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Coverage Optimization and Conservation of Connectivity with Load Balance for Wireless Sensor Networks

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Abstract—*The main aim of wireless sensor networks is to provide full access of sensing field as long duration as possible. As the energy of sensor nodes is limited, forming these nodes into a maximum number of cover sets capable of covering all the targets of interest and randomly activating them is a more challenging way to provide better service. Besides maximizing the number of node sets, to make sure the connectivity among all the nodes is a challenging way to achieve full coverage. In this brief, a new maximum connected load-balancing cover tree (MCLCT) algorithm is implemented to provide full access and guarantee the connection among the sensor nodes. This MCLCT consists two submethods 1) a COR for coverage managent and 2)a PLB for path determination. With this algorithm, traffic of nodes in sending and receiving sensed data can be shared, so energy consumption can be reduced. The simulation results shows the same.*

Keywords*: Wireless sensor networks, full access, targets, MCLCT, COR, PLB, energy consumption.*

1. INTRODUCTION

Wireless sensor networks comprises of sensor nodes connected with each other for data sensing, processing, transmitting and receiving purposes. Full coverage and maintenance of connectivity are the main issues associated with the sensor networks. Sensors with the power supply are deployed near the targets in low accessible areas. These sensors sense the data related to the discrete point of interests(DPOIs) and send it to the base station.

Sensor nodes equipped with transceivers can be connected to the other nodes or to the base station. A sensor can transmit and receive the data. In order to achieve better Quality of Service(QoS) full coverage of all targets(DPOIs) and connectivity among the sensor nodes is critically important issue. Coverage problem is associated with how well each target is covered.

2. RELATED WORKS

The Creation of sensor node cover sets that are connected to each other sets and also to the base station is an interesting point of aspect. Several studies have been proposed for formation of cover sets. For example, Cardei and Cardei [23] implemented the Connected Set Covers (CSC) problem which is related to maximizing number of cover sets in the way that each sensor node is connected to base station and to the other nodes. Also, Jaggi and Abouzeid implemented Greedy Iterative Energy-efficient Connected Coverage (GIECC) algorithm related to the CSC problem.

Following low energy consumption mode, Zhao and Gurusamy developed a method Communication Weighted Greedy Cover (CWGC) to increase the number of cover sets. Adopting scheduling techniques, Zorbas and Douligeris implemented Optimized Connected Coverage Heuristic (OCCH). With this they proved that network life time can be effectively improved.

3. MAXIMUM CONNECTED LOAD-BALANCING COVER TREE (MCLCT)

Implementing method consists of two submethods: a coverage-optimizing recursive (COR) heuristic and a probabilistic load-balancing (PLB) strategy. The objective of first submethod COR is to find maximum number of disjoint sets of nodes by setting one of the sensor node as sink node. In every set, nodes are able to cover all DPOIs together. So COR deals with full access of all DPOIs. The aim of PLB is to find the appropriate path to transfer the sensed data to the base station from each sensor node. For each transmission, the PLB provides different probabilities in order to reduce the traffic burden on each sensor node. Flow chart of the implementing method is shown in fig.1. First, after organizing the WSN, a group of disjoint sets DS, S and P are initialized. Then, S_a, a set of available nodes which cover atleast one DPOI, is formed by eliminating the unavailable nodes which do not cover any DPOI from S. Then from S_a, the COR will form as many disjoint sets (Ci) as possible until all the nodes in S_a are completed. All the disjoint sets (C_i) can cover all the DPOIs together. For the full coverage purpose, we have to collect the subsets of available nodes (S_a), DS={C_1, C_2, C_3,.. . . C_w}.

Then after, we can form residual nodes by S_{srd} = S/DS. The nodes available in S_{srd} are to be gone to sleep mode to preserve energy and to be activated by a wake-up sign. Next, S_{srd} and DS are used to form the dynamic cover trees and the corresponding time period of each tree is taken from the set { $\tau_1,\tau_2, ... \tau_w$}. At first, each element from the set { $\tau_1, \tau_2,. . . . . . \tau_w$} is set to zero. Afterwards, for every τ_j

($1 \leq j \leq w$), the constructed tree $T(\tau_j)$ is able to achieve full access and BS-connectivity can be determined.

