Optimal Number of Nodes Deployment Method in Corona-Based WSN

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***Abstract*—Wireless sensor networks (WSNs) consist of several nodes with limited and non-rechargeable power resources. Therefore, energy efficiency and network lifetime depend on the utilize way of sensor nodes. Recently, some methods and strategies have been employed in this regard. Most of them could improve network lifespan to an acceptable level. Energy hole is one of inherent problems which can decrease the network lifetime to 89%. In multi-hop WSNs, the sensors located closer to sink must relay more data packets in comparison with other ones, thus their power supplies will be exhausted earlier than other nodes. Whereas, the sensor nodes belonging to other layers still have required energy for transmitting their data packets. This asynchronous energy depletion is considered as a problem. In this paper, we present a mathematical model for non-uniform node deployment for corona-based WSNs. According to results, Optimal Number of Nodes Deployment Method (ONNDM) enhance the network lifetime via balancing energy consumption and workload among coronas. In ONNDM, the optimum number of nodes in each corona is obtained by a mathematical formula, which can outperform other proposed strategies.**

Index Terms*—*Wireless Sensor Networks; Network Lifetime; Energy Holes.

I. INTRODUCTION

Wireless sensor network is comprehensively defined as the set of sensors located in an area for sensing the environment. Sensors can gather different types of data based on their defined functions. After some processing operations, the collected data are sent to the sink. This process is done by different routing ways. One of components of sensor or mote (chiefly in North America) is battery or power source that is limited and non-rechargeable. On the other hand, these sensors are located in areas that are not accessible by humans; thus, it is not possible to recharge or exchange these components. As a result, energy efficiency is a very important issue in WSNs.

In hop by hop or multi-hop WSNs, the nodes located within the network relay the data packets from outer sensors to inner sensors. Hence, those located around base station have to relay more data packets in comparison with other ones and their energy resources are depleted quicker than other sensor nodes. Therefore, energy holes appear which can decrease the network lifetime to 89% [1]. Several strategies have been proposed for solving this problem, including Non-uniform node deployment strategies that can alleviate energy holes in WSN to an extent [2, 3]. Clustering is another method to mitigate this problem through grouping the nodes into clusters [4, 5]. Furthermore, sink mobility [6, 7] and adjusting the transmission range of sensor nodes [8, 9] are other methods to alleviate energy holes. Proposed ONNDM strategy in this paper is designed efficiently for corona based WSNs in order to solve the unbalanced energy expenditure among coronas by obtaining the optimal number of nodes in coronas.

The remaining of this paper is presented as follows: the related work and literature review is presented in the second section. Assumption and network model is introduced in the third section. In the fourth section, proposed method (ONNDM) and its mathematical formulas are presented. In the fifth section, the results are shown; in this section, we will demonstrate that our method could mitigate efficiently the energy hole problem and a comparison is made between our strategy and other proposed methods. Finally, the sixth section concludes the paper.

II. RELATED WORKS

Generally, sensor nodes placement in the network depends on the environment, application and type of the components [10]. Node deployment strategies are categorized into two groups, non-uniform deployment and uniform deployment [1]. In [11], authors proposed a non-uniform node deployment strategy for overcoming the energy hole problem. In their proposed strategy, the density ratio of nodes in two adjacent coronas is changed based on a geometric proportion. This method can guarantee the efficiency in consumption of energy. Authors, in [12], used the strategy proposed by themselves in [11]. They proposed a new strategy for non-uniform node distribution to acquire semi-balanced energy depletion among coronas. They calculate the number of nodes in each corona and derived the ratio between two adjacent coronas. Additionally, a q-switch routing algorithm was introduced in that paper. In [13], the optimal distance between two adjacent sensors was obtained; and in order to increase the network lifetime, the distance of nodes located around the sink was minimized. Ferng *et al.*, in [14], introduced three strategies for a corona-based WSN to alleviate the energy hole problem. In the first strategy, the unbalance energy depletion problem is solved; in the second strategy, the longest network lifetime is provided with full network coverage; and the highest efficiency is prepared to use sensor nodes to achieve full coverage in the third strategy. Their observation is tested through simulation and analytical approaches. In [15], an energy aware distribution function is proposed. In their work, more number of nodes are deployed nearby the sink to provide the required energy of innermost corona for transmitting the data packets of outermost coronas. in [10], node deployment strategy is introduced to mitigate the energy hole problem. In this proposed method by Atiq et al. the sensors are in Gaussian fashion. Tao Liu in [16] employed a mixed routing strategy to solve the unbalanced energy consumption of nodes both within the coronas and within the different coronas.

