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Research Article

Sub-Balanced Energy Consumption through Engineered Gaussian Deployment Strategies in Corona-Based Wireless Sensor Network

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Abstract: Wireless sensor networks (WSNs) are getting more widespread use and can be used in a wide range of applications, such as environmental monitoring, smart homes, military surveillance, forests, habitat monitoring, farmlands and precision agriculture. Due to the limited battery power, energy efficiency is the most challenging problem in wireless sensor network. For various applications, it is necessary to deploy sensor node in efficient way to monitor the event precisely, achieve balance energy depletion and extend the network lifetime. In many-to-one traffic pattern, nodes closer to the sink have heavier traffic loads and deplete their energy quickly; this leads to energy holes around the sink. Due to the creation of energy holes, data can no longer be delivered to the sink, although most of sensor nodes have enough residual energy. To overcome the problem of energy hole and achieving sub-balanced energy consumption in corona-based wireless sensor network, engineered Gaussian deployment strategies are proposed. Simulation result shows that the proposed technique maximizes the network lifetime, data delivery, energy consumption and also reducing the chances of energy-hole formation in a network.

Keywords: Arithmetic and geometric proportions, corona-based wireless sensor network, engineered Gaussian deployment, energy hole problem

INTRODUCTION

Wireless Sensor Networks (WSNs) have been used in a wide range of applications such as target tracking, environmental surveillance, smart homes, forests, habitat monitoring, farmlands, industrial applications, remote parameters detection and data collection for factors such as humidity, temperature, light and pressure or the weight, velocity and movement direction of an object in the area of the interest. Wireless sensor technologies have broadened their applications by recent advances. WSNs are used for many civil and military applications (Akyildiz *et al*., 2002; Dantu *et al*., 2005; Srivastava *et al*., 2001). The success of WSNs highly depends on the sensor node positions which are known by deployment of the network.

One of the most important technical challenges is the lifetime of a network which based on sensor node's battery of which the replacement is difficult or even impossible. The nodes closer to the information processing center (sink) have heavier traffic than the remaining part of the network and consume more energy to transmit their own data as well as the data belonging to the nodes further from information processing center. As a result, sink neighboring nodes diminish their energy earlier, although most of the sensor nodes still retain significant amounts of energy. This leads to the energy hole problem in wireless sensor network due to unbalanced energy consumption (Jian and Mohapatra, 2005). The energy hole is most often occurs in networks where the sensor nodes are uniformly deployed.

This problem is strongly related to the topology influenced by the deployment of sensor nodes in the interested area of wireless sensor network. Song *et al*. (2008) performed power control i.e. in order to increase the node density surrounding the sink node they adjust the transmission range, endeavoring to avoid the energy hole problem.

In proposed engineered Gaussian deployment strategy, the energy hole problem is reduced in sink proximity in which the number of nodes near sink vicinity is increased. This technique maximize network lifetime up to some extant but balance energy depletion cannot be achieved by simply increasing sink neighboring nodes. Because if we only increase sink neighboring nodes then neighbor to neighbor nodes early diminish their energy while sink neighbor nodes have enough residual energy. To overcome this problem we propose Gaussian deployment strategies in which the network is divided in coronas and number of

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nodes decreases from inner to outer corona with arithmetic and geometric proportions.

If the network has some constraint e.g., limited number of nodes and the primary importance is to maximize the network lifetime or coverage, or achieve balanced energy consumption. Due to these factors, seven different sensor node deployment strategies are proposed in which the same number of sensor nodes is distributed in different fashion and analyze its impact on the performance of WSNs. Our main focus in this study is to overcome the energy hole problem, maximize the energy consumption ratio and to find the optimum number of sensor node in all coronas of engineered Gaussian corona-based deployment strategy in WSNs.

LITRATURE REVIEW

On the analysis of the energy hole problem, balanced energy consumption, lifetime model and lifetime optimization techniques, a related work will briefly discuss in this section. The authors examine the complex network properties introduced by the graphs that represent WSNs and proposed the use of a new centrality measure called Sink Betweenness. They use this metric to elaborate a new data-collection algorithm able to mitigate the energy hole problem by evenly balancing the relay load and thus, increasing the network lifetime. Simulation results show that their solution can considerably decrease the difference of the number of transmissions among the nodes that are located close to the sink (Ramos *et al*., 2012).

Especially in asynchronous MAC-based Wireless Sensor Networks (WSNs) the energy hole problem is caused by sooner turning off of sensor nodes close to the sink due to more successive data transmission. The authors resolve this problem by controlling the number of data transmission with a burst length based and time-out based transmissions. They proposed Energy-aware Hybrid Data Aggregation Mechanism (EHDAM) in which they set the burst length threshold value in reverse proportion to the remaining energy state of the nodes. So the sensor node lifetime which is affected by energy hole problem, EHDAM maximize their lifetime by reducing the number of data transmission (Min-Gon *et al*., 2011).

Instead of the standard approach relying on just one sink, another method to improve the lifetime of WSNs is to deploy multiple sinks. Some authors assume unconstrained sink node deployment i.e., the sinks can be placed anywhere. But in practice some areas are not feasible for sink placement due to obstacles or beyond wireless range. The authors focused on the optimal placement of a given number of sinks. They consider constraints deployment and avoid connection black holes. Their simulation results show that a constraint based deployment algorithm is superior to get the full potential of multiple sink WSNs (Flathagen *et al*., 2011).