If the cover tree $T(\tau_j)$ does not have full access of DPOIs, the nodes performing MCLCT activate the neighbor nodes in S_{rsd}. If both full coverage of DPOIs and base station connectivity of $T(\tau_j)$ are achieved, the time period τ_j will be updated by one second. If the full coverage or base station connectivity fails, then the currently activated dynamic cover tree $T(\tau_j)$ will be de-activated and the remaining nodes of $T(\tau_j)$ are added to the S_{rsd} and will be switched off after receiving sleep message.

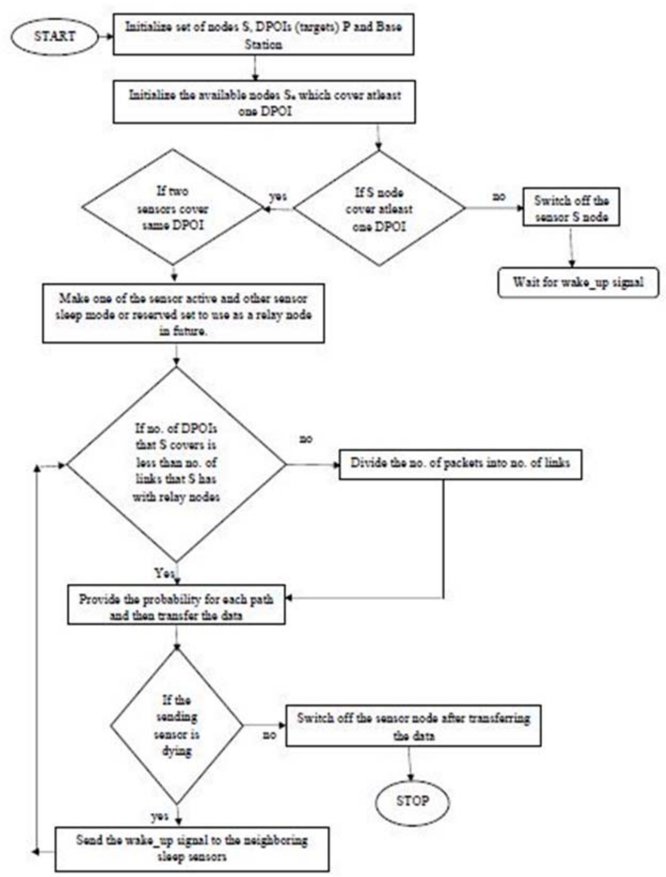


Fig. 1: The flow chart of implementing method (MCLCT).

After that, the next unused dynamic cover tree $T(\tau_{j+1})$ will be activated. The iteration process will be continuously performed and stops when the energy of all nodes will be over. Lastly, the life time of the network will be obtained by adding all the τ_j ($1 \leq j \leq w$).

The Coverage-Optimizing Recursive (COR) heuristic

The first submethod of MCLCT algorithm which is used to find maximum number of disjoint sets of nodes, DS. All the nodes in every disjoint set C_i can cover all the DPOIs. By activating these disjoint sets randomly, we can get longer network life time and full coverage.

First, we have to activate each disjoint set $C_{i,}$ individually to find the coverage range of all DPOIs. The COR heuristic continuously selects the appropriate nodes into a new disjoint set until it achieves full coverage. By doing this process, the COR can form number of disjoint sets according to DPOIs are covered by all nodes.

The Probabilistic Load-Balancing (PLB) strategy

As mentioned before, the PLB performs the load balance among the sensor nodes by varying transmission probabilities. Consider the node s_i and it has v number of parent nodes denoted by set $Prt(s_i) = \{ s_{r1}, s_{r2}, ..., s_{rv}\}$. The forwarding probabilities from s_i at τ' are denoted as: $\{P(s_i, s_{r1}, \tau') , P(s_i, s_{r2}, \tau'), ... , P(s_i, s_{rv}, \tau')\}$. According to the structure of the dynamic cover tree, the sensor nodes are situated at the end points i.e, they do not have descendents. The only duty of these sensor nodes is to sense the DPOIs and send the sensed data to the base station. The forward probability for the parent node $s_{rj} \epsilon Prt(s_i)$ when *s_i used as the sensing node is given by,*

$$P(s_i, s_{rj}, \tau') = \frac{\left(\frac{e_{rj}(\tau')}{d_{i,rj}}\right)^{\alpha}}{\sum_{k \epsilon Prt(s_i)} \left(\frac{e_k(\tau')}{d_{i,k}}\right)^{\alpha}}$$

where $e_a(\tau')$ is the residual energy of the sensor node s_f at τ' and α is the exponential factor to tune the response of the graph of energy-to-distance ratio. We use α = 2 i.e, square of the ratio of energy to distance. While transmitting the sensed data, the sensor node consumes more energy than sensing the data. The energy for transmitting the sensed data is exponentially proportional to the distance between the two sensor nodes.

