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TRAFFIC BASED RANDOM DEPLOYMENT OF RELAY NODES IN WIRELESS SENSOR NETWORKS

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ABSTRACT

Relay nodes are used in the transfer of the data packets to the base station (BS) via the sensor nodes (SN). The placement of RNs influences the lifetime and connectivity of a Wireless Sensor Network (WSN) system. A traffic aware random deployment technique for the relay nodes is proposed in this paper. The scalability and traffic of the WSN are analyzed. A traffic aware RN selection is performed for both single hop and multi hop communication cases. Traffic based random deployment methods of RN, namely, lifetime-oriented deployment, and hybrid deployment, solve the issue of a short WSN lifetime and insufficient energy utilization. The trade-off between the lifetime extension and connectivity of SN in a WSN is considered in the performance analysis. The proposed method provides an efficient approach for the placement of RNs in a heterogeneous WSN.

Keywords: *Base Station (BS), Biased Energy Consumption Rate (BECR), Data Collection Round (DCR), Energy Depletion Intensity (EDI), Relay Node (RN), and Wireless Sensor Network (WSN).*

1. INTRODUCTION

The deployment of the nodes in the WSN determines several intrinsic parameters such as connectivity and lifetime. The deployment of the devices in a WSN on a random basis is not suitable when the number of nodes to be placed is large and when the environment is remote and inaccessible. A deployment density function needs to be designed for the efficient deployment of nodes in a WSN. Relay nodes (RN) are employed in the communication of data packets to the base station (BS) via the sensor nodes (SN). A group of SN will contain a RN for transferring the information from the SN to the BS.

The uniform random deployment is the conventional method for the deployment of nodes in a WSN. It is an inefficient technique in terms of energy consumption as it involves Biased Energy Consumption Rate (BECR) problem. For a WSN of uniformly deployed SNs and RNs, the traffic is generated at the SNs and terminates at the BS via RNs and variations in consumption of energy among the RNs are considered. When a single hop heterogeneous WSN is considered, the RNs transfer the data packets to the BS in a single step by varying the transmission power. The RNs at a greater distance from the BS would have to consume more energy than the RNs closer to the BS. The RNs near the BS depletes more energy than the RNs farther away from the BS, because of the traffic accumulated on RNs near the BS, when a multi hop heterogeneous WSN is considered.

A traffic aware random deployment technique for the relay nodes is proposed in this paper. The pre-analysis of the deployment technique involves analysis of WSN scalability and traffic. A traffic aware RN selection is performed for both single hop and multi hop WSN models. Traffic based random deployment techniques of RN, namely, connectivity-oriented deployment, lifetime-oriented deployment, and hybrid deployment, solve the issue of a short WSN lifetime and insufficient energy utilization.

The remaining part of the paper is organized as follows: Section 2 involves the works related

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to the deployment techniques of nodes in a WSN. Section 3 involves a brief outline of the proposed method of traffic based random deployment of RNs in WSN. Section 4 involves

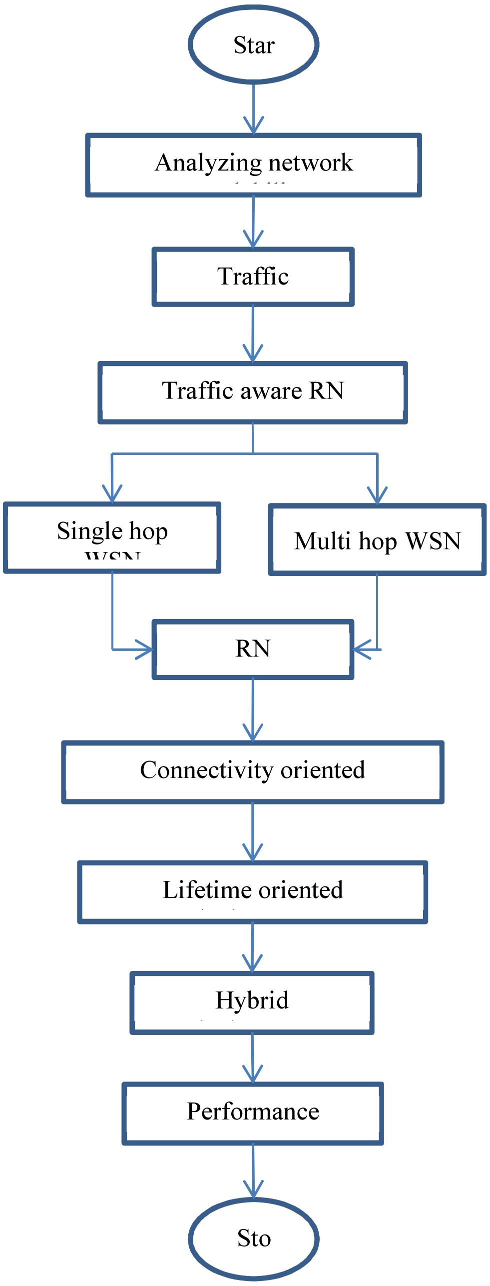

Fig. 1. Working Of Proposed Deployment Model.