Jia *et al*. (2012) discussed the theoretical aspects of the network load and the node density. They proved the accessibility condition to satisfy that all the working sensors deplete their energy with the same ratio. To achieve balanced energy depletion per node they proposed an algorithm for density control with the concept of equivalent sensing radius. To minimize the repetition of identical messages a new pixel-based transmission mechanism is adopted. To balance the energy consumption and enhance the network lifetime, nodes are activated with non-uniform distribution on different energy layers. Simulation results show the effectiveness of their algorithm.

For the avoidance of energy holes in a wireless sensor network the authors proposed several design criteria with uniform node deployment (Olariu and Stojmenovic, 2006). To construct a hierarchical network structure, heterogeneous deployment use two types of sensors, low energy sensors and high energy sensors. But, this approach raises the deployment and implementation complexity (Jae-Joon *et al*., 2004).

Sensor nodes near to sink are involved in more data forwarding that's the way there should have a high density of sensor nodes. The authors address the problem of Movement-assisted Sensor Positioning (MSP) to achieve theoretical sensor densities with the objective to minimize sensor movement and increase the network lifetime. Their proposed solutions are: an integer-programming formulation, a localized matching method and a distributed corona-radius scanning algorithm (Cardei *et al*., 2008).

To solve energy hole problem, the authors proposed a strategy which is based on the non-uniform distribution of the sensor nodes in the sensing field. In this strategy the sensing area is divided into multiple regions and place more nodes in the regions near to the sink node to balance the energy consumption (Demin *et al*., 2008)

For alleviating power consumption an N-policy M/G/1 queue has been reported in Jiang *et al*. (2009). In this scheme, a queue threshold N is specified for the concept of queued wake up. The threshold is used to control the latency delay for the buffered data packets and the number of times the data radio is turned on. In the queued wakeup scheme when the queue holds N packets, the sensor node triggers its data radio, conducts the process of medium-contention and sends the queued packets in a burst.

To maximize network lifetime the authors proposed an in-network data aggregation scheme in Liang and Jxa (2011). Each node multiplies its reading with a random coefficient and sends results to the next hop to calculate weighted sum of all messages. Instead of individual node reading the base station will receive weighted sum and restore the original data. Energy consumption of all sensor nodes is same because each node to calculate the weighted sum only performs one addition and one multiplication.

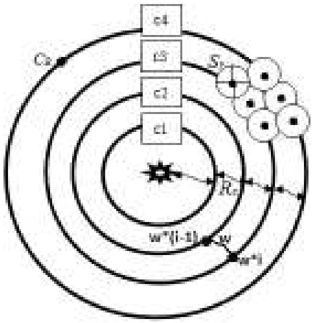

Fig. 1: Corona based deployment strategy normally

In a wireless sensor network the sensor node deployment is one of the key problems for researchers. The authors in Zhiming and Lin (2009) proposed particle swarm optimization concept for efficient deployment of sensor nodes. Simulation results show that particle swarm optimization reduces the network energy consumption and increase the whole coverage ratio.

In Kenan *et al*. (2010) the authors proposed two random deployment strategies for avoiding energy hole problem. First, the lifetime-oriented deployment strategy is proposed to prolong the network lifetime by achieving balanced energy consumption of Relay Nodes (RNs) and second the hybrid deployment concern with connectivity. Both the strategies provide guidelines for better deployment of sensor nodes and Relay nodes in heterogeneous WSN.

METHODOLOGY

Proposed engineered corona-based deployment strategies: In the proposed corona based wireless sensor network deployment strategies, the sensor nodes are distributed in the coronas and each of the corona's sensor nodes can communicate with its neighboring corona's nodes directly through one hop. The sensor nodes are deployed through seven different methods using arithmetic and geometric proportions and assess their impact on the performance of the wireless sensor network. The main purpose here is to investigate the optimal strategies for corona based network deployment with full and limited control over the positioning of network nodes.

Analytical analysis of the proposed network model: In corona based networks, the sensor nodes are deployed in a circular fashion of radius r with a static sink located in the center. The sensors are homogenous and each of them uses the same sensing range S_r and communication range R_c. The circular area is further divided into R adjacent coronas and each corona width is represented by w as shown in Fig. 1, where C_i denotes the ith corona. Obviously, C_i is composed of nodes whose distance to the sink are between w*(i-1) and w*i. Assuming that C_1 can only communicate directly with the sink node and each sensor node generates and sends L bits of data per unit time, except for the outer corona, all the other coronas will forward both the data generated by themselves and the data generated by the nodes from adjacent outer coronas. The nodes in the outermost corona, C_R, however, need not forward any data. The node consumes p_1 units of energy when sending one bit and depletes p_2 units of energy when receiving one bit, where $p_1 > p_2 > 0$:

$$R_s \le {}^{R_c}/_{2} \tag{1}$$

The proposed network considers that the communication range of the sensor node is twice the sensing range as shown:

