TTS: A Two-Tiered Scheduling Algorithm for Effective Energy Conservation in Wireless Sensor Networks

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Abstract—**In this paper, we present a two-tiered scheduling scheme that provides *effective* energy conservation in wireless sensor networks. The effectiveness of this scheme relies on *dynamically* updated *two-tiered* scheduling architecture. We aim to prolong network lifetime, while preserving the major requirements of wireless sensor networks: coverage and connectivity. In this approach, sensors are periodically scheduled to sleep in two phases using weighted greedy algorithms. First, we establish a *coverage-tier* by selecting a set of sensors that covers the sensing field in order to provide fully monitoring of entire field. Sensors that are not selected for the coverage-tier, are put into sleep immediately. Then, a second tier, called *connectivity-tier*, is formed on top of the coverage-tier to forward the data traffic to sink node. Thus sensors, essential to coverage-tier but not in connectivity-tier may periodically sleep and become active only for sending new sensing measurement and receiving query from the sink to preserve coverage. By this way, we may allow more nodes to sleep with different sleeping behaviors, i.e., continuous sleep or periodic sleep/active. Moreover, fair energy consumption among sensors is achieved by periodically rotating the coverage and connectivity tiers. Through extensive simulations in ns2, we demonstrate that the two-tier scheduling can reduce average energy consumption up to 40% while balancing the residual energy of sensors.**

I. INTRODUCTION

In a wireless sensor network (WSN), a large number of sensor nodes, each having limited battery power, monitor the events of interest queried by the sink [2]. In many applications, sensor nodes are densely deployed and transmit their data to the sink in an event-driven or continuous manner. In such dense networks, energy-efficient scheduling is a key factor to extend the functionality and lifetime of the network. By this way, only the nodes maintaining the functionality stay active whereas others are scheduled to sleep, e.g., switch to power saving mode. Therefore, the energy dissipation in sending/receiving and idle time can be significantly reduced and by rotating the sleeping nodes, network lifetime can be prolonged in an efficient way.

The fundamental challenge is to maximize the number of sleeping nodes to conserve more energy while maintaining the functionality of the WSN. For this purpose, several approaches have been proposed that make use of topological information which can be categorized into three groups: (i) *connectivity preserving* scheduling schemes [5], [6], [10], [17]; (ii) *coverage preserving* scheduling schemes [4], [13], [14]; and (iii) *connectivity and coverage* preserving scheduling [9], [16]. Connectivity preserving schemes have been proposed to put nodes into sleep mode based on their transmission ranges. Network topology is formed based on the connectivity of the network. For example, in GAF [17], sensing area is divided into grids, thus one sensor stays active for each grid, whereas other sensors are put into the sleep mode. Grid size is defined based on the transmission range of nodes. SPAN [6] is presented as a distributed algorithm to form a coordinator backbone of active nodes. It attempts to minimize the number of coordinators ensuring that enough coordinators are elected so that every node is in radio range of at least one coordinator.

On the other hand, coverage preserving scheduling mechanisms have selected nodes for full coverage based on their sensing ranges [4], [13]. The goal of these methods is to organize sensors to preserve the sensing coverage without blind points in the sensing field. Therefore, only the sensors covering the field stay awake while others are put into sleep mode. For example, the sensing range of a sensor node might be approximately in between *1-30 m*, whereas the transmission range of that sensor might be in between *150-300 m* [18]. Even though the coverage might imply connectivity under given conditions [16], more nodes stay active in *coverage preserving schemes* than in *connectivity preserving schemes*. The nodes which are essential to coverage are not needed to stay active all the time. Instead, some may wake up periodically to send their sensing measurement and receive queries, and then go back to sleep. Similarly, when we integrate connectivity and coverage for scheduling, at least, the minimum number of nodes preserving coverage must stay active [9], [16].

