

# Extension of Lifespan in WSN

Kusum Yadav\* and Hula Mahmoud Alkhasawneh

Department of Computer Science, College of Computer Science and Engineering,  
University of Hail, Hail, Kingdom of Saudi Arabia;  
Kusumasyadav0@gmail.com, h.alkhasawneh@uoh.edu.sa

## Abstract

**Objectives:** Since Wireless Sensor Network has played a crucial role in our life, further research is needed to enhance its performance. For missions to be accomplished successfully, the lifetime span has to be prolonged. The lifetime of WSNs is considered a crucial issue that has to be studied further. **Methods/Findings:** Thus, numerous researches from different perspectives have been proposed. In this study and research, it has been found that there is a harmful process called sink isolation (hotspot zone) because of neighbor nodes of sink running out of energy more than the others. Our point of view is that these hotspot zones are of more concern than far away zones. Thus, a pioneering Q-metric is studied which tackles the energy consumption at each hotspot zone relative to the dimension of its interconnected nodes at the far away zone. **Application:** Accordingly, the Q can be manipulated to switch data traffic to alternative routes lead to a more proper hotspot zone and hence an exhausted hotspot zones will be avoided and consequently lifetime of this network will be extended.

**Keywords:** Hotspot, Lifetime, Tree Topology, Route Metric, WSN

## 1. Introduction

In last so many years, a large research has addressed the prospective of alliance among sensors in data collection as well as its processing and the coordination and management of the sensing activity were conducted. However, most of the sensor nodes are restricted in energy supply as well as data transmission rate. Thus, innovative techniques that eliminate energy inefficiencies that would shorten the network lifetime are very much required. Such restrictions combined with a typical deployment of large sensor nodes result to impose many challenges to the design and management of WSNs and result into energy-awareness at all the layers of the networking protocol stack implementation of Wireless Sensor Networks (WSN) in our contemporary life has attracted

research community for further study. However, there is a problem in a tree routing that packets follow the tree topology to the destination (sink) even if the destination is located nearby (auto routing protocol). Thus, deficiency in the performance is expected when multiple trees are constructed in WSNs with multiple sinks. In addition to that, such network is prone to sinks hotspot phenomenon due to un-fair load forwarding towards some sinks. In this paper, we also introduce a new framework of topology management-based data routing that overcome these deficiencies in order to extend the lifetime

Initial deployments of Wireless Sensor Networks (WSNs) were based on a many-to-one communication paradigm, where a single sink gathers the data from the different data sources. Just recently, however, scenarios with multiple sinks are increasingly being proposed,

\*Author for correspondence

e.g., to deal with actuator nodes or to support a number of high-level programming abstractions. The resulting many-to-many communication makes the present solutions for single-sink scenarios very much inefficient. Recent developments, however, call for scenarios where the data sensed must be transmitted to multiple sinks. This network architecture is clearly required if the same Wireless Sensor Network is serving a large number of applications, each running on a distinct device.

For purposes such as temperature, light, humidity, noise level, patient monitoring, intruder detection, enemy tracking, battlefield and surveillance, hundreds or thousands of sensors nodes are spread out in the vicinity area of interest<sup>1,3</sup>. However, due to sensors' constrained battery it is prone to die fast and consequently, the network faces a problem of failure to complete its tasks and. The time taken by network to face a problem of node death (running out of battery) is known as the lifetime span. Different points of views have been tackled by some researchers to prolong this span. Energy-aware based-routing protocol, topology control, data dissemination, media access control is some of them<sup>4,5</sup>. Another perspective is the load balance across the entire network and reduces the energy dissipation rate at each node<sup>6-8</sup>.

One of the issues that are addressed by WSN interested researcher is that tree topology routing tables are not required to send the packet to the destination and just blindly follows this designed tree to its intended destination (sink) even if the destination itself has located nearby the forward nodes<sup>9</sup>. This phenomenon is called tree's autorouting.

In Tree topology application, a graphical map of the network is the fundamental data used for each node. To produce its map, each node floods the entire network with information about the other nodes it can connect to. Each node then independently assembles this information into a map. The tree routing suffers from various limitations

- Tree Formation is very much tedious, prolonged and complex.
- It is very prone to node breakdown. If a parent node breaks down, then the complete sub-tree

becomes isolated from the corresponding base station throughout the current time span.

