ISSN : 0974 - 7435 Volume 10 Issue 12

2014

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 10(12), 2014 [6808-6813]

A method for evaluating the security of wireless sensor network with hesitant fuzzy linguistic information

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ABSTRACT

The problem of evaluating security of Wireless Sensor Network (WSN) with hesitant fuzzy linguistic information is the multiple attribute decision making problems. In this paper, we investigate the multiple attribute decision making problems for evaluating the security of wireless sensor networks with hesitant fuzzy linguistic information. We utilize the hesitant fuzzy linguistic hybrid average (HFLHA) operator to aggregate the hesitant fuzzy linguistic information corresponding to each alternative and derive the overall value of the alternatives, then rank the alternatives and select the most desirable one (s) according to the score function. Finally an illustrative example has been given to show the developed approach.

KEYWORDS

Multiple attribute decision making (MADM); Hesitant fuzzy linguistic information; Wireless sensor network; Wireless sensor network (WSN).

INTRODUCTION

Wireless sensor networks, which can be tasked with a target monitoring or tracking mission in various complicated environments, are guiding a revolution of sensing and gathering information, and have a bright future in a wide range of fields[1]. Wireless sensor networks are vulnerable to various types of security threats and pose unique challenges to security techniques due to many factors such as deployment in unattended environments, broadcast nature of the unreliable wireless channel, larger scale and multi-hop networking property in an ad hoc fashion, special data-centric traffic flow model, inter-node unconditional collaborative and trust relationship, and severe resource constraints etc[2]. Therefore, the key issue in further widely application of wireless sensor networks is how to give consideration to both availability and security for wireless sensor networks. In recent years, with the in-depth research of related technologies and the improvement in hardware, more and more wireless sensor networks have been put into application and they go deep into the military detection, the resource protection and other data-sensitive areas[3-4]. The security of wireless sensor network is the important guarantee of the normal operation of the applications. It makes it feasible that the wireless sensor network eliminates the interference of the enemy, normally interacts with the users and provides the data for the decision. But it is a great challenge, because the nodes in the wireless sensor network are limited to their energy, memories, computing capability and own security. So, how to make the efficient security protocols according to the characteristic of wireless sensor network become current research focuses. Aiming at the inherent characteristics of wireless sensor network and the limitation of current work, this dissertation takes the security of data in wireless sensor network as the goal and studies some key technologies of the security of wireless sensor network comprehensivel[5-6].

The problem of evaluating security of Wireless Sensor Network (WSN) with hesitant fuzzy linguistic information is the multiple attribute decision making problems. In this paper, we investigate the multiple attribute decision making problems for evaluating the security of wireless sensor networks with hesitant fuzzy linguistic information. We utilize the hesitant fuzzy linguistic hybrid average (HFLHA) operator to aggregate the hesitant fuzzy linguistic information corresponding to each alternative and derive the overall value of the alternatives, then rank the alternatives and select the most desirable one (s) according to the score function. Finally an illustrative example has been given to show the developed approach.

PRELIMINARIES

Based on the hesitant fuzzy set[7-8] and linguistic term set[9-11], in the following, Lin et al[12] proposed some basic concepts and basic operational laws related to hesitant fuzzy linguistic set.

Definition 1[12]. Given a fixed set X , then a hesitant fuzzy linguistic set (HFLS) on X is in terms of a function that when applied to X returns a sunset of $\left[0,1\right]$. To be easily understood, the HFLS can be expressed by mathematical symbol as follows:

$$A=\left(\left\langle x,s_{\theta(x)},h_A\left(x\right)\right\rangle \middle| x\in X\right) \quad \textbf{(1)}$$

where $h_A\left(x\right)$ is a set of some values in $\left[0,1\right]$, denoting the possible membership degree of the element $x\in X$ to the linguistic set $s_{\theta(x)}$. For convenience, we called $a=\left\langle s_{\theta(x)},h_A\left(x\right)\right\rangle$ a hesitant fuzzy linguistic element (HFLE) and A the set of all HFLEs.

Definition 2[12]. For a HFLE $a=\left\langle s_{\theta(x)},h_A\left(x\right)\right\rangle$, $s\left(a\right)=\left(\frac{1}{\#h}\sum_{\gamma\in h}\gamma\right)s_{\theta(x)}$ is called the score function of a , where $\#h$ is the number of the elements in h . For two HFLEs a_1 and a_2, if $s\left(a_1\right)>s\left(a_2\right)$, then $a_1>a_2$; if $s\left(a_1\right)=s\left(a_2\right)$, then $a_1=a_2$.