This work differs from existing scheduling mechanisms in various aspects. Recent scheduling schemes have classified sensors as either active or sleeping nodes. In this work, we integrate coverage and connectivity by a tiered approach; thus, nodes having been used for connectivity or coverage have different sleeping behavior. Hence, we enable more nodes to sleep while maintaining the coverage and connectivity of the network. Nodes, which are not selected for coverage or connectivity-tier, are put into sleep immediately. On the

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other hand, nodes in the connectivity-tier stay active whereas sensors responsible for coverage only wake up to send their data to sink and go back to sleep mode.

In addition, we rotate the connectivity- and coverage-tiers dynamically to balance the energy consumption. In every update interval, the sink re-performs greedy algorithms to form the new coverage set and dominating set by maximizing their total residual energy. Thus, a dominating set, whose energy consumption is high, might be an non-essential node for the next update interval. This dynamic rotation also helps handling the topology changes due to unexpected node failures.

In this context, the contributions of this paper can be summarized as follows. We propose a two-tiered scheduling scheme for efficient energy conservation. For this purpose, nodes are classified in two steps having different sleeping behavior. Nodes in the coverage set can monitor the entire sensing field and periodically wake up to send and receive to/from the sink. Therefore, we guarantee that an event can be detected by at least one node in the coverage set and queries sent by the sink affects the entire sensing field. On the other hand, dominating nodes, selected from the coverage set, stay active to forward the traffic whereas others are in sleep mode during the predefined round. Finally, energy consumption is balanced among sensor nodes by dynamic rotation of coverage and connected dominating set in each round.

The remainder of the paper is organized as follows. The problem formulation is given in Section II. We describe the proposed two-tiered architecture and algorithms in detail in Section III. Following, simulation results are presented in Section IV. Section V concludes the paper.

II. PROBLEM FORMULATION

Let $\mathbf{S} = \{s_1, s_2, s_3, \ldots, s_N\}$ be the finite set of sensors, distributed randomly in a two-dimensional area $\mathbf{A}$, where there are sufficient sensors to monitor the field. Each sensor s_i has a unique *identifier*. We also assume that each node is equipped to learn its location information via any lightweight localization technique for wireless networks [7]. Therefore, all sensor nodes and the sink know their location coordinates (x_i, y_i), *sensing range* r_i^s, and *transmission range* r_i^t. Transmission range is assumed to be at least as twice as sensing range which is the case for many sensor nodes [18]. All nodes have similar processing and communication capabilities; messages are sent in a multi-hop fashion.

In this context, sensor network can be represented as an undirected graph $G(\mathbf{S}, E)$, where $\mathbf{S}$ is the set of sensors, and E is the set of edges. When sensor s_j is within the transmission range of sensor s_i, then edge (s_i, s_j) is in E.

A. Coverage and Connected Dominating Sets

The *sensing region* R_i of a node s_i is the circular area with its center at (x_i, y_i) and radius of r_i^s. A subset of sensors, $\mathbf{C} \subseteq \mathbf{S}$ is called a *coverage set* if the union of the sensing regions of the $s_i \in \mathbf{C}$ covers the entire field $\mathbf{A}$, that is $\mathbf{A} \subseteq \bigcup_{s_i \in \mathbf{C}} R_i$. We consider a sensor node to be an *essential* (E) node in $\mathbf{C}$ if $s_i \in \mathbf{C}$. This E-node is referred to as $s^{(E)}$. Otherwise, it is a non-essential (N) node, $s^{(N)}$.

Given the sensor network $G(\mathbf{S}, E)$ with the set of sensors $\mathbf{S}$ and the set of edges E, a connected dominating set (CDS), denoted by $\mathbf{D}$, is a connected set of E-nodes ($\mathbf{D} \subseteq \mathbf{C}$), where each E-node in $\mathbf{C} - \mathbf{D}$ can directly communicate with one of the sensors in $\mathbf{D}$. Our goal is to construct a connected dominating set having minimum number of dominating nodes. We consider a sensor node to be an *essential dominating* (ED) node in $\mathbf{D}$ if $s_i \in \mathbf{D}$. This ED-node is denoted by $s^{(ED)}$.

