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

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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 energy depletion more quickly. 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, sensed data will not be forwarded to the intended sink; accordingly, the network will not be able to completely fulfill its required tasks. In this paper, an effective sensors placement strategy is proposed to avoid or alleviate energy hole problem in 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, though sustaining the network coverage and connectivity. To achieve this aim, the number of sensors should be optimized with respect 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 showed that the proposed sensors placement strategy is capable to increase the network life time considerably compared to the conventional uniform strategy.

Keywords: Wireless Sensor network, Sensor Placement, Corona WSN

Nomenclatures

A_i	The energy increment ratio of corona i
ε_0	Initial energy of each node
E_{elec}	The electronic energy consumption
E_{rx}	The reception energy
E_{tx}	The transmission energy
E_{ri}	The energy needed in corona i for relay data come from outer corona.
E_{si}	The energy needed of corona i to sending data
R	Transmission range and corona width
R_{area}	Network radius
N_{total}	Number of nodes in the network
N_i	Number of nodes in the corona i

Greek Symbols

α	Energy dissipate in the op-amp

Abbreviations

WSN	Wireless Sensor Network
PLE	Path Loss Exponent

1. Introduction

Wireless sensor networks (WSNs) are formed of many sensing nodes designed to monitor natural phenomena. Sensing nodes in WSN communicate over short distance to complete different tasks. Wireless sensors 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 a 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 nodes to a sink 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 center of the area. Unlike traditional networks, WSNs are designed specifically for the application and environment within which they are to be used. Since they suffer from limited communication range, bandwidth, and processing and memory resources, the application and its 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 do 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 [1].

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. Therefore, once 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 [2] [9]. Figures 1, 2, and 3 illustrate roughly the sensor network architecture, general diagrams of sensor node architecture, and sensor node software architecture, respectively.

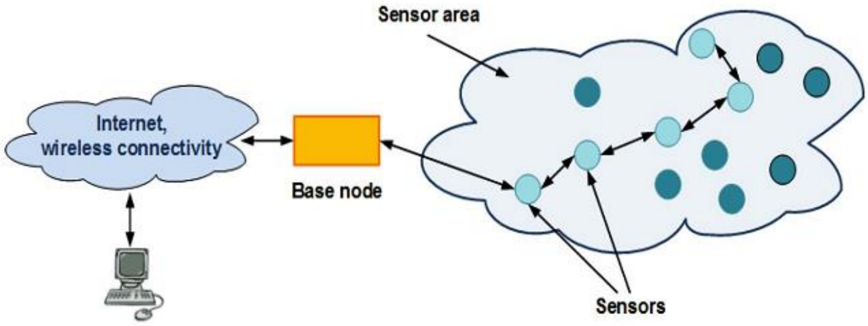

Fig. 1. Sensor Network Architecture.

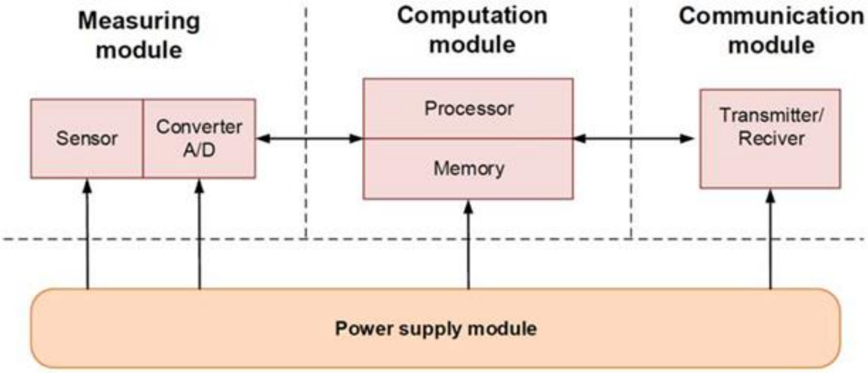

Fig. 2. Sensor Node Architecture.

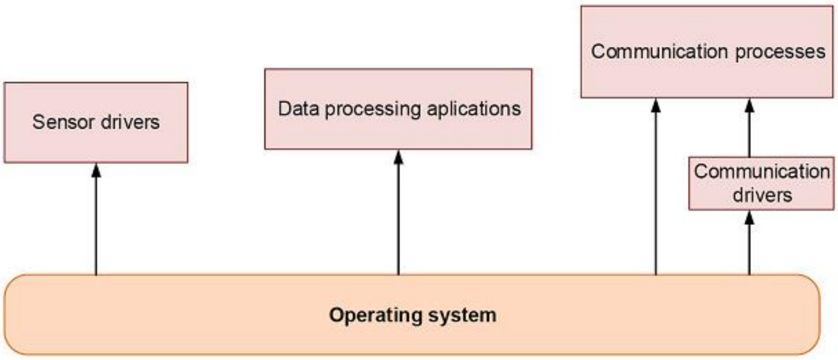

Fig. 3. Sensor Software Architecture.

