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Using Fuzzy Network Method to Analysis the Performance of Wireless Sensor Networks

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ABSTRACT

With the constant development of Wireless Sensor Networks (WSN), the problem of these networks has become gradually serious. People are beginning to study the performance analysis of WSNs. It is very important to correctly understanding and analyzing these networks. In this paper, we seek to use the Fuzzy Analytical Network Process (FANP) for analysis of the WSNs performance and selecting the best strategies for improving it. The method is validated using the structural validation approach. The research outcome is the formulation and detection of the priorities of wireless sensor network management strategies with the help of ANP with AHP techniques.

KEY WORDS: Wireless, Sensor Networks, Fuzzy Analytical Network Process (FANP), Management,Performance.

1. INTRODUCTION

The problems of WSNs performance are recently become as one of the main problem in the wireless sensor networks.A Wireless Sensor Network (WSN) consists of spatially distributed autonomoussensorswhich are deployed densely in close proximity to the phenomenon to be monitored. Each of these nodes collects data and sent it back to a sink. Today, this type of network can use in military, rescue [1,2] and also in many industrial and consumer applications such as industrial process monitoring and control, natural disaster relief [3], machine health monitoring[4,5] and so on.

Considering the widespread use of this type of networks, it is important to know, how to use WSNs efficiently.We should be able to answer some basic questions, so analyzing the following problems should be done: What WSNs performance type should be used? And also provides conditions for output quality and also provides conditions for improvement network quality. What factors affected on the conditions of improvement of WSNs performance, and how they can identify and provide the appropriate response to them? It needs to select the best strategy based on the suitable method. There are various decision-making techniques. However, the algorithm that has been presented in this paper is based on the FANP; because of it can measure a relationship between the strategic factors that can make good methods such as AHP, ANP methods based on the independence factors. The AHP technique cannot measure to exist dependence between the factors, because the AHP compared to factors completely independent, and finally this method cannot effectively be an appropriate method considers assessing the effect of internal and environmental factors [1, 4, 6].

The rest of thisresearch work is organized as follow. Section 2 is concerned with the related works. In Section 3 we have presented the research methodology. Section 4 describes the proposed algorithm based on the FANP method. Section 5 is expressed case study, and in the next sections, it will be discussed analysis and presentation of research findings and suggestions for future research results.

2. Related Works

In our research work, for given a strong background and motivation for modeling the proposed scheme, we have studied many other works in the past. Before we start the description of design and implementation solution, we offer a brief review of the prominent works that exist within the scope of our problem.

In a WSN, all nodesare used a single channel for packet transmission, so, unconstrained transmission may lead to the time overlap of two or more packet receptions, called collision. The collision results that, some packets corrupted and don't reach, safely, to destination. Also, thecollided packets increase the system delay and decrease the throughput of network, because they must be retransmitted. Therefore, the WSNs performance analysis must be scheduled to avoid any collision, that is, collision-free transmission should be guaranteed [4, 7, 8]. These works address the problem in an isolated fashion [9] or jointly with routing and topology/power control [10, 11].

The WSNs is composed by a group of nodes, attached with wireless signaling devices. The nodes exchange information by relaying packets from their sources to destinations. A WSN uses broadcasting (flooding) because it is simple and immediate. However, flooding introduces the broadcasting storm problem [12, 13, 14]. Because the flooding broadcast requires each receiver node to relay and forward a broadcast message to all of its one-hop neighbors, the number of broadcast packets grows exponentially [15].

An experimental soil monitoring network using a WSN is presented in [16], which explores real-time measurements at temporal and spatial granularities. In [17] a state-of-the-art system that combines multiple sensor types to provide measurements to perform deformation monitoring, has been described. A durable wireless sensor node has been developed [18], which can be employed in expandable wireless sensor networks for remote monitoring of soil conditions in areas conducive to slope stability failures.