III. ASSUMPTION AND NETWORK MODEL

It is considered that the area of the network is circular with radius *R*, sensors are uniformly distributed throughout the area and the sink is located at the center of this area. The network is divided into k adjacent rings or coronas with thickness *r* (Figure 1). C_i denotes the *i*th corona and the inner most corona is denoted by C_1. Assume sensor nodes sense and transmit *l* bits data per unit of time and data packets will be sent to the nodes located in inner corona with *d* transmission range. We assume there is connectivity on the network and the area is environment with the path loss exponent *n*. An ideal MAC layer is assumed with no collisions and retransmissions.

It is also considered that sensors have *ε0* initial energy, whereas, sink node is a resource rich device. In this paper, the energy model proposed in [17] is used , the energy consumption for receiving and transmitting l bits data packet will be as follow respectively:

$$E_{rx} = l(E_{\text{elec}}) \tag{1}$$

$$E_{rx} = l(E_{\text{elec}} + \alpha \, \mathrm{d}^n) \tag{2}$$

All parameters are explained in Table 1. *n* represents the path loss exponent that can be variable between 2 and 6 depending on environmental situations.

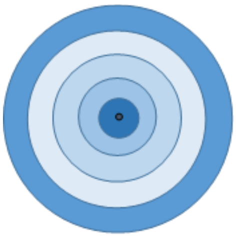

Figure 1: A corona based WSN with five corona

Table 1
Used parameters in this paper

Parameter	Define of parameters	Value
n	Path loss exponent	2
α	Energy dissipated in the op-amp	0.0013e-12
d	Width of each corona	100
Eelec	The electrical energy consumption	50e-9
Etx	Energy usage for data transmission	Equation 2
Erx	Energy consumption for data receiving	Equation 1
k	The number coronas	9
M	Total number of nodes	-
Ni	The number of nodes in *i*th corona	-
Nk	The number of nodes in the last corona	33
R	The network radius	900
ε0	Initial energy of each corona	0.5 j~4j
Li	The lifetime of *i*th corona	-
Ei	The energy expenditure in *i*th corona	-
x	The percent of occupied space for relay nodes in each corona	0.5
l	Length of data	400

IV. CRITICAL CORONA

Since the nodes belonging to innermost corona have the most workload, this corona is known as critical corona [18]. The nodes located in each corona receive and transmit the data packets from outer corona which it is defined as the workload of coronas:

$$wl_i = \frac{M - \sum_{j=1}^{i-1} N_j}{N_i}, \; 1 \le i < k \tag{3}$$

In uniform node deployment strategies the number of nodes in coronas increase ascending from innermost to outermost corona [19]. Therefore, the innermost corona has the most traffic load in comparison with other ones. When a network with 4 coronas is considered, the following relation can proof this claim.

$$\frac{N_2 + N_3 + N_4}{N_1} > \frac{N_3 + N_4}{N_2} > \frac{N_4}{N_3} \qquad N_1 > N_2 > N_3 > N_4 \tag{4}$$

The traffic load of coronas must be equaled as much as possible to increase the network lifetime. The main goal of proposed ONNDM in this work is to balance the traffic load among different layers of the network as follow:

$$wl_i = wl_j \qquad \{\forall i, j | 1 \le i, j < k\} \tag{5}$$

Note that the last corona would have less workload than other coronas since the nodes located in this layer of the network send only their own data packets. In proposed method, we describe the network lifetime as the time when first node exhausts its power supply. Therefore, the lifetime of a corona can be determined as follow:

$$l_i = \frac{N_i \varepsilon_0}{E_i} \tag{6}$$

where E_i denotes the total energy consumption of ith corona defined as follow:

$$E_i = l\left(N_i E_{rx} + \sum_{j=i+1}^{k} N_j \left(E_{tx} + E_{rx} \right) \right) + l N_i E_d \tag{7}$$

where E_d shows the energy consumption for aggregating *l* bit data in *i*th corona in each time unit. In this work, it is considered that nodes do not consume energy for sensing data. Since, the innermost corona is the critical corona [18] the network lifetime depends on the innermost coronas lifetime. Furthermore, Last corona is important for satisfying the network in terms of connectivity and coverage [20]. Authors in [20] proposed a formula for obtaining the least number of nodes in last corona to satisfy the network in terms of connectivity and coverage. Therefore, this formula is used in this work to determine the minimum number of nodes of last corona so that connectivity and coverage are guaranteed.

