

# Prolonging the lifetime of wireless sensor networks using secondary sink nodes

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**Abstract** This work proposes an approach for improving energy-efficiency and thus increasing network lifetime in wireless sensor network (WSN) using a logical energy tree (LET). In our scheme, LET is constructed using the remaining available energy in each node. Two routing algorithms are framed based on LET: one with centralized sink node called LETCSN and the other with centralized sink node and secondary sink nodes called LETSSN. sensor nodes are deployed in some fixed patterns. A mathematical model is devised to understand the effect of node deployment pattern on improving network lifetime. Both proposed routing algorithms are evaluated with seven different deployment patterns, simulated in ns-2 and are compared with the existing classic algorithms based on the number of data packets, throughput, network lifetime, and data packet's average network lifetime product. Our evaluation and simulation results show that LETSSN maximizes the network lifetime for all node-deployment patterns taken into consideration.

**Keywords** Deployment · Energy · Lifetime · Node · Tree · Wireless

## 1 Introduction

Smart environments are very essential today in structural, industrial, home, and transportation systems' automation and they rely mainly on sensory data from the real world. Data<sup>1</sup> come from multiple sensors of different systems situated at distributed locations. The methods of collecting, processing, and evaluating data for making decisions based on that are often very complex. Whatever complexity is present in the data handling stages, the basic inputs are generated as simple bits by hundreds of tiny devices called sensor motes which form a wireless sensor network (WSN). In many applications, the sensory data produced by sensors in a WSN are vital for providing effective control of critical or emergency situations such as earthquake and other natural disasters. A WSN generally consists of a base station (or, "gateway") that can communicate with a number of wireless sensors via a radio link. Data are passed through the network hop-by-hop, compressed if needed, and transmitted to the gateway directly or, if required, other wireless sensor nodes are used to forward data to the gateway [1–3]. Consumption of energy is the most important feature of WSN, as each sensor is often involved in generating sensor reading data or passes data to the neighboring node.

Every application and battery operated sensor node deployment require maximal lifetime of the network for robust and fault-tolerant communications. Node failure due to battery outage could cut off segments of the network. Hence, what is expected is a graceful degradation of the overall energy of the network throughout its lifetime. If the nodes remain constantly active for various operations, the energy may be drained out quickly and often the nodes have one-time battery as the source of energy, which is not replaceable once

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<sup>1</sup> The term 'Data' is considered plural. Singular is 'Datum'.

a node is deployed on the area of interest (AoI). Since the batteries need to be changed constantly, if more energy is to be consumed by the wide spread use of WSN, the design of sensor nodes is to be given due consideration. The sensor nodes need to be designed in a way to minimize energy consumption to ensure the entire network provides some guarantee of communications as long as it is needed for a specific application. The energy could also be managed efficiently by providing better routes for routing operations and minimizing the number of packet drops [4,5]. The efficiency is determined on how the nodes are deployed throughout the entire area [6].

A logical energy tree (LET) is formed based on the residual energy in each node. After calculating the residual energy the nodes are placed at level 1 and 2. The root node is the destination (or sink) node. The directional characteristics (unidirectional or bidirectional) is fixed based on the positions of the nodes (level 1 or level 2) and routing is done accordingly. This process leads to energy saving by avoiding unnecessary communication between neighbors. Neighboring nodes energy information is collected by transmitting a one-hop beacon request and that information then is used to form the LET. Neighboring information and positioning information is used to make routing decision.

This paper proposes two routing algorithms and seven fixed node distribution (deployment)<sup>2</sup> patterns to increase the energy-efficiency of the WSNs. The proposal of routing algorithms are based on Logical Energy Tree (LET). Based on the remaining energy in each node, the routing of packets to the sink node of this LET is done more efficiently. In usual case, in any WSN, there is one centralized sink node which collects information from the sensor nodes and transfers that to a system for processing. This acts as a bottleneck if the volume of information increases. Also, every sensor node, when used to forward the packets, needs to send data through the nodes (those that are in between) to the sink node, which may involve more energy consumption. Considering this issue, in our approach, additional sink nodes called Secondary Sink Nodes (SSN) are placed in the network at suitable locations. This would assist the centralized sink node by collecting the information from the nearby sensor nodes (Secondary Sink nodes) and transmit the information to the centralized sink node in a single hop. The initial energy in each of these sink nodes should be high in order to transmit and connect to the Centralized Sink Node (CSN) in a single hop.

This paper proposes the following two routing algorithms:

- With only central sink node—called LETCSN
- With additional secondary sink nodes—called LETSSN

Implementation of the proposed routing algorithms LETCSN and LETSSN are made in ns-2 [7] and the implementation

includes the seven node placement patterns. This work aims to evaluate the performance of LETCSN algorithm and compare it with the existing algorithms. Then, by placing the Secondary Sink Nodes (SSNs), the LETSSN algorithm is evaluated and compared with the existing multisink routing algorithms.

This research paper is presented in 7 sections including this introduction Sect. 1. Section 2 mentions the related works and our motivation for this work. Section 3 describes our proposal with network assumptions, preliminaries and all necessary details. Section 4 presents mathematical modeling of WSN's lifetime. Experiments on various network patterns and a variation of our idea are presented in Sect. 5. Simulation results and analysis are presented in Sect. 6. Finally, Sect. 7 concludes the paper with future research directions.

## 2 Related works

WSN routing protocols have been studied extensively from various perspectives [8–10]. The development of these protocols is based on the particular application needs and the architecture of the network. However, among several factors that should be taken into consideration when developing routing protocols for WSNs, energy-efficiency is the most important since it directly affects the lifetime of the network. There have been a few efforts in the literature pursuing energy-efficiency in WSNs. Here, we mention those works that motivated us toward the design and development of the proposed protocols.

Low energy adaptive clustering hierarchy (LEACH) [11] introduced a clustering algorithm for sensor networks. LEACH helps to arrange the nodes as clusters in the network and to take autonomous decision without any centralized control. After arranging all the clusters it chooses one of them as a cluster Head. Energy is saved during transmissions as it is done by the cluster heads. Number of cluster heads chosen will be optimum if it is 5 % of the total sensor nodes. Data fusion and data aggregation are done in the cluster heads. Change of cluster heads are effected for balancing the dissipation of energy and the change is normally done at random intervals of time. The change is made by assigning a random number between 0 and 1 to the cluster heads and choosing the maximum. LEACH reduces energy dissipation in comparison to direct communication. Nodes get dropped randomly due to dearth of energy. Clustering is dynamic and this makes the increase in network lifetime. The distributed nature of LEACH does not necessitate global knowledge. But, due to the single-hop routing of LEACH, there will be a direct transmission between node and cluster-head/sink that makes it not suitable to networks having large regions of deployment. Enhanced LEACH [12] extended LEACH protocol by balancing energy consumption in the network. The simulation

<sup>2</sup> The terms 'deployment' and 'distribution' are used interchangeably throughout the work.

results show that the Enhanced LEACH performs better in terms of network lifetime and minimizes energy consumption than LEACH. Low energy-consumption chain-based routing protocol LEACH-CC [13] protocol is characterized by each node would send information about its current location and energy level to BS. Ad-LEACH [14] is a static clustering based heterogeneous routing protocol with a cluster head selection technique adopted from DEEC [15]. It enhances both LEACH and DEEC protocols both in terms of energy-efficiency and throughput.

