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Uneven Deployment Model for Maximizing the Upper Bound of WSN Lifetime

Uneven Deployment for WSN Lifetime Maximization

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Abstract: Wireless Sensor Network (WSN) are ad - hoc networks, comprising of light weight sensor nodes, which are traditionally operated by battery power. Due to static power source and deployment in hostile environment, it becomes a challenging task to replenish the power source or change batteries. Thus, the network has to optimally utilize the existing power source to improvise the lifetime of these sensor nodes. The congestion zone problem arises near the sink, due to frequent utilization of available energy by these nodes from the energy utilization equation of lifetime. In this paper, the uneven deployment mechanism to the congestion zone has been addressed to improvise the lifetime and collectable information of a network. As a result, it is observed that, the maximum achievable upper bound on collectable information and network lifetime has fairly improved.

Keywords: Congestion Zone, Network Lifetime, Uneven Deployment, Wireless Sensor Network (WSN)

1. INTRODUCTION

Wireless sensor networks often comprise of numerous nodes which are usually used for various applications such as surveillance, battlefield monitoring, forest fire detection, to name few. These applications generally require the placing of sensor nodes in hostile environments. Sensor nodes are generally battery-operated, which acts as a constraint in functionality, due to limited power [1][2]. So, there is a fair chance that the network deployed for a certain application collapse before the expected time. Therefore, optimum measures have been required for judicious utilization of the energy resources as well as extending the lifetime.

It is a fact that majority of energy in the sensor nodes is utilized in the communication process (i.e., reception and transmission of the data) rather than sensing. So, the energy optimization for these processes would help in enhancing the network lifetime [3]. The network lifetime of the WSN gets seriously affected by the node lifetime inside the congestion area. Nodes near sink in the congestion zone are frequently involved in the process of relaying packets coming from the far away nodes. This additional overhead along with transmission of the sensed data causes a significant amount of energy loss in the process. This energy loss can lead to the energy hole problem or congestion zone [4], leading to less reliability in the network, thereby affecting the performance of the network. Therefore, the lifetime of the nodes inside congestion zone affects the network lifetime significantly.

Another important factor which contributes to the enhancement of network lifetime is deployment. Deployment is basically configuring a functional sensor network in an actual environment. The deployment pattern should ensure proper connectivity as well as coverage, also ensuring maximum lifetime and energy utilization. There are basically two types of deployment patterns - Ad-hoc Deployment and pre-planned Deployment [1] [2]. The ad-hoc deployment is a non-deterministic approach, where the nodes are either dropped from an airplane or placed into the target area randomly. This type of deployment can be used in large scale applications, but it can be less cost-effective, as in order to overcome uncertainty, redundant nodes are placed. On the other hand, in case of pre-planned deployment, it is planned in advance, for optimal deployment. There are various methods used for various applications like grid - based deployment and 2D and 3D deployment models [2]. The optimal deployment is generally application-specific, suitable for small applications, and is placed in some vital areas for specific purpose, which leads to less utilization of energy than random deployment. The grid-based deployment can be used for moderate to large-scale

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coverage-oriented deployment, as it is simple and scalable. Duty Cycle is the mechanism where the node sleeps most of the time and wakes up periodically only at scheduled moments to sense/ communicate data to save energy, rather than spending energy on being completely active. In case of sensor node deployment generally, duty cycle plays significant role in the process of the energy utilization of the sensor nodes. Among different methods of duty cycling, random duty cycle is considered to be simple in design and has no overhead, it has been considered for the reduction of traffic in [5], thereby improving the lifetime of the network. Therefore, keeping the above parameters in mind, there was a requirement to focus on judiciously utilizing and improve network lifetime of the WSN.

2. Review of the Related Work

Deployment pattern facilitates the optimum coverage and connectivity, ensuring enhanced network lifetime. Duty cycle contributes to reduction in energy consumption in a WSN. There have been numerous studies on lifetime of WSN [3] [4] [5] [6] [7]. In [3], network lifetime upper bound is derived for a non-duty cycled WSN with uniform distribution of nodes. Authors Wang et al. [8], have derived network lifetime upper bound with respect to the congestion zone in [8]. Lee et. al [9] have derived the network lifetime's upper bound for clustered sensor networks.