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Duty cycling is one of the most widely used mechanisms for energy-efficient MAC protocols in sensor networks. Authors [19, 20, 21,22,23,24,25] have proposed and discussed duty cycling mechanisms in their MAC protocols. A duty cycling MAC protocol applies suitable sleep/wake up mechanisms to conserve energy. In one of early works, authors in [21] reported that sleep mode power consumption is much less than idle mode power consumption in MICA2 Mote sensors. Whenever there is no need for communication, the radio is put to sleep mode. It is definite that one way towards lower energy consumption is to turn off (sleep) all unused components (e.g., transceiver).Although duty cycling is a popular means to conserve energy, it has some disadvantages. Putting sensors into sleep mode hampers working of whole network or at least certain part of the network. As mentioned by authors of [27], a few issues are needed to overcome such as when a device switch to low power mode or for how long should a device switch to low power mode? To resolve these, efficient and flexible duty-cycling techniques have been proposed as in the works in [21, 26]. Knowledge of traffic patterns can also help to take decisions about wake up easier. This method is known as adaptive duty cycling. In fact, S-MAC [21] is one of the first major energy-efficient MAC protocols to exploit the idea of adaptive duty cycling proficiently.

Hierarchical routing is the procedure of arranging routers in a hierarchical manner. The basic idea of hierarchical routing protocol is to organize sensor nodes into cluster based on the received signal strength and use local cluster-heads as routers to base station. The clustering schemes are used to reduce energy and increase performance efficiency. Clustering provides scalability and robustness for the network; it allows spatial reuse of the bandwidth and simpler routing decisions and results in decreased energy dissipation and also increases performance of the whole system by minimizing the number of nodes that takes part in long distance communication [28]. Clustering-based approaches are showing the most exiting result through their ability to reduce energy consumption and decrease system performance by multiple ways [29]. Authors in [31] have provided a comparison of various clustering algorithms used in wireless sensor networks. They have concluded that all of the algorithms are concerned with how to prolong the lifetime of the sensor network and how to make a more efficient use of the critical resources located at the sensor nodes, without decreasing the communication functionalities, but creating more intelligent clusters, minimizing the maximum number of nodes in a cluster, and minimizing clusters with only a single node (i.e., the cluster head). In fact, hierarchical clustering reduces the amount of query packets via intercluster query dissemination and the amount of data packets by aggregating collected data. Classification of the clustering schemes into four categories—heuristic, hierarchical, weighted, and grid scheme—is proposed in [30].

There are some other mechanisms used in MAC protocols. Data rate adaptation is proposed in [32]. It uses variable rate signaling in WSN as a way to reduce the average network power consumption. Channel polling is another method used in MAC protocols for energy efficiency. Y-MAC [33] is such a MAC protocol for multichannel dense network environment. Hybrid approach is also common and popular in MAC approach to maximize energy saving and increase overall performance. A hybrid approach makes a MAC protocol flexible and enables to use the benefits of all the approaches it combines. For example, LEACH is a hybrid MAC protocol that uses clustering and routing to maximize its performance. This applies to many other MAC protocols as well.

The studied works mainly focused on developing various types of algorithms and evaluating their performance gain through a number of simulations and empirical measurements. However, there is a lack of mathematical analysis on the performance study of WSNs. In this research work, we carry out an analytical approach to study the potential capacity enhancement of performance in WSNs.

3. RESEARCH METHODOLOGY

The analytical and descriptive research using FANP Method has been used as research methodology of this paper. This analytical and descriptive type research has been carried out using the questionnaire as the research tool for gathering the required data. Data's gathering involved both reference material and a questionnaire survey. Sampling was simple random sampling and the data-gathering instrument was the questionnaire. The author had already undertaken research in this field, which had stimulated the decision-making techniques used to analyze this case study, based on FANP Method.

