n \omega_j = 1$.

Derived from Definition 4, the subsequent result can be obtained:

Theorem 1. The fused value by the IVIFWA operator could also be an IVIFN, where

$$\text{IVIFWA}_\omega(I_1, I_2, \dots, I_n) = \oplus_{j=1}^n (\omega_j I_j)$$

$$= \left(\left[1 - \prod_{j=1}^n (1 - \mu_{I_j}^L)^{\omega_j}, 1 - \prod_{j=1}^n (1 - \mu_{I_j}^R)^{\omega_j} \right], \left[\prod_{j=1}^n (\nu_{I_j}^L)^{\omega_j}, \prod_{j=1}^n (\nu_{I_j}^R)^{\omega_j} \right] \right), \quad (9)$$

where $\omega = (\omega_1, \omega_2, \dots, \omega_n)^T$ is the weight vector of I_j ($j = 1, 2, \dots, n$) and $\omega_j > 0$, $\sum_{j=1}^n \omega_j = 1$.

Definition 5 (see [44]). Let I_j ($j = 1, 2, \dots, n$) be a set of IVIFNs; the IVIFWG operator can be given as

$$\text{IVIFWG}_\omega(I_1, I_2, \dots, I_n) = \otimes_{j=1}^n (I_j)^{\omega_j}, \quad (10)$$

where $\omega = (\omega_1, \omega_2, \dots, \omega_n)^T$ is the weight vector of I_j ($j = 1, 2, \dots, n$) and $\omega_j > 0$, $\sum_{j=1}^n \omega_j = 1$.

Derived from Definition 5, the detailed result can be obtained.

Theorem 2. The fused value by using the IVIFWG operator could also be an IVIFN, where

$$\text{IVIFWG}_\omega(I_1, I_2, \dots, I_n) = \bigotimes_{j=1}^n (I_j)^{\omega_j} \\ = \left(\left[\prod_{j=1}^n (\mu_{I_j}^L)^{\omega_j}, \prod_{j=1}^n (\mu_{I_j}^R)^{\omega_j} \right], \left[1 - \prod_{j=1}^n (1 - \nu_{I_j}^L)^{\omega_j}, 1 - \prod_{j=1}^n (1 - \nu_{I_j}^R)^{\omega_j} \right] \right), \quad (11)$$

where $\omega = (\omega_1, \omega_2, \dots, \omega_n)^T$ is the weight vector of I_j ($j = 1, 2, \dots, n$) and $\omega_j > 0$, $\sum_{j=1}^n \omega_j = 1$.

3. The EDAS Method with IVIFNs

Integrating the EDAS method with IVIFSs, we build the IVIF-EDAS method in which the assessment values are given by IVIFNs. The calculating procedures of the developed method can be described subsequently.

Let $Z = \{Z_1, Z_2, \dots, Z_n\}$ be the attribute set and $z = \{z_1, z_2, \dots, z_n\}$ be the attribute weight Z_j , where $z_j \in [0, 1]$, $j = 1, 2, \dots, n$, $\sum_{j=1}^n z_j = 1$. Assume $D = \{D_1, D_2, \dots, D_l\}$ is a set of decision makers that have a significant degree of $d = \{d_1, d_2, \dots, d_l\}$, where $d_k \in [0, 1]$, $k = 1, 2, \dots, l$, $\sum_{k=1}^l d_k = 1$. Let $Y = \{Y_1, Y_2, \dots, Y_m\}$ be a discrete collection of alternatives. And $Q = (q_{ij})_{m \times n}$ is the overall IVIFN decision matrix; q_{ij} means the value of alternative Y_i regarding attribute Z_j . Subsequently, the specific calculating procedures will be depicted.