Rout et al. [4] have derived network lifetime's upper bound with respect to congestion zone for duty cycled WSN with uniform distribution of nodes. Authors have also implemented network coding, along with duty cycling with network coding for the enhancement of upper bound on network lifetime, but, with uniform distribution of nodes. In [5], Ashraf et al. have proposed deployment pattern for increasing the network lifetime of sensor nodes in a linear array.

The literature review reveals that no focus was given towards deployment pattern of the network, for significant contribution to the improvisation of network lifetime in the existing work. To address this research gap on upper bound enhancement of network lifetime, the proposed work focusses on to improve the expected lifetime of the network, considering efficient deployment pattern as well as duty cycle for the congestion zone. The work is focused to evaluate the achievable network lifetime upper bound network for WSN considering duty cycling and network coding along with uneven deployment pattern for the nodes inside congestion zone area.

The remaining section of this paper has been arranged as follows. In the Section 3, it discusses network life time and the effect of the congestion zone on it. It also illustrates the effect of uneven deployment on the upper bound of lifetime of network. The expression for upper bound on collectable information with uneven deployment using duty cycle, as well as both duty cycle along with network coding, is given later in section 4. The conclusion and future scope for this paper is given in Section 7.

3. Network lifetime and Uneven deployment

Network Lifetime (NL) can be defined as total period of time for which network is active. It is measured by total energy possessed by network with regards to total energy used by network. A major segment of the energy is utilized in the communication process. The nodes present near sink are frequently involved in relaying data coming from nodes away from the sink, along with communicating their own sensed data. Therefore, these nodes are prone to failure, and failure of these nodes causes congestion for whole network. Therefore, the total area neighboring sink is termed as congestion zone [5].

.The energy of nodes present inside congestion zone is utilized combined in sensing data, communicating its own sensed data as well as relaying data collected from outside congestion zone area. The network lifetime is calculated from the energy used by the nodes inside congestion zone [5]. In the present work, attempt is made to maximize lifetime of network, by changing the deployment just inside the congestion zone.

A. Network Model

A is the area of the network over which number of nodes are deployed. The congestion zone, with a circular area, B_A , has a radius, R_B , with sink, S, at the centre of A. Let us consider all of the sensor nodes are deployed uniformly throughout network. The network density of the whole network can be given as $\frac{N_T}{A}$, with uniform deployment. The network density of the congestion zone can be given as $N_T\frac{B_A}{A}$, and the network density of the area outside the congestion zone, but within A, is given by, $N_T\frac{A-B_A}{A}$.

The total number of the nodes inside congestion zone is equal to the network density, $N_T\frac{B_A}{A}$,has been deployed unevenly in the form of radial arrays in this paper. The uneven deployment of these nodes targets at improving network lifetime, as it ensures equal energy dissipation throughout the network [4]. The remaining area has uniformly distributed sensor nodes.

The Uneven Deployment of the nodes inside Congestion zone [UDC method] is done in the form of radial arrays around the sink as shown in Fig. 1. The focus in the figure by uneven deployment of nodes is to improve network lifetime by reducing the combined energy spent in sensing, communication and relaying by nodes in congestion zone. This ensures uniform energy consumption throughout the network [8], thereby increasing upper bound on network lifetime dealt. The method described in [5] [10], is employed here to deploy the nodes in the form of radial arrays around the sink, only inside congestion zone area. The total number of radial arrays for the uneven deployment for the nodes present inside congestion zone area is,

$$N_{RA} = \frac{\pi R_B}{S_r} \quad (1)$$

where, S_r is the sensing radius of a node. A multi-hop network, where the maximum probability of node failure is of these nodes that are placed near to the sink is considered. The nodes are placed across the radial arrays, with an inter-node hop distance of $I - h$

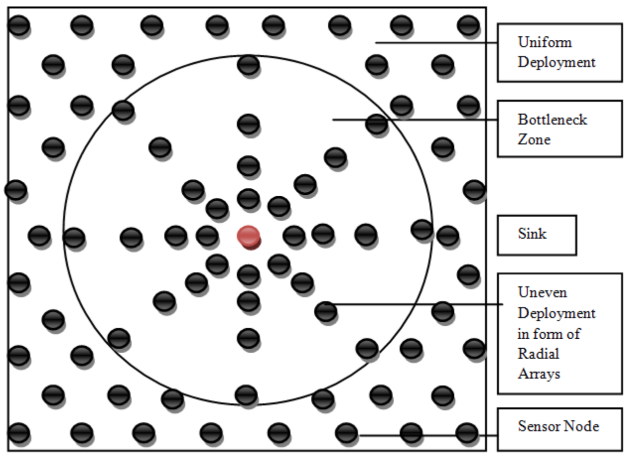

Figure 1. Deployment Pattern & Congestion Zone in a Typical WSN

$$I_h = \left[\frac{1}{(K-h+1)E_2}\left[E_{\min} + (K-i)(2E_{id} - E_{12}) - \left(PT_{dg} - 1\right)E_{id} - E_{11}(K-h+1)\right]\right]^{\frac{1}{\alpha}} \quad (2)$$

