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Study on Evaluating Wireless Sensor Network Security Based on Uncertain Linguistic Information

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Abstract: Wireless sensor network (WSN), as an integrated network which can perform information gathering, processing and delivering, can connect the real world and logistic information world. It is greatly changing the interaction between people and nature. There are wide potential applications for wireless sensor network, such as industry, agriculture, military affairs, environment monitoring, biomedicine, city managing and disaster succoring. The problem of evaluating security of Wireless Sensor Network (WSN) with uncertain linguistic information is the multiple attribute group decision making (MAGDM). In this paper, we investigate the multiple attribute group decision making (MAGDM) problems for evaluating the wireless sensor network (WSN) security with uncertain linguistic information. We utilize the uncertain linguistic weighted averaging (ULWA) operator to aggregate the uncertain linguistic information corresponding to each alternative and get the overall value of the alternatives, then rank the alternatives and select the most desirable one(s) by using the formula of the degree of possibility for the comparison between two uncertain linguistic variables. Finally, an illustrative example is given. *Copyright © 2013 IFSA.*

Keywords: Multiple attribute group decision-making (MAGDM), Uncertain linguistic information, Uncertain linguistic weighted averaging (ULWA) operator, Network security evaluation.

1. Introduction

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. For the increasingly complex and severe security environment of WSN, the traditional assessment techniques of computer network security have been insufficient to meet this requirement. The traditional intrusion detection tools can only deliver alerts on limited knowledge of attacks, while the alert stream is always poor in quality and can easily be over-whelming, which makes it very hard to know how much threat the detected attacks pose to the network and which security states the hosts are in. Meanwhile, the traditional security assessment approaches can't assess the real time security situation. These problems make the security operators very difficult to know the current security threat and situation by the traditional security tools. Network security threat and situation assessment aims to extract knowledge of current security threat and situation from raw security data reported by traditional security tools, through the techniques of data fusion, and predict the future security situation based on historical security information and the present attacks.

And the problems for evaluating the wireless sensor network (WSN) security with uncertain information is the multiple attribute group decision making (MAGDM) problems [1-7]. The aim of this paper is to develop the appraisal model of wireless sensor network (WSN) security with uncertain information. The remainder of this paper is set out as follows. In the next section, we introduce some basic concepts related to uncertain variables. In Section 3 we introduce the MAGDM problem deal with appraisal model of wireless sensor network (WSN) security with uncertain information, in which the information about attribute weights is completely known, and the attribute values take the form of uncertain information. Then, we utilize the uncertain linguistic weighted averaging (ULWA) operator to aggregate the uncertain information corresponding to each alternative and get the overall value of the alternatives, then rank the alternatives and select the most desirable one(s) by using the formula of the degree of possibility for the comparison between two uncertain variables. In Section 4, an illustrative example is pointed out. In Section 5 we conclude the paper and give some remarks.

2. Preliminaries

Let $S=\{s_i | i=1,2,\cdots,t\}$ be a linguistic term set with odd cardinality. Any label, s_i represents a possible value for a linguistic variable, and it should satisfy the following characteristics [8-12]: 1) The set is ordered: $s_i > s_j$, if $i > j$; 2) There is the negation operator: $neg(s_i)=s_j$ such that $j=t+1-i$. For example, S can be defined as

$$S=\{s_1=extremely\ poor, s_2=very\ poor, s_3=poor, s_4=medium, s_5=good, s_6=very\ good, s_7=extremely\ good\}$$

Let $\tilde{s}=[s_\alpha, s_\beta]$, where $s_\alpha, s_\beta \in S$, s_α and s_β are the lower and the upper limits, respectively. We call $\tilde{s}$ the uncertain linguistic variable. Let $\tilde{S}$ be the set of all the uncertain linguistic variables.

Definition 1. Let $\mathrm{ULWA}: \tilde{S}^n \rightarrow \tilde{S}$, if

$$\mathrm{ULWA}_\omega(\tilde{s}_1,\tilde{s}_2,\cdots,\tilde{s}_n) = \omega_1\times\tilde{s}_1 \oplus \omega_2\times\tilde{s}_2 \oplus\cdots \omega_n\times\tilde{s}_n, \tag{1}$$

where $\omega=(\omega_1,\omega_2,\cdots,\omega_n)$ is the weighting vector of uncertain linguistic variables $\tilde{s}_i\left(\tilde{s}_i\in\tilde{S}, i=1,2,\cdots,n\right)$ with $\omega_i\in[0,1]$, $\sum_{i=1}^{n}\omega_i=1$, then the function ULWA is called the uncertain linguistic weighted averaging (ULWA) operator of dimension n [8].

