Journal of Engineering Science and Technology
Vol. 12, No. 9 (2017) 2461 - 2475

ANALYTICAL MODELING OF INNOVATIVE SENSOR PLACEMENT STRATEGY FOR CORONA-BASED WIRELESS SENSOR NETWORKS

HASSAN H. EKAL*, JIWA B. ABDULLAH

Department of Communication Engineering, Faculty of Electrical and Electronic
Engineering, University Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia
*Corresponding Author: hassanhamid1985@gmail.com

Abstract

Wireless Sensor Networks (WSNs) applications are increasing rapidly, thanks to their broad potential in ecological monitoring, biomedical health monitoring, data gathering and many others. Imbalance energy of sensors causes significant reduction in the lifetime of the network. In many-to-one communication (corona) WSNs, sensor nodes located nearby the data collector (sink) forward data sensed data received from other nodes, hence, having heavier workloads. These nodes consume more energy than the others, leading to quicker energy depletion .Consequently, this results in *energy hole* problem, where the network becomes separate islands, which affect the lifetime of the network negatively. When this situation occurs, the sensed data will not be forwarded to the intended sink; accordingly, the network will not be able to completely fulfil its required tasks. In this paper, an effective sensors placement strategy is proposed to avoid or alleviate energy hole problem in such type of WSNs. The proposed strategy aims to improve, scale, and balance the energy consumption among sensor nodes and to maximize the network lifetime, by sustaining the network coverage and connectivity. To achieve this aim, the number of sensors should be optimized to create sub-balanced coronas in the sense of energy consumption, while satisfying the network coverage and connectivity requirements. The theoretical design and modelling of the proposed sensors placement strategy promise a considerable improvement in the lifetime of corona-based networks. The Experimental evaluation results have shown that the proposed sensors placement strategy is capable to increase the network lifetime considerably compared to conventional uniform strategy.

Keywords: Wireless sensor network, Sensor placement, Corona WSN.

Nomenclatures

A_i	Energy increment ratio of corona i
E_{elec}	Electronic energy consumption
E_{rx}	Reception energy
E_{tx}	Transmission energy
E_{ri}	Energy needed by corona i to relay data from outer corona.
E_{si}	Energy needed by corona i to sending data
N_{total}	Number of nodes in the network
N_i	Number of nodes in the corona i
R	Transmission range and corona width
R_{area}	Network radius

Greek Symbols

α	Energy dissipate in the op-amp
ε_0	Initial energy of each node

Abbreviations

PLE	Path Loss Exponent
WSN	Wireless Sensor Network

1. Introduction

Wireless sensor networks (WSNs) consist of many sensing nodes designed to monitor natural phenomena. Sensing nodes in WSN communicate over short distance to complete different tasks. Wireless sensor networking is a promising technology due to their sensing capabilities for various applications such as environmental monitoring, tracing and tracking mobile objects, telemedicine, and applications for civilian and military domains. A sensor network consists of many inexpensive nodes that are small-sized and low-powered devices equipped with a radio, a microprocessor, a power supply, memory, and an actuator. The sensed data are sent from the nodes to a sink either directly or through multi-hops. In corona-based WSNs, the nodes are distributed in a circular area and a sink node is situated in the centre of the area [1]. Unlike traditional networks, WSNs are designed specifically for the application and environment where they are to be used. Since they suffer from limited communication range, bandwidth, and processing and memory resources, their application and algorithms depend on the environment to be observed.

WSN architecture is considered as a distributed architecture as it is composed of processing units; each having separate processor, local memory and input/output module. Since the sensors are not equipped with shared memory, they usually communicate with each other, thus, creating a distributed communication network.

The nodes in an area or regains transfer the collected (and sometimes modified) information to the cluster node [2]. The cluster node then transmits the information collected from the sensors to a central unit, which is responsible for further processing, interpretation, and presentation of data to intended users.

This transmission can be done using Internet, communications satellite or cable. Nodes close to the sink are likely to die sooner than nodes farther away [3]. Therefore, once the sensor nodes around the sink die, residual energy from nodes farther away will be left unused. This situation is known as energy-hole problem in WSNs [4, 5]. Figures 1, 2, and 3 briefly illustrate the sensor network architecture, general diagrams of sensor node architecture, and sensor node software architecture, respectively.

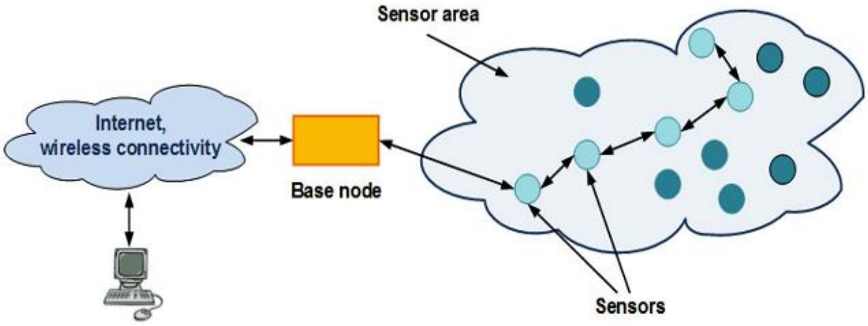

Fig. 1. Sensor network architecture.