A minimum number of RNs are utilized for the optimal design of RN placement under the conditions of connectivity and lifetime [20], [21]. The placement of relay nodes is an the detailed description of the existing and proposed random deployment techniques in both single hop communication and multi hop communication. Section 5 involves the background work pertaining to random node deployment in WSN. Section 6 involves the performance analysis and comparison of the existing and proposed random deployment techniques. The paper is concluded in Section 7.

2. RELATED WORK

The aspects of a WSN with respect to connectivity, system lifetime, and mode of node placement are discussed in this section. The deterministic placement mode [8], [10], [12], [14], [20], [21] is possible only in environments where the sensing field is accessible and the number of nodes involved is small to medium. The random placement mode [16], [18], [23], [25] is also possible in remote environments where the sensing field is inaccessible and the number of nodes involved is large.
important aspect in terms of connectivity and lifetime of the WSN [15]. The energy consumption and lifetime of WSN can be analyzed based on clustering schemes [6]. A design problem of additional RN deployment and energy provisioning is considered in [10]. The problem is solved using a mixed-integer nonlinear programming model and a heuristic algorithm. The issue of assigning initial energy levels and positions to the RNs is solved in [12]. An individual RN is assigned to a clustered group of SNs, which maximizes the lifetime of a two-level WSN [12].

The random deployment of the nodes in a WSN is based on a deployment density function. The minimum total number of SNs to be deployed determines the SN deployment density function under the limitations of network monitoring quality and lifetime [16]. The issue of transmission power control and RN deployment is considered in [25] for a multi hop WSN. The optimal placement of relay nodes in a WSN is used to increase the throughput [5] and network lifetime [11].

The RN deployment density functions are developed to solve the BECR problem, the sensing fidelity is guaranteed by the deployment of SNs and the system lifetime is improved [13]. The network is also organized hierarchically and

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the system does not involve any location based information [13].

3. PROPOSED METHOD

A traffic based random deployment of relay node in WSN is proposed, which involves two random deployment techniques namely, lifetime-oriented deployment and hybrid deployment. The flow of the proposed is given in Fig. 1.

The WSN is analyzed in terms of network scalability [1] and traffic [19]. A traffic aware RN selection is performed for both single hop and multi hop communication cases. The random deployment of RNs is analyzed in both single hop communication and multi hop communication, using connectivity-oriented deployment, lifetime oriented deployment and hybrid deployment. The performance analysis of the random deployment techniques involves the analysis of energy utilization and system lifetime of the various random deployment techniques.

4. RANDOM DEPLOYMENT TECHNIQUES

The existing connectivity-oriented random deployment technique is analyzed and its pros and cons are evaluated. The proposed lifetime-oriented random technique and hybrid deployment technique are analyzed and compared with the existing technique. The deployment techniques are considered for both single hop communication and multi hop communication in a WSN. An active RN groups the SNs in its surrounding area into a cluster.

4.1 Single Hop Communication

In a single hop WSN the RNs transfer the information directly to the BS without any deviation. The three deployment techniques are analyzed in terms of minimum of RNs to be employed and the probability that a SN communicates with at least one RN in a single hop.

1) Connectivity-Oriented Deployment

Uniform deployment is the most conventional method for the deployment of RNs in [2], [3], [4], [8], [9], [24]. The number of RNs to be placed uniformly in a WSN X of area $|X|$ is denoted by N_R. The probability that a SN communicates with at least one RN in a single hop is given by,

$$P_{SR} = 1 - (1 - \pi r_{tS}^2 P_{ch}/|X|)^{N_R}, \quad (1)$$

where r_{tS} is the transmission radius of SN and P_{ch} is the condition of the channel between an SN and an RN. The connectivity probability P_{co} for an SN, where $P_{SR} \geq P_{co}$, estimates the minimum number of RNs to be deployed in a WSN as,

$$N_R^{u\{min\}} = ln(1 - P_{co})/ln(1 - \pi r_{tS}^2 P_{ch}/|X|). \quad (2)$$

The connectivity provided by this deployment method is equal and maximum throughout the WSN. This method requires the least number of RNs under a given connectivity requirement P_{co}. Thus, it is referred to as *connectivity-oriented deployment*. But, this scheme does not solve the BECR problem.

2) Lifetime-Oriented Deployment

This method is also known as *weighted random deployment*. The total energy consumed by a RN in one data collection round (DCR) is given by E_R (i, $l_{transfer}$), where i_{RB} is the distance from RN to BS and $l_{transfer}$ is the total length of the transferring packets. The integral of E_R (i, 0) over the sensing area X is denoted as

$$E_{RX} = \int_X E_R(x,0) x\, dx\, dy. \quad (3)$$

The RN deployment density function at any location (i, j) is proportional to the energy consumption rate of an RN at distance i from the BS. The RN deployment density function at (i, j) is given by,

$$f_{dX}(i,j) = \frac{E_R(i,0)}{E_{RX}} = (a_1 + R_a \delta_2 i^k) n l_n / E_{RX}, \quad (4)$$

where $a_1 = \varepsilon + R_a\delta_1 + \eta$, n is the number of SNs for an RN under operation, l_n is the length of 'n' packets, R_a is the aggregation ratio, and ε, δ_1, δ_2, η, k are energy related parameters. f_{dX} (i, j) = 0 at any other point than (i, j). The probability that a SN communicates with at least one RN in a single hop is

$$P_{SR}(i,j) = 1 - \left(1 - P_{ch} \int_{O(i,j)} f_{dX}(x,y) x\, dx\, dy\right)^{N_R},$$