In this paper, time is divided into *rounds*, denoted by T_R. Each round is composed of *classification update interval* T_{CU} and *network operation interval* T_{NO}. The coverage set followed by CDS is updated periodically in every round during T_{CU}. We should ensure that T_{CU} is much smaller compared to T_{NO} because short T_{CU} implies less overhead and better performance of the network.

Next, we will explain the energy model and sensor lifetime.

B. Energy Model

By scheduling of nodes, we may significantly reduce the energy consumption of radio in sensors. The radio of a sensor is either in transmit, receive, idle or sleep mode. Recent works have shown that energy consumption of being idle is the same as the energy cost in receive mode. However, energy drain in sleep mode is dramatically smaller. For example, typical power consumption of Tx (transmit), Rx (receive), Idle and Sleeping modes of a Mica Mote are 24 mW, 13 mW, 13 mW, 0.01 mW, respectively [11].

Therefore, the total power consumption of the radio of a sensor node is a function of reception, $p_r(t)$, transmission, $p_t(t)$, being idle, $p_{idle}(t)$ or being in sleep mode, $p_{sleep}(t)$. The average reception and transmission power of a sensor node can be written as:

$$p_t(t) = \lambda_t(t) \cdot E_b^t, \quad \text{and} \quad p_r(t) = \lambda_r(t) \cdot E_b^r. \tag{1}$$

In the above equation, $\lambda_t(t)$ is the average transmission rate at which the sensor transmits; $\lambda_r(t)$ is the average reception rate of data; E_b^t and E_b^r are transmission and receiving energy per bit, respectively, depending on modulation and coding schemes [15].

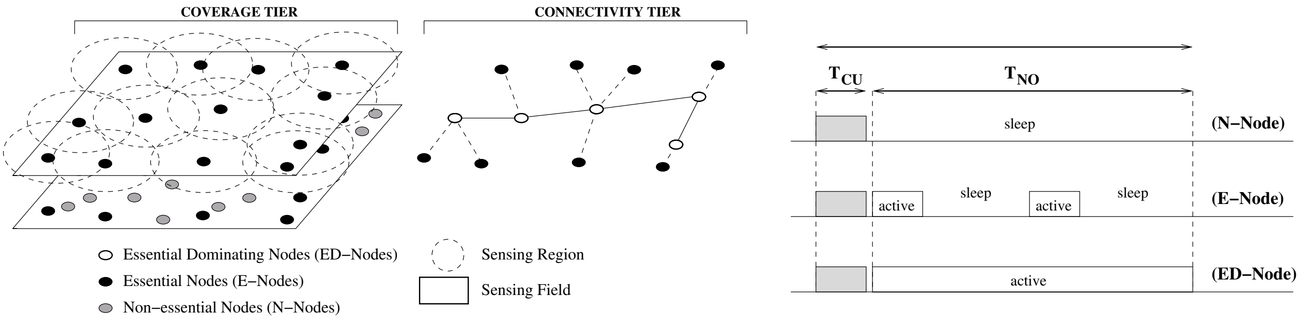
Then, the residual energy of a sensor s_i in the beginning of round T_R, when it is an N-node, E-node and ED-node, is as follows:

$$e_i^{(N)}(T_R) = e_i(T_R - 1) - \int_{T_{CU}}^{T_R-} p_{sleep}(t) \cdot dt,$$

$$\begin{aligned} e_i^{(E)}(T_R) = e_i(T_R - 1) - \int_{T_{CU}}^{T_R-} \{&\alpha_1 \cdot p_{sleep}(t) \\ &+ \beta_1 \cdot p_t(t) + \eta_1 \cdot p_r(t)\} \cdot dt, \end{aligned}$$

$$\begin{aligned} e_i^{(ED)}(T_R) = e_i(T_R - 1) - \int_{T_{CU}}^{T_R-} \{&\alpha_2 \cdot p_{idle}(t) \\ &+ \beta_2 \cdot p_t(t) + \eta_2 \cdot p_r(t)\} \cdot dt, \end{aligned}$$

where $e_i(T_R - 1)$ is the residual energy of the sensor in the beginning of round $T_R - 1$; α_1 and α_2 are being in sleep and idle mode ratios during T_{NO}; β_1, β_2 are being in transmit mode ratios of E-nodes and ED-nodes, and η_1, η_2 are being in receive mode ratios of E-nodes and ED-nodes, respectively. Note that, sensors send their current energy level in their event report to the sink. Next, we will explain the proposed algorithms to find the coverage set and CDS.