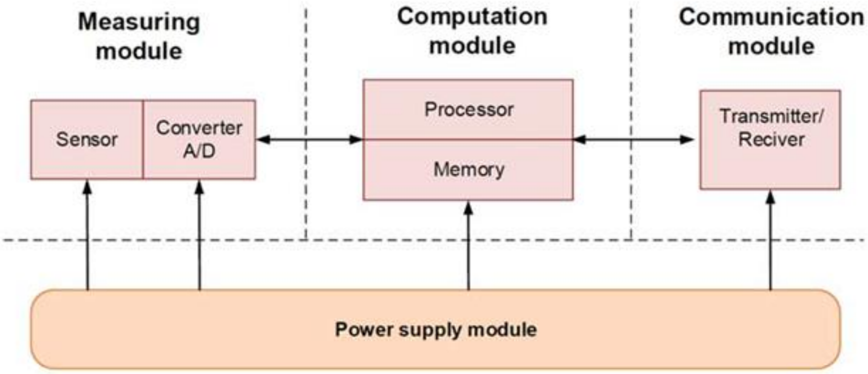

Fig. 2. Sensor node architecture.

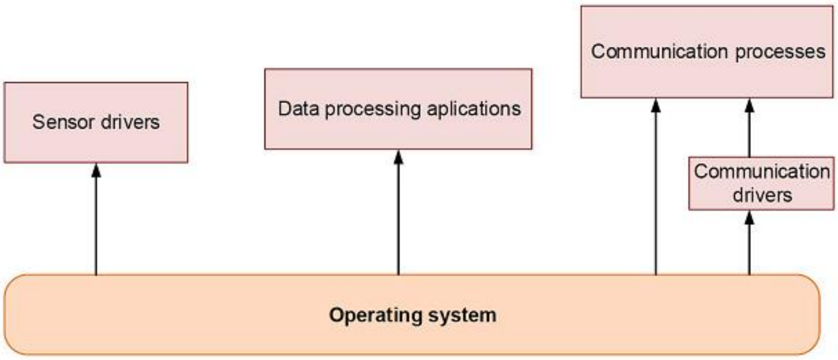

Fig. 3. Sensor software architecture.

2. Corona-Based Wireless Sensor Networks (WSNs)

In corona-based WSN, the area where the nodes are deployed is divided into k coronas that are defined by k circles of ranges $0 < r_1 < r_2 < \ldots < r_k \leq$ maximum transmission range t_x, where the cluster head (sink) is at the center of the circles [6-8]. This area is also divided into several angular wedges. Each node must know the identity of the corona where it lies in and the wedge it belongs to, as illustrated in Fig. 4.

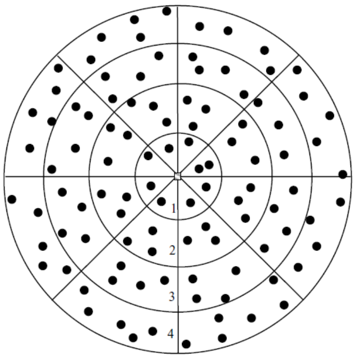

Fig. 4. Sensor nodes in corona-based WSN.

Imbalance sensors energy can decrease the network lifetime significantly. When many-to-one architecture is used, sensors that are placed nearby the sink forward the sensed data to the sink, and thus having heavier traffic loads [5]. These sensors consume more energy than others, hence exhausting their energy faster, causing energy holes in the network [9, 10]. When this situation occurs, sensed data will not be forwarded to the intended sink. This means that the network lifetime will end prematurely, and a considerable amount of energy is wasted [11]. Lian et al. [12] reported that as much as 90% of the available energy may be unused due to the hot spot and energy holes in networks, even the sensor nodes are uniformly distributed.

Node or sink mobility, non-uniform sensor distribution, adjustable transmission range, and dynamic energy balancing are among the approaches commonly used to solve or mitigate the energy hole problem [13-15]. In mobility strategy, the mobile sink node moves to avoid the energy hole. In a non-uniform distribution strategy, sensors are located in areas with energy holes to ensure the connectivity of the network. Perillo et al. [15] showed that transmission power control could affect the network lifetime, thus introducing the strategy of adjusting transmission power to balance energy and avoid energy holes.

