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Discharge Curve Backoff Sleep Protocol for Energy Efficient Coverage in Wireless Sensor Networks

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Abstract

In energy constrained wireless sensor networks, maximizing network coverage lifetime while ensuring optimized coverage is important. The challenge is to determine an appropriate duty cycle for the nodes while maintaining sufficient count of active nodes for optimal network coverage. Most of the existing work, for coverage optimization based on duty cycle, does not consider the residual energy of the active nodes. This can result in suboptimal wake-up of sleeping nodes. RBSP considers the residual energy but ignores the *active* nodes' battery discharge rate. In this paper, we propose DCBSP (*Discharge Curve Backoff Sleep Protocol*), which considers the battery discharge curve of the active nodes to determine the duty cycle of the inactive nodes. Thus in DCBSP, inactive nodes wake-up close to death of the active nodes which leads to lesser energy consumption and increased network lifetime. NS-2 simulations show the energy consumption of DCBSP is lesser than that of PEAS by 39% and lesser by 25% and 15% as compared to RBSP and PECAS respectively. Further, the coverage ratio of DCBSP is higher than PEAS by 32% and higher by 17% and 6% as compared to RBSP, PECAS respectively. Hence, DCBSP is effective in ensuring higher coverage while extending the network lifetime.

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Keywords: Wireless sensor networks, coverage, energy efficiency, battery discharge curve, backoff time;

1. Introduction

A typical Wireless Sensor Network (WSN)[1,2] is an adhoc network composed of small sensor nodes which cooperatively monitor some physical environment. Each sensor node has a sensing range or sensing coverage range[3,4,5] which is the region or area that a node can observe or monitor. Sensing coverage for a WSN could be interpreted as the collective coverage of all the sensors in the WSN. Sensing coverage ensures proper monitoring and radio coverage ensures proper data transmission within the WSN. Sensing coverage[3,4,5] is important for ensuring that the coverage of the region is adequate while radio coverage[3,4,5] is important, for data transmission towards the sink. To maximize the network lifetime it is essential to minimize the number of active nodes, while still achieving maximum possible

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sensing and radio coverage. The aim here is to ensure that sufficient number of nodes are available for the longest possible time while ensuring proper functioning of the WSN.

A sensor node has limited energy, usually supplied by a battery. In view of the limited battery life, it is essential to make these nodes energy efficient. Energy saving is important for applications that need to operate for a longer time on battery. However, in sensor networks if multiple sensor nodes are monitoring the same coverage area, then there could be a possibility of redundancy in coverage which would result in energy wastage. Hence, it is important to determine the optimal count of active nodes.

There are many techniques for ensuring optimal count of active nodes. For example, the aim of Probing Environment and Adaptive Sleeping(PEAS)[6] is to maximize network coverage and connectivity by waking up minimum number of nodes. In PEAS, the wake-up rate is randomized and spread over time based on an *exponential function*[6]. However this causes unnecessary waking up of nodes, due to which energy consumption increases and hence the network lifetime decreases. Probing Environment and Collaborating Adaptive Sleeping(PECAS)[7] is an extension to PEAS. PECAS has better energy efficiency. However, PECAS has higher message exchange overhead as compared to PEAS because of the number of probes that need to be broadcast. Random Backoff Sleep Protocol(RBSP)[8], a probe based protocol, uses a dynamic *sleeping window* for the neighbor nodes, based on the amount of residual energy at an *active* node. In RBSP, the neighboring nodes wake-up very frequently when the residual energy of the current active node is very less. In order to avoid this random and unnecessary frequent wake-ups of sleeping nodes, at lower residual energy of active nodes, we propose *Discharge Curve Backoff Sleep Protocol(DCBSP).*

DCBSP uses the active node's battery discharge curve, to decide the appropriate duty cycle of neighboring sensor nodes. DCBSP is an energy efficient coverage protocol based on battery discharge curve[9], in order to schedule sensor nodes to alternate between *active* and *sleep* state. DCBSP obtains optimal *Backoff Sleep Time* using battery discharge curve. The battery discharge curve is based on data sheet[9]. Due to this, DCBSP avoids random and unnecessary frequent wake-ups of sleeping nodes. Sleeping nodes wake-up only close to the death of an active nodes. This leads to less energy consumption and increased network lifetime.