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(5)

where $O(i, j)$ is a circle centered at (i, j) with radius r_{tS}. When r_{tS} is relatively small, $P_{SR}(i, j)$ is approximated as

$$P_{SR}(i,j) \approx 1-\left(1-\pi r_{tS}^2 P_{ch} f_{dX}(i,j)\right)^{N_R}. \quad (6)$$

Under the requirement of connectivity $P_{SR}(i, j)$ is equated to P_{co} and using the approximation in (6) the solution to i is obtained using (4).

$$i_0 = \left[\left(\frac{E_{RX}\cdot(1-(1-P_{co})^{1/N_R})}{nR_a\delta_2 l_n \pi r_{tS}^2 P_{ch}} - \frac{a_1}{R_a\delta_2}\right)\right]^{1/k}. \quad (6)$$

Equation (6) implies the cutoff distance in the sensing area. Another sensing region Y is defined as

$$Y = \{(i,j) | (i,j) \in X, i < i_0\}. \quad (7)$$

Inside the region Y the probability of connectivity of an SN is lesser than P_{co}, but outside Y it is higher than P_{co}. Equating the RHS of (6) to zero the solution to N_R is obtained.

$$N_R^{w\{min\}} = ln(1-P_{co})/ln(1-a_1 n l_n \pi r_{tS}^2 P_{ch}/E_{RX}) \quad (8)$$

When $N_R < N_R^{w\{min\}}$, the RN deployment according to (4) will not be able to satisfy the connectivity requirement in the subsection inside the cutoff region.

3) Hybrid Deployment

The lifetime-oriented deployment of RNs according to the deployment density function (4) can resolve the BECR problem. But, the connectivity also requires being satisfied in the WSN.

The principle of hybrid deployment is the equal balance among lifetime extension and connectivity.

- When $N_R < N_R^{u\{min\}}$, the connectivity in the WSN cannot be ensured.
- When $N_R \geq N_R^{w\{min\}}$, the connectivity can only be sufficient.
- When $N_R^{u\{min\}} \leq N_R < N_R^{w\{min\}}$, connectivity oriented deployment alone will not be to fulfill the connectivity.

The design of hybrid deployment involves two steps. The first step involves the lifetime extension by the deployment of N_R^l RNs, according to (4). The second step involves the connectivity satisfaction in the entire WSN by the deployment of N_R^c RNs exclusively in the region Y. The total number of given RNs is equal to the sum of the RNs to be deployed in the two steps.

The allocation of RNs for the hybrid deployment is modeled as a constrained optimization problem. When there is an increase in N_R^l, N_R^c has to be decreased. But, when N_R^c becomes too small the connectivity in the sparse area of the WSN is not guaranteed. An arbitrary variable $n_R^l < N_R$ is considered for the first step. The number of RNs for the second step is denoted as n_R^c (after the increase of connectivity in region Y). The second step involves the computation of n_R^c as a function of n_R^l. The sum of n_R^l and n_R^c is denoted as n_R, which is a non-decreasing function of n_R^l. The results of n_R^l, n_R^c, and n_R provide a solution to N_R^l for a given N_R.

The RN density at a point (i, j) is defined as the product of the density function $f_{dX}(i, j)$ and the number of RNs deployed. The connectivity in region Y (7) is satisfied when the RN density in Y is equal to the RN density level at point (i_0, j) on the boundary of Y. The number of RNs required in the second step is given by,

$$n_R^c = n_R^l + \left|\frac{nR_a l_n \delta_2 n_R^l}{E_{RX}} \int_Y (i_0^k - x^k) x \, dx \, dy\right|. \quad 9)$$

The RNs are deployed in the region Y according to the deployment density function in (10):

$$f_{dY}(i,j) = \begin{cases} \frac{f_{dX}(i_0,j) - f_{dX}(i,j)}{\int_Y (f_{dX}(i_0,y) - f_{dX}(x,y)) x \, dx \, dy}, & if \ (i,j) \in Y, \\ 0 & else. \end{cases} \quad (10)$$

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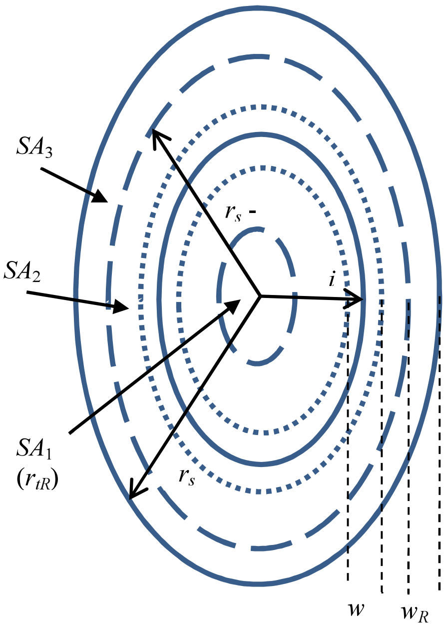