$$R_s = {}^{R_c}/_{2}$$

The area of the network is further divided into R adjacent coronas, where Ci denotes the ith corona. The radius of the network is equal to the diameter of the outer corona divided by 2 and the total number of coronas is equal to the radius of the network divided by the communication range of the sensor, i.e.:

$$R = {}^{r}/_{R_c} \tag{2}$$

The total number of coronas depends on the communication range of the sensor. ri represents the radius of each corona from the sink and Ci is composed of nodes whose distances to the sink are:

$$r_i = r_{i+1} - R_c \qquad 1 \le i \le R - 1 \tag{3}$$

when i = 1; $r_1 = r_{1+1} - R_c$ $r_1 = r_2 - R_c$
when i = 2; $r_2 = r_{2+1} - R_c$ $r_2 = r_3 - R_c$
when i = 3; $r_3 = r_{3+1} - R_c$ $r_3 = r_4 - R_c$

The radius of each corona can also be found by the following equation:

$$r_i = i * R_c \tag{4}$$

when i = 4 $r_4 = 4 * R_c$
when i = 3 $r_3 = 3 * R_c$
when i = 2 $r_2 = 2 * R_c$
when i = 1 $r_1 = 1 * R_c$

- **Engineered uniform:** In this strategy, the sensor nodes are distributed in engineered uniform corona based fashion. The density of the sensor nodes in all four coronas is the same as shown in Fig. 2 and the number of sensor nodes per unit area is shown in Fig. 3. This type of deployment can be employed

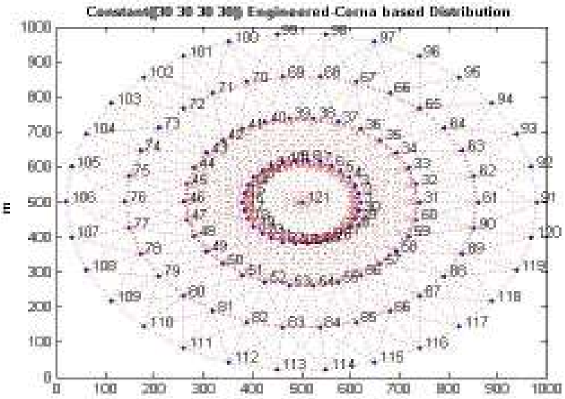

Fig. 2: Engineered uniform corona based deployment strategy

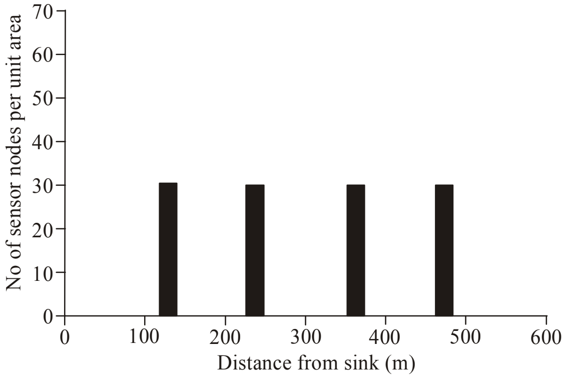

Fig. 3: Number of sensor nodes per unit area

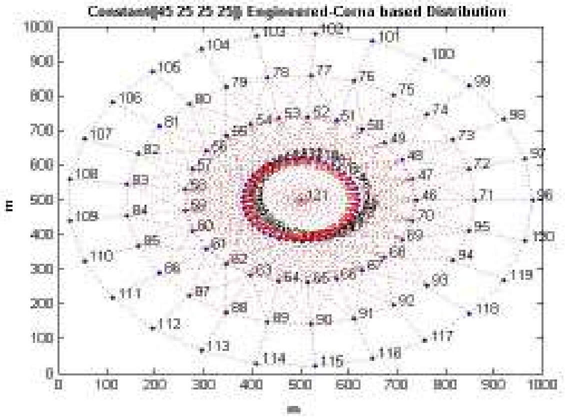

Fig. 4: Engineered Gaussian corona based deployment

when a large sensing area needs to be covered with a limited number of sensor nodes.

- **Engineered Gaussian:** In this strategy, the sensor nodes are distributed in the engineered Gaussian fashion in an observed area. The density of the sensor nodes in the first corona is higher than the other coronas as shown in Fig. 4 and the number of sensor nodes per unit area is shown in Fig. 5. Employing such a deployment strategy helps in mitigating the energy hole problem in the sink's vicinity since the load of the data transfer to the sink from all sources is distributed among the one-hop neighbours of the sink. An equitable routing across these neighbours' results in the uniform depletion of energy across the whole network and a prolonged network lifetime can be achieved.

