

A Novel Sleep / Wakeup Power Management in Wireless Sensor Network: A Fuzzy TOPSIS Approach

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Abstract

The wireless sensor network (WSN) is typically comprised many tiny nodes equipped with processors, sender/receiver antenna and limited battery in which it is impossible or not economic to recharge. Meanwhile, network lifespan is one of the most critical issues because of limited and not renewal used battery in WSN. Several mechanisms have been proposed to prolong network lifespan such as LEACH, HEED and CHEF, but in all of them nodes consume energy continuously. One of the promising techniques is to apply dynamic sleep/wake up scheduling. In this paper, a novel sleep/wake up scheduling algorithm is proposed so-called FT-ECCKN¹. Each node executes sleep/wake up scheduling right after sending/receiving data where a node changes its status to sleep mode if it has at least k neighbors awake in its radius neighborhood with more residual energy in comparison with the node executing scheduler. Whenever the number of nodes is more than $2k$, fuzzy TOPSIS method is used to rank nodes based on residual energy and coverage distance to select k out of number of nodes in ranking list. To evaluate the proposed algorithm, 25 scenarios are conducted in the experimental field 800×600 m² between 100 through 500 nodes increasing with 100 numbers and k belongs to $\{1, 2, \dots, 5\}$. Totally, our proposed algorithm outperforms 23.27 percent in term of network life time in comparison with EC-CKN method for overall scenarios. Remarkable results show that the proposed algorithm is beneficial for large scale fields with dense nodes along with smallest k .

Keywords: Wireless Sensor Network, Dynamic Sleep/Wake up Algorithm, Fuzzy TOPSIS

1. Introduction

A wireless sensor network (WSN) typically contains several tiny nodes which are battery limited and are not renewal devices [1]. Such nodes are equipped with sensors, processors and communication devices. A WSN is an economic and promising solution in harsh and tough environment which wired network is impossible or has not sense of economic. Health monitoring [2], agricultural field monitoring [3] and different emerging technologies related to surveillance ambit such as house checking [4] are several examples of WSN applications. Traditionally, sensor nodes are equipped by chemical battery with limited life time [5], even preserving energy mechanisms finally encounter with battery depletion; subsequently makes down of whole network [6]. There exist several concerns and challenges in WSN context whereas the hottest one

¹ Fuzzy TOPSIS-ECCKN

pertains to increasing network lifespan. Miscellaneous works have been presented in literature to deal with the power management and to prolong whole WSN lifespan such as LEACH, CHEF and HEED. [7-9]. For instance, Heinzelman WB. et al. have proposed a clustering method to integrate nodes which have same amount of energy in a same cluster [10]. The approach extends network lifetime, but since cluster head nodes are depleted as soon as possible the rearrangement algorithm should be executed making high rate of overhead. A Connected K-Neighbor (CKN) algorithm based on sleep-wake up has been developed to make unnecessary nodes into sleep mode, as such nodes' lifetime is extended so as whole network [11]. It is suffered from dependency to random numbers in making K-neighbors phase in which a node has greater random number in comparison to central node, decision maker node, whereas its residual energy is low. It eventually makes instability in several scenarios. An energy consumed uniformly CKN, so-called EC-CKN, algorithm is developed to cover basic CKN problem by considering residual energy instead of random number which is dedicated to any node [12]. EC-CKN extends network lifetime but susceptible to omission some district monitoring. This paper's main contributions are:

- 1- To apply sleep/wakeup technique with selecting appropriate parameter k to preclude nodes' energy wastage and to prolong network life span.
- 2- To apply fuzzy TOPSIS as a strong tool for multi-criteria decision making problem based on two objectives nodes' residual energy and far distance of zone coverage.
- 3- To apply appropriate and 2-hop technique to minimize number of awake nodes by ensuring 2-hop neighbor nodes are monitoring the maximum area.

Research reviews show drawback of published paper for power management because the idle nodes but active continuously consume energy. To bridge the gap, a novel sleep/wakeup algorithm based on fuzzy TOPSIS is developed to prolong network lifetime and not to lose coverage. It leverages both K-Neighbor and 2-hop concepts to sleep unnecessary nodes while coverage maximum area. The rest of the paper is organized as follows. Section 2 is dedicated to literature review. Section 3 details our proposed algorithm. Experimental results are brought in section 4. Section 5 concludes the paper.

2. Literature Review

In this section, we present a brief definition of WSN communication network and energy models along with fuzzy TOPSIS introduction.