In November 2009 a request for interviews and questionnaires was sent to a number of the managers (60 persons, 30% Male and 70% Female, 70% over 8 year's experience) and the staff (50 persons, 35% Male and 65% Female, 65% over 15 year's experience) in the wireless sensor network company. Prior to the interview and fill the questionnaire, the author explained the purpose of the research and made it clear that this information would be in the public domain, so any confidentiality concerns could be noted. The interview and questionnaire, from December 2010 to April 2011, lasted ten hours per week. The interview and questionnaire were semi-structured in nature, starting with general questions on the wireless sensor networks performance management to put the respondent at ease. To ensure internal validity the interview and questionnaire were transcribed and sent to the experts for check that no commercially sensitive information had been included.

4- Fuzzy Analytical Network Process

The FANP is a generalization of the Like AHP, while the AHP represents a framework with a unidirectional hierarchical AHP relationship, the FANP allows for complex interrelationships among decision levels and attributes. The FANP feedback approach replaces hierarchies with networks in which the relationships between levels are not easily represented as higher or lower, dominant or subordinate, direct or indirect [13,34].

FANP is considered comprehensive and explanatory for multipurpose decision-making discussions and also for solving complex decision-making issues. Studies by Yüksel and Dagˇdeviren used ANP to select information system projects that are internally dependent. These studies saw no requirement for doing an ideal zero and one programming. Karsak**,** Partovi and Corredoira have used ANP in quality activity development [15, 35, 36].

The ANP is composed of four major steps (37):

Step 1: Model construction and problem structuring: The problem should be stated clearly and be decomposed into a rational system, like a network. This network structure can be obtained by decision-makers through brainstorming or other appropriate methods. An example of the format of a network is shown in Fig. 1b.

Step 2: Pairwise comparison matrices and priority vectors: Similar to the comparisons performed in AHP, pairs of decision elements at each cluster are compared with respect to their importance towards their control criteria. The clusters themselves are also compared pairwise with respect to their contribution to the objective. Decision-makers are asked to respond to a series of pairwise comparisons of two elements or two clusters to be evaluated in terms of their contribution to their particular upper level criteria.

Step 3: Supermatrix formation: The supermatrix concept is similar to the Markov chain process (38) .To obtains global priorities in a system with interdependent influences, the local priority vectors are entered in the appropriate columns of a matrix.

Step 4: Selection of the best alternatives: If the supermatrix formed in Step 3 covers the whole network, the priority weights of the alternatives can be found in the column of alternatives in the normalized supermatrix. On the other hand, if a supermatrix only comprises clusters that are interrelated, additional calculations must be made to obtain the overall priorities of the alternatives. The alternative with the largest overall priority should be selected, as it is the best alternative as determined by the calculations made using matrix operations.

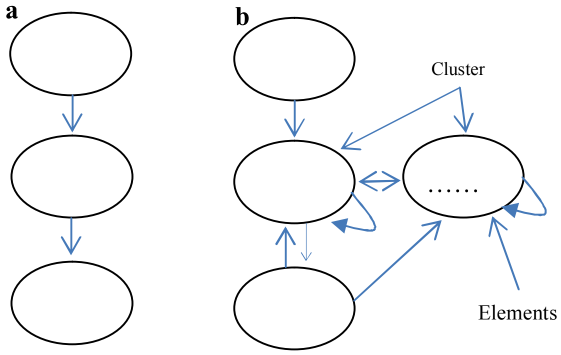

Figure 1: Structural difference between hierarchy (a) and network (b)

A system with reflective state can be explained by a network. The structural difference between the hierarchy and the network is depicted in Figure 1. The existent element in each cluster can affect all or some of the other cluster elements. A network may contain main clusters, middle clusters, and final clusters. Arrows show the relationships in the network and their direction shows the dependence. The dependence among clusters can be named external dependence and the internal dependence among elements of a cluster can be called circle dependence [14,35]. The network model used in this research is presented in Figure 2.

The proposed algorithm is derived as nine steps. In the following we have described these steps.