(a) (b)

Fig. 1. (a) Logical view of coverage and connectivity-tiers and (b) their sleep schedules.

III. TWO-TIERED SCHEDULING MECHANISM

The intuition behind two-tiered scheduling is to decompose the main functionalities of the WSN into *coverage-tier* and *connectivity-tier* as shown in Fig. 1(a). Such a decomposition allows us to schedule more nodes to be in power-savings mode, thus conserving more energy. If the coverage-tier does not exist, the proposed mechanism works like an energy-efficient topology control. On the other hand, if the connectivity-tier does not exist, it becomes a coverage preserving node scheduling scheme.

Particularly, in our two-tiered scheduling architecture, sensors are classified to achieve an efficient scheduling while maintaining the functionality of the network. In each round, selected N-nodes is in sleep mode. Meanwhile, E-nodes are responsible to provide the coverage thus, they sleep and wakeup periodically to send/receive to/from the sink. Only do the ED-nodes which forward the data to sink are active. Fig. 1(b) summarizes the sleeping behavior of different type of sensors. Next, we give the details of the algorithms to perform this two-tiered classification.

A. Establishment of the Coverage-Tier

We first explain the weighted greedy algorithm used to establish the *coverage set* which will be sufficient to detect all events of interest in the entire sensing field. In order to choose the coverage set, an ideal solution is to find the *minimum* number of sensors as our coverage set that cover the entire field. However, this problem is NP-hard, similar to the well-known set cover problem, which aims to cover a set with the smallest possible number of subsets given a ground set of elements. Therefore, we use a greedy approach for *approximating coverage set*, running in polynomial time.

Several works have addressed the problem of finding near-optimal coverage in WSNs [9]. However, we take residual energy of nodes as the weight in our weighted-greedy algorithm, since our ultimate goal is to prolong the network lifetime. We define a *cost* function for a sensor indicating its consumed energy per its covering area that can be monitored by this sensor. Thus, with lower consumed energy and monitoring larger uncovered field implies smaller cost. The sensor having the minimum cost is chosen as an E-node in each iteration to *minimize the overall cost* while covering the sensing field.

In this algorithm, we first define the cost function $w(s_i)$ that represents the consumed energy by sensor s_i such that

$$w(s_i) = 1 - \frac{e_i(t)}{e_i(0)}, \tag{2}$$

where $e_i(t)$ and $e_i(0)$ are current and energy reserve of the sensor. The objective is to find a coverage set $\mathbf{C}$ while minimizing the total cost of selected sensors, denoted by $Cost(\mathbf{C}) = \sum_{s_i \in \mathbf{C}} w(s_i)$. In each step, our algorithm (given in Fig. 2) selects one node from the unselected sensors which has the minimum cost per uncovered area such as:

$$cost^{(c)}(s_i) = \frac{w(s_i)}{(R_i \cap A)/R_{\mathbf{C}}}, \tag{3}$$

where R_i is the sensing region of sensor s_i and $R_{\mathbf{C}}$ is the total region covered by the sensors in $\mathbf{C}$.

In the initial step of **Algorithm 1**, all nodes are candidates and the coverage set $\mathbf{C}$ is empty. Then, in each iteration (line 2-8), the algorithm chooses the unselected node that has the minimum cost. After selecting a node, costs of remaining sensors are recalculated for the next iteration (lines 3-5) because by adding a new node to $\mathbf{C}$, uncovered area in $\mathbf{A}$ shrinks gradually. This operation continues until $\mathbf{A}$ is fully covered.