2.1. Communication Network Model

Multi-hop sensor networks are modeled by graph notation $G=(S, E)$ where $S=\{s_1, s_2, \dots, s_N\}$ is a set of $N=|S|$ sensor nodes and E is a set of edges which specifies nodes direct communication. For instance, $(s_i, s_j) \in E$ indicates two nodes s_i and s_j are directly connected without any interface and without any relaying. In the aforementioned communication s_i is a sender and s_j is a receiver. So, they are neighbors. Also, a node s_i is 2-hop neighbor of a node s_j when (s_i, s_j) does not belong to E and there exist a node s_r so that (s_i, s_r) and $(s_r, s_j) \in E$ or (s_j, s_r) and $(s_r, s_i) \in E$. We use l_{ij} instead of (s_i, s_j) communication presentation. Each node s_i has transmission

radius t_{ri} and interference radius f_{rj} . Suppose that the set S of sensor nodes are deployed with a homogeneous Poisson process in a two dimensions plane A . Also, each node is equipped with single radio interface and has the same amount of initial energy E_{init} . Time is split into epochs. Duration of each epoch is T . In each epoch, every node at first transmits the packets then it runs scheduler algorithm to determine the state of the next epoch as Figure 1 depicts. In this model, size of all packets is assumed to be in the same size and transmission time is assumed to be t . The sensor network lifespan is defined as average time between beginnings of scheduling till the network is run out of energy.

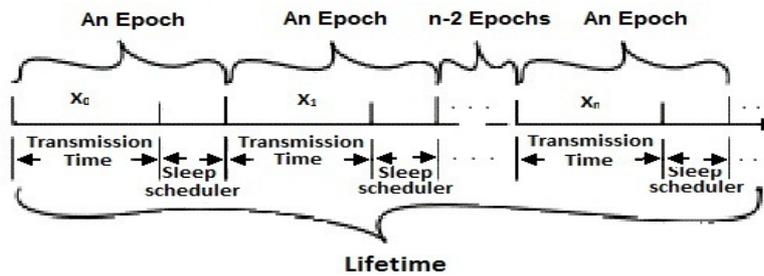


Figure 1. The S_i 's lifetime includes several epochs [12].

2.2. Energy Model

We adopt energy model for each node in WSN based on first order radio model. Equation (1) indicates the amount of energy consumption for transmitting an l -bit packet over distance d [13-14].

$$E_{Tx} = \begin{cases} l \times (E_{elec} + E_{fs} \times d^2) & , \text{if } d \leq d_0 \\ l \times (E_{elec} + E_{mp} \times d^4) & , \text{if } d > d_0 \end{cases} \quad (1)$$

Where E_{elec} is the amount of energy consumption per bit to run a transmitter or receiver circuitry. E_{fs} and E_{mp} are the amount of energy per bit dissipated in the RF amplifier according to distance d_0 which can be obtained via equation (2). It shows that the more distance is to target node, the more energy is consumed to amplify the radio signal.

$$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}} \quad (2)$$

Also, equation (3) represents calculation of power consumption for receiving an l -bit packet.

$$E_{Rx} = l \times E_{elec} \quad (3)$$

2.3. FUZZY TOPSIS- Technique for Order Performance by Similarity and Ideal Solution

TOPSIS is broadly applied in literature to handle multi-objective decision making problems in real world. Although it is easily deployed, this technique is often criticized for the sake of its vagueness and uncertainty in decision process resulting of subjective human comparison. Therefore, fuzzy TOPSIS has been developed by Hwang et al. to obviate its uncertainty [15]. Moreover, TOPSIS has been improved to deal Multi Criteria Decision Making (MCDM) with an uncertain decision matrix resulting in fuzzy TOPSIS, which has successfully been utilized to figure out various MCDM problems [16-18]. However, we apply Analytical Hierarchical Process (AHP) method to determine near to exact weight for criteria (metrics) in the inception of the work [19]. The alternatives are placed as points within a n-dimensional Euclidean space with each dimension corresponding to each criterion and their ranking is produced according to their closeness to the ideal and farness to the anti-ideal points which are modeled as hypothetical alternatives that have respectively the best and the worst utility values for each criterion [20-22]. The TOPSIS method determines the metric of “relative closeness” which is a function of the Euclidean distances of each alternative from the ideal (A^+) and the anti-ideal points (A^-) in order to represent the simultaneous satisfaction of two objectives: the best alternative should be the closest to the ideal point and the farthest from the anti-ideal point as Figure 2 illustrates. Also, the relative closeness measure is expressed as $C_i^+ = \frac{S_i^-}{S_i^- + S_i^+}$ where S_i^- and S_i^+ are the distances of alternative i from the anti-ideal and the ideal point, respectively (Figure 2).