Step 1: Determine the element sub-factors and strategic options according to sub-factors.

Step 2: Establish the Triangular Fuzzy Numbers.

Step 3: Assume that no dependencies among element factors exist, and then the importance degree of element factors is shown by the fuzzy scale.

Step 4: Determine the element factors of the internally dependent matrix by the fuzzy scale, and consider other factors by schematic view and internal dependencies among them (W2 calculation).

Step 5: Specify the internal dependencies' priorities, that is, calculated $W_{Factors} = W_2 \times W_1$.

Step 6: Specify the importance degree of element sub-factors using the fuzzy scale.

Step 7: Specify the importance degree of sub-factors.

Step 8: Specify the importance degree of strategic options, considering each sub-factor, on the fuzzy scale.

Step 9: Calculate the final priority of strategic options derived from the internal relationships among element factors and defuzzification its. $W_{alternativ} = W_4 \times W_{sub-factors}\ (global)$

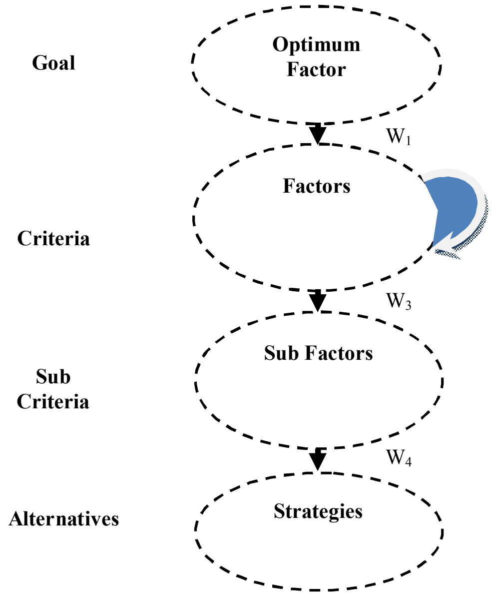

Figure 2: Network model structure

5. Case Study

This section presents an illustration of the proposed approach summarized in the previous section.The proposed algorithm is as follows:

Step 1: First, the issue is depicted as a hierarchical structure, which contains the strategic options and sub-factors for the next calculations using FANP(See Figure 3). The goal is chosen at the first level of the FANP model and the element factors are determined at the second level. The third level contains the sub-factors. Furthermore, six strategic options are given in the fourth level.

Step 2: Establish the Triangular Fuzzy Numbers. A triangular fuzzy number (TFN) is shown in Figure 4.

Since each number in the pair-wise comparison matrix represents the subjective opinion of decision makers and is an ambiguous concept, fuzzy numbers work best to consolidate fragmented expert opinions. A TFN is denoted simply as (L, M, U). The parameters L, M and U, respectively, denote the smallest possible value, the most promising value and the largest possible value that describe a fuzzy event as shows in formulae (1) to (5). The triangular fuzzy numbers u_{ij} are established as follows:

$u_{ij} = (L_{ij}, M_{ij}, U_{ij})$, (1)

$L_{ij} \leq M_{ij} \leq U_{ij}$ and $L_{ij}, M_{ij}, U_{ij}\ \varepsilon [1/9, 9]$, (2)

$L_{ij} = \min (B_{ijk})$, (3)

$M_{ij} = n\sqrt{\prod B_{ijk}}$, (4)

And

$U_{ij} = \max (B_{ijk})$, (5)

Where B_{ijk} represents a judgment of expert k for the relative importance of two criteria C_i-C_j.

Step 3: Assume that there is no dependency among the element factors. Determine the factors' pair comparison matrix using the numerical scale of 1 to 9. All the pair comparisons are completed by a team of experts. The pair comparison matrix (Table 1) is analysed using Expert Choice software and the following special vector is obtained. In addition, a final inconsistency coefficient is shown at the end of the table.