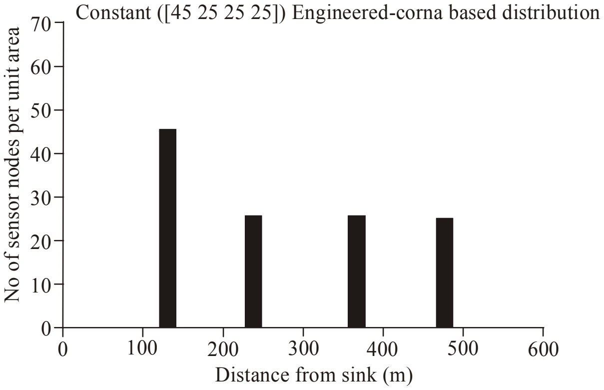

Fig. 5: Number of sensor nodes per unit area

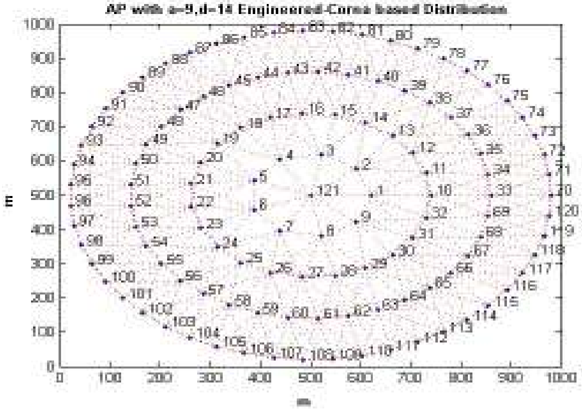

Fig. 6: Engineered Gaussian corona based deployment with Arithmetic Proportion

- **Engineered Gaussian with an arithmetic proportion:** The sequence of numbers in which the difference between two adjacent terms is constant is known as Arithmetic progression. For example, the sequence 3, 5, 7, 9, 11, 13, is an arithmetic progression with a common difference of 2. If the initial term of an arithmetic progression is C_1 and the common difference of the consecutive terms is d, then the ith term of the Arithmetic progression will be:

$$C_i = C_1 + (i-1)d \quad (5)$$

In this strategy, the sensor nodes are distributed in such a way that the density of the sensor nodes increases from the inner to the outer coronas with an arithmetic proportion to cover the area of the network.

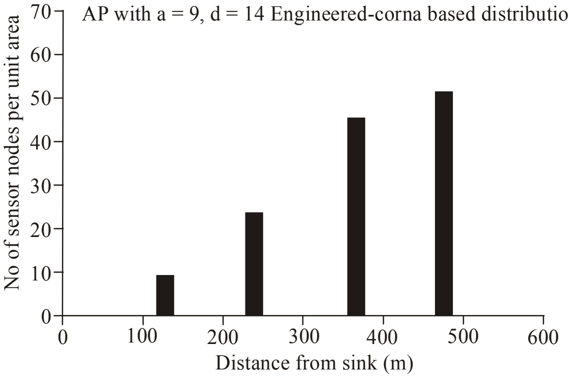

Fig. 7: Number of sensor nodes per unit area

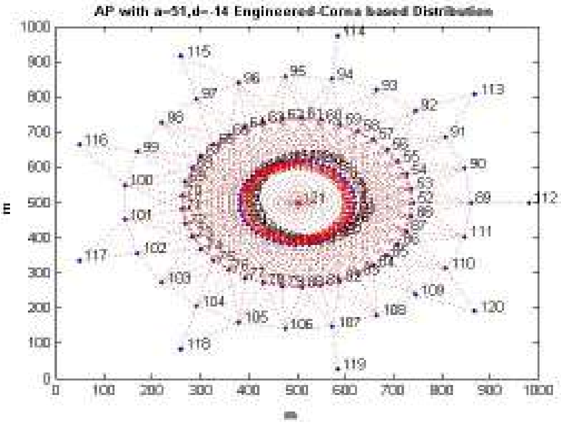

Fig. 8: Engineered Gaussian corona based deployment with Inverse Arithmetic Proportion

The density of the sensor nodes in the first corona is lower than the other coronas as shown in Fig. 6 and the number of sensor nodes per unit area is shown in Fig. 7. Although such a strategy renders itself to the energy hole problem in the sink's vicinity, it can still be applied to critical applications where a large area needs to be covered with limited sensor nodes. Another application could be in the case of heterogeneous nodes where the sink's neighbours are less in number as compared to other nodes but are more capable in terms of energy or processing power; thereby, they able to support a longer lifetime even under high load conditions for data forwarding.