Our major contributions are, designing of an energy efficient coverage protocol based on battery discharge curve. DCBSP avoids random and unnecessary frequent wake-ups of sleeping nodes as compared to other protocols. Due to this, neighbor sleeping nodes wake-up only at the required instant of time which leads to less energy consumption and increased network lifetime as compared to other protocols. DCBSP uses a probing mechanism which allows sufficient count of sensor nodes to remain in active state, due to which coverage redundancy is minimized.

The rest of the paper is organized as follows: In section II, we review some coverage optimization protocols used in wireless sensor networks. We describe the details of our proposed protocol (DCBSP), including state transition model, flow diagram and working mechanism in section III. Section IV describes performance evaluation using simulations. Finally, we present our concluding remarks and future work in section V.

2. Related Work

In this section, we discuss some of the energy efficient coverage optimization techniques used in wireless sensor networks. The coverage optimization techniques are broadly classified as *location aware* and *location unaware*. The coverage optimization techniques such as Probing Environment and Adaptive Sleeping(PEAS)[6], Probing Environment and Collaborating Adaptive Sleeping(PECAS)[7]and Random Backoff Sleep Protocol(RBSP)[8] are location unaware. In contrast, the coverage optimization techniques such as Coverage Configuration Protocol(CCP)[10], Enhanced Configuration Control Protocol(ECCP)[11], Optimal Geographical Density Control(OGDC)[12], and Probabilistic Coverage Protocol(PCP)[13] are location aware. In this section, first we discuss location unaware techniques and then we focus on location aware techniques.

Many research efforts have been made to exploit the inherent coverage redundancy to extend the lifetime of wireless sensor networks. Ye et al.[6] present Probing Environment and Adaptive Sleeping(PEAS) which is a distributed protocol, based on probing to extend network lifetime by turning on minimum number of active nodes. PEAS is a location independent protocol. PEAS is useful for a network where the node density is high. If the node density is not high enough then some of the probing nodes may enter the active state which would lead to a reduction in the network and node lifetime. PEAS does not provide a guarantee for sensing coverage. Gui et al.[7] proposed Probing Environment and Collaborating Adaptive Sleeping(PECAS) which is an extension to PEAS[6]. PECAS does not allow active nodes to operate continuously till energy depletion. However, if the *working time* duration of active nodes is small then the nodes in the network may frequently switch their states between *active* and *sleep*. This frequent switching could lead to wastage of energy.

More et al. have implemented Random Backoff Sleep Protocol(RBSP)[8], which is location unaware protocol that uses the information about the residual energy of active nodes. Each active node sends a computed *Backoff Sleep Time* to each of its neighboring nodes. This *Backoff Sleep Time* computed randomly from a sleeping window which is proportional to residual energy of current active node. The major limitation of RBSP is the randomness in *Backoff Sleep Time* derived form sleeping window. Secondly, the neighboring nodes wake-up very frequently and randomly when the residual energy of the current active node is very less.

Xing et al.[10] present Coverage Configuration Protocol(CCP) which is a decentralized protocol. In CCP, each node needs to maintain a neighborhood table, so that it can determine the coverage overlap to check “turn-off” eligibility. CCP is location aware protocol. CCP requires lesser number of active nodes but is unable to avoid sensing void. Enhanced Configuration Control Protocol(ECCP)[11] proposed by Zhang et al. provides a mechanism to avoid sensing voids in a network but, it requries more number of active sensor nodes. ECCP is a location aware protocol which ensures full coverage of the target area. One of the major limitations of ECCP is that the number of active nodes is more than CCP because of additional node turn off conditions.