3. Energy Hole Problem

Network lifetime is a major issue in the WSN field, as it depends on active nodes and connectivity [3]. When the energy of a node within a WSN has depleted, it dies and is disconnected from the sensor network, thus the application of the network is no longer fully operational. Therefore, energy must be conserved in an efficient way [16]. Batteries, which are the main power supply for nodes, are usually irreplaceable as nodes are usually deployed in unattended areas. Rechargeable batteries, on the other hand, cannot be used in some environments. This urges networking protocols to include energy-efficient techniques to prolong the network lifetime [13, 17-20]. Improving the network lifetime is one of the main challenges in the application of WSN, as it relies on several factors, including the network architecture and protocols, energy model, characteristics of wireless channel, and data collection technique [21, 22].

In corona-based WSNs, energy hole problem is the most vital cause that decreases the network lifetime [5]. Therefore, to increase the lifetime of the network, energy holes should be tackled. This paper proposes a theoretical design of operative sensor placement strategy to overcome the issue of energy hole in corona-based wireless sensor networks, which aims to extend the network lifetime. Modelling and simulations have been used to obtain the required quantitative information for the validation of the proposed strategy.

4. Proposed Sensor Placement Strategy

The proposed sensor placement strategy can be applied to achieve maximum network lifetime, by determining how many sensor nodes should be placed in the outermost corona, taking into account the coverage and connectivity; while, the number of sensors required in other coronas is computed according to other related proposed formula. In order to determine optimal sensor placement, optimal sensor placement formula in each corona must be determined according to the number of sensors in the outermost corona.

4.1. Preliminaries

In this study, a circular corona-based WSN with a fixed centered sink was considered for evaluation. Every sensor in the network had a fixed transmission range of R. The energy model utilized here is similar to the concept in [6].

The network radius is denoted as R_{area}, and the circular area is divided into k coronas of width *R*. *Ci* denotes the ith corona (i.e., *C1* symbolizes the innermost corona). Every node creates and transmits l bits per time unit, during which, nodes belong to corona *Ci* bring forward the incoming data to the next corona $(C_{i-1}|\ i\ \geq 2)$. Assuming that the Path Loss Exponent (PLE) of the monitoring area is PLE = 4, then the environment should be an indoor environment that is contention and error-free. Every node in the network has ε_0 initial energy, while the sink has no energy limitation. PLE is the rate at which the received signal strength decreases with distance.

4.2. Number of nodes calculation

For calculation of the number of nodes, M uniform nodes are assumed to form the network, where N_1 is the number of sensors that are placed in the innermost corona C_1. Hence, $N_1 = \mathrm{M}/\mathrm{k}^2$, where k is the number of corona.

$$M\pi {d_{char}}^2 = N_1\pi(d_{char}\mathrm{k})^2 \qquad \rightarrow N_1 = \frac{M}{k^2} \tag{1}$$

As the sensors are placed uniformly within the monitoring area, the number of sensors to be deployed in any corona i, in contrast to the innermost one, is calculated as follows:

$$N_i = (2i - 1)N_1 \tag{2}$$

where N_i is the number of nodes in i^{th} corona (N_1 and is the number of nodes in C_1). From Eq. (2), the area of each corona is calculated as:

$$Area_{corona\ i} = (2i - 1)\ Area_{corona\ 1} \tag{3}$$

4.3. Energy modeling

In this model, the energy needed for one data bit transmission over a certain distance d is computed as follows:

$$E_{Tx} = E_{elec} + \alpha d^n \tag{4}$$

where α represents the energy depletion during data transmission, d represents the distance between the transmitter and the receiver, while n denotes the path-loss exponent (PLE). The energy E_{rx} needed for data reception is computed as follows:

$$E_{rx} = E_{elec} \tag{5}$$

where E_{elec} represents the electron energy. The value of n changes according to the characterized environment. For instance, for free space, PLE is 2, while for other environments (indoor environments), PLE can vary between 4 and 6. As mentioned above, n in this work was equal to 4 (the path loss of normal outdoor environment). If there is k coronas in the network, then $R = R_{area}/k$, where R is corona width and R_{area} is radius of the network. Thus, based on these parameters, the following formula is obtained:

$$E_{tx} = E_{elec} + \alpha \frac{R_{area}^{\mathrm{n}}}{k^n} \tag{6}$$

The network lifetime starts to finish once any node dies; thus, it depends on the consumption of the energy in the nodes. The energy consumption and lifetime of corona i are, respectively, computed by:

$$E_{C_i} = l[N_i E_{tx} + \textstyle\sum_{j=i+1}^{k} N_j (E_{tx} + E_{rx})]\ \ 1 \le i \le k - 1 \tag{7}$$

$$L_{C_i} = \frac{N_i \varepsilon_0}{E_i} \tag{8}$$

where N_i indicates the number of nodes which should be in corona i, k indicates the total number of coronas, E_{rx} indicates the reception power required for one data bit, E_{tx} indicates the transmission power required to transfer one bit of data , l indicates the length of a packet in bits, ε_0 indicates the initial energy of sensors, while L_{C_i} indicates the lifetime of corona i.