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 [8-10]. This area is also divided into several angular wedges. Each node must know the identities of the corona where it lies in and the wedge it belongs to, as illustrated in Figure 4.

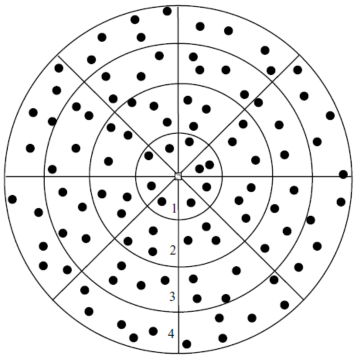

Fig. 4. Sensor Nodes in Corona-based WSN.

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 received sensed data to the sink, and thus having heavier traffic loads. These sensors consume more energy than others, hence exhausting their energy faster, causing energy holes in the network [11] [12]. 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 [13]. Lian et al. [14] reported that as much as 90% of the available energy is unused due to the hot spot and energy holes in networks, even if 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 [15] [16]. 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. M. Perillo et al. [17] 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. When the energy of a node within a WSN is 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. 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 [18-20]. Improving the network lifetime is one of the main challenges WSN, as it relies on several factors including the network architecture and protocols, the energy model, characteristics of wireless channel, and the data collection technique [21] [22].

In corona-based WSNs, energy hole problem is the most vital cause that decreases the network lifetime. 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. Modeling 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 in other coronas is computed according to other related proposed formula. In order to determine an optimal sensor placement, optimal sensor placement formula in each corona must be determined according to the number of sensors in 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 has a fixed transmission range of R. The energy model utilized here is similar to the concept in [23].

The network radius is denoted as R_{area}, and the circular area is divided into k coronas of width R. C_i denotes the ith corona (i.e. C_1 symbolizes the innermost corona). Every node creates and transmits l bits per time unit, during which, nodes belong to corona C_i bring forward the incoming data to 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 is 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. path loss exponent, which measures 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 coronas number.

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

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 $\mathrm{N_i}$ is the number of nodes in i^{th} corona ($\mathrm{N_1}$ and is the number of nodes in C_1). From Equation 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 is equal to 4 (the path loss of normal outdoor environment). If there is k coronas in the network, then $\mathrm{R} = \mathrm{R}_{\mathrm{area}}/\mathrm{k}$, where R is corona width and $\mathrm{R}_{\mathrm{area}}$ 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 the lifetime of corona i are, respectively, computed by:

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

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

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 data bit, 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 C_1 is considered as the critical corona because of the heavy forwarding load, it is important to consider the energy consumption and the 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 C_1 needs to be known. As asserted by Manish et al [24], 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 C_1 and all data packets generated in other coronas are relied from C_1 to the sink, including the data generated by C_1 itself. Assuming that every node collects and transfers l bits of data per time, the energy consumption in C_1 can be obtained using Equation (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 Equation (7) and Equation (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 $Nratio_i$ indicates the ratio of number of nodes in outside of C_{i} to number of sensors in C_{i}, Equation (11) is derived as:

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

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

It is obvious that, if 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 Equation (10) and Equation (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,

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

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

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

By using Equation (11) and Equation (13), the following Equation (15) is derived.

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

Thus, Equation (15) presents a system of equations with k-1 equations and k-1 variables $(N_1, N_2, \ldots, N_{k-1})$, 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, Equation (12) is the solution of Equation (15). Backward induction proof had been used to prove this solution.

For the base case, let k-1be the initial value for the backward induction, thus, P(k-1) asserts that:

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

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:

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

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

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

$$\Rightarrow \frac{\sum_{j=Ʈ+1}^{k} N_j + N_Ʈ}{N_{Ʈ-1}} = \frac{N_k}{N_{k-1}} \tag{20}$$

$$\frac{\frac{N_k N_Ʈ}{N_{k-1}} + N_Ʈ}{N_{Ʈ-1}} = \frac{N_k}{N_{k-1}}$$

$$\Rightarrow N_{Ʈ-1} = \frac{N_Ʈ(N_{k-1}+N_k)}{N_k}$$

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

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

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

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

4.5 Optimal Number for coverage/connectivity requirements

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 for 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 with regard to 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:

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

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 $\mathrm{N_k}$ maintains the coverage and connectivity in the outermost corona, $\mathrm{N_{k-1}}$ can be determined according to the $\mathrm{N_k}$ resulting from Equation (2) to meet the coverage and connectivity requirement in corona $\mathrm{N_{k-1}}$. Then, the ratio of number of sensors in $\mathrm{N_{k-1}}$ to $\mathrm{N_k}$ to guarantee the coverage and connectivity in $\mathrm{N_{k-1}}$ is $\frac{N_{k-1}}{N_k}$, where $\mathrm{N_{k-1}}$ and $\mathrm{N_k}$ are achieved based on normal distribution in Equation (2).