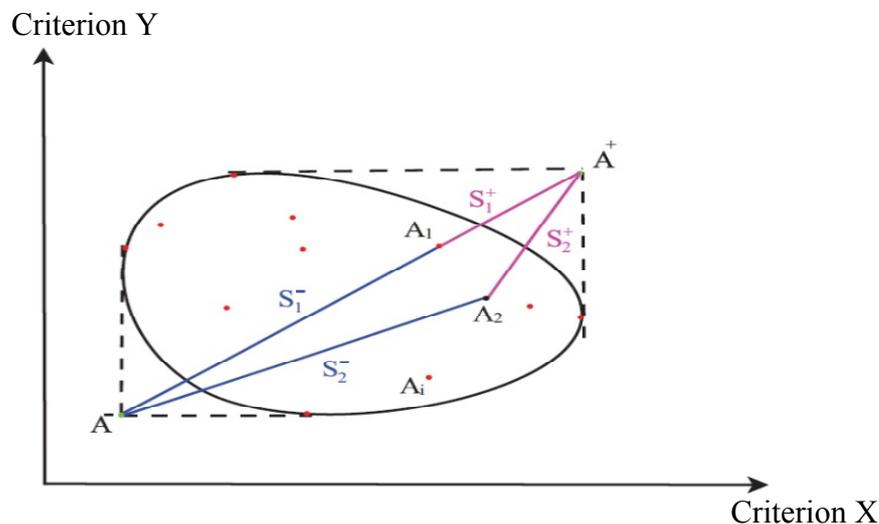


Figure 2. Alternatives as two points in 2D space corresponding to criteria x and y and their distance from ideal and anti-ideal points

The main method is elaborated as below:

Let us consider the decision matrix A which includes alternatives and metrics (criteria) as equation (4):

$$A = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} \quad (4)$$

Where A_1, A_2, \dots, A_m are alternatives, and C_1, C_2, \dots, C_n are criteria, x_{ij} indicates rate of alternative A_i regarding to criteria C_j . The weight vector $W = (w_1, w_2, \dots, w_n)$ composed weights w_k ($k=1, \dots, n$) for indication the importance of each criteria C_k subject to $\sum_{k=1}^n w_k = 1$. Moreover, criteria are divided to benefit and cost types which the first type the higher value is desirable and for the second one lower value is eligible as opposed to the first one. As the data of the decision matrix comes from different sources, it needs to become dimensionless with normalization approach which permits the comparison with various criteria. Then normalized decision matrix $R = [r_{ij}]_{m \times n}$ with $i=1, \dots, m$ and $j=1, \dots, n$ is calculated. The normalized value r_{ij} is calculated by following equation (5):

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (5)$$

Matrix R shows the relative rating of alternatives. Then weighted normalized decision matrix $P = [p_{ij}]_{m \times n}$ with $i=1, \dots, m$ and $j=1, \dots, n$ is developed. It is obtained by multiplying the normalized decision matrix and its related weights namely $P_{m \times n} = R_{m \times n} \cdot W_{n \times n}$. Where $W_{n \times n}$ is a diagonal matrix with weights placed on the main diagonal. After that, TOPSIS method is started with four steps as below:

Step 1: To identify positive ideal solution A^+ as benefit and negative ideal solution A^- as cost:

$$A^+ = (p_1^+, p_2^+, \dots, p_m^+) \quad (6)$$

$$A^- = (p_1^-, p_2^-, \dots, p_m^-) \quad (7)$$

Whereas $p_j^+ = (\max_i p_{ij}, j \in J_1; \min_i p_{ij}, j \in J_2)$ and $p_j^- = (\min_i p_{ij}, j \in J_1; \max_i p_{ij}, j \in J_2)$ where J_1 and J_2 are benefit and cost types criteria respectively.

Step 2: To calculate Euclidean distances from positive ideal solution A^+ and the negative ideal solution A^- for each alternative A_i as follows:

$$S_i^\pm = \sqrt{\sum_{j=1}^n (p_j^\pm - p_{ij})^2} \text{ with } i = 1, \dots, m \quad (8)$$

Step 3: To calculate the relative closeness C_i for each alternative A_i with respect to positive ideal solution as follow:

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (9)$$

Where $0 < C_i < 1$, A_i is closer that A^+ than to A^- as C_i approaches to 1.