Since *C1* is considered as the critical corona because of the heavy forwarding load, it is important to consider the energy consumption and lifetime of the nodes in C_1 rather than the whole network. Thus, the network lifetime can be inferred based on the lifetime of the innermost corona. Before computing the network lifetime, the energy consumption by nodes in *C1* needs to be known. As asserted by Bhardwaj et al. [22], parameters needed for energy consumption calculation are (E_{Tx}), (E_{rx}), and (E_d); with condition that there are M sensors positioned in the network, N_1 being placed in *C1* and all data packets generated in other coronas are relied from *C1* to the sink, including the data generated by *C1* itself. Assuming that every node collects and transfers l bit of data per time, the energy consumption in *C1* can be obtained using Eq. (7) as follows:

$$E_1 = l[N_1 E_{tx} + \sum_{j=2}^{k} N_j (E_{tx} + E_{rx})] \tag{9}$$

where E_{Tx} and E_{rx} are respectively the transmission power and reception power required for one data bit,, l is the number of bits, N_1 is the sensors in C_1, and k is the network coronas.

Since the energy consumption and lifetime of any corona i can be computed by using Eqs. (7) and (8), the following equations can be derived accordingly.

$$L_{C_i} = \frac{N_\mathrm{i}\varepsilon_0}{E_{C_i}} = \frac{N_\mathrm{i}\varepsilon_0}{l[\mathrm{N_i}E_{tx}+\sum_{j=i+1}^{k} N_j (E_{tx}+E_{rx})]} = \frac{\varepsilon_0}{l\left[E_{tx}+(E_{tx}+E_{rx})\frac{\sum_{j=i+1}^{k} N_j}{N_i}\right]} \tag{10}$$

where, N_i indicates the number of nodes in any corona *i (C$_i$)*, ε_0 indicates the initial energy of every node in C_i, E_{C_i}indicates the energy consumption per time in C_i, and L_{C_i} is the lifetime of C_i. By assuming that $\mathrm{Nratio_i}$ indicates the ratio of number of nodes in outside of C_i to number of sensors in C_i, Eq. (11) is derived, as:

$$Nratio_i = \frac{\sum_{\mathrm{j=i+1}}^{\mathrm{k}} \mathrm{N_j}}{\mathrm{N_i}} \text{ ,} \mathrm{i} < k \tag{11}$$

Except for N_i and N_j, the rest of parameters in Eq. (10) are constant. It is clear that L_{C_i} is dominated by the $Nratio_i$ in Eq. (11). Hence, any corona is considered as a critical corona if it produces the highest energy consumption ratio.

It is obvious that, if the nodes in the critical corona die, energy hole will appear and the network will not be able to function properly. Thus, the network lifetime depends on the lifetime of the critical coronas. It is vital to prolong the lifetime of the network, thus the lifetime of the critical corona should be maximized. The optimal number of sensors can be determined if the energy consumption and lifetime in all coronas are equal. Thus, by using Eqs. (10) and (11), $Nratio$ are equalized in the coronas ($i.e. \forall i \; Nratio_i = Nratio_j \, , i, j \leq k$).

The following subsections discuss the propositions for finding optimal number of nodes in the coronas, by considering energy consumption balance in all coronas and maximum achievable lifetime of the network, to meet coverage and connectivity requirements.

4.4. Optimal sensor placement for maximizing network lifetime

Proposition 1: The longest lifetime of sensors in a corona *i*, that is required to maximize the network lifetime, is:

$$N_i = N_{k-1} \left(\frac{N_{k-1}+N_k}{N_k}\right)^{k-i-1} \tag{12}$$

where k indicates the number of coronas in the network and N_i indicates the sensors in corona i.

Proof: In corona-based WSN, the highest lifetime of the network can be achieved if $Nratio$ is equal among all coronas. Thus,

$$\forall\ 1 \leq i,j < k \ \rightarrow\ Nratio_{\,i} = Nratio_{\,j} \tag{13}$$

To come up with a system of equations, the ratio of each corona must be equal to the ratio of definite corona k-1. Consequently, the following equation is obtained:

$$\forall\ 1 \leq i < k \ \rightarrow\ Nratio_{\,i} = Nratio_{\,k-1} \tag{14}$$

By using Eqs. (11) and (13), Eq. (15) is derived.

$$\forall\ 1 \leq i < k \ \rightarrow\ \frac{\sum_{j=i+1}^{k} N_j}{N_i} = \frac{N_k}{N_{k-1}} \tag{15}$$