where h is the hop number, K is the total number of hops from the sink to the last node inside the congestion zone, E_{min} is the minimum energy that is spent by sensor nodes inside the congestion zone per data gathering cycle, P is dealing rate of packet and T_{dg} is data gathering cycle.

The hop distance, l_1, is the distance between sink and nodes present a single hop distance away from sink. The greater is the value of the hop number, the higher is inter-node hop distance between the nodes.

After Uneven Deployment of sensor nodes in Congestion zone [UDC method] unevenly, the upper bound on lifetime of WSN using the network coding as well as duty cycling with network coding are obtained. The total of the energy consumption of sensor nodes, inside congestion zone, to relay one bit of message, when uniform deployment is implemented, is given in [4]. Similarly, for uneven deployment, the total energy being dissipated c, by sensor nodes available inside congestion zone for relay of a bit of message, is computed as in equation 3,

$$c = \sum_{h=1}^{K}\left(\alpha_1 + \alpha_2 I_h^{\alpha}\right) \quad (3)$$

where, different energy spent by sensor nodes inside congestion zone is found by deploying them unevenly. The energy which is utilized in relaying of data coming from outside of congestion zone area is as follows;

$$E_{OR} = \left[\frac{N}{A}(A - B_A)\, p_D R_s t \left[\frac{\gamma+1}{2}\right]\right]\sum_{i=1}^{K}\left(E_1 + E_2 h_i^n\right) \quad (4)$$

where, $E_{OR} = \left[\frac{N}{A}(A - B_A)\, p_D R_s t\left[\frac{\gamma+1}{2}\right]\right]\sum_{i=1}^{K}\left(E_1 + E_2 h_i^n\right)$ is average number of active neighbors who receive the redundant data inside B_A . The energy utilized by the nodes within congestion zone in sensing data inside congestion zone is given by,

$$E_{IS} = N p_D \frac{B_A}{A} R_s e_s t \quad (5)$$

The energy utilized by nodes inside congestion area to relay the data sensed by them is given in eq. 6

The energy spent by sensor nodes during sleep state by the sensor nodes available inside congestion zone is computed as,

$$E_{IR} = N_{ra} R_S P_{DC}\left[\left[\sum_{h=1}^{K}\left(\alpha_1 + \alpha_2 I_h^n\right)(K - h + 1)\right]\right. \quad (6)$$

The energy spent by sensor nodes during sleep state by the sensor nodes available inside congestion zone is computed as,

$$E_S = (1 - P_{DC})\, t N_T \frac{B_A}{A} E_{\text{sleep}} \quad (7)$$

So, the total quantity of the energy used by sensor nodes present within congestion zone is obtained as,

$$E_T = E_{OR} + E_{IS} + E_{IR} + E_S \quad (8)$$

$$\begin{aligned} E_T = \left[\frac{N_T}{A} P_{DC} R_S t\ (A - B_A)\left[\frac{\gamma+1}{2}\right]\right]\left(\sum_{h=1}^{K}\left(\alpha_1 + \alpha_2 I_h^n\right)\right) \\ \&I \\ \& + N_T P_{DC}\frac{B_A}{A} R_S e_S t + N_{ra} R_S P_{DC} t\left[\sum_{h=1}^{k}(\alpha_1\right. \\ \& + \alpha_2 I_h^m\Big)(k - h + 1)\Big] \\ \& + (1 - P_{DC})\, t N_T \frac{B_A}{A} E_{\text{sleep}} \end{aligned} \quad (9)$$