Step 1: set up each decision maker's IVIFN decision matrix $Q^{(k)} = (q_{ij}^k)_{m \times n}$, and calculate the overall IVIFN decision matrix $Q = (q_{ij})_{m \times n}$:

$$Q^{(k)} = [q_{ij}^k]_{m \times n} = \begin{bmatrix} q_{11}^k & q_{12}^k & \cdots & q_{1n}^k \\ q_{21}^k & q_{22}^k & \cdots & q_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ q_{m1}^k & q_{m2}^k & \cdots & q_{mn}^k \end{bmatrix}, \quad (12)$$

$$Q = [q_{ij}]_{m \times n} = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & \cdots & q_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix}, \quad (13)$$

$$q_{ij} = \left(\left[1 - \prod_{k=1}^l (1 - \mu_{q_{ij}^k}^L)^{d_k}, 1 - \prod_{k=1}^l (1 - \mu_{q_{ij}^k}^R)^{d_k} \right], \right. \\ \left. \cdot \left[\prod_{k=1}^l (\nu_{q_{ij}^k}^L)^{d_k}, \prod_{k=1}^l (\nu_{q_{ij}^k}^R)^{d_k} \right] \right), \quad (14)$$

where q_{ij}^k is the assessment value of alternative Y_i ($i = 1, 2, \dots, m$) on the basis of the attribute Z_j ($j = 1, 2, \dots, n$) and the decision maker D_k ($k = 1, 2, \dots, l$).

Step 2: normalize the overall IVIFN decision matrix $Q = (q_{ij})_{m \times n}$ to $Q^N = [q_{ij}^N]_{m \times n}$:

$$q_{ij}^N = \begin{cases} ([\mu_{ij}^L, \mu_{ij}^R], [\nu_{ij}^L, \nu_{ij}^R]), & Z_j \text{ is a benefit criterion,} \\ ([\nu_{ij}^L, \nu_{ij}^R], [\mu_{ij}^L, \mu_{ij}^R]), & Z_j \text{ is a cost criterion.} \end{cases} \quad (15)$$

Step 3: utilize the CRITIC method to determine the weighting matrix of attributes.

Criteria Importance through Intercriteria Correlation (CRITIC) method will be designed in this part which is utilized to decide attributes' weights. This method was initially put forward by Diakoulaki et al. [46] which took the correlations between attributes into consideration. Subsequently, the calculating procedures of this method will be presented:

- (1) Depending on the normalized overall IVIFN decision matrix $Q^N = (q_{ij}^N)_{m \times n}$, the correlation coefficient between attributes can be calculated:

$$IC_{jt} = \frac{\sum_{i=1}^m (S(q_{ij}^N) - S(q_j^N))(S(q_{it}^N) - S(q_t^N))}{\sqrt{\sum_{i=1}^m (S(q_{ij}^N) - S(q_j^N))^2} \sqrt{\sum_{i=1}^m (S(q_{it}^N) - S(q_t^N))^2}}, \\ j, t = 1, 2, \dots, n, \quad (16)$$

where $q_j^N = 1/m \sum_{i=1}^m S(q_{ij}^N)$ and $q_t^N = 1/m \sum_{i=1}^m S(q_{it}^N)$.

- (2) Calculate attributes' standard deviation:

$$IS_j = \sqrt{\frac{1}{m-1} \sum_{i=1}^m (S(q_{ij}^N) - S(q_j^N))^2}, \quad j = 1, 2, \dots, n, \quad (17)$$

where $q_j^N = 1/m \sum_{i=1}^m S(q_{ij}^N)$.

- (3) Calculate the attributes' weights:

$$z_j = \frac{IS_j \sum_{t=1}^n (1 - IC_{jt})}{\sum_{j=1}^n (IS_j \sum_{t=1}^n (1 - IC_{jt}))}, \quad j = 1, 2, \dots, n, \quad (18)$$

where $z_j \in [0, 1]$ and $\sum_{j=1}^n z_j = 1$.