Motivated by the operational law of hesitant fuzzy linguistic set and arithmetic aggregation operators[13], in the following, Lin et al.[12] developed some hesitant fuzzy linguistic arithmetic aggregation operator.

Definition 3[12]. Let $a_j=\left(s_{\theta(a_j)},h(a_j)\right)\ (j=1,2,\cdots,n)$ be a collection of HFLEs, then we define the hesitant fuzzy linguistic weighted average (HFLWA) operator:

$$\begin{aligned}&\mathrm{HFLWA}_{\omega}(a_1,a_2,\cdots,a_n)=\overset{n}{\underset{j=1}{\oplus}}(\omega_j a_j)\\&=\left\langle \sum_{j=1}^{n}\omega_j s_{\theta(a_j)},\left(\bigcup_{\gamma(a_1)\in h(a_1),\gamma(a_2)\in h(a_2),\cdots,\gamma(a_n)\in h(a_n)}\left\{1-\prod_{j=1}^{n}\left(1-\gamma(a_j)\right)^{\omega_j}\right\}\right)\right\rangle\end{aligned} \tag{2}$$

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

Definition 4[12]. Let $a_j=\left(s_{\theta(a_j)},h(a_j)\right)\ (j=1,2,\cdots,n)$ be a collection of HFLEs, then we define the hesitant fuzzy linguistic ordered weighted average (HFLOWA) operator as follows:

$$\begin{aligned}&\mathrm{HFLOWA}_{\mathrm{w}}(a_1,a_2,\cdots,a_n)\\&=\overset{n}{\underset{j=1}{\oplus}}\left(w_j a_{\sigma(j)}\right)\\&=\left\langle \sum_{j=1}^{n}w_j s_{\theta(a_{\sigma(j)})},\left(\bigcup_{\gamma(a_{\sigma(1)})\in h(a_{\sigma(1)}),\gamma(a_{\sigma(2)})\in h(a_{\sigma(2)}),\cdots,\gamma(a_{\sigma(n)})\in h(a_{\sigma(n)})}\left\{1-\prod_{j=1}^{n}\left(1-\gamma(a_{\sigma(j)})\right)^{w_j}\right\}\right)\right\rangle\end{aligned} \tag{3}$$

where $(\sigma(1),\sigma(2),\cdots,\sigma(n))$ is a permutation of $(1,2,\cdots,n)$, such that $a_{\sigma(j-1)}\ge a_{\sigma(j)}$ for all $j=2,\cdots,n$, and $w=(w_1,w_2,\cdots,w_n)^T$ is the aggregation-associated weight vector such that $w_j\in[0,1]$ and $\sum_{j=1}^{n}w_j=1$.

Definition 5[12]. A hesitant fuzzy linguistic hybrid average (HFLHA) operator is defined as follows:

$$\begin{aligned}&\mathrm{HFLHA}_{w,\omega}(a_1,a_2,\cdots,a_n)\\&=\overset{n}{\underset{j=1}{\oplus}}\left(w_j \dot{a}_{\sigma(j)}\right)\\&=\left\langle \sum_{j=1}^{n}w_j s_{\theta(\dot{a}_{\sigma(j)})},\left(\bigcup_{\gamma(\dot{a}_{\sigma(1)})\in h(\dot{a}_{\sigma(1)}),\gamma(\dot{a}_{\sigma(2)})\in h(\dot{a}_{\sigma(2)}),\cdots,\gamma(\dot{a}_{\sigma(n)})\in h(\dot{a}_{\sigma(n)})}\left\{1-\prod_{j=1}^{n}\left(1-\gamma(\dot{a}_{\sigma(j)})\right)^{w_j}\right\}\right)\right\rangle\end{aligned} \tag{4}$$

where $w=(w_1,w_2,\cdots,w_n)$ is the associated weighting vector, with $w_j\in[0,1]$, $\sum_{j=1}^{n}w_j=1$, and $\dot{h}_{\sigma(j)}$ is the j-th largest element of the hesitant fuzzy linguistic arguments $\dot{a}_{\sigma(j)}\left(\dot{a}_{\sigma(j)}=n\omega_j a_j,\ j=1,2,\cdots,n\right)$, $\omega=(\omega_1,\omega_2,\cdots,\omega_n)$ is the weighting vector of hesitant fuzzy linguistic arguments $a_i\ (i=1,2,\cdots,n)$, with