Fig. 2. Sections of the sensing site

The RN deployment density becomes uniform throughout the region Y and the connectivity is also fully satisfied. The overall deployment density function for single hop communication is given as,

$$f_{dO}(i,j) = \begin{cases} \frac{f_{dX}(i_0,j)}{f_{dX}(i_0,j)|Y| + \int_{X-Y} f_{dX}(x,y)x\,dx\,dy}, & if\ (i,j) \in Y, \\ \frac{f_{dX}(i,j)}{f_{dX}(i_0,j)|Y| + \int_{X-Y} f_{dX}(x,y)x\,dx\,dy}, & if\ (i,j) \in X - Y. \end{cases} \quad (11)$$

4.2 Multi Hop Communication

In a multi hop WSN the RNs transfer the information via multiple RNs. The three deployment techniques are analyzed in terms of minimum of RNs to be employed and the probability that a SN communicates with at least one RN in a single hop.

1) Connectivity-Oriented Deployment

The connectivity-oriented deployment in the multi hop communication case is also similar to the single hop communication case, in terms of connectivity and deployment density function. It lacks energy efficiency due to the BECR problem.

2) Lifetime-Oriented Deployment

An optimal deployment density function in the multi hop communication is more complex than the single hop communication, due to the aggregation effect of traffic. A heuristic suboptimal deployment density function is developed.

The mean deployment density in a sensing area depends on the mean total energy depletion rate and the size of the sensing area. The energy depletion rate of a sensing area is the total energy depleted during the data transfer by the RNs per DCR. The mean deployment density should be proportional to the energy depletion rate and inversely proportional to the size of the sensing area, which solves BECR issue.

3) Energy Depletion Intensity (EDI) of a sensing area defines the ratio of the energy depletion rate of the sensing area to the size of the sensing area. The deployment density function should be proportional to the *EDI* at any point in the sensing area.

The amount of intracluster traffic and intercluster traffic of various sections of the WSN is derived to obtain the *EDI*. A parameter $w_R = w * r_{tR}$, where w is an ad hoc parameter of value between 0 and 1, and r_{tR} is the fixed transmission range of RN. The mean intracluster traffic managed by the RNs in any subsection of the sensing area is proportional to the size of the subsection.

A sensing field with radius r_s is partitioned into three shells, as shown in Fig. 2. The section which is surrounded by the inner broken circle of radius r_{tS} is the first shell area, denoted by SA_1. An active RN is able to transmit data to the BS in a single hop in SA_1. The shell between the two dotted circles of radius $r_s - w_R$ and r_{tR} is the second shell area, denoted by SA_2. The remaining section between the broken circle of radius $r_s - w_R$ and the bounding circle of radius r_s is the third shell area, denoted by SA_3. The intercluster traffic is negligible in SA_3.

The *EDI* at a position over a specific shell area is equal to the sum of the energy spent in intercluster communication and intracluster communication divided by the size of the specified shell. The *EDI* at any point (i, j) in shell area SA_1 is given by,

$$EDI^{(SA_1)}(i,j) = \frac{N_S l_n}{\pi r_s^2}\left(a_1 + R_a \delta_2 r_{tR}^k + a_2 R_a \left(\frac{r_s^2}{r_{tR}^2} - 1\right)\right). \quad (12)$$

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The integral of $EDI^{(SA_1)}(i,j)$ over the shell area SA_1 is given by,

$$I^{(SA_1)} = \frac{N_S l_n}{r_s^2}\left(a_1 r_{tR}^2 + R_a \delta_2 r_{tR}^{2+k} + a_2 R_a (r_s^2 - r_{tR}^2)\right). \quad (13)$$

The EDI at various positions in SA_2 varies to a large extent, as RNs at various positions relay different loads of traffic. The EDI at a position (i, j) is approximated from two dotted circles of radius ($i - w_R/2$) and ($i + w_R/2$). The EDI at any point (i, j) in shell area SA_2 is given by,

$$EDI^{(SA_2)}(i,j) = \frac{N_S l_n}{\pi r_s^2}\left[a_1 + R_a \delta_2 r_{tR}^k + \frac{a_2 R_a}{2 i w_R}\left(r_s^2 - \left(i + \frac{w_R}{2}\right)^2\right)\right]. \quad (14)$$

The integral of $EDI^{(SA_2)}(i,j)$ over the shell area SA_2 is given by,

$$I^{(SA_2)} = \frac{N_S l_n}{r_s^2}\left[(a_1 + R_a \delta_2 r_{tR}^k)((r_s - w_R)^2 - r_{tR}^2) + a_2 R_a\left(r_s^2(r_s - w_R - r_{tR}) + \frac{(2r_{tR}+w_R)^3 - (2r_s - w_R)^3}{24}\right)\right]. \quad (15)$$

The EDI at any point (i, j) in shell area SA_3 is given by,

$$EDI^{(SA_3)}(i,j) = \frac{(a_1 + R_a \delta_2 r_{tR}^k) N_S l_n}{\pi r_s^2}. \quad (16)$$

The integral of $EDI^{(SA_3)}(i,j)$ over the shell area SA_3 is given by,

$$I^{(SA_3)} = \frac{(a_1 + R_a \delta_2 r_{tR}^k) N_S l_n (2r_s - w_R) w_R}{r_s^2}. \quad (17)$$

The resultant integral for the individual shell areas is denoted as $I = I^{(SA_1)} + I^{(SA_2)} + I^{(SA_3)}$. The deployment density function for the three individual shell areas is equal to the ratio of the respective EDI at the point (i, j) to the integral of the respective EDI over the specified shell area.