V. OPTIMAL NUMBER OF NODE DEPLOYMENT METHOD (ONNDM)

A solution for energy hole problem is to increase the number of nodes in critical area within the network [18]. In fact, to balance the energy consumption of coronas in non-uniform node deployment methods, the most number of nodes are allocated to critical corona[10]. To balance the workload among coronas, the number of nodes in each corona should be determined according to the summation of number of nodes belonging to outer coronas. Accordingly, the least number of nodes in each corona will be as follow:

$$N_i = 2^{k-i-2}\left(2N_k\right) \tag{8}$$

As shown in Table 1, k and N_k denote the number of coronas in the network and the number of nodes in the last corona, respectively. The number of nodes in the last corona denoted by N_k is determined according to the equation provided by Ferng et al. in [14]. Consequently, 33 is derived for this parameter. Let us assume that nodes in each corona (C_i) are distributed with $\boldsymbol{\rho}_i$ density as follow:

$$\rho_i = \frac{N_i}{S_i} \tag{9}$$

N_i represents the number of nodes that is assigned for the *i*th corona and S_i denotes the area of that corona which can be determined by following equation:

$$\begin{gathered} S_i = \pi d^2\left(2i-1\right) \\ S_1 < S_2 < S_3 < \ldots < S_k \end{gathered} \tag{10}$$

In ONNDM strategy, the optimal number of nodes in coronas are determined according to the area of coronas, so that the workload will be balanced among coronas. Based on Equation 3 and 8, the *i*th corona (C_i) should have at least q_i nodes for relaying the received data packets from outer coronas which is determined by following equation:

$$qi = \sum_{j=i+1}^{k} N_j \tag{11}$$

We assume that q_i nodes located in *i*th corona for relaying the data packets from outer coronas, occupy *x* percent of area of the *i*th corona and the remaining space is allocated for other nodes.

$$\begin{gathered} \rho_i = \frac{q_i}{S_i\, x} \\ 0 < x < 1 \end{gathered} \tag{12}$$

where $\boldsymbol{\rho}_i$ denotes the node density in *x* percent space of the *i*th corona (Si). The number of nodes in each corona is obtained as follows:

$$N_i = \rho_i S_i \tag{13}$$

From Equation 12 and 13, below equation will be derived:

$$\begin{gathered} N_i = \frac{q_i}{x} \\ 0 < x < 1 \end{gathered} \tag{14}$$

As a result, total number of nodes in each corona is obtained based on the number of nodes in the last corona as follow:

$$\begin{gathered} N_i = \frac{N_k}{x^{k-i}}\left(\sum_{j=1}^{k-i-1}\prod_{f=1}^{j}\frac{k-i-f}{f}x^j\right)+1 \\ 0 \le x \le 1 \end{gathered} \tag{15}$$

All parameters are presented in Table 1. Above equation is evaluated for different values of *x* in Matlab.

VI. NUMERICAL RESULT

In this section, the performance of ONNDM is evaluated. MATLAB is used to compare the proposed method in this paper with other strategies.

A. Balancing the workload

Figure 2 shows the workload of different coronas in ONNDM. As can be seen, the workload of coronas is equaled among eight coronas, however, last corona still has the lowest workload in comparison with other coronas.

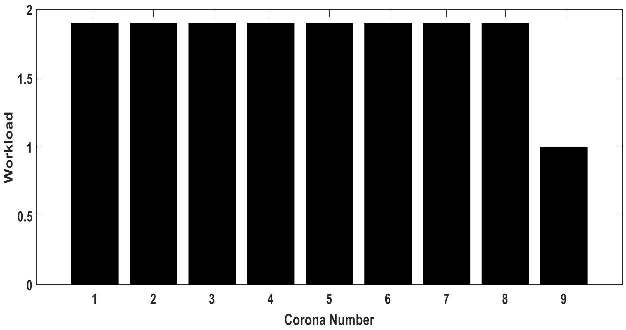

Figure 2: The coronas workload in ONNDM method

B. Network Lifetime

Figure 3 demonstrates the coronas lifetime in uniform node deployment strategy and ONNDM. As can be seen, the lifetime of innermost corona is 40 times more than uniform node deployment strategy. Since, the innermost corona is critical, the network lifetime depends on innermost corona lifespan. Consequently, the network lifetime will be remarkably enhanced by applying ONNDM.

Figure 4 shows the number of nodes in different coronas. One issue that should be considered in the network is the cost of setting up a network that depends on the different factors such as total number of nodes in the network. On the other hand, the optimal number of nodes is required to avoid the energy hole problem. Moreover, Figure 5 depicts the network lifetime in four different methods, ONNDM; q-switch; Strategy I of Ferng strategies [14] and Random. As shown, ONNDM outperforms the other strategies. Consequently, the network lifetime in our model is longer than three other strategies.