Optimal Geographic Density Control(OGDC)[12] presented by Zhang et al. is one more location aware protocol. The energy consumption of OGDC is controlled by the density of active nodes. In OGDC overlap of sensing area is used as a parameter for switching off nodes for energy conservation. OGDC has 50% improvement with respect to number of working nodes as compared to PEAS. Probabilistic Coverage Protocol(PCP)[13] is location aware distributed coverage protocol. PCP activates sets of nodes to form hexagonal structures in the field which is to be monitored. PCP controls the density of activated nodes by turning on only the required active nodes, due to which PCP increases network lifetime.

The coverage protocols[10,11,12,13] require suitable hardware like GPS module, directional antenna etc. However, adding a GPS module on the sensor node is not always feasible due to power consumption of the GPS module, which would reduce the battery life of the sensor node and this in turn would reduce the network lifetime. Also the size of the GPS module may be large as compared to the size of the node. This could create deployment problems where the size of the node is crucial. Hence, we focus on location unaware protocols such as PECAS, RBSP and PEAS.

Jayshree et al.[14] have developed a novel energy efficient battery aware MAC protocol (BAMAC(k)) for minimal power consumption and longer life for the nodes of ad hoc wireless network. (BAMAC(k)) considers the state of nodes' batteries in its design for transmission of k packets. However, the energy efficient coverage is not addressed in reference[14]; Kijun et al.[15] have proposed MAC protocol which is based on a backoff algorithm for wireless sensor networks. It uses dynamic contention period based on residual energy at each node. In both references, the node battery is considered only for medium access and not for planning the coverage. In the next section, we discuss details about our protocol DCBSP.

3. *Discharge Curve Backoff Sleep Protocol(DCBSP)*

We state our assumptions before describing the DCBSP protocol. The communication range is same as the sensing range. The sensing coverage and radio coverage of a sensor node are assumed to be a *“perfect disk”*, which means that, if the sensing range of a node is R_s, then the node can sense the target only if it is within a distance of R_s from the node. The sensor nodes does not have location information. If the sensor node is in *active* state then it can be transmit, receive or remain idle state. The internal resistance of the battery is assumed to be constant during its discharge cycle. The rate of battery discharge does not change with the change in amplitude of current or battery temperature (no Peukert effect). Further, the battery capacity is same for all the nodes and battery does not self-discharge.

3.1. Wake-up cycle of DCBSP

We propose *DCBSP* protocol for determining duty cycle of sensor nodes. In DCBSP the determination of duty cycle for sleeping nodes is based on optimal *Backoff Sleep Time* derived from battery discharge curve. Fig.1[16] shows a typical discharge characteristic, for a 1.2V, 245mA Nickel-Metal-Hydrid cell. DCBSP uses this typical battery

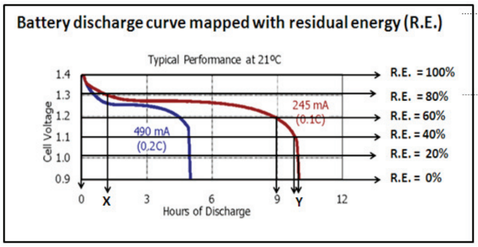


Fig. 1: Battery discharge curve [16]

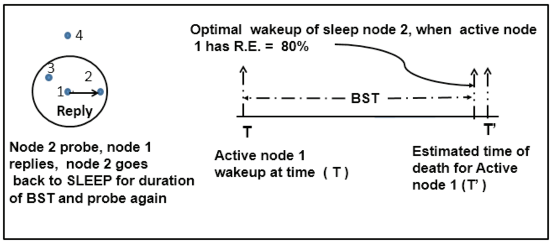


Fig. 2: Optimal wakeup of DCBSP

discharge curve to determine the duty cycle for the neighboring sleeping nodes based on residual energy of an active node. For example, if residual energy of a current active node is 80%, which indicates that current active node has consumed 20% of its total energy. From figure 1, we observe that the time required for 20% of energy consumption is approximately 'X' = 1.5 hrs we call this time as *Current Consumption Time*. Similarly, the time requires for active node to consume 100% of energy is approximately 'Y' = 10 hrs from figure 1 we call this time as *Total Discharge Time*. The *Total Discharge Time* indicates that, after 10 hrs of operation, battery will be fully discharged. Hence, we derive the *Backoff Sleep Time* as

$$\textit{Backoff Sleep Time} = \textit{Total Discharge Time} - \textit{Current Consumption Time} \tag{1}$$