Step 4: To rank alternatives according to the relative closeness, so the ranking is done based on parameter C_i in decreasing order which means the higher values C_i is closer to positive ideal solution.

3. Fuzzy TOPSIS Energy Consumed Uniformly-CKN (FT-ECCKN)

As previously explained, the WSN is suffered from short lifetime and field coverage omission due to quick battery depletion and unbalanced nodes' energy consumption. To address the issue, we propose an advanced fuzzy TOPSIS energy consumed uniformly-CKN algorithm so-called FT-ECCKN in short. The pseudo code of our proposed algorithm which is executed by each node in each epoch is depicted in Table 1.

Table 1. Pseudo code of proposed FT-ECCKN algorithm

Algorithm: Fuzzy TOPSIS Energy Consumed Uniformly-CKN (FT-ECCKN)

/* The FT-CKN Algorithm is run at each node s_u */

Input: Remaining energy as $Erank_u$.

Output: Change nodes status

Step 1. Get the information of current remaining energy as $Erank_u$.

Step 2. Broadcast $Erank_u$ and receive the energy ranks of its currently awake neighbors N_u . Let R_u be the set of these ranks.

Step 3. Broadcast R_u and receive R_v from each $s_v \in N_u$.

Step 4. If $|N_u| < k$ or $|N_v| < k$ for any $s_v \in N_v$, remain awake. Return.

Step 5. Compute $C_u = \{s_v | s_v \in N_u \text{ and } Erank_v > Erank_u\}$;

Step 6. If $|C_u| = m > 2k$ then

Step 6.1. Rank elements of C_u considering multi-objectives Erank(more) and Distance(far) from node s_u by Fuzzy TOPSIS method.

Step 6.2. Select $2k$ out of m elements from C_u based on new rankings and put it in E_u .

Else

Step 6.3. Copy C_u in E_u .

Step 7. Go to sleep mode if both the following conditions are met. Remain awake otherwise.

Conditions are:

Step 7.1. Any two nodes in E_u are connected either directly themselves or indirectly through nodes which are in the s_u 's 2-hop neighborhood that have $Erank_v$ larger than $Erank_u$.

Step 7.2. Any two node in N_u has at least k neighbors from E_u .

Step 8. Return.

FT-ECCKN algorithm takes number k as its input parameter, the required minimum number of awake neighbors per node. The proposed algorithm leverages several techniques to meet variety needs such as sleep/wakeup technique to turn unnecessary nodes into sleep mode once the node is recognized has at least k awake neighbor nodes. It guarantees to conserve local zone surveillance along with precluding power wastage since an idle sensor node but active consumes power continuously. It also takes benefit of 2-hop technique to determine when indirect neighbors are on the zone is under control. In a word, if k number of 2-hop neighbors are on, it guarantees that the zone is under control [12]. As algorithm steps 1 through 3 shows, each node gets its current remaining energy as an energy rank, an indicator. Then it broadcasts this information to its current awake neighbors and receives their same information from its currently awake neighbors. All of gathered information are saved into appropriate data structures. Step 4 of algorithm stipulates for each node u that if number of current awake neighbor nodes, direct nodes, are less than k nodes, or the number of k 2-hop neighbors, indirect nodes, are less than k nodes then the node u must stay awake. In step5, each node compute set of neighbors C_u which have more residual energy in comparison with current node u . Step 6 determines whether the number of nodes in C_u is more than $2k$ or not. If so, a fuzzy TOPSIS method, as a strong tool for ranking in multi criteria decision making problem, is used to rank nodes in C_u according to two objectives residual

energy and far distance from node u both in decreasing order. Then k top rank nodes out of m nodes in ranked list will be selected to copy into E_u . If not so, all of the nodes in C_u will be copied into E_u . It is clear-cut in sub steps 6.1, 6.2 and 6.3. The number $2k$ is attained experimentally via different executions. Step 7 has two conditions to be met for switching node u to sleep mode, otherwise node u must stay awake. The former condition says any two nodes in E_u must be connected directly or indirectly through nodes which are in the s'_u 's 2-hop neighborhood that have $Eranks_v$ larger than $Eranks_u$. The latter indicates any two node in N_u has at least k neighbors from E_u . It guarantees that the network is maximally under coverage.

4. Evaluation

Inasmuch as EC-CKN obviously outperforms over CKN, we compare our proposed algorithm, FT-ECCKN, with EC-CKN to evaluate our work.