In the worst case, $\mathbf{S}$ is the minimum coverage set, thus all nodes are selected as E-node. In this case, number of iterations (lines 2-8) in **Algorithm 1** will be $O(N)$.

B. Establishment of the Connectivity-Tier

In the second phase, we select a *connected dominating set* from the coverage set, where all other nodes in $\mathbf{C} - \mathbf{D}$

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Algorithm 1 Finding the Coverage Set
Input: The entire sensor set $\mathbf{S}$
Output: Coverage set $\mathbf{C}$
1 $\mathbf{C} \leftarrow \emptyset$
2 while ($\mathbf{A} \supset \bigcup_{s_i \in \mathbf{C}} R_i$) do
3   for all $s_i \in \mathbf{S} - \mathbf{C}$ do
4     $cost^{(c)}(s_i) \leftarrow \frac{w(s_i)}{(R_i \cap A)/R_{\mathbf{C}}}$
5   end for all
6   select $s_i$ from $\mathbf{S} - \mathbf{C}$ having $\min\{cost^{(c)}\}$
7   $\mathbf{C} \leftarrow s_i \cup \mathbf{C}$
8 end
9 return $\mathbf{C}$
```

Fig. 2. Algorithm of selecting E-nodes for the coverage-tier.

can directly communicate with a dominating node. The most effective approach to conserving energy is to establish the *minimum connected dominating set (MCDS)*, which is NP-hard as well as finding CDS [8]. Thus, we use a weighted-greedy algorithm to find a CDS among nodes which have already been selected as E-nodes.

Since CDS may widely be used in many applications in wireless networks, there have been many research work that has proposed different solutions [3]. We use a similar greedy heuristic method considering the consumed energy of sensors as *cost* and aim to minimize the total cost while conserving connectivity. Cost function is calculated as the *consumed energy per degree of connectivity* where degree of connectivity is the number of neighboring nodes. Therefore, having higher residual energy and degree of connectivity result in higher change of being a dominating node.

Algorithm 2 starts with our coverage set to be a CDS, since the established coverage set is always connected based upon the assumption that coverage implies connectivity when transmission range is at least as twice as sensing range [16]. Among nodes from coverage set, we start selecting a node having minimum connectivity and decide either to remove it from CDS or lock it as a dominating node. A node can be removed from CDS if and only if the remaining set is still connected. For this reason, we start checking nodes with the minimum connectivities. Also, while removing a node, we have to ensure that at least one of its neighbor has already been locked. Otherwise, we select one of its neighbors to be a dominating node. This operation continues until all remaining nodes in CDS are locked as dominating nodes.

Let $\mathcal{N}(s_i)$ be the neighboring set of sensor s_i which is decided to be removed. The number of neighbors of sensor s_i is denoted by $\chi(s_i) = ||\mathcal{N}(s_i)||$. We first search its neighbor having minimum cost per neighbors given as:

$$cost^{(d)}(s_i) = \frac{w(s_i)}{\chi(s_i)}, \tag{4}$$

where $w(s_i)$ is the energy consumption of sensor s_i given in Equation (3). Therefore, we attempt to minimize the total cost of CDS, denoted by $Cost(\mathbf{D}) = \sum_{s_i \in \mathbf{D}} w(s_i)$.

The pseudo code of the **Algorithm 2** is given in Fig. 3, where set $\mathbf{D}$ denotes the final CDS that will be returned at the end. In the representation of the algorithm, $\mathbf{L}$ is a temporary set of the CDS which is initialized to $\mathbf{C}$. Nodes, locked as dominating node $\in \mathbf{L}$, added to $\mathbf{D}$ immediately, while others are removed from $\mathbf{L}$. Algorithm terminates when $\mathbf{D}$ and $\mathbf{L}$ are equivalent. Sink node is a default member of CDS.

In each iteration (line 8), the sink checks if the current CDS is connected or not. In the implementation of the algorithm, to check whether the set is connected, we simply use *depth-first-search (DFS)*. We test whether all nodes are visited starting from a random dominating node. The running time of DFS is $O(||\mathbf{C}|| + ||E^{'}||)$, where $E^{'} \subseteq E$ is the set of edges belonging to the E-nodes, $E^{'} = \{(s_i, s_j) | s_i \in \mathbf{C}, s_j \in \mathbf{C}\}$.

Consider the worst case in which any node subtraction from CDS may cause the remaining set disconnected. In this case, all nodes should be added to $\mathbf{D}$ (line 16) before the algorithm terminates.

Algorithm 2 Finding the Connected Dominating Set

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Input: Coverage set $\mathbf{C}$
Output: Connected dominating set $\mathbf{D}$
1  $\mathbf{D} \leftarrow \{sink\}$, $\mathbf{L} \leftarrow \mathbf{C} \cup \{sink\}$
2  while ($\mathbf{L} - \mathbf{D} \neq \emptyset$)
3    for all $s_i \in \mathbf{L} - \mathbf{D}$ do
4      $\chi(s_i) \leftarrow ||\mathcal{N}(s_i) \cap \mathbf{L}||$
5      $cost^{(d)}(s_i) \leftarrow \frac{w(s_i)}{\chi(s_i)}$
6    end for all
7    select $s_i$ from $\mathbf{L} - \mathbf{D}$ having $\min\{\chi(s_i)\}$
8    if ($\mathbf{L} - s_i$ is connected)
9      $\mathbf{L} \leftarrow \mathbf{L} - s_i$
10     if ($\mathcal{N}(s_i) \cap \mathbf{D} == \emptyset$)
11       select $s_j$ from $\mathcal{N}(s_i)$ having $\min\{cost^{(d)}(s_i)\}$
12       $\mathbf{D} \leftarrow s_j \cup \mathbf{D}$
13     end if
14   end if
15   else
16     $\mathbf{D} \leftarrow s_i \cup \mathbf{D}$
17 end
18 return $\mathbf{D}$
```