Thus, Eq. (15) presents a system of equations with *k-1* equations and *k-1* variables $(N_1, N_2, \dots, N_{k-1})$, where N_k indicates the constant that should be quantified according to the coverage and connectivity requirements in the network. With regard to proposition 1, Eq. (12) is the solution of Eq. (15). Backward induction proof has been used to prove this solution. For the base case, let *k-1* be the initial value for the backward induction, thus, *P(k-1)* asserts that:

$$\begin{aligned} &= k-1 \xrightarrow{yields} N_{k-1} = N_{k-1}\left(\frac{N_{k-1}+N_k}{N_k}\right)^{k-(k-1)-1} \\ &\Rightarrow\ N_{k-1} = N_{k-1}\left(\frac{N_{k-1}+N_k}{N_k}\right)^{0} \\ &\Rightarrow\ N_{k-1} = N_{k-1} \end{aligned} \tag{16}$$

Thus, the equation holds for the base case. For the induction hypothesis, it is assumed that for some integer Ʈ< k, P(Ʈ) is true, then the following formula is obtained:

$$N_{Ʈ} = N_{k-1}\left(\frac{N_{k-1}+N_k}{N_k}\right)^{k-Ʈ-1} \tag{17}$$

Induction Step: *P(Ʈ-1)* is proved to be true as presented in the following equation:

$$\begin{aligned} N_{Ʈ-1} &= N_{k-1}\left(\frac{N_{k-1}+N_k}{N_k}\right)^{k-(Ʈ-1)-1} \\ &= N_{k-1}\left(\frac{N_{k-1}+N_k}{N_k}\right)^{k-Ʈ} \end{aligned} \tag{18}$$

Proof of the inductive step: By letting i= Ʈ, and using Eq. (15), the following equation is derived:

$$\frac{\sum_{j=Ʈ+1}^{k} N_j}{N_{Ʈ}} = \frac{N_k}{N_{k-1}} \Rightarrow \sum_{j=Ʈ+1}^{k} N_j = \frac{N_k N_{Ʈ}}{N_{k-1}} \tag{19}$$

and by letting i= $Ʈ - 1$, by Eq. (15), the following equation is derived:

$$\begin{aligned} &\frac{\sum_{j=Ʈ}^{k} N_j}{N_{Ʈ-1}} = \frac{N_k}{N_{k-1}} \Rightarrow \frac{\sum_{j=Ʈ+1}^{k} N_j + N_{Ʈ}}{N_{Ʈ-1}} = \frac{N_k}{N_{k-1}} \\ &\frac{\frac{N_k N_{Ʈ}}{N_{k-1}} + N_{Ʈ}}{N_{Ʈ-1}} = \frac{N_k}{N_{k-1}} \Rightarrow N_{Ʈ-1} = \frac{N_{Ʈ}(N_{k-1}+N_k)}{N_k} \end{aligned} \tag{20}$$

Then, by using Eqs. (17) and (20), the following equation is obtained:

$$N_{\text{Ʈ}-1} = \frac{(N_{k-1}+N_k)N_{k-1}\left(\frac{N_{k-1}+N_k}{N_k}\right)^{k-\text{Ʈ}-1}}{N_k} \tag{21}$$

$$\Rightarrow N_{\text{Ʈ}-1} = N_{k-1}\left(\frac{N_{k-1}+N_k}{N_k}\right)^{k-\text{Ʈ}}$$

Thus, induction step and proposition 1 have been proven true.

4.5. Optimal number for coverage/connectivity requirement

Coverage and connectivity requirements are important issues to be considered when distributing sensors in the network. In most WSNs, the outer coronas require more sensors, and even sometimes with different transmission ranges in order to ensure the connectivity and coverage requirements [19]. Thus, outermost corona is considered as the most critical corona since it is the only one that suffers from the connectivity and coverage problem [20]. Therefore, in several research works, the quantity of nodes in the last (outermost) corona was determined beforehand in order to guarantee meeting the coverage and connectivity requirements [19]. Hence, the number of nodes in other coronas could be obtained regardless of how many sensors are required in the last corona.

Proposition 2: With intention to maintain the coverage and connectivity in the last corona, if $\mathrm{N_k}$ signifies the sensors in the network, then the highest lifetime efficiency of sensor placement in every corona, while preserving the coverage and connectivity, is calculated as:

$$N_i = N_k\left(\frac{2k-3}{2k-1}\right)\left(\frac{(4k-4)}{(2k-1)}\right)^{k-i-1} \tag{22}$$

where k indicates the number of coronas in the network and N_i indicates the number of sensors that should be placed in corona i.

Proof: As N_k maintains the coverage and connectivity in the outermost corona, N_{k-1} can be determined according to N_k resulting from Eq. (2) to meet the coverage and connectivity requirement in corona N_{k-1} . Then, the ratio of number of sensors in N_{k-1} to N_k to guarantee the coverage and connectivity in N_{k-1} is $\frac{N_{k-1}}{N_k}$, where N_{k-1} and N_k are achieved based on the normal distribution in Eq. (2). Therefore, to meet the coverage and connectivity in corona *k-1*, the minimum number of sensors in the corona $Nk{-}1$ is calculated as:

$$N_{k-1} = \left(\frac{(2(k-1)-1)}{2k-1}\right)N_k \quad \Rightarrow \quad N_{k-1} = \left(\frac{2k-3}{2k-1}\right)N_k \tag{23}$$

Note that Eq. (22) can be obtained through substituting Eq. (23) in Eq. (12). Accordingly, the proposition has been proven true.