- Power consumption is not even across the nodes. The nodes in the neighbourhood of the base station absorb a large power to forward the different packets from all the nodes in their sub-tree, while the leaf nodes in the spanning tree are not concerned with any forwarding and absorb the minimum energy.
- There is a large delay in sending the data to the root node from the leaf.
- Overhead for the tree maintenance is also high.

The routing cost in term of hop counting due to the autorouting is reduced. An addressing mechanism and autorouting in the tree topology was the focus of so it proposed assignment pattern to design the nodes addresses to route data from node to the next. Present the approach of tree overlapping to derive a mesh topology to enhance data routing.

On the other hand, the performance of WSN with multiple sinks has been tackled by some researchers. In<sup>10</sup> the concern was in data collection where it minimizes its latency. Multiple sink localization and how to route traffic to them is addressed by<sup>11</sup>. In<sup>12</sup> partitioned the network into clusters to increase the manageability of the network as well as reduces the energy dissipation at each node. In<sup>13</sup> design a mathematical model that determine sinks' locations to minimizing the sensors' average route distance. According to their requests it builds efficient routes with high sharing degree from the coordinator to multiple sink nodes.

In<sup>14</sup> the tree-based topology with Reinforcement Learning and Q-Routing techniques to approximate goodness of possible routing decision "action". The lower routing cost in a spanning tree is selected. It has been highlighted that lifetime span of WSN with multiple sinks is influenced by the number of sinks and their exact locations<sup>15</sup>. EEDARS in<sup>16</sup> dual-sink algorithm which utilizes both static and mobile sinks to switch between them to send data to the nearest sink hence shortens the path. Also, loads balance among sink's deputy

nodes, where a deputy nodes are randomly select as its destination and a forward factor based on dividing its neighbors' residual energy by the shortest hops to the destination, is used to help to find the next hop during data routing procedure. The vast majority of research in particular WSNs with multiple sinks aims to extend the lifetime either through topology manageability or routing mechanism independently.

## 2. Literature Survey

This section summarizes some studies that proposed resolutions to enhance the efficiency of implementing WSN with multiple sinks. An Optimal Multi-sink Positioning and energy-efficient Routing mechanism have been proposed in WSN. It emphasizes on proper multiple sinks positioning in a sensor network and shows the effect of varying the number of the multiple sink. In addition to that, the data traffic is routed to one or more sink through different paths. Enhancement in lifetime and fairness are achieved.

Data forwarding from sensor nodes to multiple sinks has been presented in<sup>12</sup>. It designs an approximation algorithm that schedules the time slot in order to schedule the data collection while prevents links from being interfered at the same time. The algorithm minimizes the latency of data collection with a constant-factor performance guarantee clustered the sensor network with a number of multiple sinks to enhance the manageability of the network as well as reducing the energy dissipation at each node.

A Multipath Routing in large scale sensor networks with Multiple Sink nodes (MRMS) protocol has been presented in<sup>17</sup>. Some approaches and mechanisms such as multiple sinks, a new path cost metric, dynamic cluster maintenance, and path switching are adopted to improve path selection and to enhance the energy efficiency, tackles the problem of multiple sink loactions to shorten the mean dstances between the sensors and nearst sink. Also it address the sink hotspot problem and resolve it through sink relocating from timeto time. A Dynamic Route-Sharing Protocol (DRSP) was proposed in<sup>18</sup> to

prolong the lifetime of the network by reducing energy consumption and saving the bandwidth. Based on data requests from multiple sink nodes efficient routes are built with a high degree of sharing between the coordinator and request initiators.

The tree-based connection between sensors was adopted by A Feedback Routing for Optimizing Multiple Sinks in WSN with Reinforcement Learning (FROMS) protocol had been proposed in<sup>18</sup>, which uses localized techniques such as reinforcement learning and Q-Routing techniques to approximate goodness of possible routing decision "action" for a data packet. Out of the set of possible sub-actions, the lower routing cost in a spanning tree is selected. Two techniques have been used to select an action; greedy (based Q) and stochastic (based probability). It has been stated that the FROMS protocol significantly decreases the network overhead to route data.

It has been highlighted that finding out the lifetime of the sensor network influence by the number as well as the location of the multiple sink nodes.