Table 1: Pair wise comparisons (independent status)

Weight	D	C	B	A	Factors
0.428	1	2	3	1	A
0.140	0.9	1/3	1		B
0.238	2	1			C
0.194	1				D

CR=0.03

$$W_1 = \begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix} = \begin{bmatrix} .0.428 \\ 0.140 \\ 0.238 \\ 0.194 \end{bmatrix}$$

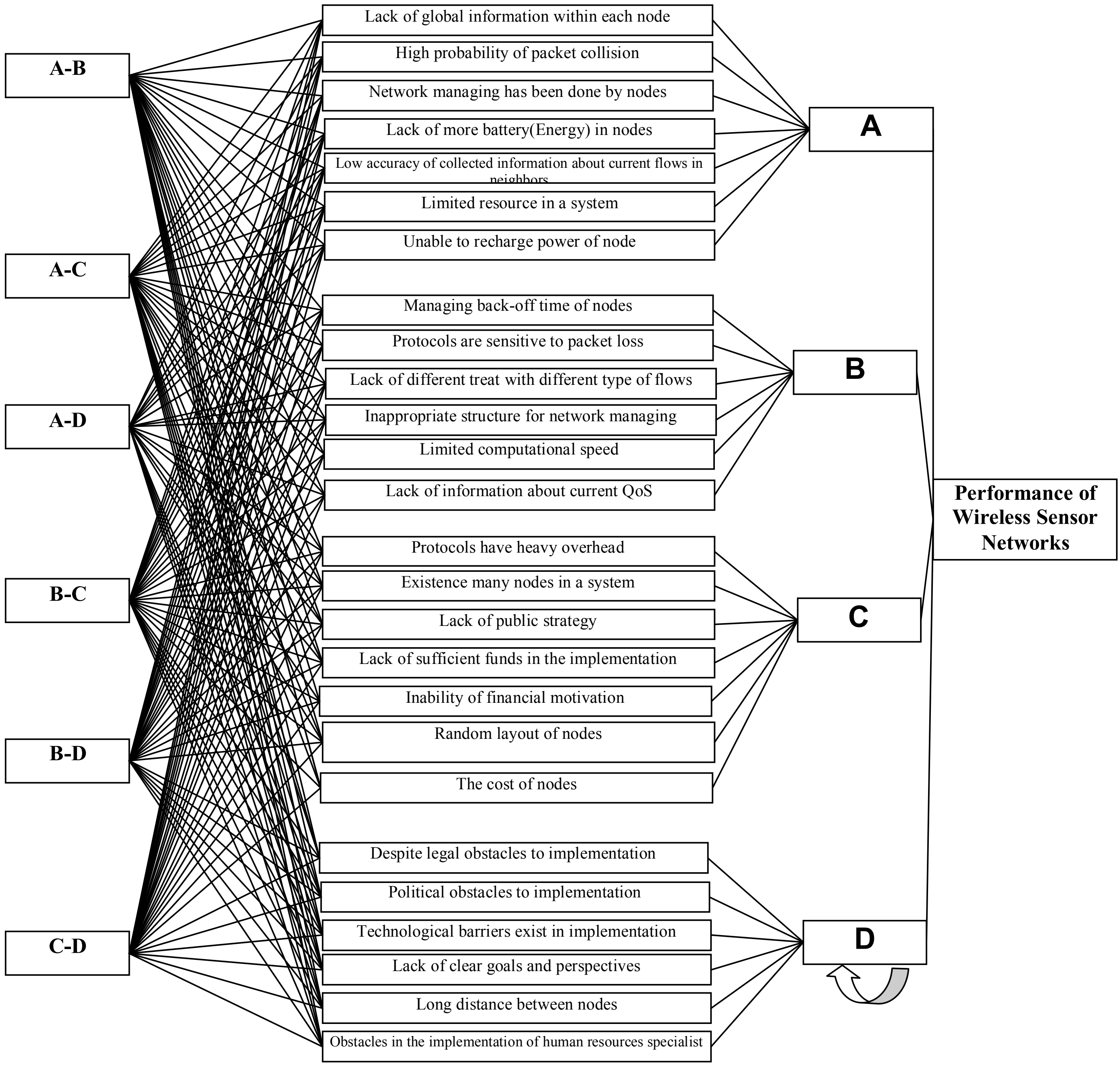

Figure 3: strategies influencing on the mobile ad hoc networks performance

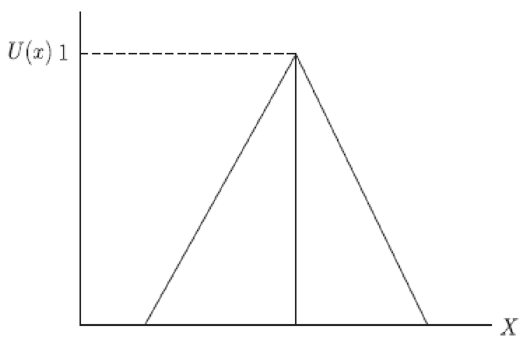

Figure 4: Triangular Fuzzy Numbers

Step 4: The internal dependency among element factors is determined by comparing the effect of each factor on other factors. As mentioned in the preface, considering independence among the element factors is not always possible. Suitable and realistic results are obtained from the FANP technique and element analysis. An analysis of internal and external environment elements reveals the element factors' dependencies as shown in Figure 5.Based on the internal dependency presented in Fig. 5, pairwise comparison matrices are formed for the factors (Tables 2–5). Alsothe results obtained from the special vectors are depicted in the last column of Tables 2 to 5. The internal dependency of the element matrix, based on the calculated relative importance weights, is shown by W2. While opportunities are only influenced by strengths, a pair comparison matrix cannot be formulated for the opportunities. Internal dependency of factors is defined in Figure 5.

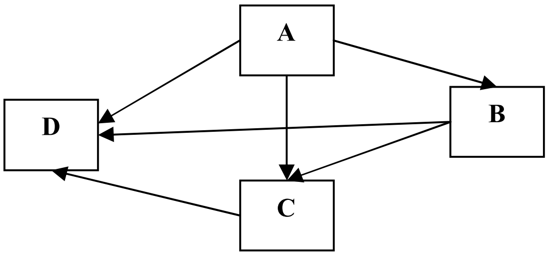