Step 4: calculate the average solution (AV) regarding all designed attributes:

$$AV = [AV_j]_{1 \times n} = \left[\frac{\sum_{i=1}^m \hat{q}_{ij}^N}{m} \right]_{1 \times n}, \quad (19)$$

$$[AV_j]_{1 \times n} = \left[\frac{\sum_{i=1}^m \hat{q}_{ij}^N}{m} \right]_{1 \times n} = \left(\begin{bmatrix} 1 - \prod_{i=1}^m \left(1 - (\mu_{ij}^N)^L \right)^{1/m}, 1 - \prod_{i=1}^m \left(1 - (\mu_{ij}^N)^R \right)^{1/m} \\ \left[\prod_{i=1}^m \left((\nu_{ij}^N)^L \right)^{1/m}, \prod_{i=1}^m \left((\nu_{ij}^N)^R \right)^{1/m} \right] \end{bmatrix} \right)_{1 \times n} \quad (20)$$

Step 5: depending on the AV's results, the positive distance from average (PDA) and negative distance from average (NDA) can be defined:

$$PDA_{ij} = [PDA_{ij}]_{m \times n} = \frac{\max(0, (s(q_{ij}^N) - s(AV_j)))}{s(AV_j)}, \quad (21)$$

$$NDA_{ij} = [NDA_{ij}]_{m \times n} = \frac{\max(0, (s(AV_j) - s(q_{ij}^N)))}{s(AV_j)}. \quad (22)$$

Step 6: calculate SP_i and SN_i which express the weighted sum of PDA and NDA:

$$SP_i = \sum_{j=1}^n z_j \cdot PDA_{ij}, NP_i = \sum_{j=1}^n z_j \cdot NDA_{ij}. \quad (23)$$

Step 7: depending on the above calculated results, SP_i and SN_i can be normalized as

$$\begin{aligned} NSP_i &= \frac{SP_i}{\max_i (SP_i)}, \\ NSN_i &= 1 - \frac{SN_i}{\max_i (SN_i)}. \end{aligned} \quad (24)$$

Step 8: calculate the appraisal score AS_i regarding every alternative's NSP_i and NSN_i :

$$AS_i = \frac{1}{2} (NSP_i + NSN_i). \quad (25)$$

Step 9: according to AS_i , all the alternatives can be ranked. The higher the value of AS_i is, the optimal alternative will be selected.

4. The Empirical Example and Comparative Analysis

4.1. An Empirical Example. With the development of research on wireless technique and other related techniques, wireless sensor networks (WSNs) have been widely used in various applications which involve diverse working environments, monitoring objects, and data conditions. Different applications require different quality of service (QoS) for data collection and data transmission. Thus, it is essential to provide QoS

guarantee mechanisms in WSNs to achieve good performance in various applications. Accordingly, it is of great significance to study the QoS guarantee mechanisms in WSNs. In general terms, the QoS of WSNs focuses on timeliness and reliability of data transmission, as well as coverage and connectivity of the network topology for data collection. The QoS guarantee implementation relies on different mechanisms in WSNs. Although many methods and techniques have been proposed in the existing literature, the QoS guarantee mechanism is still faced with the following challenges in complex applications: (1) there exist several types of data traffic which have different QoS requirements. Therefore, a multiple-level QoS guarantee mechanism is in great demand. (2) There could be multiple QoS requirements for one data traffic. Thus, it is necessary to provide multiple-QoS guarantee mechanisms for these traffics. (3) Since the traffic distributes are nonuniform in space and time, a method for the efficient transmission in a dynamic traffic is required. (4) There exists nonuniform replacement of the nodes as well as dynamic and changeful topology in many applications of the WSN. It is necessary to provide an efficient deployment method to satisfy the requirement of effectively covering. In this chapter, an empirical example for evaluating the service quality of wireless sensor networks which considered the complex MAGDM issues [47–54] will be provided by making use of the IVIF-EDAS method. Thus, in such a section, we present a numerical example to assess computer network systems with IVIFNs in order to show the designed method. There are five wireless sensor networks $A_i (i = 1, 2, 3, 4, 5)$ to select. The expert group selects four attributes to evaluate these five wireless sensor networks: ① G_1 is the product quality factor; ② G_2 is the technology factor; ③ G_3 is the delivery factor; and ④ G_4 is the price factor. Taking its own business development into consideration, a company wants to choose a wireless sensor network. There are five potential wireless sensor networks $Y_i (i = 1, 2, 3, 4, 5)$. In order to select the optimal wireless sensor network, the expert group invites five experts $D = \{D_1, D_2, D_3, D_4, D_5\}$ (expert's weight $d = (1/5, 1/5, 1/5, 1/5, 1/5)$) to assess these wireless sensor networks. All experts give their assessment information depending on the four subsequently attributes: ① Z_1 is the traffic convenience; ② Z_2 is the product price; ③ Z_3 is the green environmental protection ability; and ④ Z_4 is the service quality. Evidently, Z_2 is the g cost attribute, while Z_1, Z_3 , and Z_4 are the benefit attributes. To obtain the optimal wireless sensor network, the calculating procedures are involved:

Step 1: set up each decision maker's IVIFN evaluation matrix $Q^{(k)} = (q_{ij}^k)_{m \times n} (i = 1, 2, \dots, m, j = 1, 2, \dots, n)$ as in Tables 1–5. Derived from these tables and equations (12)–(14), the overall IVIFN decision matrix could be calculated. The results are recorded in Table 6.

Step 2: normalize the evaluation matrix $Q = [q_{ij}]_{m \times n}$ to $Q^N = [q_{ij}^N]_{m \times n}$ (see Table 7).

TABLE 1: IVIFN evaluation information by D_1 .

	Z_1	Z_2	Z_3	Z_4
Y_1	[[0.35, 0.38], [0.58, 0.62]]	[[0.21, 0.31], [0.33, 0.69]]	[[0.24, 0.33], [0.41, 0.66]]	[[0.32, 0.43], [0.45, 0.57]]
Y_2	[[0.29, 0.39], [0.44, 0.61]]	[[0.28, 0.34], [0.46, 0.64]]	[[0.11, 0.25], [0.32, 0.75]]	[[0.39, 0.44], [0.52, 0.61]]
Y_3	[[0.40, 0.49], [0.51, 0.60]]	[[0.33, 0.51], [0.53, 0.67]]	[[0.44, 0.50], [0.52, 0.56]]	[[0.28, 0.39], [0.61, 0.72]]
Y_4	[[0.33, 0.48], [0.54, 0.67]]	[[0.42, 0.49], [0.51, 0.58]]	[[0.41, 0.44], [0.46, 0.59]]	[[0.41, 0.46], [0.49, 0.53]]
Y_5	[[0.26, 0.48], [0.61, 0.74]]	[[0.42, 0.47], [0.52, 0.58]]	[[0.41, 0.48], [0.51, 0.59]]	[[0.38, 0.53], [0.55, 0.62]]

TABLE 2: IVIFN evaluation information by D_2 .

	Z_1	Z_2	Z_3	Z_4
Y_1	[[0.38, 0.42], [0.55, 0.62]]	[[0.43, 0.49], [0.51, 0.57]]	[[0.29, 0.39], [0.59, 0.71]]	[[0.45, 0.48], [0.50, 0.55]]
Y_2	[[0.37, 0.48], [0.56, 0.63]]	[[0.34, 0.44], [0.51, 0.66]]	[[0.46, 0.50], [0.52, 0.54]]	[[0.39, 0.48], [0.50, 0.61]]
Y_3	[[0.37, 0.50], [0.54, 0.63]]	[[0.27, 0.39], [0.67, 0.73]]	[[0.41, 0.52], [0.54, 0.59]]	[[0.16, 0.33], [0.72, 0.84]]
Y_4	[[0.46, 0.49], [0.52, 0.54]]	[[0.32, 0.38], [0.56, 0.68]]	[[0.37, 0.43], [0.47, 0.63]]	[[0.29, 0.34], [0.68, 0.71]]
Y_5	[[0.40, 0.48], [0.52, 0.60]]	[[0.46, 0.49], [0.51, 0.54]]	[[0.42, 0.47], [0.55, 0.58]]	[[0.33, 0.38], [0.62, 0.67]]

TABLE 3: IVIFN evaluation information by D_3 .