The proper decision for that depends on several and various design criteria<sup>19</sup>. Some of the important key points are summarized as follows:

- The location of the sink nodes; the metric of Euclidean distance is used to indicate the center of mass of the nodes within a cluster as the place of the sink nodes. Thus by completion of the clustering algorithm, the best sink locations (BSL) locations of the sink nodes are easily found.
- The number of clusters; should be given as a decision parameter to the algorithms.
- Minimum number of Sinks; methods were presented to deploy economically feasible amount of sink nodes while prolonging the network lifetime

The Energy-Efficient Dual-Sink Algorithm with Role Switching (EEDARS) mechanism was proposed in<sup>6</sup>. It based on two type of sink one is static, and the other is mobile. The stationary sink is used for avoiding any repeatedly flooding to localize the sink whereas the mobile sink adaptively walks to aim for the event region

for the purpose of data collection. Also, a mechanism of the switching of role is implemented to the protocol so as to transmit the nearest sink to the latest event area, so as to reduce the path length. It has been mentioned that the EEDARS demonstrates a significant improvement in the network metrics especially the lifetime, the load and the end-to-end delay.

To maintain the equilibrium between the loads and hence to increase the lifetime of WSN a Multi-Sink and Load-Balance Routing (MSLBR) algorithm was proposed<sup>10</sup>. The adjacencies of sink nodes which are known as deputies are selected randomly as destinations by the nodes plan to send its data. The routing decision implements a forward factor to find the next hop to forward the data traffic. This metric was based upon splitting its adjacent members' remaining energy by their smallest path lengths to the receiver.

In <sup>20</sup> proposed a least-failure and less energy consuming multipath route in multi-sink wireless sensor networks. This approach considers anyone hop node distance from the sink as representative nodes. Based on some parameters such as residual energy, transmission success rate and hop count, the rest of the nodes construct neighbor and representative node table. When the node wants to send the data from transmitter to receiver, it maintains the various numbers of efficient paths for sending of data based on the weight of the link and its estimate based on the parameters such as energy level and transmission delivery success rate stored in the neighbor table. It has been argued that the approach discussed decreases the consumption of energy and link failures.

As results of the previous studies, we have found that there are numerous phenomena that affect the performance of WSN. We have summarized some of the critical issues still need to be addressed for further research. For instance, Table 1 compares some of the research that focused on WSN with multiple sinks.

### 3. Proposed Model

When topology and routing mechanism are designed, the lifetime span metric should be considered to ensure

successful completion of WSNs mission. The aim of this work is to improve this metric, which we define as the begging time when the network is activated to the time at which it is no longer able to carry out its assigned task. However, the degradation of this metric is in connection with some phenomena such as unfair energy consumption due to inefficient data routing or un-balanced data load, links failure as well as sinks isolation (hotspot phenomenon).

In this study, our primary goal is to enhance the lifetime specifically in WSN with multiple sinks rooted trees. Some researches stated that there is a problem in a tree routing that packets follow the tree topology to the destination (sink) even if the destination is located nearby (auto routing). Due to these disparities, some innovative algorithms have been suggested to the problem embedded in routing in Wireless Sensor Networks. These routing processes have considered the various specific features of Wireless Sensor Networks along with the different applications, implementations and architecture requirements. The task of obtaining and establishing the routes in Wireless Sensor Networks is nontrivial since energy constraints as well as abrupt differences in node status (e.g., failure) cause large and unpredictable changes in the topology.

Our model assumes that there are “N” static sinks (multiple sinks) and “M” sensors spread all over the monitoring area. Each sink sends requests to its surrounding sensors to associate their  $N$  independent sink-rooted trees topology ( $N$  one-dimensional tree). Allowing some sensors to receive and accept more than one join requests from different sinks out of  $N$ , shared nodes “R” are created.

Each sink owns some restriction such as address space or tree depth that influences the total number of R. For the simplicity in this paper we assume that there are two sinks, means our topology is 2-one dimensional trees.

The core process to construct this topology;

- i. Nodes association to a sink with some restrictions (e.g., tree depth  $d$ ),

- ii. Address mechanism to determine which trees and sub-trees the nodes belong to.
- iii. flags with energy metric is set by this node to declare that it is address-overlapped node ( one of R).