An improved protocol over LEACH is the Power-efficient gathering in sensor information systems (PEGASIS) [16]. In this protocol chains are formed from sensor nodes to transmit and receive between each node and one among the nodes is selected to transmit the aggregated data collected from the nodes to the BS (or, sink).

Hierarchical PEGASIS [17] is an extension to PEGASIS in which the data gathering problem is solved with the due consideration given to the energy  $\times$  delay metric. In PEGASIS, simultaneous transmissions of data messages are pursued to reduce the delay. Two approaches have been investigated that aims the avoidance of collisions and possible interference between sensors. The first approach incorporates signal coding, e.g. code division multiple access (CDMA). Spatially separated nodes alone are granted for simultaneous transmission. This protocol constructs a tree like hierarchy of chain of nodes capable of CDMA. Node selected in a particular level transmits data to the next level node in the hierarchy.

Threshold sensitive energy efficient sensor network protocol (TEEN) [18] hierarchically clusters nodes. This protocol is designed in order to respond to sudden changes of the attributes that changes due to environment such as temperature. For applications that are time-critical in nature, it is important to have responsiveness and the network operates in reactive mode. The protocol uses hierarchical grouping that clusters closer nodes to one level and the grouping goes to the higher level till the sink node is reached. The protocol also uses data-centric mechanism.

Energy-efficient Multi-sink Clustering Algorithm (EMCA) [19] EMCA is a multisink routing protocol which is used to solve energy hole problem. One major disadvantage of single sink WSN is that sensors near the sink or on the critical path in certain cases consume energy faster compared to other sensor nodes. Cluster head in EMCA is selected on the criterion of residual energy. An inter- and intra-cluster routing in EMCA is used for minimizing the energy consumption. This ensures the optimal path from sensor nodes to the cluster head. Within the cluster data is transmitted in multi hops.

Location and Energy Based Dynamical Pre-Clustering Algorithm (LEBDPC) [20] LEBDPC is a multisink routing protocol which divides the network range and dynamically

adjusts the relative position of the pre-divided clusters to balance energy consumption. During the cluster head choosing phase and transmission between cluster heads phase, location and energy of relevant nodes are taken into account. LEBDPC not only balances energy consumption of nodes in the same cluster, but also energy consumption of nodes in different clusters.

IPv6 Routing Protocol for Low-Power and Lossy Networks RFC 6550 (RPL) [21] is a multisink routing protocol which shows that the concept of a virtual root can work and can be implemented with a minimal complexity (demonstrating an easy to roll out support on existing infrastructure (only sinks need to be adapted)). Multiple sinks in RPL increase the number of sinks but the average energy consumption is decreased. By using a positioning algorithm to determine the optimal position, for the sinks, possibly even better performance can be obtained.

### 3 Our proposal

#### 3.1 Basic network assumptions and definitions

We assume a network of sensors where all the nodes transmit the signals isotropically (i.e., in all directions). However, to characterize the communication direction of a node while operating in the network (i.e., handling incoming and outgoing data), two specific definitions are used:

*Unidirectional link/node status* when in this status, a node only “receives” data collected from the neighboring sensor nodes. This node does not produce own data for transmission.

*Bidirectional link/node status* when in this status, a node receives data collected from the neighboring sensor nodes as well as produces its own data to transmit. This node transmits both own data and others’ data.

#### 3.2 Mathematical notations

Table 1 shows all the mathematical notations that will be used for describing our scheme and model with all necessary details.

#### 3.3 Logical energy tree with one central sink node (LETCSN)

In this subsection, we present our routing algorithm: LETCSN. Later, we will analyze different energy models and deployment patterns as parts of this work. The basic idea of our routing algorithm is that the residual energy of sensor nodes is used as an additional parameter for taking routing decision. In the logical energy tree (LET), there are two levels for the deployed nodes: *Level 1* and *Level 2*. Level 0 is the root which is basically for the sink or base station. Based on the

**Table 1** Important mathematical notations used in the Paper

Notation	Meaning
$E_i$	Initial energy of a node in Joule or Watt second
$P_{Total}$	Total energy consumed by the sensor node
$e_{ct}$	Power consumed for transmitting the data
$e_{cr}$	Power consumed for receiving the data
$e_{cp}$	Power consumed for sensing and processing the data
$f(x)$	Weighting function
$AN$	Average number of nodes
$C^P$	Cost factor depending on the pattern
$\alpha(x)$	Weighting function
$f(x)$	Normal distribution weighting
$\theta$	Number of data packets delivered
$n$	Number of nodes
SN	Sensor nodes

remaining energy in a participating subordinate or ordinary node (i.e., other than sink), it is placed in either Level 1 or Level 2 in the generated LET. Level 1 nodes are bidirectional and Level 2 nodes are unidirectional. Beacon request packets are used to collect energy information from neighboring nodes periodically. The LET is constructed by comparing the remaining energy of each sensor node. As shown in Fig. 1, LET is a three level logical tree. The destination node for all lower level nodes is the Level 0 node. A threshold value of energy is used to fix each sensor nodes at Level 1 (more than the Threshold) or Level 2 (Less than the Threshold)

during LET updating (Threshold Energy 0.1Joule). This is depicted in Fig. 1. Level 1 nodes have bidirectional links. This is evident as they have higher energy. Level 2 nodes have only unidirectional links and will only receive information collected from the neighboring sensor nodes. But, in the case of emergency situations, Level 2 nodes are used for both transmitting and receiving functions. By splitting the unidirectional nodes, energy is saved. So the network life-time is increased. LET is constructed by the data center node and the logical structure is sent to all the nodes. Routing decisions are made at each node using the updated copy of LET obtained along with other metrics. The LETCSN data forwarding flowchart as shown in Fig. 2.

For constructing or updating LET, sensor nodes with more energy (Level 1) will broadcast a beacon request to all the neighboring sensor nodes to collect the information. The neighboring Level 1 nodes in turn will respond to these beacon requests by sending the remaining energy information, location information. When LET is used for routing/forwarding the information from the sensor nodes to the destination node (i.e., the sink), the sensor node will always select the neighboring Level 1 node that is the closest to the destination node. Routing of the packet is changed when the forwarded packet reaches a node that has no Level 1 neighboring node close to the destination node. Next hop is deducted using the fixed routing algorithm. It means that if a particular path fails (or, any one of the nodes fails), automatically the next hop is chosen using shortest path routing algorithm.