4.1 Implementation

All experiments were implemented using Sony VAIO laptop with a 2.26 GHz Intel Core 2 Duo processor and 4 GB RAM and using Matlab 2015. Here, we define the sensor network configuration under study same as in [12] to create common condition. Implementation environment is $800 \times 600 m^2$. The number of nodes varies from 100 to 500 by increasing by 100 numbers. The number of k increases from 1 to 5 by one. Consequently, 25 scenarios are defined. Table 2, illustrates configuration parameters.

Table 2. Network Configuration Parameters

Parameter	Concept	Value
Rad	Neighbor radius coverage	60m
InitEnergy	Initialize Energy	1000mj
Energy	Residual Energy	
EnergyIdle	Energy consumed of each node in wakeup mode, but idle	Joule
Eelect	Energy consumed for receiving of one bit	50 nj/bit
	E Energy consumption factor	10 pJ/bit/ m^2
	E Energy for amplification	0.0013 pJ/bit/ m^4
L	Transferring/ Receiving bits	5 bits
K	Neighbor parameter	Variable numbers in $\{1,2,\dots,5\}$
Number	Number of random nodes in environment	Variable numbers in $\{100, 200,\dots,500\}$

Moreover, the source node is deployed at location of (50, 50), and a sink node is deployed at (750, 550). The radius for transmission is considered 60m for each node. Figure 3 illustrates comparison of network lifespan for proposed algorithm (FT-ECCKN) and EC-CKN by variable number of nodes along with variation of parameter k .