There are various mechanisms proposed to construct tree topologies, such as Shortest Path Trees (SPTs), Depth-First Search (DFS) and Breadth-First Search (BFS). Initially, we assume that our tree's graph is laying on DFS mechanism. Thus;

- i. According to the ratio between the total number of multiple sinks “N” and the total number of the sensors “M”, the DFS algorithm formulates its tree depth and set it in the phase of the “join request”
- ii. The basic pseudo code of A DFS ( $v$ );  
Input:  $G (V, E)$  is a graph;  $v \in V$   
Output: visited ( $u$ ) for each visited nodes from  $v$   
For each edge  $(v, u) \in E$  do  
if not visited ( $v$ ) then  
EXPLORE ( $u$ )
- iii. Address overlapped nodes are created by modifying this DFS pseudo code with the following main steps;
  - a. Initially, the entire nodes in the network marked as unvisited.
  - b. to add node to a tree,

If the node is unvisited before by any sink-join request of a tree  $T_i$ , then it is going to be added and assigned  $s$  identifications.

Else-if the node is visited by another sink-join request from tree  $T_h$ , then it will be shared by both trees and a flag will be set.

Else, node waits for a request and no change in the topology.

- iv. Both the size of the tree depth  $d$  and the address spaces set by N sinks of the network plays a role

in the size of R. Thus, their initial setting in these sinks should be somehow adjusted to be larger than the ordinary setting in normal case of former studies.

- v. A sufficient number of R nodes optimize the efficiency of finding out more alternative routes between trees and subtrees. For statistical purposes, once the node becomes a member of R, it informs its second joined request initiator. Based on this statistical information each sinks updates its setting of the tree depth parameter by  $(d \pm \epsilon)$  at each round to vary the size of R for more optimized performance. This optimization needs further research.

In this paper, based on an assumption of formula that assesses the hotspot zone which is out of the scope of this paper a routing mechanism is proposed. The objective is to reduce the rate of autorouting as well as avoiding fast sink isolation via a proper hotspot zone metric-based trees switching.

The address-overlapped nodes with the metric of hotspot zone enable the data load to be switched between the most proper N-one dimensional trees.

There are various mechanisms to construct tree topologies such as Depth-First Search (DFS) and Breadth-First Search (BFS). Assuming that our tree's graph is laying on DFS mechanism, thus;

- vi. Based on the ratio between the total number of multiple sinks and the total number of the vertex (sensors), the DFS set its depth.
- vii. The pseudo code of A DFS ( $v$ );  
Input:  $G (V, E)$  is a graph;  $v \in V$   
Output: visited ( $u$ ) for each visited nodes from  $v$   
For each edge  $(v, u) \in E$  do  
if not visited ( $v$ ) then  
EXPLORE ( $u$ )

- viii. Creating some unique nodes by modifying DFS pseudo code with the following;
  - a. Initially, the entire nodes in the network marked as un-visited.
  - b. To decide whether to add node or no to the tree,
    - If** node is not visited by any sink-join request of a tree  $T_i$  then it is going to be added and assigned  $T_i$ 's label.
      - Else-if** node is visited by sink-join request from a different tree then it will also be shared by this tree  $T_h$ , and this node sets a flag.
        - Else**, no change in the topology if no join request is received by the node.

There are some various methods to construct tree topologies such as Depth-First Search (DFS) and Breadth-First Search (BFS).

In our proposed idea for WSN with multiple sink;

- ix. Initially, the tree's depth is set by each sink could be calibrated based on the ratio between the total number of multiple sink and the total number of vertex (sensors) or the address spaces that is lunched by the destination.
- x. Assuming that DFS is used to construct a spanning tree. The pseudo code of **A DFS( $v$ )**;
  - Input:** A vertex  $v$  in a graph
  - Output:** A labeling of the edges as "discovery" edges and "backedges"
  - for** each edge  $e$  incident on  $v$  **do**
  - if** edge  $e$  is unexplored **then**
  - let  $w$  be the other endpoint of  $e$
  - if** vertex  $w$  is unexplored **then**
  - label  $e$  as a discovery edge
  - recursively call **DFS( $w$ )**
  - else**
  - label  $e$  as a backedge
- xi. Creating some unique nodes by modifying DFS pseudo code by the following;

- a. Initiate the entire nodes in the network as un-visited.
- b. To decide whether to add node or no to the tree,
  - If** node is not visited by any sink-join request of a tree  $T_i$  then it is going to be added and assigned  $T_i$ 's label.
    - Else-if** node is visited by sink-join request from different tree such as  $T_h$  then it will be also shared by this tree and a flag is set on.
      - Else**, no change in the topology if no join request is received by the node.