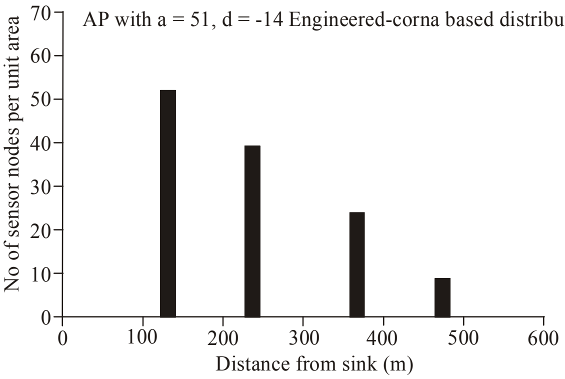

Fig. 9: Number of sensor nodes per unit area

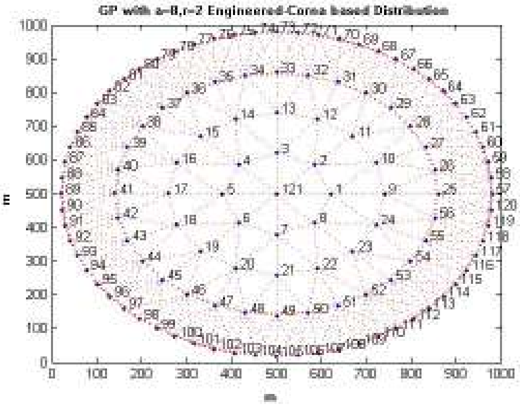

Fig. 10: Engineered Gaussian corona based deployment with Geometric Proportion

- **Engineered Gaussian with an inverse arithmetic proportion:** In this strategy, the sensor nodes are distributed in the engineered Gaussian fashion in such a way that the density of the sensor nodes decreases from the inner to the outer coronas with the arithmetic proportion to mitigate the energy hole problem near the sink's locality in the wireless sensor network as shown in Fig. 8 and the number of sensor nodes per unit area is shown in Fig. 9. This strategy is an alternative to the random Gaussian deployment and is beneficial in scenarios where all the nodes are similar in power and processing capabilities.
- **Engineered Gaussian with a geometric proportion:** A sequence of numbers in which the next term is calculated by multiplying the previous term with a common ratio is called geometric progression. For example, the sequence 2, 6, 18, 54, is a geometric progression with a common ratio 3. Thus, the general form of a geometric sequence is $C, Cr, Cr^2, Cr^3, Cr^4, \ldots\ldots\ldots$the ith term of a geometric sequence with the initial value 'C' and the common ratio r is given by:

$$C_i = Cr^{i-1} \tag{6}$$

In this strategy, the sensor nodes are distributed in the engineered Gaussian fashion such that, the density of the sensor nodes increases from the inner to the outer coronas with a geometric proportion. The rationale is to cover the observed area and to mitigate the energy hole problem in a network as shown in Fig. 10 and the number of the sensor nodes per unit area is shown in Fig. 11.

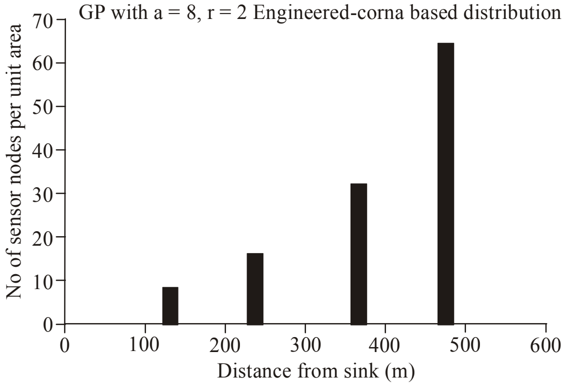

Fig. 11: Number of sensor nodes per unit area

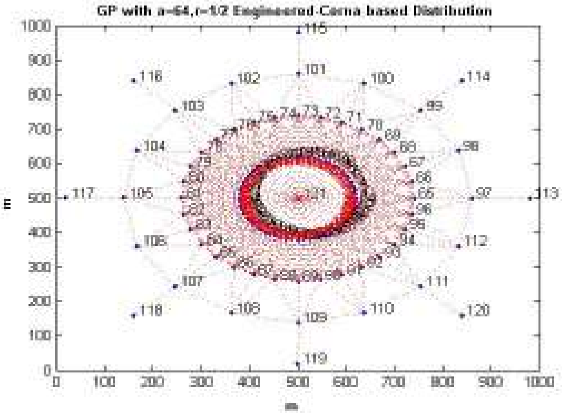

Fig. 12: Engineered Gaussian corona based deployment with Inverse Geometric Proportion

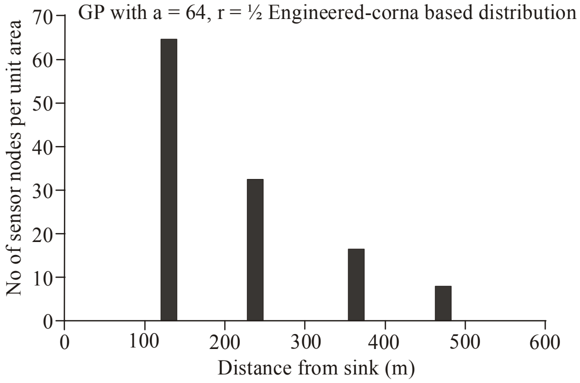

Fig. 13: Number of sensor nodes per unit area

- **Engineered Gaussian with an inverse geometric proportion:** In this strategy, the sensor nodes are distributed in the engineered Gaussian fashion, such that the density of the sensor nodes decreases from the inner to the outer coronas with an inverse geometric proportion of the ratio 2. This is to mitigate the energy hole problem near the sink's locality as shown in Fig. 12 and the number of sensor nodes per unit area is shown in Fig. 13.