The properties of the deployment density function are analyzed in terms of connectivity. When N_R RNs are deployed according to the deployment density function, (6) is used to estimate the probability that a SN communicates with at least one RN in a single hop. The connectivity probability for an SN whose transmission range is in SA_x, where x = 1, 2, 3, is given by,

$$P_{SR}{}^{(SA_x)}(i,j) = 1 - \left(1 - \pi r_{tS}^2 P_{ch} EDI^{(SA_x)}(i,j)/I\right)^{N_R}. \quad (18)$$

When a connectivity probability P_{ch} is required for shell area SA_1, the solution to N_R is given as,

$$N_R^{w\{min1\}} = ln(1 - P_{co})/ln\left(1 - \pi r_{tS}^2 P_{ch} EDI^{(SA_1)}(i,j)/I\right). \quad (19)$$

The deployment will be fulfilled in terms of connectivity when $N_R \geq N_R^{w\{min1\}}$.

The limits of N_R in the shell area SA_2 are defined as,

$$N_R^{w\{min2\}} = ln(1 - P_{co})/ln\left(1 - \pi r_{tS}^2 P_{ch} EDI^{(SA_2)}(r_s - w_R, j)/I\right). \quad (20)$$

$$N_R^{w\{min2-\}} = ln(1 - P_{co})/ln\left(1 - \pi r_{tS}^2 P_{ch} EDI^{(SA_2)}(r_s, j)/I\right). \quad (21)$$

When $N_R < N_R^{w\{min2-\}}$ the deployment does not fulfill the connectivity requirement, but when $N_R \geq N_R^{w\{min2\}}$ the connectivity requirement is fully satisfied throughout SA_2.

When $N_R^{w\{min2-\}} \leq N_R < N_R^{w\{min2\}}$ the connectivity requirement is satisfied only partially. $P_{SR}{}^{(SA_2)}(i,j)$ is equated to P_{ch} and the solution to i is calculated using Newton's method. A region Y is defined as,

$$Y = \{(i,j) | i_0 < i \leq r_s - w_R\}. \quad (22)$$

The number of RNs to be deployed in shell area SA_3 is similarly defined as,

$$N_R^{w\{min3\}} = ln(1 - P_{co})/ln\left(1 - \pi r_{tS}^2 P_{ch} EDI^{(SA_3)}(i,j)/I\right). \quad (23)$$

The optimal number of RNs to be deployed ($N_R^{\{min\}}$) is defined as the maximum of the number of RNs to be deployed in the respective shell areas. The connectivity can be fulfilled throughout the sensing area, when $N_R \geq N_R^{w\{min\}}$.

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Hybrid Deployment

The design of hybrid deployment involves the two steps as in the case of single hop communication. In the shell areas SA_1 and SA_3, the number of RNs required are

$$n_R^{c1} = max\left(0, \frac{ln(1-P_{co})}{ln(1-r_{tS}^2/r_{tR}^2)} - n_R^l I^{(SA_1)}/I\right), \quad (24)$$

$$n_R^{c3} = max\left(0, \frac{ln(1-P_{co})}{ln(1-r_{tS}^2/(2r_s w_R - w_R^2))} - n_R^l I^{(SA_3)}/I\right). \quad (25)$$

For the shell area SA_2, the compensation deployment is analyzed in two cases: $N_R^{w\{min2-\}} \leq N_R < N_R^{w\{min2\}}$, and $N_R < N_R^{w\{min2-\}}$. The RN density at a point (i, j) is defined as the product of the density function $f_{dX}(i, j)$ and the number of RNs deployed. The connectivity in region Y (22) is satisfied when the RN density in Y is equal to the RN density level at point (i_0, j) on the boundary of Y. The total number of RNs required in the second step for the shell area SA_2 is simplified as,

$$n_R^{c2} = \left[\left(N_R^{u\{min\}} - n_R^l\right)\frac{((r_s-w_R)^2-r_{tS}^2)}{r_s^2}\right]. \quad (26)$$

The deployment density function for shell areas SA_1 and SA_3 is uniform. The total number of RNs deployed is $n_R = n_R^l + n_R^{c1} + n_R^{c2} + n_R^{c3}$ The deployment density function for shell is SA_2 for the first case is

$$f_{dY}(i,j) = \frac{f_{dX}(i_0,j) - f_{dX}(i,j)}{\iint_{0,i_0}^{2\pi, r_s - w_R}(f_{dX}(i_0,y) - f_{dX}(x,y))x\,dx\,dy}. \quad (27)$$

The deployment density function for shell is SA_2 for the second case is

$$f_{dY}(i,j) = \frac{N_R^{u\{min\}}/\pi r_s^2 - n_R^l f_{dX}(i,j)}{\iint_{0,i_0}^{2\pi, r_s-w_R}\left(N_R^{u\{min\}}/\pi r_s^2 - n_R^l f_{dX}(x,y)\right)x\,dx\,dy}. \quad (28)$$

5. BACKGROUND WORK

The background work pertaining to random node deployment in WSN is discussed in the following section.