The wake-up cycle for a sleeping node in DCBSP is explained with the help of an example. Figure 2 shows four deployed nodes where node 1 is active state and reaming nodes (2,3,4) are in the sleep state. The sleeping nodes (2,3) are within sensing range of active node 1. Node 1 has a residual energy of 80%. This means that its battery would discharge fully after approximately 8.5 hrs from figure 1 and equation 1. Node 2 is in the sensing range of node 1. Hence, node 1 replies to the probe of node 2. This reply contains the *Backoff sleep time(BST) = 8.5 hrs*. Hence, node 2 goes into sleep state for the time duration of *BST*. Thus, in DCBSP the sleeping nodes wake-up close to the death of the active nodes which ensures that energy is not wasted in unnecessary wake-ups. In the next subsection, we describe the probing mechanism with the help of state and flow transition diagrams of DCBSP.

3.2. State Transition and flow diagram of DCBSP

Each node in DCBSP has three operating states which are similar to RBSP[8]: *SLEEP*, *FLOAT* and *ACTIVE*. The state transition diagram for all three modes is shown in figure 3. In the SLEEP state, a node turns its radio off to conserve energy. Each node in FLOATING state broadcasts HELLO message within its sensing range *Rs*, where *Rs* is the maximum sensing range within which an event can be observed or detected. The ACTIVE node continuously senses the physical environment and communicates with other sensor nodes. The flow diagram of DCBSP is shown in fig. 4. Nodes are initially in sleeping state where each node sleeps for a backoff sleep time interval which is a small random time. After the node wakes up, it enters into a FLOATING state. The FLOATING node broadcasts HELLO message within its sensing range R_s. If active node/nodes within the sensing range responds with a REPLY message which includes a *Backoff Sleep Time(BST)*, then its state changes to SLEEP mode. The FLOATING node waits for *Reply Time Out(RTO)* which is the time interval between sending HELLO packet to receipt of REPLY message. The floating node estimated the RTO as $2 * \frac{R_s}{c}$, where c is the velocity of light. If the FLOATING node does not hear any REPLY in any RTO period, it enters into ACTIVE state and starts its timer to measure the current working time $T_{current}$. The current working time $T_{current}$ is define as the time elapsed from the instant the floating node turns active. In DCBSP, if floating node enters into the ACTIVE state, the node remains active until it consumes all of its energy. Thus, by using DCBSP each sleeping node determines its *ACTIVE* and *SLEEP* cycle based on the residual energy of current active node. In the next subsection, we describe how DCBSP computes BST at an active node, using battery discharge curve.