Fig. 3. Algorithm of selecting ED-nodes for connectivity-tier.

C. Updating Coverage and Connectivity-Tiers

The energy consumption of ED-nodes may be higher than the E-nodes; and N-nodes may have the lowest energy consumption due to continuous sleep. Thus, to balance the energy consumption, we update the coverage and connectivity-tiers process every T_R. In each round, current residual energy of sensors is used for calculating the cost. Thus, sensors whose residual energy is lower are less likely to become an E-node or ED-node in the next round. Instead, N-nodes with higher energy levels may be selected as essential nodes. This is achieved by informing the sink about the estimated energy levels via event reports. Therefore, the sink keeps the energy level information up-to-date whenever a new message is received. Based on this information, when an update process is triggered, a new essential set is constructed. Since the algorithm runs on the sink, it does not incur any overhead to sensor nodes.

D. Discussion

Now we elaborate on the reasonings behind proposing a sink-based algorithm. The main reason behind the centralized approach is the residual energy information of a node on which node selection algorithms are based. In [1], it is shown that collecting information from a sink node is more power-efficient manner compared to spreading this information to each and every other node within the network. In addition, choosing the sink node as the target of data propagation is reasonable if we considers that the sink node has ample energy and computing power compared to individual sensor nodes. Having the global view of the network at the sink node provisions algorithms for closer-to-optimal coverage set determination as well. Finally, using a centralized scheme can relieve processing load from the sensors in the field and help in extending the overall network lifetime by reducing energy consumption at individual nodes. Additionally, maintaining the node set selections (i.e., E-node updates) can be realized through low cost information diffusion methods.

IV. PERFORMANCE EVALUATION

We present the performance of the two-tiered scheduling by simulation showing three sets of experiments. In the first set of experiments, we evaluate the number of active nodes: E-nodes and ED-nodes. Second, we measure energy consumption and the residual energy distribution among nodes. Finally, we investigate the effect of our protocol in prolonging the network lifetime.