Figure 5: Internal dependency of factors

Internal dependency matrix of factor A,B,C and Dare defined in Tables 2,3,4,5.

Table 2: Internal dependency matrix of factor A

Weights	D	C	B	A
0.648	2	5	1	B
0.230	3	1		C
0.122	1			D

CR=0.00

Table 3: Internal dependency matrix of factor B

Weight	D	C	A	B
0.430	9	7	1	A
0.270	3	1		C
0.300	1			D

CR=0.00

Table 4: Internal dependency matrix of factor C

Weight	D	B	A	C
0.301	7	3	1	A
0.439	2	1		B
0.260	1			D

CR=0.00

Table 5: Internal dependency matrix of factor D

Weight	C	B	A	D
0.273	6	4	1	A
0.184	2	1		B
0.541	1			C

CR=0.00

$$W_2 = \begin{bmatrix} 1 & 0.430 & 0.301 & 0.273 \\ 0.648 & 1 & 0.439 & 0.184 \\ 0.230 & 0.270 & 1 & 0.541 \\ 0.122 & 0.300 & 0.260 & 1 \end{bmatrix}$$

Step 5: Priorities for internal dependencies among the factors are calculated as follows (after normalization):

$$W_{factors} = W_2 * W_1 = \begin{bmatrix} 1 & 0.430 & 0.301 & 0.273 \\ 0.648 & 1 & 0.439 & 0.184 \\ 0.230 & 0.270 & 1 & 0.541 \\ 0.122 & 0.300 & 0.260 & 1 \end{bmatrix} * \begin{bmatrix} 0.428 \\ 0.140 \\ 0.238 \\ 0.194 \end{bmatrix} = \begin{bmatrix} 0.306 \\ 0.279 \\ 0.240 \\ 0.175 \end{bmatrix}$$

The significant differences observed in the above results when compared with those in Table 1 are due to the lack of information about internal dependencies. Factor priority results including A, B, C, D have changed from 0.428 to 0.306, from 0.140 to 0.279, from 0.238 to 0.240, from 0.194 to 0.175.