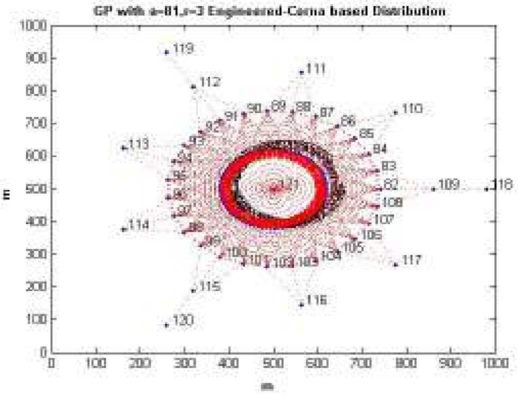

Fig. 14: Engineered Gaussian corona based deployment with Geometric Proportion of ratio = 3

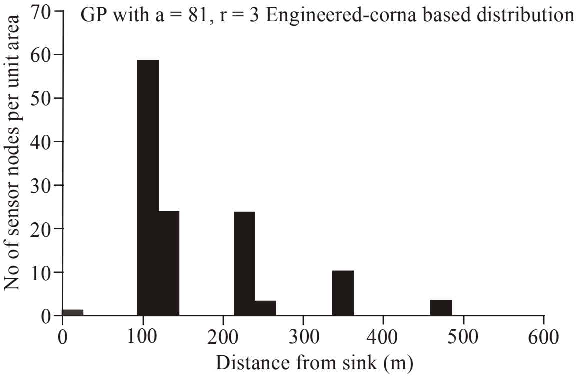

Fig. 15: Number of sensor nodes per unit area

- **Engineered Gaussian with a Geometric proportion of ratio 3:** In this strategy, the sensor nodes are distributed in the engineered Gaussian fashion, such that the density of the sensor nodes decreases from the inner to the outer coronas with a geometric proportion of ratio 3. The reason is to mitigate the energy hole problem near the sink's locality as shown in Fig. 14 and the number of sensor nodes per unit area is shown in Fig. 15.
  The Fig. 14 shows the sparse placement of nodes away from the sink, whereas those closer to the sink are dense and congested.

PERFORMANCE ANALYSIS AND SIMULATION RESULTS OF THE PROPOSED DEPLOYMENT STRATEGIES

In this section, the performance analysis of the proposed deployment strategies of WSNs is evaluated and compared with the following.

- Random uniform deployment strategy (Ishizuka and Aida, 2004; Lian *et al*., 2006; Tilak *et al*., 2002).
- Engineered uniform deployment strategy (Brooks *et al*., 2006; Dhillon and Chakrabarty, 2003; Petrushin *et al*., 2006; Tilak *et al*., 2002).

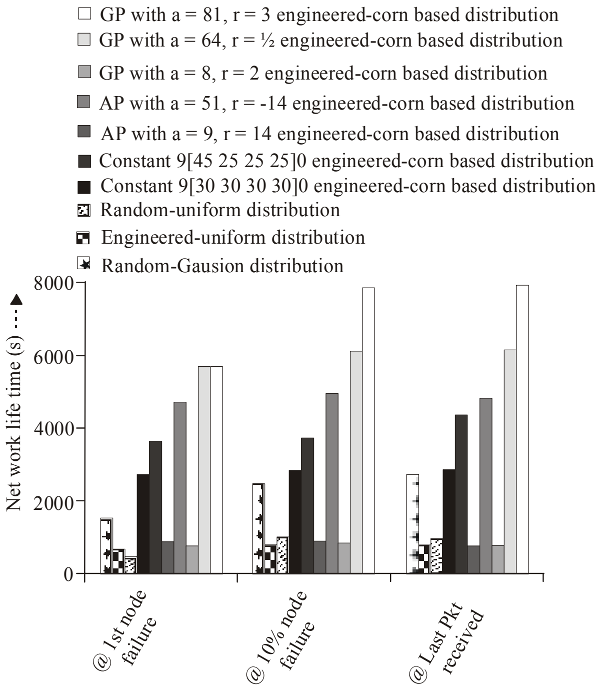

Fig. 16: Network lifetime of engineered corona based deployment strategies

- Random Gaussian deployment strategy (Ishizuka and Aida, 2004).

Simulation results demonstrate that the proper placement of sensor nodes guaranteed full coverage, connectivity, enhanced lifetime, data delivery and most importantly optimized balanced energy consumption of the sensor node in WSNs.

Simulations have been performed on homogeneous nodes, random uniform traffic and stationary sink at the center of topology. In order to evaluate the proposed strategies, several simulated networks were implemented. The simulated networks were deployed in a geographical area of 1000×1000 m^2. The area was divided into four coronas. The number of sensor nodes in the network was kept at 120 and their transmission range to 150 m. The initial energy assigned to each node was 1 Joule, whereas the energy consumption during transmission was set to be 10 milli Joule (Table 1). The performance of the network was evaluated using metrics such as network lifetime, data delivery, network consumed energy and network residual energy.

- **Network lifetime:** The performance of the network according to the different deployment strategies is evaluated using the following network lifetime models.
- The time until the first node fails or runs out of energy.
- The time until ten percent of the total nodes fail or run out of energy.

Table 1: Simulation parameters

Parameters	Values
Area	1000*1000 m^2
No of source node	120
Transmission range (maximum)	150 m
Initial node energy	1 Joule
Energy consumption (during transmission)	10 mili Joule
Energy consumption (during receiving)	0.1 mJ
Total number of coronas	4

- The time until last packet is received at sink from any arbitrary source node, i.e., the total time in which nodes can communicate with the sink. In other words, when all of the one hop neighbors of sink drain their energy levels such that there is no path available for communication with the sink.