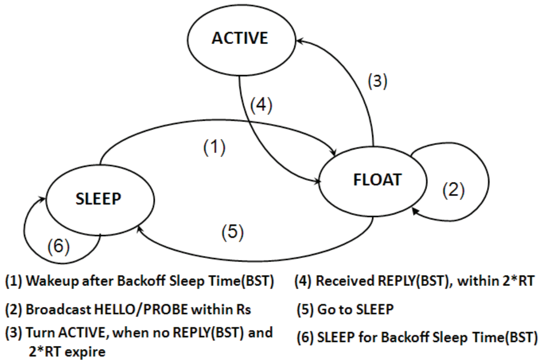


Fig. 3: State Transition Diagram of DCBSP

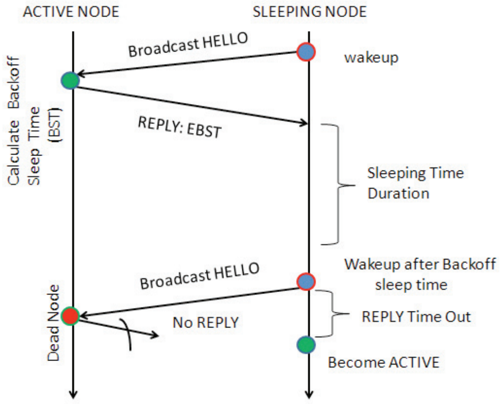


Fig. 4: Flow diagram of DCBSP

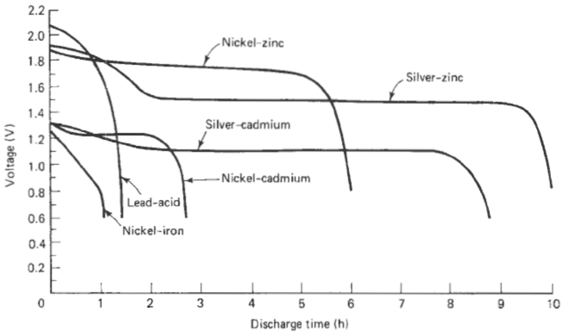


Fig. 5: Battery discharge curve patterns[9]

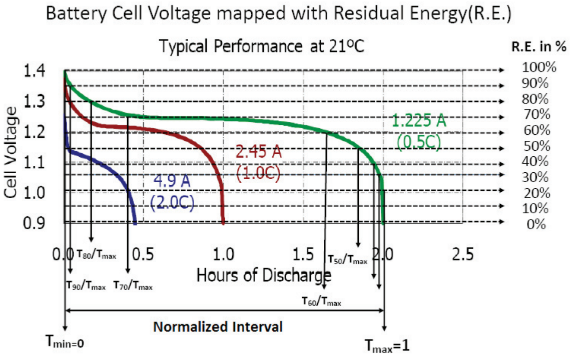


Fig. 6: Normalized battery discharge curve[16]

3.3. *Estimation of* Backoff Sleep Time (BST) *in DCBSP)*

The battery discharge curve can accurately represent the behavior of many battery types as shown in figure 5[9], provided the parameters are well determined. According to reference[9], all the batteries including Nickel-Zinc, Nickel-Cadmium, Silver-Cadmium, Silver-Zinc and Lead Acid batteries follow the same pattern of discharge, even when current rating or load conditions are different. In figure 6[16] there are three discharge curves, each having different current rating such as 4.9A, 2.45A and 1.225A. In our protocol design, we have used the discharge curve for a constant current of 1.225A (0.5 C rate1), which indicates that after 2 hours of operation, battery will be fully discharged. This selection of battery discharge curve does not have an impact on our results, since the curve follows the same pattern of discharge even in case of different current rating. Similarly, for a constant current of 2.45A (1.0 C rate1), the battery will be fully discharged after 1 hour. This indicates that, the discharge time of a battery is dependent on the current rating or load conditions. However, to simplify the computation we create a battery discharge curve with a ***normalized*** time range of 0 to 1 as shown in figure 6. Here, T_{min} is the minimum time and is set to 0 while, T_{max} is the maximum time and is set to 1. *Normalized curve* is a generic battery curve used for computations. The normalized discharge curve is used to estimate the fraction of time remaining for battery discharge. Once the fraction of *Normalized Current Time* (N_{CT}) for particular energy level has been determined from the normalized discharge curve then ***de-normalization*** is done to obtained actual full discharge time of battery. This actual full discharge time of battery value is used to calculate BST.

In our protocol, each node has *10* residual energy levels. The residual energy levels are mapped by using the battery discharge curve[9] as shown in figure 6. To compute the normalized time values, we first divide curve into 10 equals parts across the y-axis. We note the y-axis values for each of the intercepts of these 10 lines across the y axis. Let, each node initially start from residual energy level $i = 10$, where it's residual energy is between $90\% < R.E. \leq 100\%$. If an active node has 100% residual energy, the *Normalized Current Time* (N_{CT}) for node is $\frac{T_{100}}{T_{max}}$ as shown in figure 6. When the active node consumes more than 10% of its residual energy, its residual energy level changes to $i = 9$ where its residual energy is between $80\% < R.E. \leq 90\%$. Therefore, the N_{CT} for 90% of residual energy is $\frac{T_{90}}{T_{max}}$. In this way, when the node consumes more power, residual energy level becomes low and the N_{CT} approaches unity ($T_{max} = 1$). According to the above mechanism, the *Normalized Current Time* ($\frac{T_{100}}{T_{max}}, \frac{T_{90}}{T_{max}}, \frac{T_{80}}{T_{max}} \ldots\ldots\ldots\ldots \frac{T_{10}}{T_{max}}$) based on residual energy levels is computed. We used *interpolation*[17] to compute intermediate values of the N_{CT}.