Before calculating the forward probability of relay node, we first have to find weight of each path from the relay node s_k to its parent node $s_{rh} \epsilon Prt(s_k)$ as

$$weight(s_k, s_{rh}, \tau') = \left(\frac{e_{rh}(\tau')}{\left(Lexp\left(s_{rh,\tau'}\right) + 1\right)}\right)^{\beta}$$

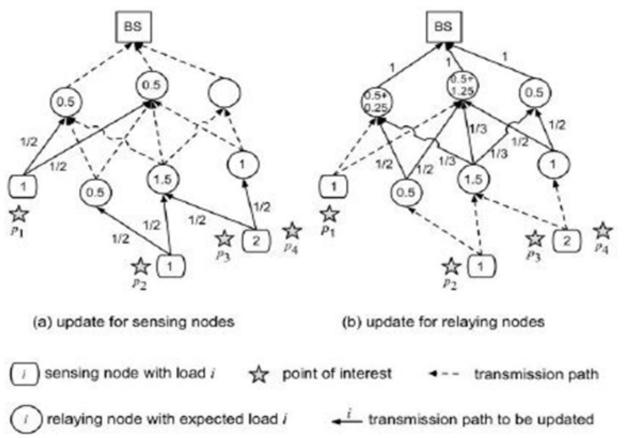
where β = exponential factor. We set the β = 4 for performing the load balance. Lexp(s_i) is the expected load of the sensor node s_i.

Let
$Dev(weight) = weight - \widehat{weight}$

Where Dev(weight) = deviation of weight

$\widehat{weight}$ = mean of weight

Then the forward probability of relay node s_k to its parent nodes $Prt(s_k)$ is given *by*



$$P(s_k, s_{rh}, \tau') = \frac{Dev\big(weight(s_k, s_{rh}, \tau')\big) - 2.minDev}{\sum_{k \epsilon Prt(s_k)}\big(Dev(weight(s_k, s_{rh}, \tau')) - 2.minDev\big)}$$

Fig. 2: Illustration of update of forward probability and expected load.

4. RESULTS

The NS2 software is used to produce the simulation results. The parameters that we have varied are number of nodes and number of DPOIs. Figs. 3-4 shows the simulation results for the implementing method. We have taken the field of size 100m x 100m and the average value of network life with standard deviation of 95% confidence interval.

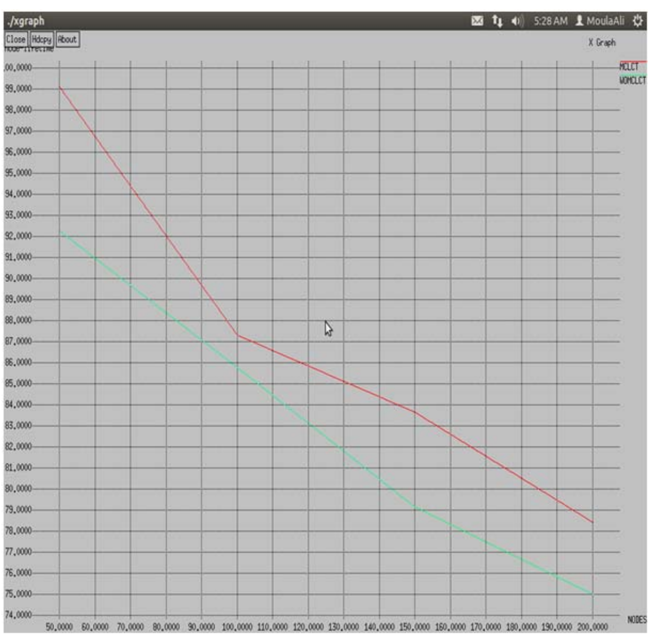


Fig. 3. Network life time when various number of nodes are considered and number of DPOIs are fixed at 30.

The following parameters are taken for the comparison purpose.

ec_s= 100nJ/bit, ec_r = 100nJ/bit, ec_t = 50nJ/bit, packet_size =500bytes, E_0=20 J. Each DPOI is generated with a data rate of 1 Kbps.