Figure 16 shows that at first node failure, the lifetime of random uniform deployed network is about 400-simulation sec and for random Gaussian, it is about 1600 sec simulation time. There is a sharp increase of about 1200-simulation sec time. The lifetime of engineered uniform is about 800 sec of simulation time and for engineered uniform corona-based distribution it is about 2700 sec of simulation time. When the sensor nodes increase in first corona, it becomes Gaussian distribution. The lifetime enhances up to 3800 sec of simulation time. There is a sharp increase of about 1100 sec. The result of Gaussian distribution shows that deployment of the network should be in such a way as to find the optimum number of nodes in each corona.

In many to one traffic pattern, the number of sensor nodes increase as we move near to the sink. In the proposed deployment strategies, the sensor nodes are distributed in coronas according to the arithmetic and inverse arithmetic proportions. The results show enhancement in network lifetime as the sensor nodes are increased from outer towards the inner corona. The lifetime enhanced up to 4800 sec of simulation time.

Then the sensor nodes are deployed in coronas according to the geometric and the inverse geometric proportion of ratio 2. The results show more enhancements in network lifetime as the number of sensor nodes increases from outer towards the inner corona. The lifetime is extended by up to 5800 sec of simulation time.

As a final scenario, the sensor nodes were distributed according to the geometric proportion of ratio 3 from outer to inner coronas. The result did not show any performance improvement in network lifetime at first node failure as compared to the geometric proportion of ratio (02) but increases the network lifetime of ten percent of the total node failures. The lifetime enhanced up to 7900 sec of simulation time.

The same increase shows for the third definition of the network lifetime i.e. the time until last packet received at sink from any arbitrary source node.

- **Data delivery:** According to the Fig. 17, the ratio of packets sent and received is the same in

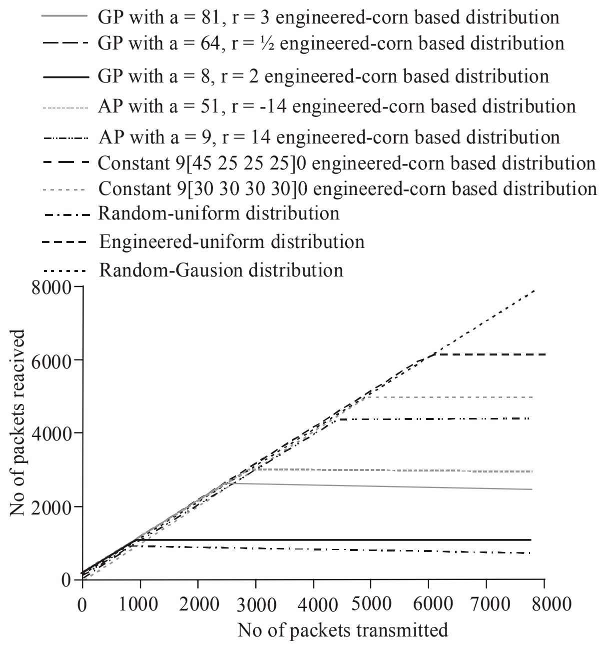

Fig. 17: Data delivery of engineered corona based deployment strategies

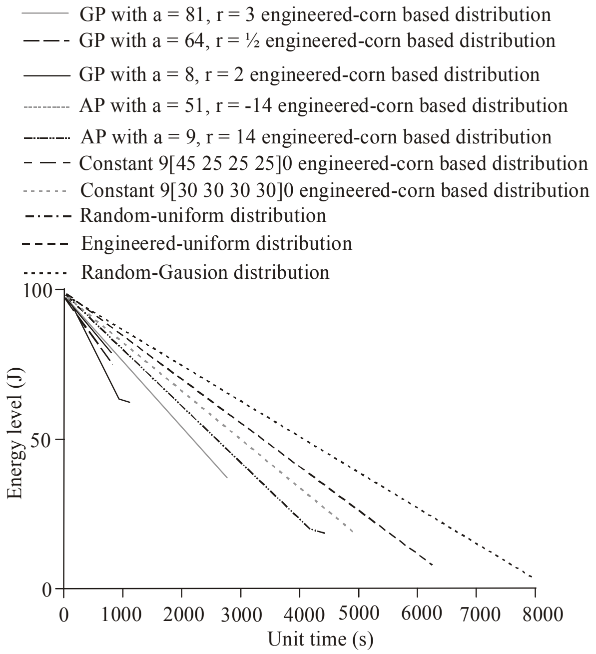

Fig. 18: Energy consumption of engineered corona based deployment strategies

engineered uniform corona based deployment strategy, once the neighbor nodes of the sink die out. It has been observed that even though the sensing nodes are sending packets, but the sink is not able to receive them due to lack of paths. In engineered Gaussian deployment with arithmetic and geometric proportions, the sensor nodes are increased in sink locality. It has been observed again, that in engineered Gaussian deployment with both arithmetic and geometric proportion strategies, the percentage of data delivery is increased as compared to engineered uniform.

In case of random uniform and engineered uniform deployment the source sends about 1000 packets towards the sink but when the first corona nodes drain out their energy, then the sensor nodes are sending packets but the sink is not able to receive them due to the energy hole occurrences near sink locality.