5.1 Traffic-Aware Relay Node Deployment

The sensor nodes are randomly deployed in a massive quantity [7]. The relay nodes in the WSN are limited in terms of energy and their operation time depends on its communication range and traffic volume. The positions of the relay node placement determine the network lifetime. The deployment has to ensure connectivity and traffic flows from various sources. With this technique, optimal solutions are developed for one source node under single and multiple traffic flows.

5.2 Optimal Relay Node Placement using Node Cut Inequalities

The optimal relay node placement is used when additional relay nodes are required to be deployed in a subset of specified potential relay locations [17]. A group of strong inequalities is identified in the sub-space of relay node variables and are known as node cut inequalities. An integer programming method along with node cut inequalities are used to solve the problem of RN deployment.

5.3 Locally Optimal Allocation of Relay Nodes

A minimum number of RNs enables the efficient relaying of traffic from the existing SNs to the BS [22]. Two heuristic solutions are proposed for the RN placement namely, Collaborative Placement with Locally Optimal Allocation Decision (CPLOAD) and Independent Placement with Direct Allocation (IPDA).

6. PERFORMANCE ANALYSIS

The parameters to be analyzed are system lifetime and energy utilization of the various RN deployment techniques. Two metrics are defined to analyze the performance of the RN deployment techniques. The first parameter, normalized DCR is defined as the number of DCR normalized to the initial RN energy before the lifetime of the WSN expires. The system lifetime is expressed in terms of normalized DCR. The second parameter, energy utilization in the network is defined as the ratio of total depleted energy of RNs to the total initial energy.

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6.1 Comparison of Deployment Techniques in Single Hop Communication

The mean energy utilization and system lifetime is analyzed with respect to the number of RNs and is shown in Fig. 3., and Fig. 4., respectively. The hybrid deployment technique performs better than the lifetime-oriented deployment and connectivity-oriented deployment in terms of system lifetime and energy utilization. The system lifetime can be extended by 5% to 15% according to the hybrid deployment as compared to the lifetime-oriented deployment.

It can be observed that lifetime-oriented deployment results in lower energy utilization and shorter lifetime than connectivity when the number of RNs deployed is small. This is due to the weak connectivity in the area of the sensing field nearer to the BS. The energy utilization or system lifetime cannot be enhanced by the connectivity-oriented deployment, when N_R cannot even fulfill the desired connectivity. When N_R increases, the performance of the lifetime-oriented deployment enhances and exceeds the connectivity-oriented deployment on both energy utilization and system lifetime.

The hybrid deployment performs better on an overall basis, compared to the other two deployment techniques. It provides both lifetime extension and better energy efficiency than a lifetime-oriented deployment, while also fulfilling the connectivity requirement. The energy utilization seems to attain a saturation level as N_R increases, while the normalized DCR increases approximately in a linear manner. The performance analysis of the connectivity-oriented deployment shows a smaller DCR increase slope and lower energy utilization saturation level compared to the lifetime-oriented deployment or hybrid deployment performance analysis.

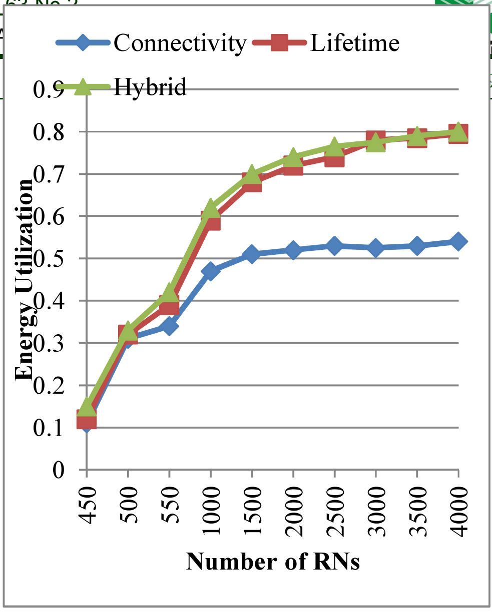

Fig. 3. Comparison Of Three Deployment Techniques By Energy Utilization In Single Hop Communication.

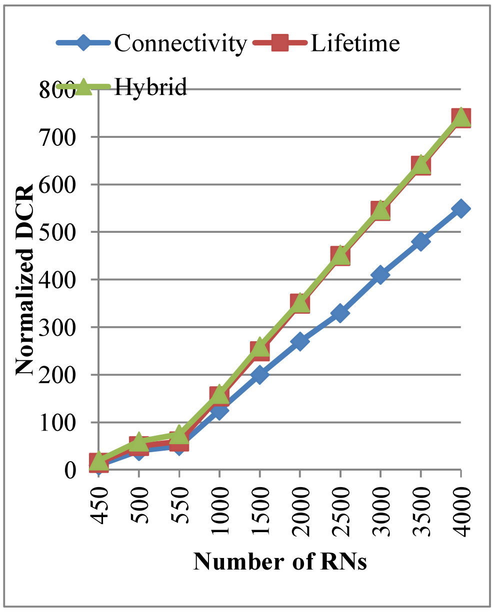

Fig. 4. Comparison Of Three Deployment Techniques By DCR In Single Hop Communication.