The performance of our tiered approach is evaluated using ns2 simulator [12]. Simulations are performed in an 250 m x 250 m area consisting of different numbers of sensors distributed randomly. In the basic scenario, 100 fixed sensor nodes having transmission range of 100 m and sensing ranges of 25 m are used. We use the energy model and radio power consumption parameters given in Section II-B. The energy consumption of turning the radio on/off is negligible and not considered. The buffer size of sensor nodes is chosen as 50 and the packet length is 100 bytes.

In our experiments, we use a mobile tracking application in which the movements of a mobile node are reported to the sink in every sensing period. Movements of the mobile (phenomenon) node are generated with *random waypoint* model. *Event-driven* data delivery model is used from sensors to the sink, where sensors send an event report if the phenomenon is detected in their sensing region. Sensor sends event reports in every 0.5 sec during phenomenon node is in its sensing range. On the other hand, sink sends periodic queries to the sensors in every 2 sec. The sink is located at the center of the sensing field for all experiments.

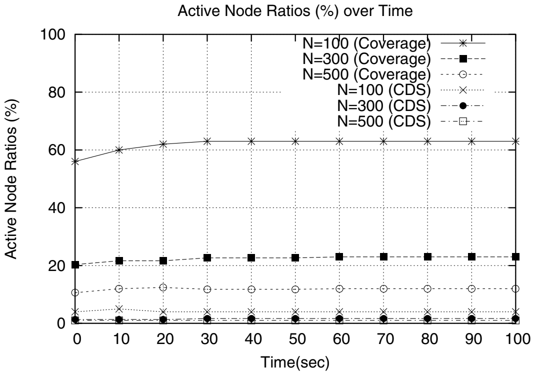


Fig. 4. Active node ratio.

We first measure the number of E-nodes and ED-nodes for each round. In the basic scenario, we take the ratio of transmission range over sensing range (r^t/r^s) as 4, that holds for most commercially available sensor nodes [18]. Fig. 4 shows the percentage of active nodes of three networks of different node densities. To cover an 250 m x 250 m area with sensing range of 25 m, we use random placement of 100, 300 and 500 nodes. From Fig. 4, we can observe that among these three scenarios, network having 500 nodes has the lowest ratio of E-nodes and ED-nodes, thus showing that the greedy algorithms perform even better in densely deployed network. Also results indicate that the ratio of active nodes remain stable over time of the simulation.

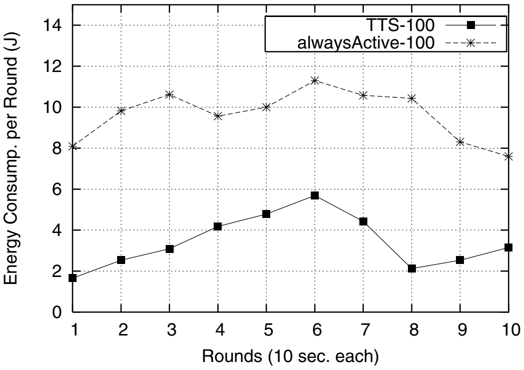


Fig. 5. Energy consumption per round.

Second, we evaluate the energy consumption of our two-tiered approach, comparing with *alwaysActive* scheme, where nodes are not scheduled to sleep. In our experiments, we show that two-tiered scheduling provides a significant energy consumption compared to *alwaysActive* scheme while providing fully monitored sensing field. In Fig. 5, we show the energy dissipation per round. By two-tiered scheduling, labeled as *TTS*, the energy dissipation is reduced around 100% compared to *alwaysActive* scenario. Meanwhile, we notice that energy savings resulted from the proposed two-tiered scheduling is accompanied by the message overhead of rotation.