The residual energy fraction (*Normalized Current Time*) is known from the normalized battery curve using interpolation. The actual current time $T_{current}$ has been measured by the active node. Using the normalized discharge curve and $T_{current}$, in effect, we create a battery discharge curve for the prevailing load. Using these two values the actual full discharge time of the battery can be determined, we call this ***de-normalization*** of the *Normalized Current Time (N_{CT}).* This is done using equation 2.

$$T_{Discharge} = \frac{T_{current}}{Normalized\ Current\ Time\ (N_{CT})} \tag{2}$$

Where, $T_{current}$ is the current working time of active node. $T_{Discharge}$ is actual full discharge time or de-normalized time and it indicates that after $T_{Discharge}$ hours of operation, the battery will be fully discharged. Therefore, the *Backoff Sleep Time (BST)* is calculated by the active node as follows:

$$Backoff\ Sleep\ Time(BST) = T_{Discharge} - T_{current} \tag{3}$$

In this way, the *Backoff Sleep Time (BST)* is derived by the active node based on battery discharge curve. In the next section, we evaluate the performance of DCBSP and compare it with PECAS, RBSP and PEAS.

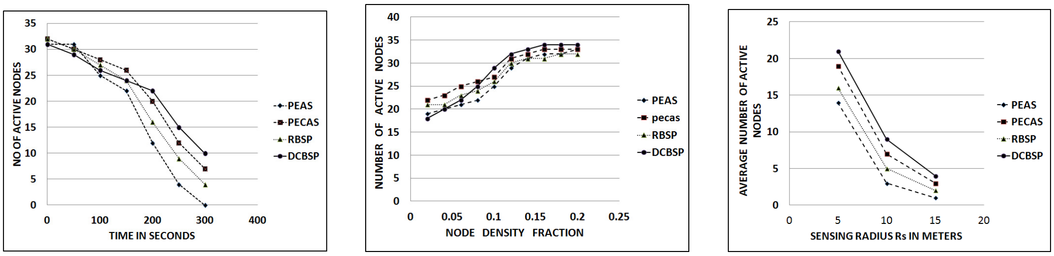
4. Simulation results

We have implemented DCBSP in ns-2[18]. The energy model, in this protocol, is similar to RBSP[8], where Sleep:Idle :Tx:Rx as 0.03mW:12mW:60mW:12mW. We assume that, the maximum sensing range is 5 meters and is equal to the transmission range for initial setup. The initial energy of each node is set at 2 Joule. We run the simulation for 300 sec. The packet size of HELLO and REPLY messages are 25 bytes each. We deployed 100 sensor nodes over $50 \times 50m^2$ network field. Nodes are randomly deployed in the field and remain stationary after deployment. We ran each simulation 5 times and represent the average result of the 5 runs.

We have used *active node count* as one of the parameter for evaluating the performance of DCBSP. The *active node count* over time as a measure for the lifetime of coverage in the network. So, protocol with large number of active node for a longer duration is better for maintaining adequate coverage. We conduct simulations with varying node density and varying sensing range to evaluate the performance of DCBSP under varying conditions. We can see that even under varying conditions DCBSP gives better performance than PECAS, RBSP and PEAS. Figure 7(a) shows the total number of active nodes with respect to time. We can see that DCBSP has larger number of active nodes at the end of simulation at 300 seconds. DCBSP has 33%, 21% and 11% of active nodes as compared to PEAS, RBSP and PECAS respectively.