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**Algorithm: Pseudo code of Data forwarding using LETCSN:**

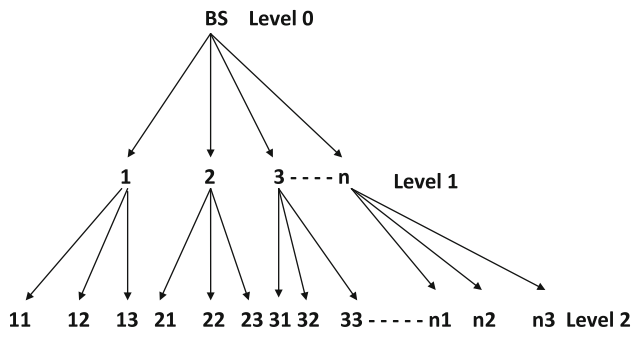
```

Input:  Number of sensor Nodes n;
        Initial energy level  $E_i$ ;
        Destination node  $d(p)$ ;
        Position of node  $p$ ;
        Node identification id;
        List of nodes  $L\{SN_i(id, E, P)\}$ ;

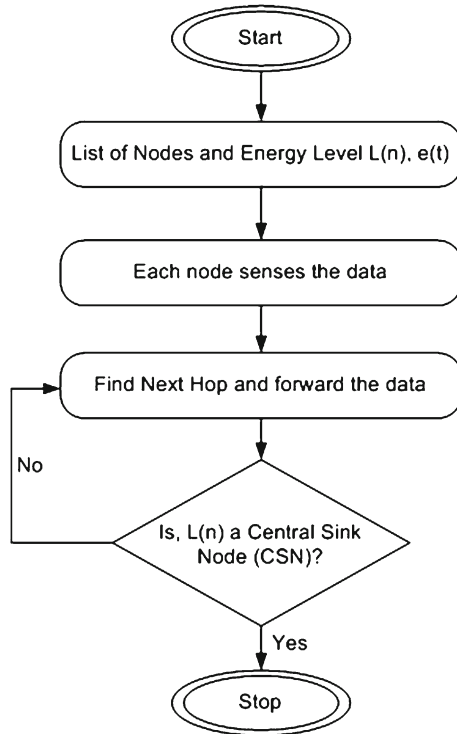
LET_use
{
    for each node  $SN_x$  with sensed data
    {
        Repeat (till central sink node CSN is reached)
        Find Next_Hop ( $SN_y$ ) using LET;
        Data(Next_Hop ( $SN_y$ ))  $\leftarrow$  Data( $SN_x$ );
    }
    /* from last SN forward data to CSN */
    Data(CSN)  $\leftarrow$  Data(Next_Hop( $SN_y$ ));
}

```

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**Fig. 1** Pictorial representation of logical energy tree (LET)



**Fig. 2** Flow diagram for LETCSN data forwarding

In our approach, as a node's involvement in transmission and reception is decided based on residual energy, each node's energy consumption is effectively managed. With low energy, nodes are not allowed to take part in transmission of own data which would have otherwise consumed significant amount of energy than just reception. Thus, the overall lifetime of the node is increased and consequently, the network lifetime is increased.

After presenting our main routing algorithm (a variation would be presented later in the paper), in the next section, we will present how to model network lifetime for a WSN.

#### 4 Analysis of network lifetime formulation

Various models and analyses of Network Lifetime (NLT) of WSN have been proposed by a number of researchers. Most

of the works chose a generic model for the NLT. For example, some models are proposed for a cluster based WSN and some researchers have proposed model to maximize the NLT by placing the nodes in the optimal positions [22]. Similarly, a number of other researchers suggested a model specific to the environment and application which a particular WSN is intended for [23–25]. Our investigation so far shows that there is no generalized approach available to be used for all types of networks. Many, if not, most of the researchers used heuristic-based approach for modeling the system. A heuristic model for the Network Lifetime (NLT) is proposed in this paper which is also based on the concepts of the research in [22–25].

The model proposed for the maximum NLT i.e. the time for which the network remains alive depends on the initial energy of the sensor node, consumption of energy due to transmission, energy required for reception and the energy for data processing in the sensor nodes. This Maximum NLT ( $MaxLT_N$ ) is defined to be,

$$MaxLT_N = \frac{E_i}{P_{Total}} \quad (1)$$

Where  $E_i$  is sensor node's initial energy in Joules or watt-seconds and  $P_{Total}$  is the total energy consumed by the sensor node for sensing and transmitting the sensed data to the base station node which is represented by watt.

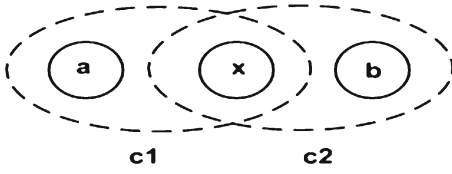
This total energy  $P_{Total}$  is evaluated to be,

$$P_{Total} = (e_{ct} + e_{cr} + e_{cp}) \times \alpha(x) \times AN \quad (2)$$

where,  $e_{ct}$  is the consumption of power for data transmission,  $e_{cr}$  is the consumption of power for data reception,  $e_{cp}$  is the consumption of power for data sensing and internal processing,  $\alpha(x)$  is a probabilistic weighting function (considering any two sensor nodes, this function represents the probabilistic behavior of the two nodes involving in a transmission or not) and  $AN$  is the number of nodes in an average involving in data transmission from source node to BS node.

The total power consumed ( $P_{Total}$ ) is the sum of power consumption of a sensor node due to transmission and reception of data packets with the neighboring nodes and consumption due to internal operations i.e. both sensing data and processing data. Data packets are forwarded through a number of intermediate nodes. The total power required include the power consumption of all the intermediate nodes. Hence,  $P_{Total}$  is to be multiplied by the number of nodes involved in transmission on an average. In WSN, the sensor nodes are deployed over a sensing field in a particular pattern called deployment pattern. The environment parameter to be sensed may occur at any point on the sensing field randomly. This parameter will be identified by the sensor node closer to that point. The node that senses the parameter could be





**Fig. 3** Node  $a$  or  $b$  senses the data and transmits to the base station  $x$

either closer to the BS or far away, giving a randomly varying value for the number of sensing nodes involved in sensing and transmission, with a minimum value being as shown in Fig. 3. In this figure, the data sensed by node  $a$  is transmitted and is received at BS  $x$ , being the neighbor. The probability that these two nodes getting involved in data transmission can be evaluated using the probability distribution function. This paper assumes the probability distribution function as normal distribution. Hence, in such a network, the modeling assumes the weighting function as the normal probability distribution function [26] given by,  $f(x)$  is given by

$$f(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \quad (3)$$

From Eq. 3, the probability that an environment parameter is sensed and transmission of data occurs between two sensor nodes may be evaluated by substituting a value of 2 for  $x$ . Figure 3, shows two such possible transmissions of sensed parameter, represented by  $c1$  and  $c2$ . Hence, the probability for data sensing and transmission involving two nodes may be given by,

$$\begin{aligned} \alpha(x) &= f(x) |c1 + \varphi(x)| c2 \\ &= 2 \times f(x) \\ &= 2 \times \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \end{aligned} \quad (4)$$