	Z_1	Z_2	Z_3	Z_4
Y_1	[[0.44, 0.48], [0.52, 0.56]]	[[0.38, 0.42], [0.48, 0.62]]	[[0.31, 0.42], [0.59, 0.69]]	[[0.40, 0.49], [0.58, 0.60]]
Y_2	[[0.38, 0.42], [0.59, 0.62]]	[[0.35, 0.43], [0.58, 0.65]]	[[0.42, 0.48], [0.52, 0.58]]	[[0.26, 0.33], [0.59, 0.74]]
Y_3	[[0.35, 0.42], [0.59, 0.65]]	[[0.48, 0.50], [0.51, 0.52]]	[[0.18, 0.36], [0.64, 0.82]]	[[0.38, 0.43], [0.56, 0.62]]
Y_4	[[0.27, 0.34], [0.59, 0.73]]	[[0.26, 0.43], [0.62, 0.74]]	[[0.38, 0.46], [0.52, 0.62]]	[[0.31, 0.45], [0.62, 0.69]]
Y_5	[[0.46, 0.51], [0.52, 0.54]]	[[0.44, 0.51], [0.52, 0.56]]	[[0.34, 0.45], [0.62, 0.66]]	[[0.35, 0.45], [0.55, 0.65]]

TABLE 4: IVIFN evaluation information by D_4 .

	Z_1	Z_2	Z_3	Z_4
Y_1	[[0.42, 0.48], [0.51, 0.58]]	[[0.37, 0.44], [0.59, 0.63]]	[[0.25, 0.37], [0.68, 0.75]]	[[0.22, 0.35], [0.67, 0.78]]
Y_2	[[0.41, 0.49], [0.52, 0.59]]	[[0.36, 0.39], [0.49, 0.64]]	[[0.27, 0.43], [0.65, 0.73]]	[[0.42, 0.45], [0.52, 0.58]]
Y_3	[[0.43, 0.48], [0.52, 0.57]]	[[0.42, 0.48], [0.52, 0.58]]	[[0.41, 0.48], [0.54, 0.59]]	[[0.34, 0.49], [0.58, 0.66]]
Y_4	[[0.32, 0.43], [0.64, 0.67]]	[[0.32, 0.43], [0.59, 0.68]]	[[0.36, 0.39], [0.58, 0.64]]	[[0.15, 0.39], [0.64, 0.85]]
Y_5	[[0.37, 0.45], [0.56, 0.63]]	[[0.36, 0.45], [0.55, 0.64]]	[[0.42, 0.50], [0.52, 0.58]]	[[0.27, 0.45], [0.65, 0.73]]

TABLE 5: IVIFN evaluation information by D_5 .

	Z_1	Z_2	Z_3	Z_4
Y_1	[[0.63, 0.66], [0.69, 0.37]]	[[0.45, 0.46], [0.48, 0.55]]	[[0.39, 0.45], [0.59, 0.61]]	[[0.43, 0.47], [0.54, 0.57]]
Y_2	[[0.43, 0.47], [0.52, 0.57]]	[[0.37, 0.43], [0.59, 0.63]]	[[0.40, 0.50], [0.52, 0.60]]	[[0.41, 0.48], [0.52, 0.59]]
Y_3	[[0.47, 0.49], [0.51, 0.53]]	[[0.29, 0.35], [0.65, 0.71]]	[[0.42, 0.48], [0.53, 0.58]]	[[0.27, 0.43], [0.67, 0.73]]
Y_4	[[0.41, 0.49], [0.52, 0.59]]	[[0.43, 0.47], [0.52, 0.57]]	[[0.46, 0.48], [0.52, 0.54]]	[[0.19, 0.38], [0.67, 0.81]]
Y_5	[[0.33, 0.45], [0.64, 0.67]]	[[0.48, 0.50], [0.51, 0.52]]	[[0.44, 0.46], [0.53, 0.56]]	[[0.21, 0.37], [0.68, 0.79]]