Step 6: Local priorities of sub-factors are calculated using the pair comparisons matrixthat their findings are in Table 6.

Step 7: Global priorities of the element sub-factors are calculated by multiplying the internal dependency priorities, obtained in Step 4, by the local priorities of element sub-factors, obtained in Step 5. The results are depicted. Vector $w_{\text{sub-factors(global)}}$ which is obtained from the global priority amounts in the last column of table 6.

Step 8: The degree of strategic options' importance is calculated from each element's sub-factor viewpoints. Special vectors are calculated from the analysis of this matrix and matrix W4.

$$W_4 = \begin{matrix} .303 & .578 & .427 & .372 & .223 & .623 & .121 & .563 & .185 & .034 & .303 & .509 & .395 & .201 & .332 & .398 & .352 & .408 & .511 & .333 & .445 & .637 & .458 & .408 & .307 & .463 \\ .201 & .103 & .051 & .209 & .083 & .024 & .173 & .128 & .142 & .201 & .178 & .109 & .113 & .215 & .140 & .178 & .121 & .106 & .209 & .115 & .306 & .007 & .053 & .203 & .193 & .120 \\ .078 & .056 & .206 & .101 & .098 & .121 & .012 & .101 & .194 & .012 & .107 & .057 & .117 & .150 & .214 & .115 & .193 & .019 & .101 & .210 & .021 & .104 & .104 & .095 & .102 & .160 \\ .187 & .101 & .146 & .218 & .296 & .232 & .294 & .067 & .240 & .453 & .202 & .105 & .225 & .204 & .144 & .177 & .214 & .177 & .109 & .132 & .109 & .052 & .085 & .094 & .198 & .117 \\ .180 & .062 & .081 & .075 & .101 & .181 & .054 & .141 & .119 & .218 & .018 & .055 & .060 & .192 & .151 & .044 & .051 & .096 & .017 & .101 & .079 & .101 & .214 & .104 & .038 & .092 \\ .051 & .100 & .089 & .025 & .199 & .219 & .087 & .098 & .120 & .082 & .192 & .165 & .090 & .038 & .019 & .088 & .069 & .193 & .052 & .109 & .039 & .099 & .086 & .096 & .162 & .048 \end{matrix}$$

Table 6: Local and Global priority of sub-factors

Factors	Priority of Factors	Sub-Factors	Local Priority	Global Priorities
A	0.306	Lack of global information within each node	0.255	0.078
		High probability of packet collision	0.211	0.064
		Network managing has been done by nodes	0.09	0.027
		Lack of more battery(Energy) in nodes	0.119	0.036
		Low accuracy of collected information about current flows in neighbors	0.213	0.065
		Limited resource in a system	0.092	0.028
		Unable to recharge power of nodes	0.02	0.006
B	0.279	Managing back-off time of nodes	0.218	0.060
		Protocols are sensitive to packet loss	0.12	0.033
		Lack of different treat with different type of flows	0.209	0.058
		Inappropriate structure for network managing	0.291	0.081
		Limited computational speed	0.027	0.007
		Lack of information about current QoS	0.132	0.036
C	0.240	Protocols have heavy overhead	0.093	0.022
		Existence many nodes in a system	0.051	0.012
		Lack of public strategy	0.028	0.006
		Lack of sufficient funds in the implementation	0.192	0.046
		Inability of financial motivation	0.198	0.047
		Random layout of nodes	0.256	0.061
		The cost of nodes	0.182	0.043
D	0.175	Despite legal obstacles to implementation	0.189	0.033
		Political obstacles to implementation	0.158	0.027
		Technological barriers exist in implementation	0.372	0.065
		Lack of clear goals and perspectives	0.002	0.0003
		Long distance between nodes	0.191	0.033
		Obstacles in the implementation of human resources specialist	0.083	0.014