Hence, the total power ( $P_{Total}$ ) is given by,

$$\begin{aligned} P_{Total} &= (e_{ct} + e_{cr} + e_{cp}) \times \alpha(x) \times AN \\ &= (e_{ct} + e_{cr} + e_{cp}) \times \left\{ 2 \times \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \right\} \times AN \end{aligned} \quad (5)$$

Substituting this in the Eq. (1),  $Max LT_N$  is calculated as,

$$Max LT_N = \frac{E_i}{(e_{ct} + e_{cr} + e_{cp}) \times \left\{ 2 \times \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \right\} \times AN} \quad (6)$$

The maximum Lifetime  $Max LT_N$  is further influenced by how the nodes are deployed (topology or node placement pattern) on the entire field for sensing the parameter. Assuming the deployment of sensor nodes is uniform over the field,

pattern like ALL pattern shown in Fig. 4a is obtained. So, this deployment pattern is taken as the reference pattern and the value of  $Max LT_N$  is given in Eq. (6). The  $Max LT_N$  of other pattern or topology can be modeled as follows:

$$Max LT_{N(p)} = NLT_{max} \times C^p \quad (7)$$

where,  $C^p$  is a cost factor depending on the pattern.

The main differences between each node deployment patterns or topology are: the number of nodes, the pattern of node placement and the density of nodes. Hence, to accommodate these differences an additional factor called  $C^p$  (Cost factor) is devised. It may be represented as a ratio of number of nodes in the pattern under evaluation to the number of nodes in the reference pattern and is given by,

$$C^p = \sqrt{\frac{N_P}{N_{ALL}}} \quad (8)$$

where,  $N_P$  is the number of nodes in the pattern for  $Max LT_N$  to be calculated and  $N_{ALL}$  is the number of nodes in the reference pattern(ALL).

Hence, the general form of  $NLT_{max}$  is given by,

$$Max LT_N = \frac{E_i}{(e_{ct} + e_{cr} + e_{cp}) \times \left\{ 2 \times \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \right\} \times AN \times C^p} \quad (9)$$

Or,

$$Max LT_N = \frac{E_i}{(e_{ct} + e_{cr} + e_{cp}) \times \left\{ 2 \times \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \right\} \times AN \times \sqrt{\frac{N_P}{N_{ALL}}}} \quad (10)$$

This model is used for evaluating the maximum lifetime of the network of different node distribution patterns.. The value of  $Max LT_N$  is calculated for a particular pattern by substituting the initial energy of each sensor node, consumption of energy by each node for transmission of data, reception of data, internal processing of data and the number of nodes deployed. The theoretical value can be compared with the value of NLT obtained by conducting the experiments.

**Calculation of  $Max LT_N$  for ALL Pattern:** The values used for the simulation experiments conducted to find the  $Max LT_N$  are used and substituted in Eq. (1).

These values are,

$$\begin{aligned} \text{Initial energy } E_i &= 0.5 \text{ J or } 0.5 \text{ watt-seconds} \\ (1 \text{ J} &= 2.778 \times 10^7 \text{ KWh}) \end{aligned}$$

Energy consumed for transmitting the data,  $e_{ct} = 0.08$  w  
 Energy consumed for receiving the data,  $e_{cr} = 0.02$  w  
 Energy consumed for sensing and processing the data,  
 $e_{cp} = 0$  w.

Compared to the values of energy consumed for transmission and reception, the consumption of energy for sensing the phenomenon and internal processing in the sensor node will be very negligible and hence assumed as 0 w.

The probability of the two nodes involved sensing and transmitting data to the base station is obtained by substituting  $x=2$  in  $f(x)$  the weighting function. Hence,

$$f(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} = 0.108 \quad (11)$$

AN is the average number of nodes involved in the transmission of data from the source to the base station and this value for the all pattern is approximately 3.

The number of nodes in ALL pattern is 50. Hence the cost factor  $C^p$  is calculated as,

$$C^p = \sqrt{\frac{N_P}{N_{ALL}}} = 1 (\text{since } N_P = N_{ALL}) \quad (12)$$

Substituting all these values in equation for  $Max LT_N$

$$\begin{aligned} Max LT_N &= \frac{E_i}{(e_{ct} + e_{cr} + e_{cp}) \times \left\{ 2 \times \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \right\} \times AN} \times C^p \\ &= \frac{0.5}{(0.08+0.02) \times 0.108 \times 3} \times 1 \\ &= 15.43 \text{ s.} \end{aligned} \quad (13)$$

This value is the theoretical maximum of the NLT for ALL pattern. Similarly, the value of  $Max LT_N$  may be calculated for other patterns.

## 5 Experiments on the network models

### 5.1 Node distribution patterns for WSN

Placement of sensor nodes plays a very important role on sensor networks [27,28]. Efficiency of signal detection depends on the position of the sensor nodes. Hence, in this work, we analyze seven different distribution patterns of placing the nodes. Figure 4 shows the seven node distribution patterns that we simulated. Pattern 1 shown in Fig. 4a is a matrix of