Step 3: decide the attribute weights z_j ($j = 1, 2, \dots, n$) by making use of the CRITIC method as recorded in Table 8.

Step 4: depending on the calculated results of Table 8, the value of average solution (AV) can be obtained on the basis of all proposed attributes by equations (19) and (20) (see Table 9).

Step 5: relying on the results of AV, the PDA and NDA can be calculated by utilizing equations (21) and (22) (see Tables 10 and 11).

Step 6: on the basis of equation (23) and attribute weighting vector $\omega = (0.1311, 0.2162, 0.2233, 0.4094)$, the values of SP_i and SN_i can be calculated:

$$SP_1 = 0.0018, SP_2 = 0.2063, SP_3 = 0.0375, SP_4$$

$$= 0.0659, SP_5 = 0.0000,$$

$$SN_1 = 0.1379, SN_2 = 0.0356, SN_3 = 0.0689, SN_4$$

$$= 0.1052, SN_5 = 0.0338.$$

(26)

TABLE 6: Overall IVIFN evaluation information.

	Z_1	Z_2	Z_3	Z_4
Y_1	([0.4341, 0.4442], [0.5051, 0.5233])	([0.4722, 0.4833], [0.4901, 0.5189])	([0.2798, 0.2980], [0.6087, 0.6455])	([0.4376, 0.4521], [0.5475, 0.5499])
Y_2	([0.5341, 0.5365], [0.4152, 0.42532])	([0.5502, 0.5708], [0.4209, 0.4429])	([0.6432, 0.6679], [0.3807, 0.3988])	([0.5908, 0.6213], [0.3216, 0.4453])
Y_3	([0.4325, 0.4365], [0.5472, 0.5711])	([0.4029, 0.4233], [0.5120, 0.5431])	([0.4458, 0.4687], [0.4897, 0.4988])	([0.3246, 0.4362], [0.2109, 0.4907])
Y_4	([0.5231, 0.5433], [0.4761, 0.4866])	([0.4877, 0.4902], [0.4211, 0.4766])	([0.5765, 0.5870], [0.4211, 0.4465])	([0.3287, 0.4309], [0.4870, 0.4998])
Y_5	([0.4168, 0.4561], [0.5232, 0.5690])	([0.4907, 0.5142], [0.4606, 0.4980])	([0.4755, 0.5219], [0.4658, 0.4785])	([0.4598, 0.4622], [0.1121, 0.2366])

TABLE 7: The normalized IVIFN evaluation information.

	Z_1	Z_2	Z_3	Z_4
Y_1	([0.4341, 0.4442], [0.5051, 0.5233])	([0.4901, 0.5189], [0.4722, 0.4833])	([0.2798, 0.2980], [0.6087, 0.6455])	([0.4376, 0.4521], [0.5475, 0.5499])
Y_2	([0.5341, 0.5365], [0.4152, 0.42532])	([0.4209, 0.4429], [0.5502, 0.5708])	([0.6432, 0.6679], [0.3807, 0.3988])	([0.5908, 0.6213], [0.3216, 0.4453])
Y_3	([0.4325, 0.4365], [0.5472, 0.5711])	([0.5120, 0.5431], [0.4029, 0.4233])	([0.4458, 0.4687], [0.4897, 0.4988])	([0.3246, 0.4362], [0.2109, 0.4907])
Y_4	([0.5231, 0.5433], [0.4761, 0.4866])	([0.4211, 0.4766], [0.4877, 0.4902])	([0.5765, 0.5870], [0.4211, 0.4465])	([0.3287, 0.4309], [0.4870, 0.4998])
Y_5	([0.4168, 0.4561], [0.5232, 0.5690])	([0.4606, 0.4980], [0.4907, 0.5142])	([0.4755, 0.5219], [0.4658, 0.4785])	([0.4598, 0.4622], [0.1121, 0.2366])