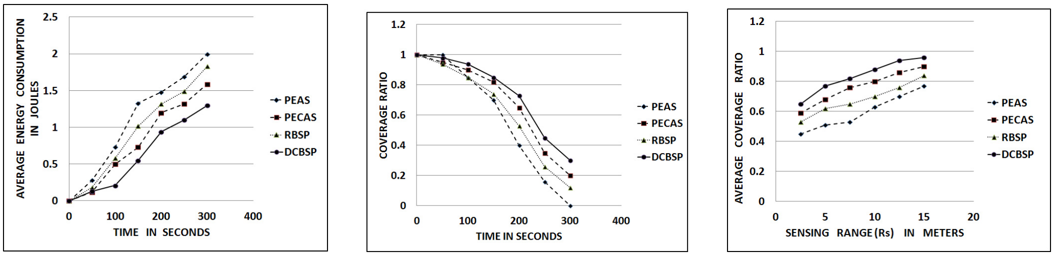
The *node density fraction* is an important parameter in wireless sensor networks. The node density fraction is the ratio of number of deployed nodes to the total area of the network field. Figure 7(b)shows the number of active nodes with varying node density. DCBSP and other protocols maintain adequate active nodes in order to monitor the intended network field. As compared to other protocols the *active node count* in DCBSP increases with respect to node density. This shows that, DCBSP performance improves as the node density increases. DCBSP is able to scale and perform better even at higher node density.

DCBSP considers uniform circular sensing range. An event that occurs within the sensing range of node is assumed to be detected with probability of *1* while any event outside the range is assumed to be of *0.* Sensing range of a node in sensor network, effects the count of active nodes. As sensing range of node increases, the sensing area per node is also increases in proportion. Hence, the total number of nodes are required to monitor the entire network field will be less in such case. We varied the sensing range as 5, 10, 15 meters. Figure 7(c) shows the average number of active



(a) Active nodes wrt time in sec. (b) Node density fraction (c) Active nodes wrt. Rs.

Fig. 7: Performance of number of active nodes wrt time and Rs, node density fraction



(a) Average energy consumption (b) Coverage ratio wrt. time (c) Average coverage ratio wrt. Rs

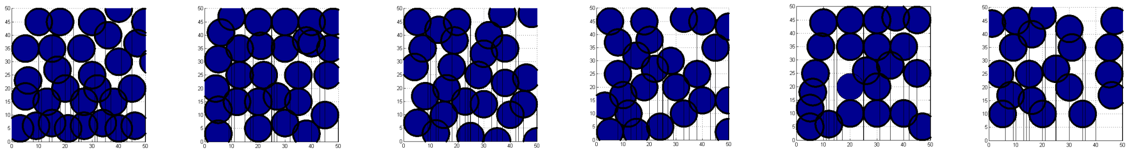
Fig. 8: Performance of average energy consumption and coverage ratio

nodes with respect to sensing range(R_s). The number of active nodes in DCBSP are more than that of other protocols due to optimal wake-ups of sleeping nodes.

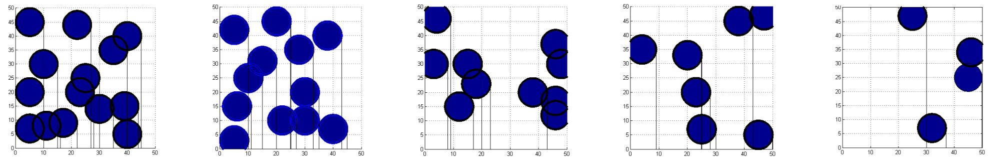
Figure 8(a) shows the average energy consumption of network with respect to time. The average energy consumption is the ratio of total energy consumption to total number of nodes in the network. The average energy consumption of DCBSP is lesser than that of PEAS by 39% and lesser by 25% and 15% as compared to RBSP and PECAS respectively. Hence, DCBSP is effective for extending the network lifetime.