5. Experimental Evaluation

In this study, experimental tests had been performed to evaluate the analytical model of the proposed strategy using MATLAB. Performance evaluation was done with the intent of verifying and analysing the design efficiency to measure its effect on the network lifetime, by setting up a set of measurement parameters and scenarios to investigate the performance and address the trade-off (whenever presented).

5.1. Parameters setup and assumptions

In evaluation scenarios, all the nodes have their own initial energy, while the sink has no energy limitation. The sensed data is collected and transmitted towards the sink using multi-hop routing. The area is in an indoor environment whose path loss exponent is n , and that is contented and error-free. A structure of variables is defined to simulate the sensor attributes and the network area. Network area is a structure that has some attributes such as the radius of the network (SurfaceRadius), number of sensors in the network (NNodes), number of corona (NCorona), width of each corona (Range), environment path lost (n) and so on. Each node in the network area has its own attributes, like initial energy (E0), energy consumption of electronic device (Eelec), energy needed to receive data (Erx), energy needed for normal sending with transmission R (EtxNormal), energy needed for direct sending with transmission range R (EtxDirect), Residual Energy of node (ResidualEnergy), number of packets that are ready to send (NReadySend), number of sent packets (NSent), number of packets that have been sent with transmission R (NDirectSent), number of received packets (NRecieved) and so on. The effectiveness of the proposed deployment strategy was first compared to the uniform sensor placement strategy, using network of 1200 nodes with 100m transmission range and 0.5J initial energy. The area under monitoring was 1000m^2. Having 1200 nodes and uniform corona width of 130m, the number of network coronas was 9, and total network energy was 600J. Then, the proposed strategy was evaluated on how many sensors would be required under certain limitations, such as energy and number of sensors in the outermost corona.

5.2. Results and discussion

The proposed innovative sensor placement strategy presented in this paper was designed based on Eq. (22). In the proposed strategy, the number of sensors that should be placed in the last (outermost) corona was defined according to connectivity and coverage requirements, while the number of sensors in other coronas is determined based on Eq. (22).

For clarification, consider a network of four coronas and the number of sensors needed in the outermost corona (which is Corona 4) is 15, based on the coverage and connectivity requirements of the network as suggested in [19]. Then, based on Eq. (22) for the proposed strategy, the number of sensors in others coronas will be as shown in Table 1. The node distribution as shown in the table is the best distribution for maximizing the lifetime, considering the coverage and connectivity requirements in the outer corona.

In this study, to find the optimal sensors placement in a network with fixed number of nodes, the proposed strategy had been evaluated according to the network setup and assumption as mentioned above, and its output was compared the output to the uniform placement strategy, as shown in Table 2. The sensor placement with the proposed strategy was again according to Eq. (22) while sensors were placed randomly throughout the network with the uniform strategy.

Table 1. Sensors distribution in a 4-corona network.

Nodes in Corona 1	Nodes in Corona 2	Nodes in Corona 3	Nodes required in Corona 4	Total number of nodes
22	14	11	15	62

It is clear from the table that, in order to maximize the lifetime, balance the consumption energy and avoid the energy hole problem, the proposed strategy requires more sensors in the inner coronas; while in the use of uniform deployment strategy, it is noticeable that the number of sensors will increase gradually towards the outer coronas. Furthermore in uniform placement, the sensors in the inner coronas will be burdened with heavy data traffic load from many sensors in the outer coronas. Thus, having energy holes is inevitable.

Table 2. Sensors distribution using the proposed strategy compared to uniform sensor placement.

Proposed strategy	Uniform	Node Deployment
563	17	Node in Corona 1
299	44	Node in Corona 2
158	74	Node in Corona 3
84	103	Node in Corona 4
44	133	Node in Corona 5
24	163	Node in Corona 6
13	192	Node in Corona 7
7	222	Node in Corona 8
7	251	Node in Corona 9
1200	1200	Total Number of Nodes

Figure 5 shows the lifetime gained by applying the proposed sensor placement strategy, compared to the uniform sensor placement for the same initial energy of 0.5J in each of the 1200 sensor nodes during the 100 second of simulation period. The graph shows that proposed strategy is capable to produce 1260000 cycles of lifetime, while the uniform random placement strategy is capable to produce only 228128 cycles of lifetime. By estimation, the proposed strategy is able to lengthen the lifetime of the network more than five times.