Definition 2. Let $\tilde{s}_1=\left[s_{\alpha_1}, s_{\beta_1}\right]$ and $\tilde{s}_2=\left[s_{\alpha_2}, s_{\beta_2}\right]$ be two uncertain linguistic variables, and let $len(\tilde{s}_1)=\beta_1-\alpha_1$, $len(\tilde{s}_2)=\beta_2-\alpha_2$, then the degree of possibility of $\tilde{s}_1\ge\tilde{s}_2$ is defined as [8-12]

$$p(\tilde{s}_1\ge\tilde{s}_2) = \frac{\max\left(0, len(\tilde{s}_1)+len(\tilde{s}_2)-\max(\beta_2-\alpha_1,0)\right)}{len(\tilde{s}_1)+len(\tilde{s}_2)} \tag{2}$$

3. An Approach to Evaluating Wireless Sensor Network Security with Uncertain Linguistic Information

Advances in Micro Electro-Mechanical System (MEMS) technologies, embedded computing technologies and wireless communication technologies have enabled the development of relatively inexpensive and low-power-consumption micro sensors with the capability of sensing, computing and communicating. Composed of a large number of these sensor nodes, a Wireless Sensor Network (WSN) can be used for detecting, collecting and analyzing the information of complex environments in real time. It has a wide range of applications in military communication, environment monitoring, traffic control, personal health monitoring, home networking, etc. The following assumptions or notations are used to represent the multiple attribute group decision making problems for evaluating the network (WSN) security with uncertain 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 set of attributes, $\omega=(\omega_1,\omega_2,\cdots,\omega_n)$ is the exponential weighting vector of the attributes

$G_j\left(j=1,2,\cdots,n\right)$, where $\omega_j\in\left[0,1\right]$, $\sum_{j=1}^{n}\omega_j=1$. Let $D=\left\{D_1,D_2,\cdots,D_t\right\}$ be the set of decision makers, and $v=\left(v_1,v_2,\cdots,v_t\right)$ be the weight vector of decision makers, where $v_k\in\left[0,1\right]$, $\sum_{k=1}^{t}v_k=1$. Suppose that $\tilde{R}_k=\left(\tilde{r}_{ij}^{(k)}\right)_{m\times n}$ is the decision matrix, where $\tilde{r}_{ij}^{(k)}\in\tilde{S}$ is a preference value, which takes the form of uncertain linguistic variables, given by the decision maker $D_k\in D$, for the alternative $A_i\in A$ with respect to the attribute $G_j\in G$.

In the following, we apply the ULWA operator to MAGDM for evaluating the wireless sensor network (WSN) security with uncertain linguistic information.

Step 1. Utilize the decision information given in matrix $\tilde{R}_k$, and the ULWA operator which has associated weighting vector $v=\left\{v_1,v_2,\cdots,v_t\right\}$

$$\tilde{r}_{ij}=\text{ULWA}_v\left(\tilde{r}_{ij}^{(1)},\tilde{r}_{ij}^{(2)},\cdots,\tilde{r}_{ij}^{(t)}\right),\quad i=1,2,\cdots,m,\ j=1,2,\cdots,n. \tag{3}$$

to aggregate all the decision matrices $\tilde{R}_k\left(k=1,2,\cdots,t\right)$ into a collective decision matrix $\tilde{R}=\left(\tilde{r}_{ij}\right)_{m\times n}$, where $v=\left\{v_1,v_2,\cdots,v_t\right\}$ be the weighting vector of decision makers.

Step 2. Utilize the decision information given in matrix $\tilde{R}$, and the ULWA operator

$$\tilde{r}_i=\text{ULWA}_\omega\left(\tilde{r}_{i1},\tilde{r}_{i2},\cdots,\tilde{r}_{in}\right),\quad i=1,2,\cdots,m. \tag{4}$$

to derive the collective overall preference values $\tilde{r}_i\left(i=1,2,\cdots,m\right)$ of the alternative A_i, where $\omega=\left(\omega_1,\omega_2,\cdots,\omega_n\right)^T$ I s the weighting vector of the attributes.