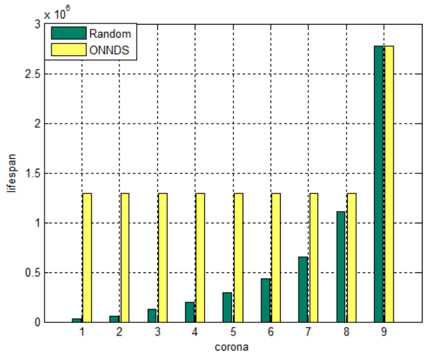

Figure 3: The lifetime of coronas in two different strategies

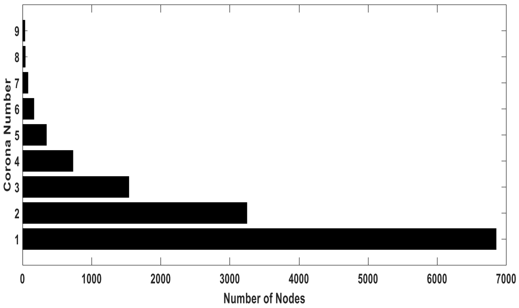

Figure 4: Number of nodes in different coronas

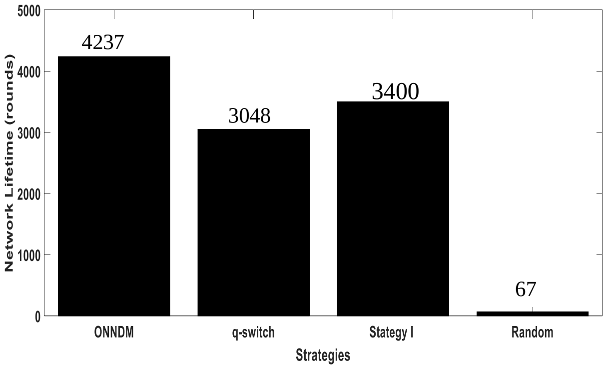

Figure 5: Network lifetime in four different methods

Figure 6 depicts the influence of the parameter of x on the network lifetime. As can be seen, by increasing the value of this parameter, the network lifetime decrease.

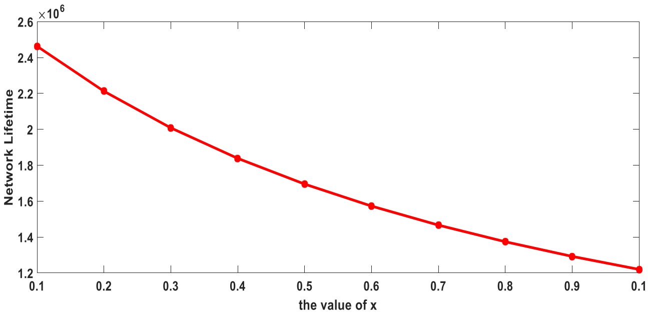

Figure 6: Influence of x on network lifetime

C. *Residual energy of network*

The residual energy is the ratio of energy remained when the network lifespan is finished to the sum of the initial energy of the nodes [12]. In fact, the residual energy ratio is the unused energy after ending of the network lifetime. Figure 7 shows the residual energy ratio of the network in three different methods. We observe that the residual energy of ONNDM is two times lower than other methods. This also implies the effectiveness of ONNDM strategy.

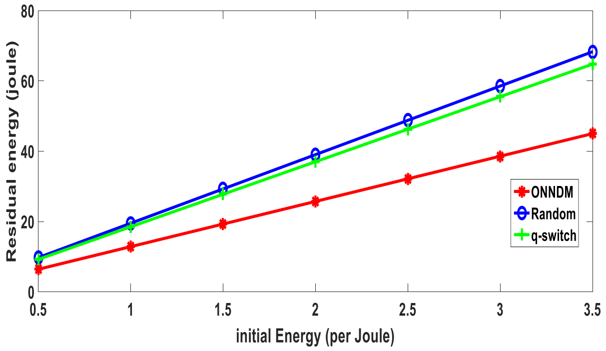

Figure 7: Residual energy ratios in three different strategies

VII. CONCLUSION

In this paper, we obtained the optimal number of nodes in coronas to increase the network lifetime. The number of nodes is determined based on the area and workload of coronas. We showed that proposed ONNDM enhances the network lifetime by balancing the energy consumption among different coronas with lower residual energy. We compared our model with q-switch, first strategy of Ferng strategies and Random uniform node deployment using the MATLAB environment. The results demonstrated that our method improved the network lifetime through balancing the energy usage in the network. Furthermore, we observed that the residual energy ratio of our model is lower than other methods.