Any coverage protocol for sensor networks needs to achieve adequate coverage of sensing region. Therefore, we need to keep sufficient number of nodes in active state. Hence, our aim is to keep sufficient number of nodes in active state while ensuring adequate coverage with minimum energy consumption. Therefore, we have considered coverage ratio as performance parameter in our simulation. For our scenario, it is worth noting that ratio of the entire sensing area to the maximum sensing area per node is about $\frac{50*50}{\pi*(5)^2} \approx 31$, which implies that at least 31 nodes are required to cover the entire area. We defined *coverage ratio* as the number of active nodes in the sensing field to the minimum number of active nodes required to monitor entire region of networks. So the coverage ratio is given by $\frac{Active-Nodes-Count}{31}$. We have plotted the graph of coverage ratio by determining the count of active nodes at 100-200-300 seconds. Here, we have ignored the coverage area overlap of the active nodes in the networks. From figure 8(b), DCBSP protocol provides approximately 38% of coverage ratio while PECAS, RBSP and PEAS provide 20%, 16% and *zero* coverage at the instant of 300 seconds. Beside the coverage ratio, Figure 8(c), shows the effect of sensing range on the average coverage ratio. We can see that DCBSP is able to maintain higher coverage even at higher sensing range. The performance improvement due to DCBSP is maintained at higher sensing range also.

We also need to evaluate the actual area coverage based on the position of active nodes in the networks. We use the active node position to plot the node sensing region as dark circle and the image processing function in MATLAB to determine area coverage. This is shown in figure 9 (a to k). The circular shaded area indicates that node is active and monitors the field while white portion indicates no active nodes monitor the field i.e. region is uncovered. For example, in figure 9(i) the percentage of shaded area is 31.84% which indicate that, for DCBSP protocol, area coverage is 31.84% at the instant of 300 seconds. Similarly, the area coverage is 25.90%, 14.88%, zero coverage for PECAS, RBSP and PEAS for the same instant. The values for 100, 200 and 300 seconds for DCBSP and other protocols are



(a) DCBSP 100sec. (b) PECAS 100sec. (c) RBSP 100sec. (d) PEAS 100sec. (e) DCBSP 200sec. (f) PECAS 200sec.



(g) RBSP 200sec. (h) PEAS 200sec. (i) DCBSP 300sec. (j) PECAS 300sec. (k) RBSP 300sec.

Fig. 9: Area coverage at 100 seconds, 200 seconds and 300 seconds of DCBSP, PECAS, RBSP and PEAS

given in table 1 based on figure 9(a-to-k). From the above results, we can observe that DCBSP protocol gives better results as compared to PECAS, RBSP and PEAS due to its optimal wakeup cycle.

Table 1: Percentage of coverage area based on figure 9

Protocols	DCBSP	PECAS	RBSP	PEAS
100 seconds	82.87%	83.56%	75.74%	71.91%
200 seconds	73.45%	63.15%	47.17%	42.62%
300 seconds	31.84%	25.90%	14.88%	00%

5. Conclusions and future work

We have proposed a Discharge Curve Backoff Sleep Protocol(DCBSP) which is a location unaware protocol that depends on *Backoff Sleep Time* derived from the battery discharge curve. Based on optimal *Backoff Sleep Time*, DCBSP avoids random and unnecessary frequent wake-ups of sleeping nodes. Due to this, sleeping nodes wake-up only at the required instant of time. This leads to less energy consumption and increased network lifetime. DCBSP allows the redundant sensor nodes to enter into *sleep* state while it is possible to keep sufficient count of nodes in active state in order to monitor the required network field.

The simulation result shows that DCBSP has sufficient count of active nodes in order to maintain adequate sensing coverage ratio. The area coverage ratio of DCBSP is 73.45% for the instant of 200 second while 63.14%, 47.17% and 42.62% for PECAS, RBSP and PEAS. The average energy consumption of DCBSP is lesser than that of PEAS by 39% and less by 25% and 15% as compared to RBSP and PECAS respectively. DCBSP maintains higher, longer coverage ratio and network lifetime as compared to other protocols. In future work, we plan to extend our protocol for providing K-coverage, in order to obtain 100% coverage ratio in an energy efficient manner. Further, we plan to extend DCBSP to handle varying sensing node ranges and other network challenges.

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