Step 3. To rank these collective overall preference values $\tilde{r}_i\left(i=1,2,\cdots,m\right)$, we first compare each $\tilde{r}_i$ with all the $\tilde{r}_j\left(j=1,2,\cdots,m\right)$ by using (2). For simplicity, we let $p_{ij}=p\left(\tilde{r}_i\geq\tilde{r}_j\right)$, then we develop a complementary matrix as $P=\left(p_{ij}\right)_{m\times m}$, where

$$p_{ij}\geq 0,\ p_{ij}+p_{ji}=1,\ p_{ii}=0.5,\quad i,j=1,2,\cdots,m$$

Summing all the elements in each line of matrix P, we have

$$p_i=\sum_{j=1}^{m}p_{ij},i=1,2,\cdots,m.$$

Step 4. Rank all the alternatives $A_i\left(i=1,2,\cdots,m\right)$ and select the best one(s) in accordance with $p_i\left(i=1,2,\cdots,m\right)$.

Step 5. End.

4. Illustrative Example

Wireless sensor network (WSN), as an integrated network which can perform information gathering, processing and delivering, can connect the real world and logistic information world. It is greatly changing the interaction between people and nature. There are wide potential applications for wireless sensor network, such as industry, agriculture, military affairs, environment monitoring, biomedicine, city managing and disaster succoring. In this section, we present an empirical case study of implementing network security system selection. The desirability levels of five possible alternatives of information systems $A_i\left(i=1,2,3,4,5\right)$ are evaluated. The team of experts must take a decision according to the following four attributes: 1) G_1 is physical and environmental security; 2) G_2 is the administrative security; 3) G_3 is the network communication security; 4) G_4 is the system security. The five possible projects $A_i\left(i=1,2,3,4,5\right)$ are to be evaluated using the linguistic term set S by the three decision makers $D_k\left(k=1,2,3\right)$ (whose weighting vector $v=\left(0.25,0.40,0.35\right)$) under the above four attributes (whose weighting vector $\omega=\left(0.20,0.10,0.40,0.30\right)^T$), and construct, respectively, the decision matrices as follows $\tilde{R}_k=\left(\tilde{r}_{ij}^{(k)}\right)_{5\times 4}\left(k=1,2,3\right)$:

$$\tilde{R}_1=\begin{array}{c} \\ A_1\\ A_2\\ A_3\\ A_4\\ A_5\end{array}\begin{array}{c}\begin{array}{cccc}G_1 & G_2 & G_3 & G_4\end{array}\\ \begin{pmatrix}[s_1,s_2] & [s_3,s_4] & [s_3,s_5] & [s_3,s_6]\\ [s_3,s_4] & [s_2,s_4] & [s_4,s_5] & [s_2,s_3]\\ [s_4,s_5] & [s_3,s_7] & [s_1,s_2] & [s_5,s_6]\\ [s_2,s_3] & [s_2,s_4] & [s_3,s_5] & [s_4,s_5]\\ [s_2,s_4] & [s_3,s_4] & [s_2,s_3] & [s_4,s_5]\end{pmatrix}\end{array}$$

$$\tilde{R}_2 = \begin{matrix} & G_1 & G_2 & G_3 & G_4 \\ A_1 & [s_1,s_2] & [s_2,s_4] & [s_3,s_4] & [s_4,s_5] \\ A_2 & [s_1,s_3] & [s_2,s_3] & [s_1,s_2] & [s_2,s_4] \\ A_3 & [s_2,s_4] & [s_5,s_7] & [s_5,s_6] & [s_3,s_5] \\ A_4 & [s_2,s_3] & [s_3,s_4] & [s_2,s_4] & [s_2,s_3] \\ A_5 & [s_6,s_7] & [s_4,s_5] & [s_3,s_5] & [s_3,s_4] \end{matrix}$$

$$\tilde{R}_3 = \begin{matrix} & G_1 & G_2 & G_3 & G_4 \\ A_1 & [s_2,s_3] & [s_3,s_5] & [s_4,s_5] & [s_3,s_4] \\ A_2 & [s_1,s_2] & [s_2,s_4] & [s_2,s_3] & [s_4,s_5] \\ A_3 & [s_1,s_4] & [s_4,s_6] & [s_2,s_4] & [s_2,s_3] \\ A_4 & [s_4,s_7] & [s_2,s_4] & [s_4,s_5] & [s_1,s_2] \\ A_5 & [s_2,s_5] & [s_5,s_6] & [s_3,s_4] & [s_4,s_6] \end{matrix}$$