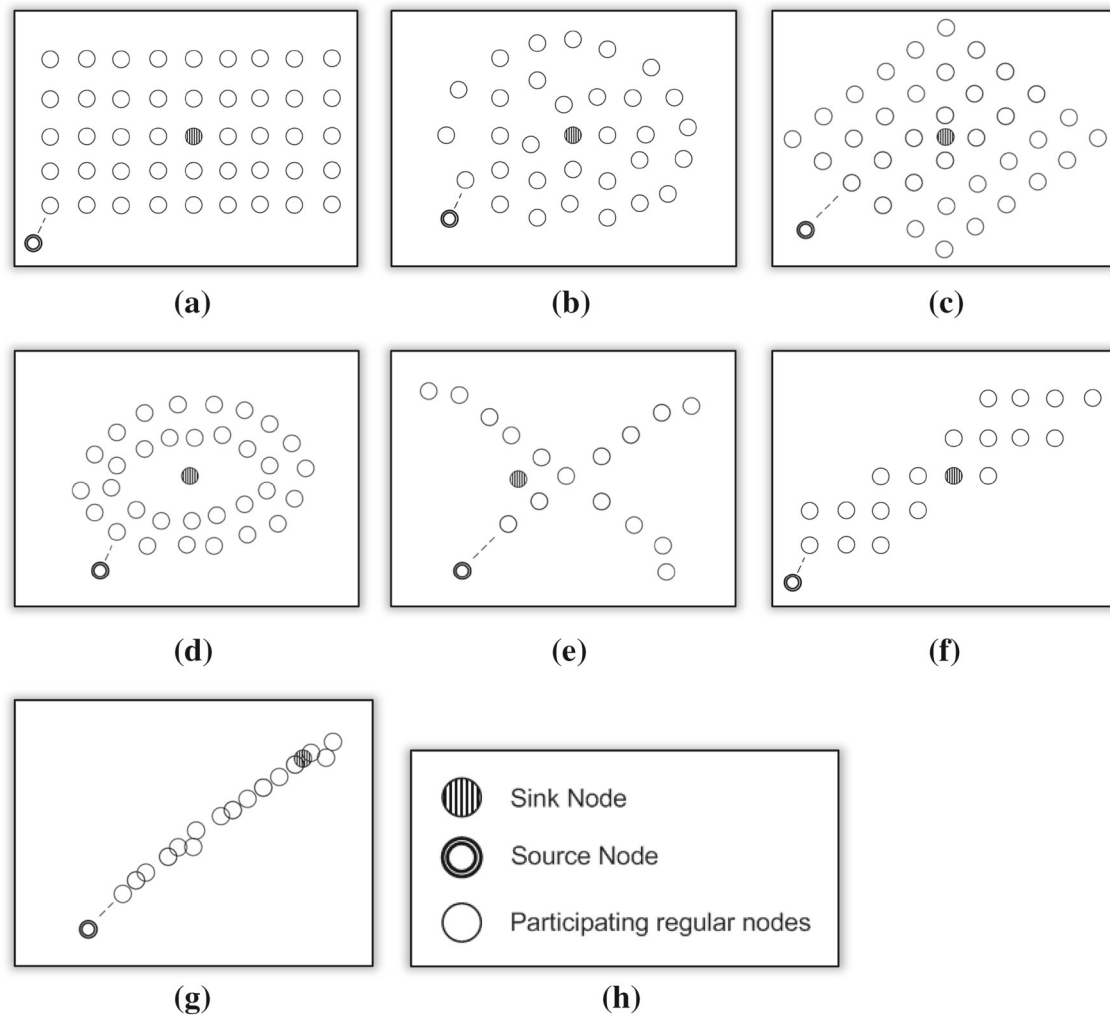
sensor nodes with nodes placed in every cross section. This pattern has redundant nodes but it is more efficient to detect the physical phenomenon to be sensed within the entire area.

A mobile node is used to simulate the occurrence of a physical phenomenon that is to be sensed by the WSN. Similarly, Pattern 2 to Pattern 7 is simulated as shown in Fig. 4b–g. These seven sensor node placement patterns are used for evaluating their performance. The patterns 1 to 7 simulated are aimed to provide placement patterns that may be used for several applications such as, structural monitoring of building, street light control, earthquake detection, habitat monitoring, etc. By using different protocols such as LEACH [11], PEGASIS [16], TEEN [18], LETCSN, and LETSSN, energy-efficiency and node lifetime analyses are performed. Simulation is performed with the packets transmitted from the sensing node (that generates the data or sensed data). This transmission of packet simulates that the phenomenon is occurring at the place of source node and the packet receiving by sensor nodes simulates the sensed data. All sensed data are transmitted to the base station or sink node through the other intermediate participating nodes. The simulation scenario generated was available in a *nam* file. When this file was executed in a *nam* editor, the simulated network was displayed.

### 5.2 Simulation of deployment patterns with secondary sink nodes (SSNs)

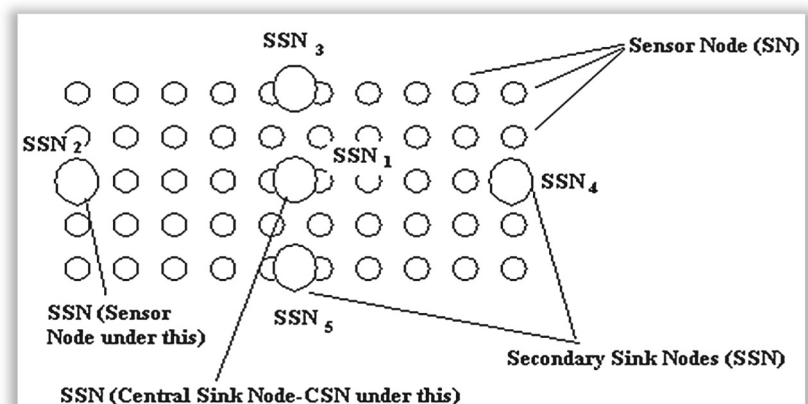
The previous subsection dealt with the simulation of WSN with deployment of nodes in fixed patterns. All these patterns use a single centralized sink node (CSN). This centralized sink node has to receive information from all the sensor nodes. The routing uses the logical energy tree based routing algorithm called LETCSN. The major problem with the single sink node is that this node becomes a bottleneck if the volume or bandwidth of data increases. The route will also be longer and hence, would consume more energy. As an alternate to this, we propose using multiple sink nodes [29,30] called Secondary Sink Nodes (SSN), placed at fixed locations. The routing algorithm proposed with these Secondary Sink Nodes is called LETSSN. The placement of secondary sink nodes in Pattern1 (ALL Pattern) is shown in Fig. 5. All the secondary sink nodes are placed above the sensor nodes deployed at the same locations. In the figure as depicted, Secondary Sink Node 1 (SSN<sub>1</sub>) is placed above the centralized sink node. The transmitting antenna power of each sensor node is adjusted such that the data transmitted from them reach the neighboring one-hop node. The antenna powers of secondary sink nodes are adjusted such that the data can reach the closest one-hop neighboring secondary sink node.

If any sensor node (say, SN<sub>x</sub> in Fig. 6) sends information, it has to identify the nearest SSN. There are three closer



**Fig. 4** Various WSN Simulation Patterns. **a** Pattern 1 (*all*), **b** Pattern 2 (*circular*), **c** Pattern 3 (*diamond*), **d** Pattern 4 (*eye*), **e** Pattern 5 (*cross*), **f** Pattern 6 (*step*), **g** Pattern 7 (*Chi square distribution*), **h** The legend for all figures (**a–g**)

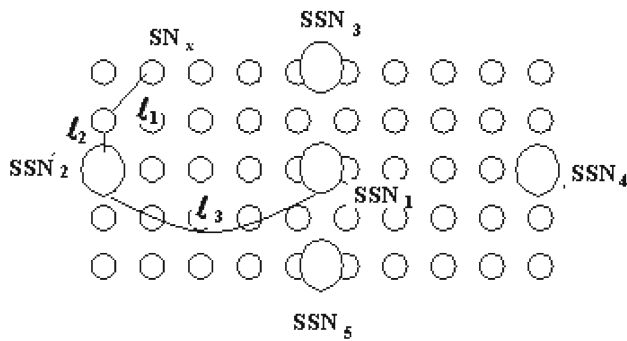
**Fig. 5** Placement of secondary sink nodes (SSN) in pattern 1 (ALL)



Secondary Sink Nodes:  $SSN_1$ ,  $SSN_2$  and  $SSN_3$  to  $SN_x$ . The locations of these Secondary Sink Nodes are known to all sensor nodes in advance. The node evaluates the distance from itself ( $SN_x$ ) to  $SSN_1/SSN_2/SSN_3$  and chooses the closest

one to it. Then, using the LETSSN, it forwards the information to the  $SSN_1$ . From the  $SSN_1$ , it transmits the information to the centralized sink node in one hop. A possible routing could be through  $l_1$ ,  $l_2$  and  $l_3$  as shown in Fig. 6.