Therefore, to meet the coverage and connectivity in corona k-1, the minimum number of sensors in the corona $\mathrm{Nk-1}$ is calculated as:

$$\begin{gathered} N_{k-1} = (\frac{(2(k-1)-1)}{2k-1})N_k \\ \Rightarrow \quad N_{k-1} = (\frac{2k-3}{2k-1})N_k \end{gathered} \tag{23}$$

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

5.0 Experimental Evaluation

Experimental tests were performed to evaluate the analytical model of the proposed strategy using MATLAB. Performance evaluation was done with the intent of verifying and analyzing 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 tradeoff (whenever presented).

5.1 Parameters Setup and Assumptions

In evaluation scenarios, all the nodes have an initial energy and 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 contention-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 for receive data (Erx), energy needed of 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 were sent with transmission R (NDirectSent), number of received packets (NRecieve) and so on.

The effectiveness of the proposed deployment strategy was first compared to the uniform sensor placement strategy for a 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 is designed based on Equation (22). In the proposed strategy, the number of sensors that should be placed in the last (outermost) corona is defined according to connectivity and coverage requirements, while the number of sensors in other coronas is determined based on Equation (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 the Equation (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.

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

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 compared the output to the uniform placement strategy, as shown in Table 2. The sensor placement with the proposed strategy was again according to Equation (22) while sensors were placed randomly throughout the network with the uniform strategy. 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. In the 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.

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

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 only produce 228128 cycles of lifetime. By estimation, the proposed strategy is able to lengthen the lifetime of the network more than five times.

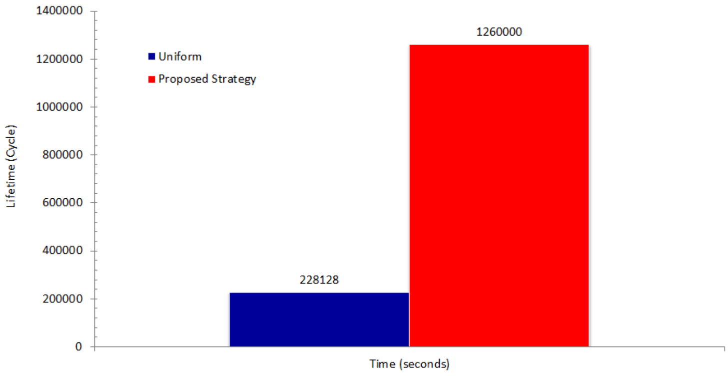

Fig. 5. Lifetime of the proposed strategy compared to the uniform placement.

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 Feng et al. [4], to guarantee the connectivity and coverage in the 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 preferred to use a lot of sensors with less initial energy to maximize the network life time and avoid the energy holes problem. 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 0.5J.

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

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 where the network lifetime, connectivity, and coverage are of concern.

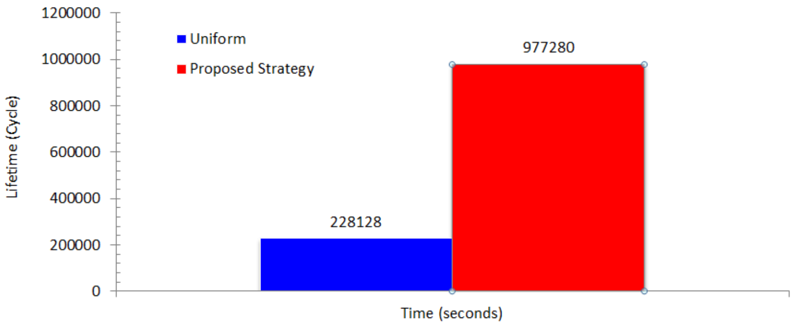

Fig. 6. Lifetime comparison under energy limitation.

6.0 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 though 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 proposes the theoretical structure and the development of innovative sensor placement strategy to mitigate the 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 the longest network lifetime can be achieved in the 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 uniform placement strategy. For future work, an energy provisioning strategy is going to be developed and integrated to work along with the proposed sensor placement strategy. It will be designed based on the concept that 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.

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