But, the total amount of energy present inside congestion zone satisfies,

$$E_T \leq N_T \frac{B_A}{A} E_{int} \tag{10}$$

Therefore, upper bound expression on lifetime of network, with respect to the congestion zone with the duty cycle and uneven deployment is given by,

$$t_D = \frac{N_T \frac{B_A}{A} E_{int}}{R_x} \tag{11}$$

where,

$$\begin{aligned} R_x = \Big[& pr_s \left\{ \tfrac{N}{A} (A - B_A) \left[\tfrac{\gamma+1}{2} \right] \left(\textstyle\sum_{i=1}^{k} \left(\alpha_1 + \alpha_2 h_i^n \right) \right) \right\} \\ & + N_{ra} \left\{ \textstyle\sum_{i=1}^{k} \left(\alpha_1 + \alpha_2 h_i^n \right) (k - i + 1) \right\} \\ & + N \tfrac{B_A}{A} e_s + (1 - p) N \tfrac{B\pi}{A} E_{\text{sleep}} \Big] \end{aligned} \tag{12}$$

The network coding is an encoding scheme, in which, the intermediate nodes encode the data packets from the neighboring nodes before the transmission of the packets onwards the next node in the network. This technique helps in improving the network bandwidth, throughput and the reliability in network. Network Coding is also responsible for decreasing the energy consumed by the network than traditional store and forward networks. The network coding scheme reduces number of transmissions, as it relays a single coded packet to two of its neighbors, using only one transmission, instead of two transmissions. If there are N numbers of sensed packets by different source nodes in the network, and the encoder node encodes maximum of Y packets at a time, so, the total encoded packets that are generated by the encoder is N/Y [11] [12].

he Uneven Deployment is used in form of radial arrays inside Congestion zone [UDC method] for maximizing the network's lifetime. Hence, using network coding technique for this type of uneven deployment will further increase network lifetime. The energy used by network coder nodes to relay a data bit is given by,

$$E_C(ij) \geq \frac{\sum_{h=1}^{K} \left(\alpha_1 + \alpha_2 I_h^n \right)}{z} \tag{13}$$

where, z is the amount of packets of data that are encoded into single coded packet. The energy used by relay nodes to relay a data bit given by,

$$E_R(ij) = \sum_{h=1}^{K} \left(\alpha_1 + \alpha_2 I_h^n \right) \tag{14}$$

The energy consumption of nodes present within congestion zone for data relay coming from outside the congestion zone is,

$$\begin{aligned} E_{ONC} = & \left(\left\lfloor \tfrac{\gamma+1}{2} \right\rfloor N_T P_{DC} R_s t \tfrac{A - B_A}{A} \tfrac{1 + z(h-1)}{\cdot zh} \right) \textstyle\sum_{i=1}^{k} (\alpha_1 \\ & + \alpha_2 I_h^n \big) - (15) \end{aligned} \tag{15}$$

The energy consumption of the sensor nodes inside congestion zone for sensing data bits is given by,

$$E_{ISNC} = N \tfrac{B}{A} pr_s e_s t \tag{16}$$

$$E_{INC} = N_{ra} pr_s t \left[\sum_{i=1}^{k} (\alpha_1 + \alpha_2 h_i^n) (\mathrm{k - i + 1}) \right] \tag{17}$$

where h_i is the energy utilized during sleep state by nodes present inside congestion zone is,

$$E_{SNC} = (1 - p_{DC}) t N \frac{B_A}{A} E_{\text{sleep}} \tag{18}$$

The total energy that is spent by sensor nodes present inside congestion zone can be calculated as,

$$E_{TNC} = E_{ONC} + E_{ISNC} + E_{INC} + E_{SNC} \tag{19}$$

$$\begin{aligned} E_{TNC} = & \left(\left| \frac{\gamma + 1}{2} \right] N_T p_{DC} R_S t \frac{A - B1 + z(h-1)}{A} \frac{zh}{} \right) \sum_{i=1}^{k} (\alpha_1 \\ & + \alpha_2 h_i^n) + N_{ra} p_{DC} r_s t \Big] \sum_{i=1}^{k} (\alpha_1 \\ & + \alpha_2 h_i^n) (k - i + 1) \Big] \\ & + N \frac{B}{} p_{DC} r_s e_s t \end{aligned} \tag{20}$$

So, the lifetime of network upper bound with respect to congestion zone with duty cycle and network coding is expressed as,

$$t_{DNC} = \frac{N \frac{B_A}{A} E_{\text{int}}}{R_y} \tag{21}$$

where,

$$R_y = \Big[p_{DC} r_s \Big\{\tfrac{N}{A}(A - B_A)[\tfrac{\gamma+1}{2}]\tfrac{1+z(h-1)}{zh}\Big(\textstyle\sum_{i=1}^{k}(\alpha_1 + \alpha_2 h_i^n)\Big)\Big\} + N_{ra}\Big\{\textstyle\sum_{i=1}^{k}\Big(\alpha_1 + \alpha_2 h_i^n\Big)(k - i + 1)\Big\} + N\tfrac{B_A}{A}e_s + (1-p)N\tfrac{B_A}{A}E_{sleep}\Big] \quad (22)$$