In the following, we apply the ULWA operator to MAGDM for evaluating the wireless sensor network (WSN) security with uncertain linguistic information. To get the most desirable information systems, the following steps are involved:

Step 1. Utilize the decision information given in matrix $\tilde{R}_k$, and the ULWA operator which has associated weight vector $v = (0.2, 0.45, 0.35)^T$, we get a collective decision matrix $\tilde{R} = (\tilde{r}_{ij})_{m\times n}$ as follows:

$$\tilde{R} = \begin{matrix} & G_1 & G_2 & G_3 & G_4 \\ A_1 & [s_{1.35},s_{2.35}] & [s_{2.60},s_{4.35}] & [s_{3.35},s_{4.60}] & [s_{3.40},s_{4.90}] \\ A_2 & [s_{1.50},s_{2.90}] & [s_{2.00},s_{3.60}] & [s_{2.10},s_{3.10}] & [s_{2.70},s_{4.10}] \\ A_3 & [s_{2.15},s_{4.25}] & [s_{4.15},s_{6.65}] & [s_{2.95},s_{4.30}] & [s_{3.15},s_{4.55}] \\ A_4 & [s_{2.70},s_{4.40}] & [s_{2.40},s_{4.00}] & [s_{2.95},s_{4.60}] & [s_{2.15},s_{3.15}] \\ A_5 & [s_{3.60},s_{5.55}] & [s_{4.10},s_{5.10}] & [s_{2.75},s_{4.15}] & [s_{3.60},s_{4.95}] \end{matrix}$$

Step 2. Utilizing the ULWA operator, we obtain the collective overall preference values $\tilde{r}_i$ of the information systems $A_i\,(i=1,2,3,4)$.

$$\tilde{r}_1 = [s_{3.69}, s_{4.25}], \tilde{r}_2 = [s_{2.99}, s_{3.51}] \tilde{r}_3 = [s_{3.73}, s_{4.63}]$$
$$\tilde{r}_4 = [s_{3.20}, s_{3.92}], \tilde{r}_5 = [s_{3.97}, s_{4.85}]$$

Step 3. Rank these collective overall preference values $\tilde{r}_i\,(i=1,2,3,4,5)$, we first compare each $\tilde{r}_i$ with all the $\tilde{r}_j\,(j=1,2,3,4,5)$ by using (2), and then develop a complementary matrix:

$$P = \begin{bmatrix} 0.500 & 1.000 & 0.356 & 0.817 & 0.194 \\ 0.000 & 0.500 & 0.000 & 0.248 & 0.000 \\ 0.644 & 1.000 & 0.500 & 0.880 & 0.370 \\ 0.183 & 0.752 & 0.120 & 0.500 & 0.000 \\ 0.806 & 1.000 & 0.630 & 1.000 & 0.500 \end{bmatrix}$$

Summing all the elements in each line of matrix P , we have

$$p_1 = 2.867, p_2 = 0.748, p_3 = 3.393$$
$$p_4 = 1.556, p_5 = 3.936.$$

Step 4. Rank all the information systems $A_i\,(i=1,2,3,4,5)$ in accordance with the overall preference values $p_i\,(i=1,2,3,4,5)$: $A_5 \succ A_3 \succ A_1 \succ A_4 \succ A_2$. Thus the most desirable information system is A_3

5. Results and Discussion

In this paper, we investigate the multiple attribute group decision making (MAGDM) problems for evaluating the E-commerce risk with uncertain linguistic information. We utilize the uncertain linguistic weighted averaging (ULWA) operator to aggregate the uncertain linguistic information corresponding to each alternative and get the overall value of the alternatives, then rank the alternatives and select the most desirable one(s) by using the formula of the degree of possibility for the comparison between two uncertain linguistic variables. Finally an illustrative example for e-commerce risk assessment has been given to show the developed approach and to demonstrate its feasibility and practicality.

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