**Fig. 6** Data forwarding using SSN

moves randomly over the entire area. The positions of secondary sink nodes are the same for all the patterns (i.e., pattern 1–7). The pseudo code for the data forwarding algorithm using LETSSN is presented below:

**Algorithm: Psudocode for Data forwarding algorithm using LET\_SSN**

```

LET_SSN_use
{
for(each node  $SN_x$  with sensed data)
{
    for( $i=1$  to  $n$ ) /* for all secondary Sink Node  $SSN_i$  */
    {
        If( $SN_x$  is closer to  $SSN_i$ )
            then Next_Hop( $SSN$ )  $\leftarrow SSN_i$ ;
        else
             $i++$ ;
    }
    /*if  $SSN_i$  is the closest secondary Sink Node*/
    Data(Next_Hop_ $SSN_i$ )  $\leftarrow$  Data( $SN_x$ );
    Data( $CSN$ )  $\leftarrow$  Data(Next_Hop_ $SSN_i$ );
}
}

```

The flow diagram for LETSSN data forwarding is shown in Fig. 7.

## 6 Performance evaluation and analysis

### 6.1 Simulation setup and parameters

Table 2 shows the simulation parameters that were used. We performed our simulations with the seven distribution patterns that have been already discussed. In all the seven scenarios, the source node was initially placed at (2, 2) and was made mobile. It was initially made to move towards the

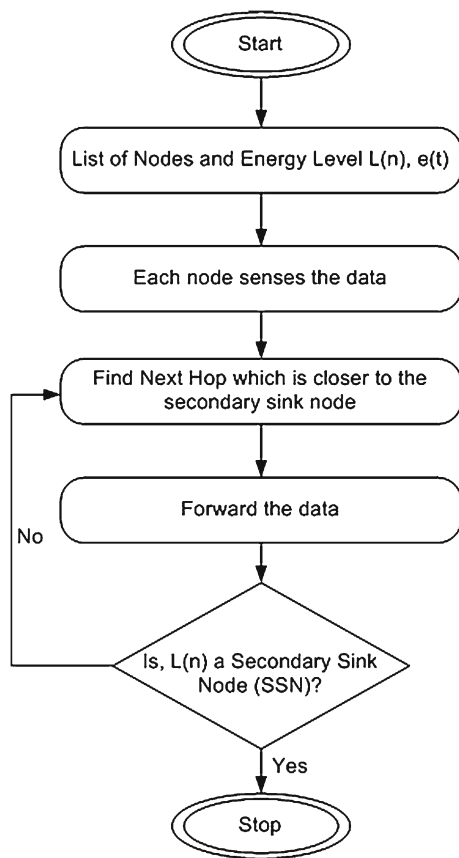
point (250, 200) and then towards (2, 500). The base station node received the information from the sensor nodes. To analyze the energy efficiency and NLT of the WSN, different single and multisink routing protocols are taken into consideration. They are: LEACH, PEGASIS, TEEN, EMCA, LEBDPC, RPL, LETCSN, and LETSSN. The simulations were performed by transmitting packets from source node to the base station node through the sensor nodes. Each simulation scenario generated the patterns which were stored in *nam* file.

### 6.2 Simulation results and analysis

LETCSN and LETSSN were implemented as new WSN routing protocols in ns-2. Fixed routing mechanism was used in LETCSN. The LET was constructed every 2 s in the simulation experiments conducted. But, this LET refreshing time

in practical implementation may be in the order of minutes. Trace files were generated during the simulation of different patterns with routing algorithms. The contents of these files were used to evaluate the network lifetime (NLT) with the initial energy of 0.5 J which would reduce to zero and this duration was taken as the network lifetime of each simulated network pattern.

We calculated the network lifetime for the seven node distribution patterns with the routing protocols: PEGASIS, TEEN, LEACH, EMCA, LEBDPC, RPL, LETCSN, and LETSSN. The results indicate that LETSSN has longer network lifetime compared to the other routing alternatives for all the node distribution patterns.



**Fig. 7** Flow diagram for LETSSN data forwarding

**Table 2** Simulation parameters

Parameters	Value/Type
Simulation area	500 m × 250 m
Number of nodes	19~50
Channel	Wireless channel
Propagation	Free space
Network interface type	Wireless physical interface
Mac type	Mac 802.11
Interface queue type	Drop tail/priority queue
Antenna	Omni antenna
Interface queue length	50
Routing protocol	LEACH/PEGASIS/TEEN/EMCA/LEBDPC/RPL/LETCSN/LETSSN
Antenna height	0.35 m
Transmission range of the sensor node	50 m
Transmission range of the secondary sink node	200 m

In order to combine three parameters: NLT, data packets, and number of nodes as a common parameter, DANLT product was devised. Average Network Life Time (ANLT) is evaluated first. From the simulation experiments conducted

for the different patterns, ANLT is calculated by:

$$ANLT = NLT/n \quad (14)$$

where,  $n$  is the number of nodes. And,

$$DANLT \text{ Product} = \theta \times ANLT \quad (15)$$

where,  $\theta$  here denotes the number of data packets delivered.

Network Life Time (NLT) is the amount of time until the first sensor in the network runs out of energy.