TABLE 8: The attribute weights z_j .

	Z_1	Z_2	Z_3	Z_4
Z_j	0.1311	0.2162	0.2233	0.4094

TABLE 9: The value of average solution.

	Average solution
Z_1	$([0.4286, 0.4782], [0.4784, 0.5231])$
Z_2	$([0.5219, 0.5690], [0.4221, 0.4410])$
Z_3	$([0.4522, 0.4897], [0.4588, 0.5099])$
Z_4	$([0.4308, 0.4906], [0.3265, 0.4128])$

TABLE 10: The results of PDA_{ij} .

	Z_1	Z_2	Z_3	Z_4
Y_1	0.0000	0.0054	0.0000	0.0000
Y_2	0.1236	0.0000	0.2833	0.3164
Y_3	0.0000	0.1436	0.0000	0.0000
Y_4	0.0929	0.0000	0.1565	0.0000
Y_5	0.0000	0.0000	0.0000	0.0000

TABLE 11: The results of NDA_{ij} .

	Z_1	Z_2	Z_3	Z_4
Y_1	0.0084	0.0000	0.3875	0.0288
Y_2	0.0000	0.1477	0.0000	0.0000
Y_3	0.0938	0.0000	0.1252	0.0245
Y_4	0.0000	0.0038	0.0000	0.3567
Y_5	0.1293	0.0368	0.0359	0.0046

Step 7: the results of Step 6 could be normalized by equation (24):

$$\begin{aligned}
 NSP_1 &= 0.0063, NSP_2 = 1.0000, NSP_3 = 0.1200, NSP_4 \\
 &= 0.3037, NSP_5 = 0.0000, \\
 NSN_1 &= 0.0000, NSN_2 = 0.7528, NSN_3 = 0.5462, NSN_4 \\
 &= 0.1982, NSN_5 = 0.7361.
 \end{aligned} \quad (27)$$

Step 8: on the basis of each alternative's NSP_i and NSN_i , the values of AS are calculated:

$$\begin{aligned}
 AS_1 &= 0.0038, AS_2 = 0.8715, AS_3 = 0.3581, AS_4 \\
 &= 0.2613, AS_5 = 0.3732.
 \end{aligned} \quad (28)$$

Step 9: according to the AS, all the alternatives can be ranked; the higher the value of AS is, the optimal alternative will be selected. Evidently, the rank of these five alternatives is $Y_2 > Y_5 > Y_3 > Y_4 > Y_1$, and Y_2 is the best wireless sensor network.

4.2. *Comparative Analysis.* In this part, our developed method is compared with some other methods to illustrate its superiority.

First of all, our presented method is compared with IVIFWA and IVIFWG operators [44]. For the IVIFWA operator, the calculated result is $S(Y_1) = 0.4364$, $S(Y_2) = 0.5806$, $S(Y_3) = 0.4852$, $S(Y_4) = 0.4941$, and $S(Y_5) = 0.4752$. Thus, the ranking order is $Y_2 > Y_4 > Y_3 > Y_5 > Y_1$. For the IVIFWG operator, the calculated result is $S(Y_1) = 0.4197$, $S(Y_2) = 0.5708$, $S(Y_3) = 0.4762$, $S(Y_4) = 0.4673$, and $S(Y_5) = 0.4733$. So, the ranking order is $Y_2 > Y_3 > Y_5 > Y_4 > Y_1$.