4. Collectable Information

The WSN deployed for numerous applications is required for collection of the required data. The data is required to be collected well within the lifetime of network. In [4], there have been studies made on upper bound on collectable information, which is defined as the maximum information quantity which could be gathered by WSN. As collectable information is collected within the network lifetime, the upper bound of collected information is determined by the network lifetime's upper bound. It is expressed in equation 23 and is taken from [4],

$$Inf_u = \bar{\beta} N_T R_S t \quad (23)$$

where, β is average amount of information weight of sensed data bits. From [6], the upper bound on collectable information for even deployment is given as,

$$Inf_E = \frac{\bar{\beta} N D_C B_A E_{int}}{P_{DC}E_1\frac{\alpha}{\alpha-1}\Big[R_B(A-B_A)+\iint_{B_A} xdS\Big]} + B_A D_C\Big[pS_r(e_s - E_r) + (1-p)E_{\text{sleep}}\Big] \quad (24)$$

The upper bound on the collectable information for uneven deployment using only duty cycle is given as follows,

$$Inf_V = \frac{\beta N R_S \frac{B_A}{A}E_{\text{int}}}{P_D R_S\{\frac{N_T}{A}(A-B_A)|\frac{\gamma+1}{2}|(\sum_{h=1}^{k}(\alpha_1+-\alpha_2 h_r^n))\}+N\frac{B_A}{A}e_S} + N_{ra}\Big\{\textstyle\sum_{i=1}^{k}\Big(\alpha_1+\alpha_2 h_i^n\Big)(k-i+1)\Big\} + (1-p)N\frac{B_A}{A}E_{\text{sleep}} \quad (25)$$

The upper bound on collectable information using both duty cycle and network coding in case of uneven deployment, is also obtained and is given as,

$$Inf_V = \bar{\beta} N S_r \frac{B_A}{A}E_{int} \; P_{DC^T}\Big\{\frac{N_T}{A}(A-B_A)\Big|\frac{\gamma+1}{2}\Big|\frac{1+z(h-1)}{zh^*}\Big(\textstyle\sum_{l=1}^{k}\Big(\alpha_1+\alpha_2 h_i^n\Big)\Big)\Big\} + N\frac{B_A}{A}e_s + N_{ra}\Big\{\textstyle\sum_{i=1}^{k}\Big(\alpha_1+\alpha_2 h_l^n\Big)(k-i+1)\Big\} + (1-p)N\frac{B_A}{A}E_{\text{sleep}} \quad (26)$$

The upper bound on collectable information using network coding and duty cycle can be similarly found for even deployment. These expressions are used for simulation as shown the effect of even and uneven deployment on the collectable information in the next section.

5. Simulation Study

The parameters used for the evaluation of network life time upper bound of WSN are specified in Table I.

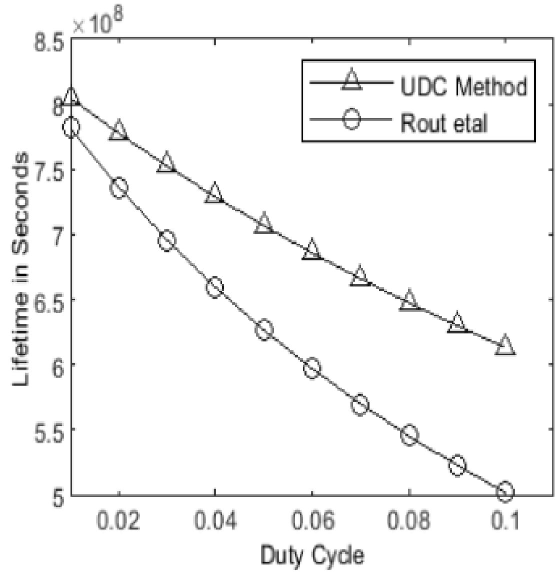

Figure 2. Network Lifetime for uniform and uneven deployment inside the congestion zone ($m = 3$)

The result depicted in Fig. 2, shows an improvement in the lifetime of the network, when uneven deployment is used just inside the congestion zone [UDC Method], instead of uniform deployment. This result is obtained only when duty cycle is implemented for finding upper bound on network lifetime. The figure depicts the results obtained by comparison between even and uneven deployment, from equation 11 and 12 , and citec6 while considering m = 3, with duty cycle.