For scenarios where the coverage and connectivity in the outmost corona should be considered, the number of sensors needed in the outer corona is computed based on the coverage and connectivity requirements, while the number of sensors in other coronas is determined based on the proposed strategy and the limited initial energy of nodes. According to Ferng et al. [6], to guarantee the connectivity and coverage in corona-based networks, the outer corona in 9-corona scenario should contain not less than 29 nodes. If the concern is on limited initial energy and not how many sensors are needed, it is encouraged to use a lot of sensors with less initial energy to maximize the network life time and avoid the energy holes problem.

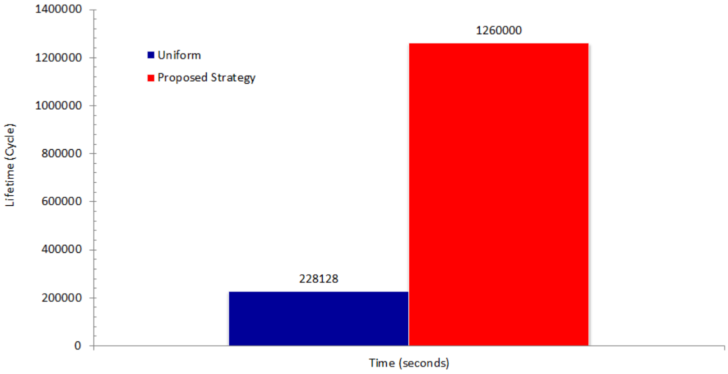

Fig. 5. Lifetime of the proposed strategy compared to the uniform placement.

Table 3 shows the number of sensors required for limited total network energy of 600J with maximum of 0.5J initial for each sensor. The data in the table suggests that to keep the network energy of 600J when using the proposed strategy, 5485 nodes are required for each 0.1095J initial energy, while the number of sensors in the inner coronas is the highest and decreasing towards the outer coronas, keeping in mind that the outer corona in such scenario should have not less than 29 nodes.

Table 3. Nodes distribution using the proposed strategy compared to uniform sensor placement under maximum energy limitation of 0.5 J.

Proposed strategy	Uniform	Node Deployment
2689	17	Node in Corona 1
1373	44	Node in Corona 2
678	74	Node in Corona 3
346	103	Node in Corona 4
188	133	Node in Corona 5
98	163	Node in Corona 6
57	192	Node in Corona 7
27	222	Node in Corona 8
29	251	Node in Corona 9
5485	**1200**	**Total Number of Nodes**
0.1095J	**0.5J**	**Node Initial Energy**

Figure 6 shows the lifetime comparison between the proposed sensor placement strategy and the uniform sensor placement. The figure shows that the proposed strategy can achieve lifetime of 977280 cycles, three times more than the uniform random placement strategy, with 228128 cycles. This confirms that it is not encouraged to use nodes with large initial energy if the network lifetime, connectivity, and coverage are the main concerns.

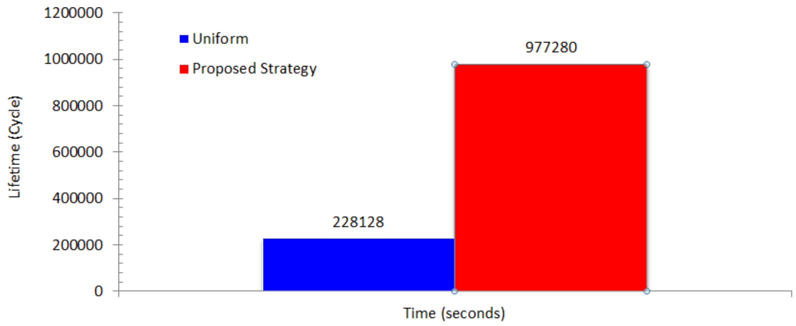

Fig. 6. Lifetime comparison under energy limitation.

6. Conclusion and Future Work

In WSNs with uniformly distributed sensors, when an energy hole appears due to the death of some sensors in critical location, data cannot be sent from other sensors to the sink, even if most of the sensors still have energy. This means that the network lifetime will end prematurely, resulting in wastage of a significant amount of energy. This paper has proposed the theoretical structure and development of innovative sensor placement strategy to mitigate energy holes problem in corona-based WSNs by balancing the energy consumption ratio in each corona; in addition to maximize the network lifetime while maintaining the coverage and connectivity. It has been shown that long network lifetime can be achieved by corona-based WSN, if the energy consumption ratio in each corona is equal to other coronas. The evaluation results show that the proposed strategy can significantly improve the lifetime of the network compared to uniform placement strategy. For future work will include development of an energy provisioning strategy, which will be integrated to work along with the proposed sensor placement strategy. The planned strategy will be designed based on the concept in which the energy increment ratio of each corona needed to balance the energy is computed first, and by establishing the relationship between increasing the network lifetime and the required initial energy for each node in every corona.