$\omega_i \in [0,1]$, $\sum_{i=1}^{n} \omega_i = 1$, and n is the balancing coefficient. Especially, if $w = (1/n, 1/n, \cdots, 1/n)^T$, then HFLHA is reduced to the hesitant fuzzy linguistic weighted average (HFLWA) operator; if $\omega = (1/n, 1/n, \cdots, 1/n)$, then HFLHA is reduced to the hesitant fuzzy linguistic ordered weighted average (HFLOWA) operator.

A METHOD FOR EVALUATING THE SECURITY OF WIRELESS SENSOR NETWORK WITH HESITANT FUZZY LINGUISTIC INFORMATION

The following assumptions or notations are used to represent the MADM problems for security evaluation of wireless sensor network with hesitant fuzzy linguistic information. Let $A = \{A_1, A_2, \cdots, A_m\}$ be a discrete set of alternatives, and $G = \{G_1, G_2, \cdots, G_n\}$ be the state of nature. If the decision makers provide several values for the alternative A_i under the state of nature G_j with respect to $s_{\theta_{ij}}$ with anonymity, these values can be considered as a hesitant fuzzy linguistic element $\langle s_{\theta_{ij}}, h_{ij} \rangle$. In the case where two decision makers provide the same value, then the value emerges only once in h_{ij}. Suppose that the decision matrix $H = \left(\tilde{h}_{ij}\right)_{m\times n} = \left(\langle s_{\theta_{ij}}, h_{ij} \rangle\right)_{m\times n}$ is the hesitant fuzzy linguistic decision matrix, where $\langle s_{\theta_{ij}}, h_{ij} \rangle (i = 1, 2, \cdots, m,\ j = 1, 2, \cdots, n)$ are in the form of HFLEs.

In the following, we apply the hesitant fuzzy linguistic hybrid average (HFLHA) operator to the MADM problems for security evaluation of wireless sensor network with hesitant fuzzy linguistic information.

Step 1. We utilize the decision information given in matrix H, and the HFLHA operator

$$\begin{aligned} h_i &= \mathrm{HFLHA}_{w,\omega}\left(h_{i1}, h_{i2}, \cdots, h_{in}\right) \\ &= \bigoplus_{j=1}^{n}\left(w_j \dot{a}_{\sigma(ij)}\right) \qquad\qquad , i = 1, 2, \cdots, m. \qquad \textbf{(5)} \\ &= \left\langle \sum_{j=1}^{n} w_j s_{\theta\left(\dot{a}_{\sigma(ij)}\right)}, \left(\bigcup_{\gamma\left(\dot{a}_{\sigma(i1)}\right)\in h\left(\dot{a}_{\sigma(i1)}\right), \gamma\left(\dot{a}_{\sigma(i2)}\right)\in h\left(\dot{a}_{\sigma(i2)}\right), \cdots, \gamma\left(\dot{a}_{\sigma(in)}\right)\in h\left(\dot{a}_{\sigma(in)}\right)} \left\{ 1 - \prod_{j=1}^{n}\left(1-\gamma\left(\dot{a}_{\sigma(ij)}\right)\right)^{w_j} \right\} \right) \right\rangle \end{aligned}$$

to derive the overall preference values $h_i \ (i = 1, 2, \cdots, m)$ of the alternative A_i.

Step 2. Calculate the scores $S(h_i)\ (i = 1, 2, \cdots, m)$ of the overall hesitant fuzzy linguistic values $h_i\ (i = 1, 2, \cdots, m)$.

Step 3. Rank all the alternatives $A_i\ (i = 1, 2, \cdots, m)$ and select the best one (s) in accordance with $S(h_i)\ (i = 1, 2, \cdots, m)$.

Step 4. End.