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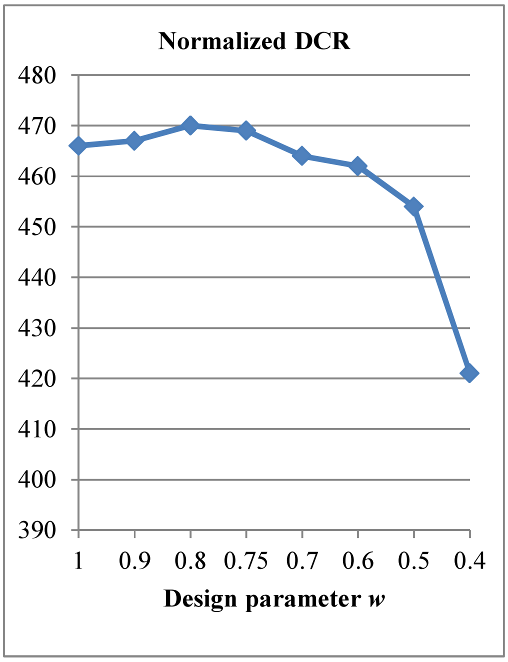

Fig. 5. Variation Of Normalized DCR For Various W In Lifetime-Oriented Deployment.

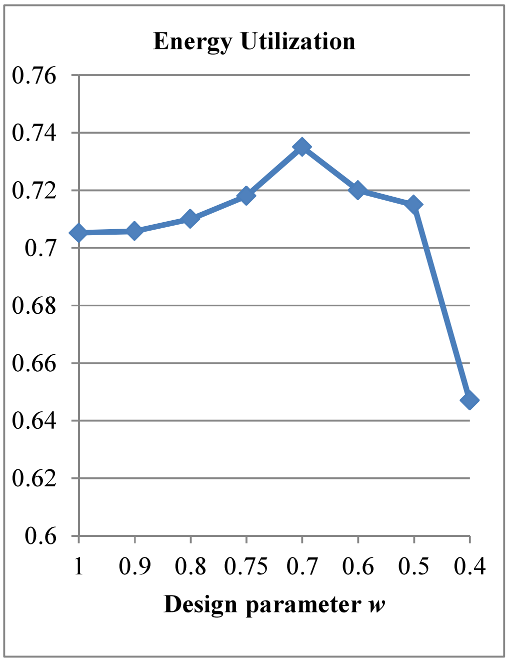

Fig. 6. Variation Of Energy Utilization For Various W In Lifetime-Oriented Deployment.

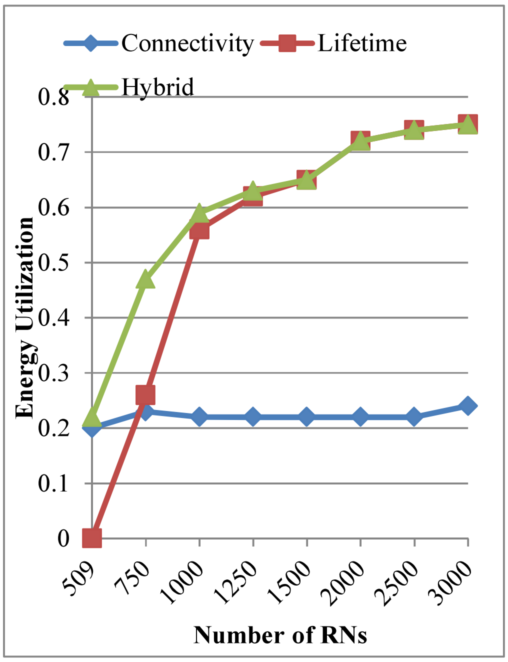

Fig. 7. Comparison Of Three Deployment Techniques By Energy Utilization In Multihop Communication.

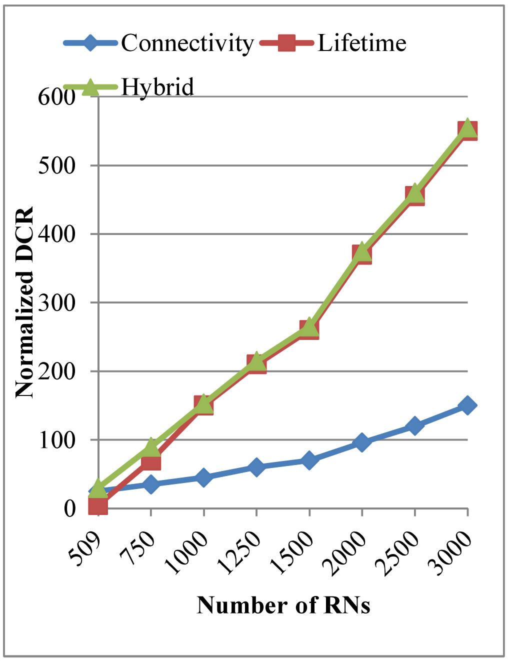

Fig. 8. Comparison Of Three Deployment Techniques By DCR In Multihop Communication.