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REFERENCES

[1] H. Asharioun, H. Asadollahi, TC. Wan, and N. Gharaei , "A Survey on Analytical Modeling and Mitigation Techniques for the Energy Hole Problem in Corona-Based Wireless Sensor Network,". Wireless Personal Communications, 2015. 81(1), pp. 161-187.

[2] J Li, and P Mohapatra, "Analytical modeling and mitigation techniques for the energy hole problem in sensor networks," Pervasive and Mobile Computing, 2007. 3(3), pp. 233-254.

[3] K Xu, H Hassanein, and G Takahara, "Relay Node Deployment Strategies in Heterogeneous Wireless Sensor Networks," Mobile Computing, IEEE Transactions on, 2010. 9(2), pp. 145-159.

[4] L Bhagyalakshmi, SK Suman, and K. Murugan,"Corona based clustering with mixed routing and data aggregation to avoid energy hole problem in wireless sensor network," in Advanced Computing (ICoAC), 2012 Fourth International Conference on. 2012. IEEE.

[5] X. Liu, "A survey on clustering routing protocols in wireless sensor networks," Sensors, 2012. 12(8), pp. 11113-11153.

[6] M Cardei, J Wu, and M Lu, "Maximum network lifetime in wireless sensor networks with adjustable sensing ranges," in Wireless and Mobile Computing, Networking and Communications, IEEE International Conference on IEEE, vol 3, pp. 438-445, 2005.

[7] M. Marta,and M. Cardei, "Using sink mobility to increase wireless sensor networks lifetime", in World of Wireless, Mobile and Multimedia Networks, WoWMoM, International Symposium on . IEEE, 2008.

[8] C. Efthymiou, S. Nikoletseas, and J. Rolim, "Energy balanced data

propagation in wireless sensor networks,"Wirel. Netw.,12(6), pp 691-707, 2006

[9] P. Leone, S. Nikoletseas, and J. Rolim, "Stochastic models and adaptive algorithms for energy balance in sensor networks," Theory of Computing Systems, 47(2), pp. 433-453, 2010

[10] H. Hasbullah, "Impact of Gaussian deployment strategies on the performance of wireless sensor network," in Computer & Information Science (ICCIS) International Conference on IEEE, 2012.

[11] X. Wu, G. Chen, and SK. Das, "On the Energy Hole Problem of Nonuniform Node Distribution in Wireless Sensor Networks," in Mobile Adhoc and Sensor Systems (MASS), IEEE International Conference, 2006.

[12] X. Wu, G. Chen, SK. Das, "Avoiding Energy Holes in Wireless Sensor Networks with Nonuniform Node Distribution," Parallel and Distributed Systems, IEEE Transactions, 19(5), pp. 710-720, 2008.

[13] J. Li, P. Mohapatra, "An analytical model for the energy hole problem in many-to-one sensor networks," IEEEvehicular technology conference, vol. 62, no. 4, pp. 2721, 1999.

[14] H.W. Ferng, M. Hadiputro, and A. Kurniawan, "Design of Novel Node Distribution Strategies in Corona-Based Wireless Sensor Networks," Mobile Computing, IEEE Transactions,(99), pp. 1297-1311, 2011.

[15] Y. Liu, H. Ngan, LM. Ni, " Power-aware node deployment in wireless sensor networks," in Sensor Networks, Ubiquitous, and Trustworthy Computing, IEEE International Conference,. 2006.

[16] T. Liu, "Avoiding energy holes to maximize network lifetime in gradient sinking sensor networks," Wireless personal communications, pp. 1-20, 2013

[17] M. Bhardwaj, T. Garnett, and A.P. Chandrakasan, "Upper Bounds on the Lifetime of Sensor Networks," in Communications, ICC 2001. IEEE International Conference, 2001.

[18] S. Olariu, and I. Stojmenovic, "Design guidelines for maximizing lifetime and avoiding energy holes in sensor networks with uniform distribution and uniform reporting," 2006.

[19] C. Efthymiou, S. Nikoletseas, and J. Rolim, "Energy balanced data propagation in wireless sensor networks," Wireless Networks, 12(6), pp. 691-707, 2006.

[20] Azad, and J. Kamruzzaman, "Energy-balanced transmission policies for wireless sensor networks," IEEE Transactions on Mobile Computing, 10(7), pp. 927-940, 2011.