By implementing both even and uneven deployment inside congestion zone, the various plots are obtained in Fig. 3, for m = 1, 3 & 5, from equation 11 and 12, and citec6. It shows that the upper bound on lifetime has improved with uneven deployment, even with increasing or number of neighboring nodes.

It is seen from Table I that deployments in the congestion zone for m values are as 1, 3 and 5. This is, because the collectable information is determined by upper bound on lifetime of network. It is further noticed that the behavior of collectable information with regards to duty cycling is observed to be similar.

It is observed from Fig. 3 that upper bound on network lifetime, obtained in the case of uneven deployment is greater than network lifetime's upper bound for even deployment. Further, it is noticed that, with the increase in value of m = 1, 3, 5, the network lifetime decreases for

TABLE I. Parameters Used

Parameters	Values
Deployment Area, A	$200 \times 200m^2$
Radius of Congestion Zone, R_b	60 m
Area of Congestion Zone, B	$\pi R_2^B m^2$
Number of Nodes, N_T	1000
Initial Energy, E_int	25 KJ
Exponent of Path Loss, α	2
Probability of Duty Cycle, P_{DC}	0.01 - 0.1
Rate of Sensing Data, R_s (H=960 bits)	$\frac{H}{(A-B)\frac{N_T}{A}}$ bits/sec
Energy consumption in transmission with initial energy loss, E_{11}	0.937 μjoule/bit
Energy used to receive data, E_{12}	0.787 μjoule/bit
Energy spent in transmission and to receive data, E_1	$E_{11} + E_{12}$
Energy used in amplification, E_2	0.0172 μjoule/bit
Energy consumed in inactive state, E_S	30 μjoule/bit
Energy spent to sense a data bit, E_{SB}	0.0001 J
Energy spent in Idle State, E_{id}	$c \times E_{12}c = 0.9$
Number of the nodes present in the radial array, N_r	6
Radius of Sensing, S_R	4
Total number of active surrounding neighbors, $\frac{m+1}{2}$	(m=1, 3, 5)

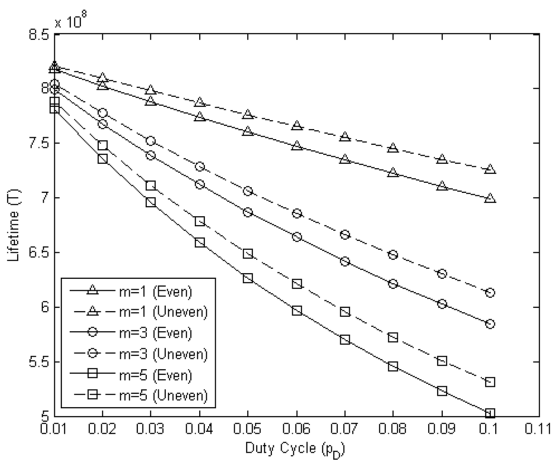

Figure 3. Network Lifetime for uniform and uneven deployment ($m = 1, 3, 5$)

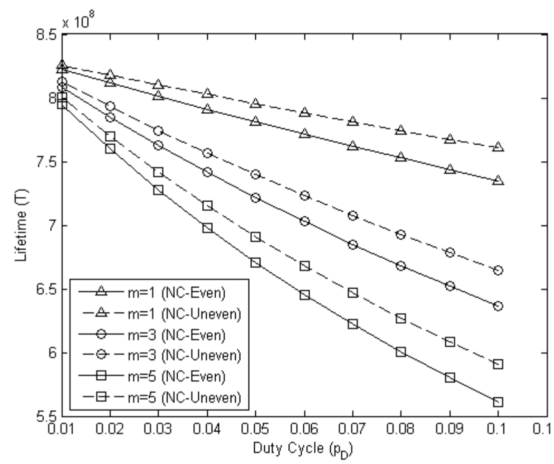

Figure 4. Network Lifetime with Network Coding for uniform & uneven deployment ($m = 1, 3, 5$)

uneven deployment is greater than the network lifetime's upper bound for even deployment with increasing values of number of neighbors.