$$T = \min T_k \quad (16)$$

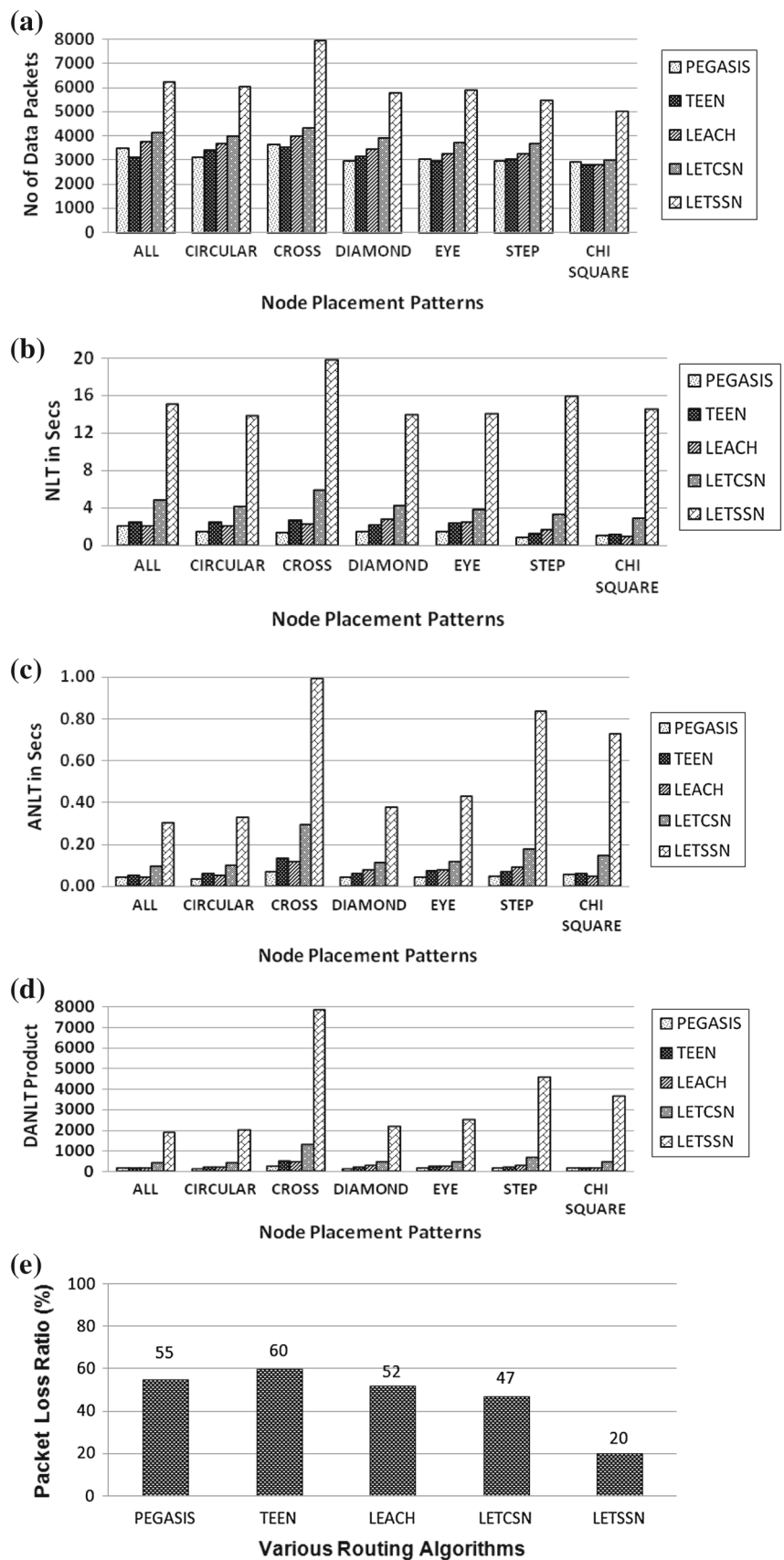
There are some interdependencies between these three parameters:

- When the number of nodes is maximum, NLT is increased.
- When NLT is maximum, data packets delivered is maximum.
- With properly switch ON and OFF the nodes, NLT is increased with smaller number of nodes.

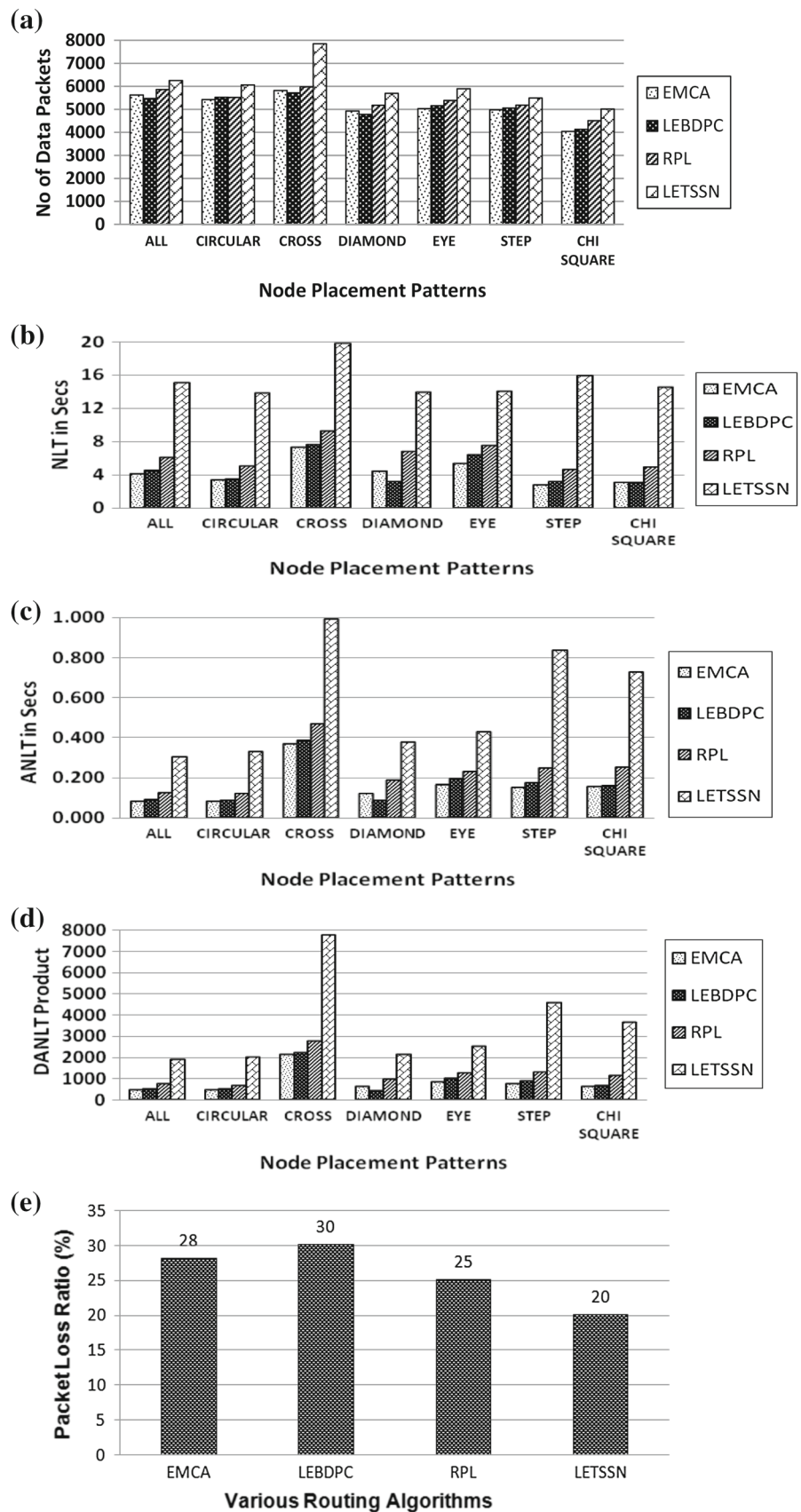
Figure 8a–d show the values of Number of data packets delivered, NLT, ANLT, DANLT product and packet loss ratio for various routing algorithms (respectively) for seven node distribution patterns with the routing algorithms: PEGASIS, TEEN, LEACH, LETCSN, and LETSSN. This shows that the routing algorithm, LETSSN performs better for all the node distribution patterns compared with other routing algorithms. Figure 8a shows that the number of data packets successfully delivered is maximum for LETSSN routing algorithm compared with other routing algorithms for seven node distribution patterns. Figure 8b shows that the NLT is maximum for LETSSN routing algorithm compared with other routing algorithms for seven node distribution patterns. Figure 8c shows that the ANLT is maximum for LETSSN routing algorithm compared with other routing algorithms for seven node distribution patterns. Similarly, Fig. 8d shows that the DANLT product is maximum for LETSSN routing algorithm compared with other routing algorithms for seven node distribution patterns. LETSSN has higher energy efficiency, throughput, and number of data packets delivered. This proves that LETSSN improved the overall efficiency of the sensor network. Figure 8e shows the packet loss ratio for various routing algorithms. This shows that LETSSN has low packet loss ratio compared with other routing algorithms.