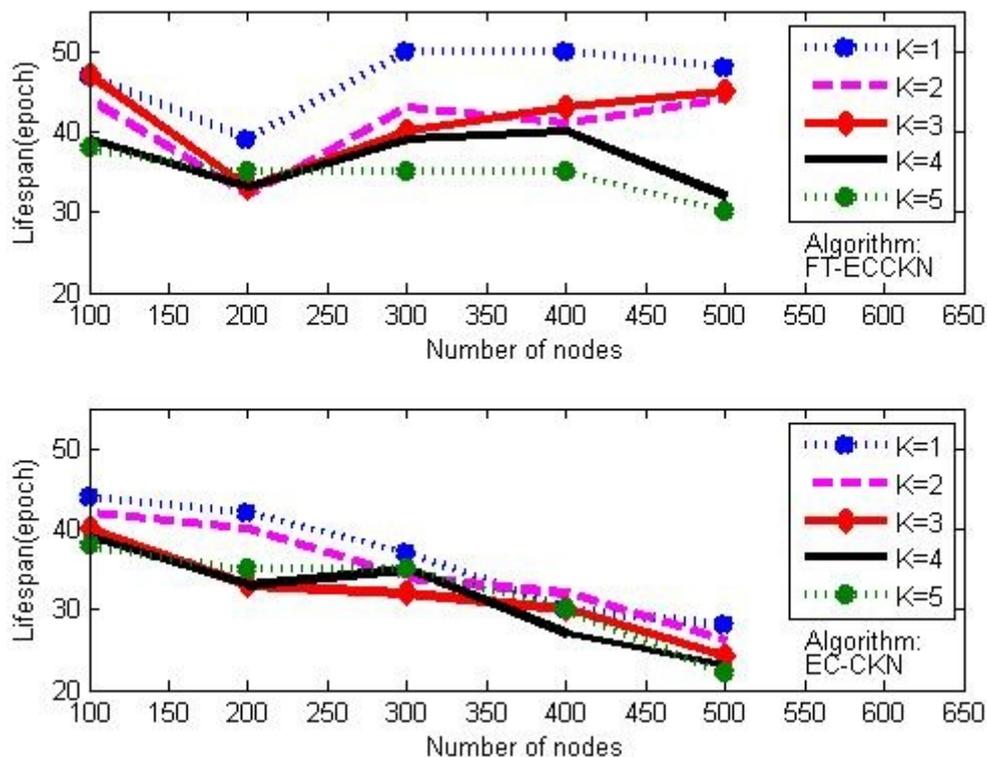


Figure 3. Comparison the network's lifetime between proposed method and EC-CCKN

Figure 3 depicts efficiency differences between FT-ECCKN and EC-CCKN in term of network life span regarding to increasing number of nodes by 100 from 100 nodes to 500 nodes. It also shows differences with variety parameter k increasing by one up to 5. In case of random dispersed 100 nodes on underlying field, FT-ECKN dominates over ECCKN for small parameter of k for instance less than 4. On the other hand, for bigger parameter k , i.e., more than 3 both algorithms have the same efficiency in term of network life time coverage. Also, if network field is randomly filled by 200 sensor nodes. The ECCKN outperforms in term of network life time over FT-ECCKN for $k=1$ and $k=2$. For $k \geq 3$, both algorithm have the same result. As such, FT-ECCKN dominance over EC-CCKN for all parameters k except for the biggest $k=5$ which the result is the same for both algorithm in term of network life span provided the field is randomly fill by 300 sensor nodes. It can be seen tangible dominance of FT-ECCKN over ECCKN for all parameters k providing the field is randomly filled by 400 sensor nodes. Finally, if the field is randomly filled by 500 sensor nodes. It can be proved that our proposed algorithm, FT-ECCKN, dominates over EC-CCKN for all parameters k . It also demonstrates the dominance of FT-ECCKN is tangible for smaller k that is $k \leq 3$. Experimental results show that our proposed algorithm, FT-ECCKN, outperforms over ECCKN in denser environment especially for smaller parameter k .

4.2 Performance Analysis

To illustrate amortized improvement analysis as final improvement of FT-ECCKN over EC-CCKN in all scenarios needs defining of improvement formula and

improvement percent formula regarding to all scenarios. Equation 10 is dedicated to calculating percentage of performance improvement (PI) life span.

$$PI = \frac{Lifespan_{Proposed Method} - Lifespan_{Old Method}}{Old Algorithm Lifespan_{Old Method}} * 100\% \quad (10)$$

Where PI is percentage of improvement in network's lifespan for the proposed method with respect to other methods. Table 3 indicates improvement percent of FT-ECCKN in term of life span by segregating scenarios.

Table 3. Improvement percent of FT-ECCKN in term of life span by segregating scenarios

Number	K=1	K=2	K=3	K=4	K=5	Average
100	6.82%	4.76%	17.5%	0%	0%	5.69%
200	-7.70%	-25%	0%	0%	0%	-6.54%
300	35.14%	26.47%	25%	11.43%	0%	19.61%
400	66.67%	28.13%	23.33%	48.15%	16.67%	36.59%
500	71.43%	69.23%	87.5%	39.13%	36.36%	60.37%

Moreover, by calculating average of improvement percent on number of all scenarios final improvement will be attained. The final improvement, total improvement on 25 scenarios in FT-ECCKN over EC-CKN is 23.27 percent. It is mean value of average column.

5. Conclusions and Future Work

WSN is a promising paradigm for monitoring a harsh environment or district which is not economic to have wired network. It comprises hundreds or even thousands number of sensor battery limited nodes. So, power management is a first class concern in such environment. To handle the problem, we have developed a novel sleep/wakeup algorithm with which each node after receiving/transmitting the signals executes scheduling algorithm. The scheduler of each node searches a round its coverage radius for at least k awake neighbor nodes or k 2-hop neighbor nodes to be self-assured to change its current mode from awake to sleep mode. Because an idle node, but awake one continuously consumes energy based on energy model. As such, our proposed algorithm, FT-ECCKN, leveraged fuzzy TOPSIS approach as a strong tool for multi-criteria decision making (MCDM) problems whereas the objectives were residual energy and far distant of coverage for each node. Indeed, a decision maker node selects its awake neighbor nodes with high residual energy and far distant coverage to put them into their neighbor list. Fortunately, FT-ECCKN is topology independent which can be applied in all environments. Experimental results on conducted scenarios show that network life time will be decreased by increasing sensor nodes for constant k owing to high rate of receiving/transmitting the signals from environment. On the other hand, the life time for network with sparse nodes will be increased owing to low rate of receiving/transmitting the signals from environment, but it suffers from out of coverage. However, we conducted 25 scenarios by dispersing nodes in environment randomly from 100 to 500 increasing by 100 and considering parameter k from set $\{1,2,3,4,5\}$. Also, the result of implementation show that our proposed sleep/wakeup algorithm is the most appropriate for denser environment with abundant nodes with the small parameter k such as less than 3. It also, guarantees that energy consumption by nodes

uniformly distribute between them. Overall, the proposed algorithm improvement dominates about 23.27 percent on average over EC-CKN in all scenarios. Our next work is to develop a sleep/wakeup algorithm which precludes aggressive scheduling along with extending a computational geometry to prove the scheduler does not violate coverage optimally. In a word, it proves the scheduler tries to cover maximum coverage environment along with efficient power management.

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