The upper bound on lifetime of network was also observed for even and uneven deployment, using the duty cycling and the network coding as provided in eqn. (21) and (22) and the mechanism in the paper citec6. The results of the simulation for m = 1, 3, and 5 are given in Fig. 4.

The upper bound on the collectable information have been obtained as well, using both even and uneven deployment, as given in Fig. 5, from eqn. [24] and [25], for m = 1, 3 & 5. Figure 5 depicts upper bound of lifetime of network, when network coding scheme is applied, both in case of even and uneven deployment of nodes in congestion zone.

The equation 26 & **??** obtained involves effect of both duty cycle and the network coding. In Fig. 6, upper bound on the collectable information in the network, along with network coding is both the cases of even and uneven deployment of the nodes in congestion zone with the values of $m = 1, 3, 5$ as shown. The upper bound for uneven deployment is found to be greater than even in this case as well.

6. Results and Discussion

It is observed that the duty cycle greatly enhances network lifetime's upper bound, and even with the increased

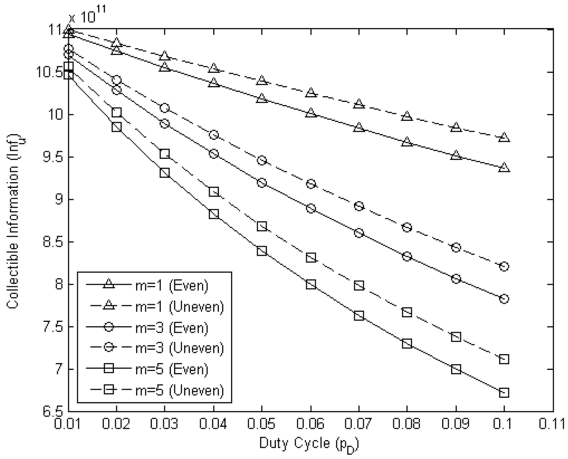

Figure 5. Collectable Information for uniform & uneven deployment ($m = 1, 3, 5$)

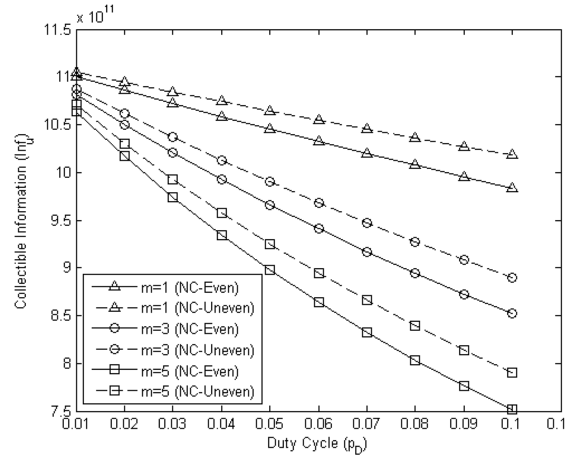

Figure 6. Collectable Information with duty cycle and the network coding for uniform & uneven deployment ($m = 1, 3, 5$)

lifetime of network, network lifetime's upper bound for uneven is also greater than for even deployment with increasing number of neighbors. The network lifetime's upper bound is further improved with network coding for both even and uneven deployment.

Thus, the major contributions obtained from the current investigations are –

1. The whole network has uniform node deployment except for the congestion zone where we have applied uneven node deployment is applied with an objective of maximizing lifetime of network.

2. The upper bound of lifetime of network for uneven deployment is obtained using duty cycling and using both network coding along with duty cycling.

3. The upper bound on the collectable information of the network has also been derived for uneven deployment both using duty cycling and network coding with duty cycle.

7. Conclusion

In the current work, the deployment of sensor nodes in congestion zone is seen to be a major factor for improving lifetime of network. The sensor nodes only inside congestion zone in an uneven manner, in contrast to even deployment throughout the whole network are deployed. This kind of deployment ensures the even energy utilization of all the nodes inside congestion zone. It is demonstrated that there is an improvement in the upper bound on the lifetime of network due to this type of deployment. It is also observed that upper bound on total collectable information of network to have increased, than in previous works. The work presented here can be further improved by the employment of other deployment patterns. Furthermore, there could be intelligent techniques used to determine the deployment patterns for optimal usage and improvement of network lifetime.

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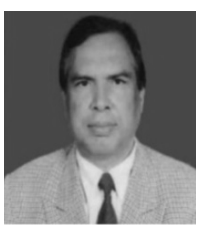

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