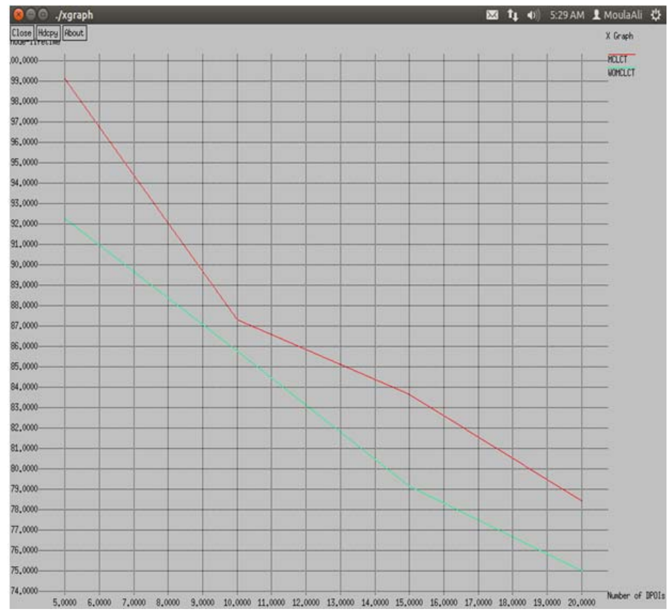


Fig. 4: Network life time when various number of DPOIs are considered and number of nodes is fixed at 200.

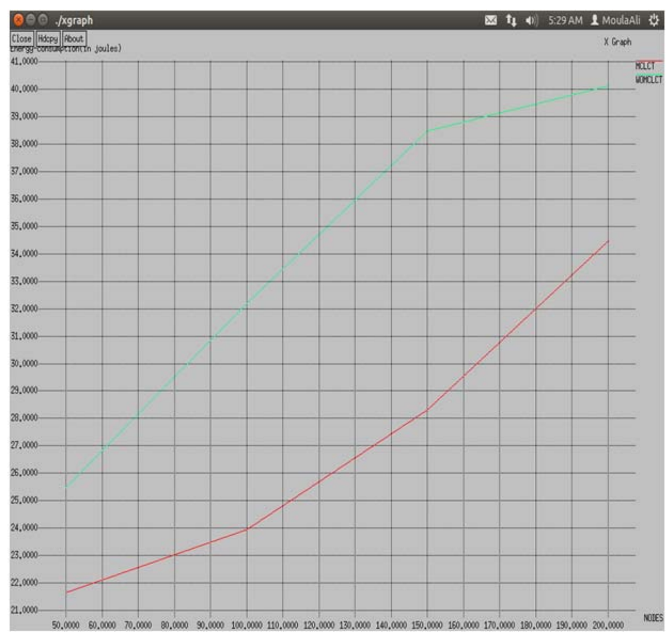


Fig. 5: Energy consumption when various number of nodes are considered.

Fig. 3 & 4 show that the comparison of the network lifetime for different number of nodes (50 to 200) and for various number of DPOIs (5 to 20). Fig. 3 shows that average network life of MCLCT is more than the existing method OCCH by 23.5% to 50.6%. Fig. 4 shows that the average network life time is more than the OCCH by 20.7% to 29.8C%.

From the simulation results, following results have been observed.

Table 1: Energy Consumption in Joules for different number of nodes.

No. of Sensor Nodes	Existing method (OCCH)	MCLCT
50	25.5	21.6
100	32.3	24
150	38.5	28.2
200	40	34.5

Table 2: Network lifetime in seconds for different number of nodes.

No. of Sensor Nodes	Existing method (OCCH)	MCLCT
50	92.1	99
100	85.5	87.5
150	79	84
200	75	78.8

Table 3: Network lifetime in seconds for different number of DPOIs

No. of DPOIs	Existing method (OCCH)	MCLCT
5	92	99
10	85.5	87.6
15	78.2	83.8
20	75	79

5. CONCLUSION

In this brief, Maximum Connected Load-balancing Cover Tree (MCLCT) algorithm is implemented. This MCLCT consists of two algorithms, a COR heuristic and a PLB strategy. The COR heuristic is responsible for the maintenance of full-coverage of all DPOIs. The PLB strategy finds the appropriate path for transmitting the sensed data from the sensor node to the Base Station. The PLB provides the probability to each path for balanced data transmission to avoid congestion or traffic burden on a particular node. With this, the energy can be utilized efficiently and the energy-efficient operation can be achieved.

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