Step 9: Finally, the general priorities of alternative strategies are calculated considering the internal dependencies of element factors, as follows:

$$W_{Alternatives} = \begin{bmatrix} A-B \\ A\_C \\ A\_D \\ B-C \\ B-D \\ C-D \end{bmatrix} = W_4 * W_{Sub-factors(Global)} = \begin{bmatrix} 0.372 \\ 0.139 \\ 0.101 \\ 0.181 \\ 0.104 \\ 0.105 \end{bmatrix}$$

The results of FANP analysis show that the most important strategy for the wireless sensor networksis strategy A-B with an global priority value of 0.372.

6- DISCUSSION

This study faced many challenges in its model validation test. The first is that the FANP model's factors are not naturally quantitative. FANP is a technique for solving multi-criteria decision making by using the dependence among quantitative and qualitative factors. However, it is not always possible to apply numerical and quantitative amounts to elements in decision-making. It is also that for each calculation, different amounts resulted. This may be due to the different viewpoints among the experts who evaluated the matrix. Thus, it seems impossible to obtain similar amounts based on the data obtained from different studies. These limitations are exacerbated by the nature of decision making. It is natural that in different circumstances, there are different priorities. It should be noted that the existent differences among the pair comparison amounts, which are due to the differences in expert viewpoints, are not sufficient reason for rejecting the proposed model's validity in FANP discussions [39, 40]. Another problem is that the validity of this model has not been tested using the latest data and that is because those data are available only to special managers. The comparison matrix which is the input for the proposed model was composed under definite conditions; hence, results may differ due to the pair comparison matrix's composition in different time periods [18]. This model may be improved as the factors and sub-factors keep changing. Each management team should apply these strategies to the model according to the strategic factors in play. Second, the amount of dependence among factors and sub-factors may vary based on the management type. For example, in The Tehran province, only the dependence among important element factors is evaluated. The inconsistent ratio resulting from the pair comparison matrix also co-organizations this model. The inconsistent ratio or CR is based on the inconsistency index and Random index. Inconsistency index or CI can be obtained through the following formula: $CI = (\lambda_{\max} - n)/(n-1)$.

Where $\lambda_{\max}$ is the highest special amount and n is the matrix dimension. Inconsistency ratio (CR) is composed of two parameters: inconsistency index (CI) and Random index (RI). The relationship between RI and n is as follows:

RI = 1.98 * [(n – 2) / n].

Where 1.98 is the ratio of average amount of all numbers for n=3 till n=15, each having been multiplied by (n-2)/n. The calculated amount for the inconsistency ratio in FANP should not be less than 0.1. The inconsistency ratio of the pair comparison matrix is calculated using Expert Choice. All inconsistency ratio amounts are less than 0.1. The proposed model is the first of its kind and is hence considered unique. The results were re-rating of the experts who confirmed that 79.5 percent, and it suggest for reliability. Validity of the model is used the Cronbach' alpha value was 88.2 percent, which indicates validity of the model.

7. Conclusion

We have defined and classified the effective factors of the wireless sensor networks performance management and analysed them using FANP. The performance of wireless sensor networks is one of the most powerful elicitors of subjective emotion, yet it is not clear whether emotions elicited by the wireless sensor networks performance management are similar to emotions elicited by visual stimuli. In this research work, we present the best strategies influence on the performance of wireless sensor networks. Consequent to this analysis, we have presented strategies for improving the wireless sensor networks, which were verified and validated in a case study.

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