Furthermore, our presented method is compared with the modified VIKOR method with IVIFSs [55]. Then, we can obtain the calculation result. The closest ideal score values are determined as $CI^+(Y_1) = 1.0000$, $CI^+(Y_2) = 0.1705$, $CI^+(Y_3) = 0.3404$, $CI^+(Y_4) = 0.6723$, and $CI^+(Y_5) = 0.4065$. And the farthest worst score values are determined as $CI^-(Y_1) = 0.0000$, $CI^-(Y_2) = 0.5103$, $CI^-(Y_3) = 0.7247$, $CI^-(Y_4) = 0.1856$, and $CI^-(Y_5) = 0.1139$. Then, each alternative's relative closeness is calculated as $DRC_1 = 1.0000$, $DRC_2 = 0.2652$, $DRC_3 = 0.3265$, $DRC_4 = 0.7982$, and $DRC_5 = 0.8077$. Hence, the ranking order of alternatives is $Y_2 > Y_3 > Y_4 > Y_5 > Y_1$.

In the end, our presented method is compared with GRA-based IVIFSs [56]. Then, we can obtain the calculation result. The grey relational grades of each alternative are calculated as $\gamma_1 = 0.8398$, $\gamma_2 = 1.0000$, $\gamma_3 = 0.8307$, $\gamma_4 = 0.8821$, and $\gamma_5 = 0.8672$. Therefore, the ranking order of alternatives is $Y_2 > Y_4 > Y_5 > Y_1 > Y_3$.

Eventually, the results of dissimilar methods are recorded in Table 12.

Derived from Table 12, it is evident that the optimal wireless sensor network is Y_2 in the mentioned methods, while the worst choice is Y_1 in most situations. In other words, these methods' ranking results are slightly different. Different methods could effectively tackle MAGDM issues from different kinds of angles. IVIFWA and IVIFWG operators emphasize to aggregate evaluation information. The modified VIKOR method with IVIFSs emphasizes the closest to the ideal solution and the farthest to the worst solution. The GRA-based IVIFSs emphasize the degree of similarity or difference between two sequences on the basis of the relation. However, our developed method emphasizes to calculate the expected function from the average solution. Compared with the aforementioned methods, it is more practical and effective since the procedures of calculation are simpler, and it is more convenient to apply to the practical situations.

TABLE 12: Evaluation results of dissimilar methods.

Methods	Ranking order	The optimal alternative	The worst alternative
IVIFWA	$Y_2 > Y_4 > Y_3 > Y_5 > Y_1$	Y_2	Y_1
IVIFWG	$Y_2 > Y_3 > Y_5 > Y_4 > Y_1$	Y_2	Y_1
The modified VIKOR	$Y_2 > Y_3 > Y_4 > Y_5 > Y_1$	Y_2	Y_1
The GRA method	$Y_2 > Y_4 > Y_5 > Y_1 > Y_3$	Y_2	Y_3
The developed method	$Y_2 > Y_5 > Y_3 > Y_4 > Y_1$	Y_2	Y_1

5. Conclusion

In this paper, IVIF-EDAS method is developed to tackle the MAGDM issues based on the description of the EDAS method and some fundamental notions of IVIFSs. To begin with, the fundamental information of IVIFSs is simply introduced. After that, the IVIFWA and IVIFWG operators are utilized to integrate the IVIFNs. Subsequently, relying on the CRITIC method, the attributes' weights are decided. In addition, applying the EDAS method to the IVIFSs, a new method is designed, and the calculating procedures are listed in detail. Finally, an application for assessing the service quality of wireless sensor networks has been given to show the superiority of this novel method, and comparative analysis between the IVIF-EDAS method and some other methods could also be made to further verify some merits of such a method. In our future works, the EDAS method and the CRITIC method will be extensively applied in different uncertain and ambiguous environments [57–67].

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

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