References

1. Ahmed, A.A. (2015). A comparative study of QoS performance for location based and corona based real-time routing protocol in mobile wireless sensor networks. *Wireless Networks*, 21(3), 1015-1031.
2. Fan, C.-S. (2015). An energy-efficient two phases cluster head selection in corona-based wireless sensor networks. *International Journal of Ad Hoc and Ubiquitous Computing*, 20(1), 17-25.
3. Liu, A.-F.; Wu, X.-Y.; Chen, Z.-G.; and Gui, W.-H. (2010). Research on the energy hole problem based on unequal cluster-radius for wireless sensor networks. *Computer Communications*, 33(3), 302-321.

4. Varalakshmi, L.M.; and Preethi, M. (2016). Non uniform sensor deployment for green Mac power saving protocol for corona-based wireless sensor networks. *International Journal of Engineering Science and Computing*, 6(3), 2984-2989.
5. Rahman, A.U.; Alharby, A.; Hasbullah, H.; and Almuzaini, K. (2016). Corona based deployment strategies in wireless sensor network: A survey. *Journal of Network and Computer Applications*, 64, 176-193.
6. Ferng, H.-W.; Hadiputro, M.; and Kurniawan, A. (2011). Design of novel node distribution strategies in corona-based wireless sensor networks. *IEEE Transactions on Mobile Computing*, 10(9), 1297-1311.
7. Ferng, H.-W.; and Tendean, R. (2011). Design of an energy-efficient routing protocol for a corona-based wireless sensor network. *Proceedings of IEEE International Conference on Machine Learning and Cybernetics*, 1, 437-442.
8. Wu, X.; Chen, G.; and Das, S.K. (2008). Avoiding energy holes in wireless sensor networks with nonuniform node distribution. *IEEE Transactions on Parallel and Distributed Systems*, 19(5), 710-720.
9. Perillo, M.; Cheng, Z.; and Heinzelman, W. (2005). An analysis of strategies for mitigating the sensor network hot spot problem. *The Second Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services*, 474-478.
10. Lai, W.K.; Fan, C.-S.; and Shieh, C.-S. (2014). Efficient cluster radius and transmission ranges in corona-based wireless sensor networks. *KSII Transactions on Internet and Information Systems*, 8(4), 1237-1255.
11. Wu, X.; and Chen, G. (2007). Dual-sink: Using mobile and static sinks for lifetime improvement in wireless sensor networks. *Proceedings of the 16th International Conference on Computer Communications and Networks, ICCCN* 2007.
12. Lian, J.; Naik, K., and Agnew, G.B. (2006). Data capacity improvement of wireless sensor networks using non-uniform sensor distribution. *International Journal of Distributed Sensor Networks*, 2(2), 121-145.
13. Dong, T.; Zhang, D.; Shen, Y.; and Guo, M. (2010). Energy efficient transmission distance adjustment under non-uniform distributed wireless sensor networks. *Proceedings of International Conference on Communications and Mobile Computing* (*CMC*), 490-495.
14. Marta, M.; and Cardei, M. (2008). Using sink mobility to increase wireless sensor networks lifetime. Proceedings of *International Symposium on a World of Wireless, Mobile and Multimedia Networks*, *WoWMoM* 2008, 1-10.
15. Perillo, M.; Cheng, Z.; and Heinzelman, W. (2004). On the problem of unbalanced load distribution in wireless sensor networks. *Proceedings of the IEEE Global Telecommunications Conference Workshops, GlobeCom Workshops 2004.*
16. Thanigaivelu, K.; and Murugan, K. (2012). Grid-based clustering with dual cluster heads to alleviate energy hole problem for non-uniform node distribution in wireless sensor networks. *International Journal of Mobile Network Design and Innovation*, 4(1), 3-13.
17. Dietrich, I.; and Dressler, F. (2009). On the lifetime of wireless sensor networks. *ACM Transactions on Sensor Networks* (*TOSN*), 5(1), 1-38.

18. Yuan, H.; Xie, J.; and Hu, N. (2011). Lifetime-optimal sensor deployment for wireless sensor networks with mobile sink. Proceedings of the 6th IEEE *Joint International Information Technology and Artificial Intelligence*, 1, 451-455.
19. Zorbas, D.; and Razafindralambo, T. (2013). Prolonging network lifetime under probabilistic target coverage in wireless mobile sensor networks. *Computer Communications*, 36(9), 1039-1053.
20. Chen, Y.; and Zhao, Q. (2005). On the lifetime of wireless sensor networks. *IEEE Communications Letters*, 9(11), 976-978.
21. Yang, J.; Li, Z.; Lin, Y.; and Zhao, W. (2010). A novel energy-efficient data gathering algorithm for wireless sensor networks. *Proceedings of the 8th World Congress on Intelligent Control and Automation*, 07/2010.
22. Bhardwaj, M.; Garnett, T.; and Chandraskan, A.P. (2001). Upper bounds on the lifetime of sensor networks. *IEEE International Conference on Communications*, 3, 785-790.