Figure 9a–d shows the values of Number of data packets delivered, NLT, ANLT, DANLT product and packet loss ratio for various routing algorithms (respectively) for seven node distribution patterns with the various multisink routing algorithms: EMCA, LEBDPC, RPL, and LETSSN. Figure 9a

**Fig. 8** **a** Number of Data Packets for various node placement patterns -; **b** NLT for various node placement patterns -; **c** ANLT product for various node placement patterns -; **d** DANLT product for various node placement patterns—with various routing algorithms-; **e** packet loss ratio for various routing algorithms



**Fig. 9** **a** Number of Data Packets for various node placement patterns -; **b** NLT for various node placement patterns -; **c** ANLT product for various node placement patterns -; **d** DANLT product for various node placement patterns—with various multisink routing algorithms-; **e** packet loss ratio for various multisink routing algorithms



shows that the number of data packets successfully delivered is maximum for LETSSN routing algorithm compared with other multisink routing algorithms for seven node distribution patterns. Figure 9b shows that the NLT is maximum for LETSSN routing algorithm compared with other multisink routing algorithms for seven node distribution patterns. Figure 9c depicts that the ANLT is maximum for LETSSN routing algorithm compared with other multisink routing algorithms for seven node distribution patterns and similarly, Fig. 9d shows that the DANLT product is maximum for LETSSN routing algorithm compared with other multisink routing algorithms for seven node distribution patterns. This shows that the routing algorithm, LETSSN performs better for all the node distribution patterns compared with other multisink routing algorithms. LETSSN has higher energy efficiency, throughput, and number of data packets delivered. This proves that LETSSN improved the overall efficiency of the sensor network. Figure 9e shows the packet loss ratio for various multisink routing algorithms. This shows that LETSSN has low packet loss ratio compared with other multisink routing algorithms.

### 6.3 Connectivity of the network for reliable communication

Disconnected portions of the network due to battery outage of certain linking nodes would hinder reliable communication in the network. Considering this issue, our approach ensures good connectivity in the network. As residual energies are used to construct the LET, each time the higher energy nodes are used more than the less energy nodes. This ensures a graceful degradation of performance of the network and extends the overall lifetime, keeping the entire network connected as long as possible.

### 6.4 Memory requirement, scalability, and neighbor information related to LET

LET is a logically constructed tree to maintain the network. The logical structure of the LET (which includes a node and all its surrounding nodes) is sent to all the nodes for taking routing decision along with other routing metrics. Hence, it does not require any significant amount of extra memory for the nodes (to keep it) but when the participating nodes follow the algorithms in making decisions of their own (whether to transmit own data or not), the method works. The memory requirement thus would be similar to other traditional approaches based on the usage pattern of the network. Our approach does not restrict the network to become large in size however, as the studies have revealed, small to medium-sized WSNs would be the best application scenarios for achieving communication reliability by preservation of energy to the maximum possible lifetime.

From graph theory, for the case of planar graph, it is proven that every plane graph can be at best 6-colored [31]. That means a vertex  $v$  has no more than 5 neighbors. If the network is considered as a planar graph, this would be true. In that case, the number of neighbors would be reasonable for transmission fairness among the nodes. Dense deployment is possible however, may be inefficient if all the nodes within the same neighboring range compete with each other to get the clearance of the same channel. From this perspective, the number of exchanged beacon messages for collecting residual energy information would still be manageable in our approach. Interested readers are referred to a study presented in [32] on the number of beacon messages required for neighborhood discovery based on different neighborhood size of a network.

### 6.5 Further discussion

As could be seen from our obtained results, both algorithms perform fine after implementation. LETSSN, with its secondary nodes would increase the operational cost of the network but the gain is with maximum lifetime and guaranteed packet delivery. While WSNs are envisioned to be low-cost networks for reliable data supply, our model would need slight increase of cost if LETSSN approach is used. This trade-off is justified by the overall gain in various aspects as noted above. Otherwise, LETCSN would be the algorithmic choice. We used in all cases, some fixed patterns of node deployment. Such deployments are not imaginary as all random deployments would get any of these patterns or a combination of these in reality, and can be done with some specific tools; for instance, deploying nodes from vehicle with controlled approximate distance (by controlling the power to throw/launch the nodes). Even if the patterns are not strictly followed while deployment, the routing strategies are still applicable and would perform better than the classic energy-efficient routing protocols.

## 7 Conclusions and future works

Two routing algorithms, LETCSN and LETSSN are proposed in this work. The improvement of energy efficiency is further attempted by using seven fixed node distribution patterns for WSN. The proposed algorithms, LETCSN and LETSSN were implemented in ns-2. The performances of the LETCSN algorithms were compared with the existing classic routing algorithms PEGASIS, TEEN, LEACH, and LETSSN. Similarly the performances of the LETSSN algorithms were compared with the existing multisink routing algorithms EMCA, LEBDPC, and RPL. The results clearly show that the routing approach, LETSSN maximizes network lifetime for all the node distribution patterns taken into con-



sideration in our experiments. Among these patterns, Pattern 5 (CROSS) performs the best in terms of energy efficiency, Network Lifetime, Number of data packets delivered, and throughput. Also, LETSSN has low packet loss ratio compared with other single and multi sink routing algorithms. To ensure reliable communication in WSN, our approach does offer a good solution that would be useful in many application scenarios where number of nodes may vary but not very large. As our future work, we plan to form efficient pattern by placing the nodes randomly and readjusting the positions by evaluating their DANLT product. Node mobility may be permitted even in larger scale. Optimization techniques may also be used for maximizing the DANLT product by adjusting the positions of Sensor Nodes and Secondary Sink Nodes (SSNs).

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