ILLUSTRATIVE EXAMPLE

As the next generation network, wireless sensor networks (WSN) is developing rapidly for the widely potential applications in military and civilian areas. It is a kind of network which integrates different technologies (including the technology of wireless communications, computer networks and data transmission and sensor signal processing etc.) into one, to provide context-aware web services and information. It is a hot spot in the current research. Since context-aware service and information provided in WSN are always related to users' personal privacy and security, the security evaluation and corresponding defense issues become particularly important. Suppose a company plans to evaluate the security of Wireless Sensor Network (WSN). There is a panel with four possible computer network systems $A_i\left(i=1,2,3,4,5\right)$ to select. The company selects five attribute to evaluate the five possible computer network systems: ①G_1 is the tactics; ②G_2 is the technology; ③G_3 is the economy; ④G_4 is the logistics and strategy. In order to avoid influence each other, the decision makers are required to evaluate the four possible wireless sensor networks $A_i\left(i=1,2,3,4\right)$ under the above four attributes in anonymity and the decision matrix $H=\left(\tilde{h}_{ij}\right)_{4\times4}=\left(\left\langle s_{\theta_{ij}},h_{ij}\right\rangle\right)_{4\times4}$ is presented in TABLE 1, where $h_{ij}\left(i=1,2,3,4,\ j=1,2,3,4\right)$ are in the form of HFEs.

TABLE 1: Hesitant fuzzy linguistic decision matrix

	G_1	G_2	G_3	G_4
A_1	$\langle s_3,(0.4,0.5,0.6)\rangle$	$\langle s_6,(0.3,0.4)\rangle$	$\langle s_3,(0.3,0.4,0.5)\rangle$	$\langle s_3,(0.5,0.7)\rangle$
A_2	$\langle s_2,(0.3,0.4,0.5)\rangle$	$\langle s_4,(0.6,0.7)\rangle$	$\langle s_3,(0.2,0.4)\rangle$	$\langle s_6,(0.3,0.4)\rangle$
A_3	$\langle s_6,(0.7,0.8)\rangle$	$\langle s_5,(0.5,0.6)\rangle$	$\langle s_4,(0.4,0.5,0.6,0.7)\rangle$	$\langle s_3,(0.3,0.4,0.5)\rangle$
A_4	$\langle s_4,(0.2,0.3)\rangle$	$\langle s_4,(0.2,0.3)\rangle$	$\langle s_2,(0.5,0.6,0.7)\rangle$	$\langle s_4,(0.3,0.4)\rangle$

In the following, we utilize the approach developed to show the evaluation of wireless sensor networks.

Step 1. If we apply the HFLHA operator to decision making with hesitant fuzzy linguistic information, we suppose that the weight of HFLHA operator is: $w=\left(0.15,0.30,0.35,0.20\right)$.

Step 2. We utilize the decision information given in matrix H, and the HFLHA operator to obtain the overall preference values h_i of the alternatives $A_i\left(i=1,2,3,4\right)$ and Calculate the scores $s\left(h_i\right)\left(i=1,2,3,4\right)$ of the overall hesitant fuzzy linguistic values $h_i\left(i=1,2,3,4\right)$:

$$s\left(h_1\right)=s_{2.15},s\left(h_2\right)=s_{3.22},s\left(h_3\right)=s_{4.56},s\left(h_4\right)=s_{1.87}$$

Step 3. Rank all the wireless sensor networks $A_i\left(i=1,2,3,4\right)$ in accordance with the scores $s\left(h_i\right)\left(i=1,2,3,4\right)$ of the overall hesitant fuzzy linguistic values: $A_3\succ A_2\succ A_1\succ A_4$, and thus the most desirable wireless sensor network is A_3.

CONCLUSION

As the key technology of pervasive computing, wireless sensor network’s node is very limited in its energy, processing power, storage capacity and communications capability, so it’s usually to be considered unsuitable for the use of public key encryption technology. As the application environment is enlarging, more and more security requirements are proposed. But we can’t solve all these problems only with the symmetric-key technology. The identity-based encryption (IBE) give use a new method to deal with such security problems. A new security solution in wireless sensor network has been proposed, with the technology of identity-based cryptography. New encryption, signature and broadcast encryption schemes has been proposed, after analyzing the security threaten in wireless sensor network, concluding the security requirements and other special requirements. In this paper, we investigate the multiple attribute decision making problems for evaluating the security of wireless sensor networks with hesitant fuzzy linguistic information. We utilize the hesitant fuzzy linguistic hybrid average (HFLHA) operator to aggregate the hesitant fuzzy linguistic information corresponding to each alternative and derive the overall value of the alternatives, then rank the alternatives and select the most desirable one (s) according to the score function. Finally an illustrative example has been given to show the developed approach.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this article.

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