In case of random Gaussian 2300 packets received at sink and engineered uniform corona-based deployment strategy about 3000 packets received at sink. In engineered Gaussian distribution, the sensor nodes are increases at first corona by up to 45 nodes and the remaining coronas have the same number of nodes i.e., 25. In this case, 4000 packets were received at the sink. The sensor nodes are sending packets but the sink is not able to receive them because the second corona nodes drain out their energy. The results of Gaussian distribution show that the sensor nodes should be deployed in such a way as to find the optimum number of nodes in each corona. In many to one traffic pattern, it is required to increase the number of sensor nodes from outer to inner coronas, especially near the sink. We deployed the sensor nodes in coronas according to the arithmetic and geometric proportions. The results show much more enhancement in data delivery.

In case of engineered Gaussian distribution with arithmetic proportion, the sensor nodes are increased from outer to inner coronas according to the traffic load. The sink received 5000 packets but the maximum energy of the network is not utilized.

In case of engineered Gaussian distribution with geometric proportion, the sensor nodes are increased from inner to outer coronas with ratio 2 and 3, the maximum packets 6000 and 8000 received at sink respectively.

- **Consumed energy:** It has been observed in our analysis that the network density does not affect the energy consumption rates of a network but rather the proper placement of nodes affects it. The energy consumption stays at different levels under same node densities for the seven considered deployment strategies. This implies that the network lifetime cannot be prolonged and an equitable consumption cannot be ensured by simply increasing the density of the deployed nodes.

The Fig. 18, the graph depicts that random uniform and engineered uniform almost consumed 25% of their total energy during the network lifetime. A random Gaussian and an engineered uniform corona-based deployment resulted in consumption of 60% of the total energy. Engineered Gaussian deployment and

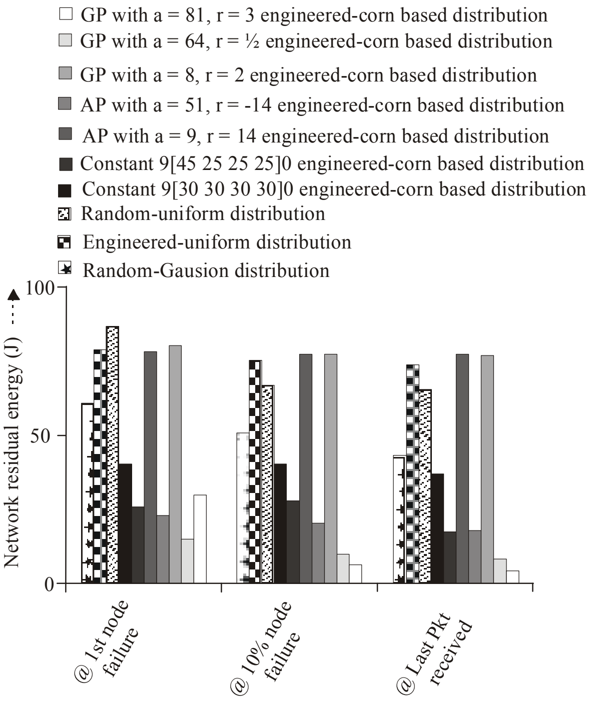

Fig. 19: Network residual energy of engineered corona based deployment strategies

engineered Gaussian with arithmetic proportion consume about 80% of the total energy. Engineered Gaussian deployment with the geometric proportion of ratio 2 and 3 consume 90% and 95% of the total energy respectively during the network lifetime.

- **Network residual energy:** The energy consumption rate is higher in sink vicinity due to multi-hop traffic pattern in sensor networks. It has been validated from Fig. 19, that if the sensor nodes are uniformly distributed in a network, up to 90% of the total energy of the network is left unused if the network lifetime is considered to be over at first node's failure and 65% of the total energy of the network are left unused when the network lifetime is considered to be over at last packet received at the sink. For engineered uniform deployment, the residual energy is about 80% of the total energy at first node failure and 75% of the total energy of the network is left unused when the network lifetime over at last packet received.

The residual energy of random Gaussian deployment is about 60% of the total energy at first node failure and 40% of the total energy when the network lifetime ends at last packet received. In engineered uniform corona-based deployment, the density of sensor nodes is uniform in all corona of the network then up to 40% of the total energy of the network is left unused during network lifetime at first node failure. The residual energy of engineered Gaussian deployment is about 28%, engineered Gaussian with arithmetic proportion and geometric proportion of ratio 2 is about 21 and 13% respectively. The residual energy for Engineered Gaussian deployment with a geometric proportion of ratio 3 is 30% when the network lifetime ends at first node failure and 5% at last packet received.

CONCLUSIONS AND RECOMMENDATIONS

Energy efficient deployment strategy is the most important consideration for wireless sensor networks. The Gaussian deployment strategy is simple, efficient and less costly as compared to other intelligent techniques. A good sensor deployment strategy is one that achieves an optimum utilization of energy.

The main factor for achieving this optimum utilization of energy is to deploy more nodes at sink locality, rather than other performance factors such as increased energy level and transmission range of all the sensor nodes. Our work can be extended to analyze the performance for other deployment strategies.

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