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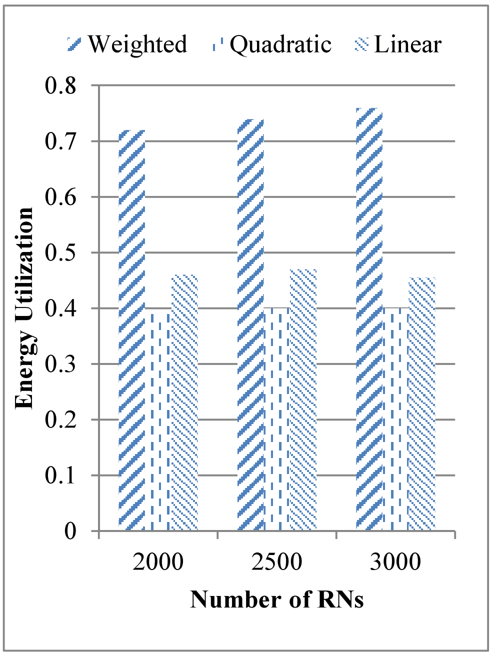

Fig. 9. Comparison Of Deployment Density Functions By Energy Utilization.

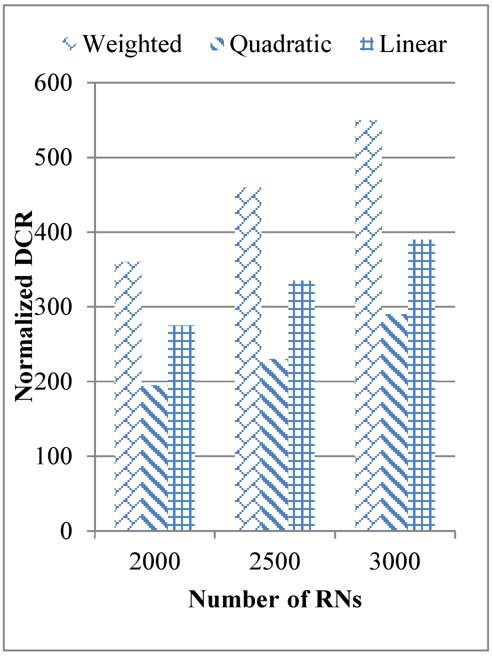

Fig. 10. Comparison Of Deployment Density Functions By Normalized DCR.

6.2 Comparison of Deployment Techniques in Multi Hop Communication

The design parameter w has an effect on the normalized DCR and energy utilization. The variations of normalized DCR and energy utilization with respect to w are given in Fig. 5., and Fig. 6., respectively. The mean energy utilization and system lifetime is analyzed with respect to the number of RNs and is shown in Fig. 7., and Fig. 8., respectively.

For the connectivity-oriented deployment, the normalized DCR increases slowly in an approximately linear manner as N_R increases. The overall performance characteristics highlight the significance of the RNs closer to the BS.

For the lifetime-oriented deployment, the *EDI* at different positions depends not only on the local traffic, but also on the traffic relayed from far to near regions. This deployment technique results in better performance compared to connectivity-oriented deployment as the number of RNs increases. The normalized DCR increases much quicker than for connectivity-oriented deployment as the number of RNs increases.

The hybrid deployment performs better on an overall basis, compared to the other two deployment techniques. It provides both lifetime extension and better energy efficiency than a lifetime-oriented deployment, while also fulfilling the connectivity requirement.

The locations farther away from the BS generally receive only less density of data while using the weighted deployment density function. Two optional deployment density functions are compared with the weighted deployment density function.

The first deployment density function is a quadratic density function. The traffic relaying the RNs in the sensing area is approximately equal to the traffic produced from SNs farther than the BS. The quadratic deployment density function is defined as

$$f_{dq}(i,j) = \frac{2(r_s^2 - i^2)}{\pi r_s^4}. \quad (29)$$

The linear deployment density function is defined as

$$f_{dl}(i,j) = \frac{3(r_s - i)}{\pi r_s^3}. \quad (30)$$

The mean energy utilization and system

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lifetime is analyzed with respect to the different deployment density functions for N_R = 2000, N_R = 2500, and N_R = 3000, and is shown in Fig. 9., and Fig. 10., respectively. The performance of linear density function is better than the quadratic density function. Both the quadratic density function and linear density function solve the BECR issue only to a small extent. The weighted density function gives the best performance compared to the other two deployment density functions.

7. CONCLUSION

The number and locations of the devices to be deployed in the WSN defines the usability of the WSN in terms of lifetime and connectivity. The impacts of random device deployment are analyzed on connectivity and lifetime. The short system lifetime and low energy utilization of relay nodes are solved by proposing traffic based random deployment techniques, namely, lifetime-oriented deployment and hybrid deployment. The hybrid deployment is preferred when the number of RNs is relatively small. The hybrid deployment is similar to lifetime deployment when the number of relay nodes is large. The future work of the random deployment of relay nodes involves the deployment of nodes in three-dimensional space and consideration of survivability to support fault-tolerance.

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