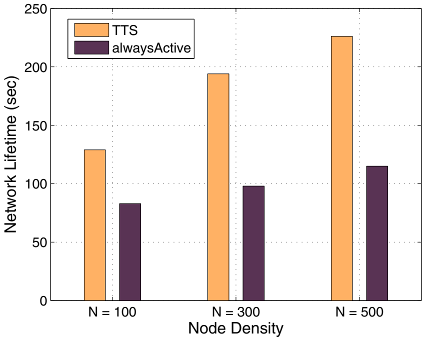
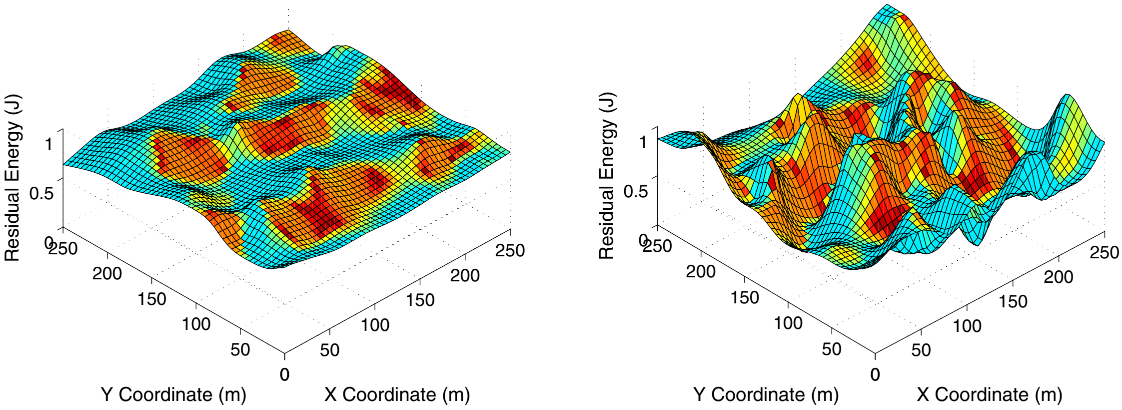


Fig. 6. Network lifetime.

Third, we show the network lifetime in Fig. 6 compared to *alwaysActive* scheme with the initial energy of 1 J. We consider a WSN as alive when the sensing field is fully covered. In other words, a network is alive when every point in **A** is covered by at least one sensor. According to this, we observe that network lifetime is prolonged significantly in two-tiered scheme compared to *alwaysActive*, especially in high dense networks. Even in low density with node number 100, network lifetime is prolonged around 28% which shows the effective energy dissipation of proposed tiered approach.

As a matter of fact, the rotation of the E-nodes, which provides balanced energy distribution among sensors, is also effective in prolonging lifetime. To show the energy distribution, we depict the residual energy reserves of sensors in Figure 7(a) and (b) where x-y plane represents the sensing field. Nodes are positioned their actual locations as in the simulation and z axis represents their residual energy at t=60 sec. In Fig. 7(a), coverage set and CDS is updated in every



(a) Two-Tiered Scheduling with Updating.

(b) Two-Tiered Scheduling without Updating.

Fig. 7. Residual energy distribution of sensor nodes.

round based on their new residual energy levels. However, in Fig. 7 (b) coverage and CDS is established once at the beginning and nodes do not updated over time. Note that the surface in Fig. 7(a) does not fluctuate dramatically as in Fig. 7(b), indicating that the residual energy of sensors in Fig. 7(a) are close to each other. Therefore, by updating nodes, we balance the energy consumption of sensors and extend the lifetime of a sensor network.

V. CONCLUSION

In this paper, we presented a tiered approach to addressing the efficient scheduling issue in wireless sensor networks. In order to prolong network lifetime, we schedule sensors to be in power saving mode, while preserving coverage and connectivity. We decomposed the coverage and connectivity functionalities of a sensor network into two-tiers; thus, nodes having been used for connectivity or coverage have different sleeping behaviors. We first established the coverage-tier based on the sensing areas of sensors by a weighted greedy algorithm. Nodes in the coverage-tier can monitor the entire sensing field and periodically wake up to send and receive to/from the sink, whereas dominating nodes selected for the connectivity-tier stay active to forward data traffic. Simulation experiments have validated that a significant energy saving is achieved by the proposed scheduling algorithms while providing full coverage and connectivity.

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