The node that is capable of being shared with more than one tree must inform its secondary join request initiators (sink) for statistical purposes.

- i. Based on this statistical information sinks could update their tree depth parameter ( $d \pm \epsilon$ ) or address spaces of their spanning tree to ensure sufficient number of shared nodes in order to optimize the probability of switching between subtrees by exploiting these nodes.
- ii. Based on both the assessment of sink hotspot zones that aid in finding out relatively what is the preferable sinks and the nodes that shared to create possibilities for switching to other subtrees routing decision will be taken. Both tree depth  $d$  and address space set by the sink plays a role in the total number of R nodes.
- iii. A sufficient number of R nodes optimize the efficiency of switching between trees. Each address-overlapped node must inform its secondary join request initiators (sink) for statistical purposes that there is a shared node. Based on this statistical information this sink could update their setting of the tree depth parameter ( $d$ ) or address spaces to be used in the next mechanism's iteration.
- iv. Both the assessment of sink hotspot zones and exploiting the R nodes playing an important role

in routing decision by finding out relatively what are the preferable sinks and its appropriate tree.

### 3.1 Efficient Intra Routing

- i. It clarifies that once the address-overlapped node ( $N_k$ ) is created by the modified DFS pseudo code that means it interfaced with at least two independent sinks rooted trees out of  $N$ , such as sinks  $T_A$  and  $T_B$ .
- ii. Once it realized that it is address overlapped, this node  $N_k, \{T_A/ T_B\}$  immediately set a flag to its neighbor declares its capability to switch data load of the surrounding zone to the proper tree of appropriate hotspot zone.
- iii. To conserve the network from sink isolation, it is assumed that per each  $T_p$ , a metric for power consumption at hotspot zone or any kind of subtree's weight is received by the entire nodes.
- iv. This unique node sets a flag with the best metric it has  $LW_{\bar{z}}$  and accordingly, the surrounding nodes will compare it with its main metric  $LW_B$ .
- v. Moreover, since "anycast" is one of our communication features, so the node takes the decision to forward its data either through its main tree (route) or to a most appropriate tree through  $N_k$ .
- vi. Anyhow, the forward node could be in one of two states in respect to the node  $N_k$ ; so either as  $N_i$  that directly connected or through a chain of hops such as node  $N_m$ . However,  $N_m$  has to consider the subtree weight (node's chain  $LW_C$  that connects it with  $N_k$ .
  - Once the appropriate tree is elected by the current router node, then the destination field of this data either being as it is (original or main route) or set it to imaginary destination known as  $N_k$  if its metric set by the flag is best.

- Upon receipt of this load by  $N_k$ , instantly, it will reorganize to forward this data through one of its interfaces to the tree of the best metric.

It is clearly that, our intra communication model dissimilar from former proposals aims to prolong the lifetime. It immunizes the network from sink isolation as well as reduces the rate of autorouting. Our model is expected to perform more efficiently once it combined with a well-designed metric for the power consumption at hotspot zone. Currently, this metric is out of the scope of this study. Also, this approach is considered competitive to cluster approach in term of no power consumption due to clustering phase and re-cluster head selection (CH). In addition to that, it eliminates the need for a large address space specifically in large scale WSNs with multiple sinks.

## 4. Status and Further Work

This study has reviewed some proposals to prolong the lifetime span of WSN. A framework with a new point of views and assumptions is proposed to extend the span of WSNs with multiple sinks. Sink isolation, as well as trees' autorouting phenomena, have enormous influence. Accordingly, it is required to mitigate the fast degradation of power consumption at sink's hotspot zone and to reduce the rate of autorouting in consequence.

Based on an assumption of a metric for power consumption at hotspot zone (which is out of the scope of this paper) a model for efficient routing is proposed. With the aid of both address-overlapped nodes having multiple interfaces with a number of one-dimensional trees out of the  $N$ -one dimensional trees and the metrics of the hotspot zones, appropriate routing decisions are taken.

The data is switched between the most proper sink-rooted trees, relying on metrics differentiation at multiple interfaces of routing nodes. This framework is applicable in a very large scale WSN since there is no problem due to the limitation in address space that launch by sinks. It is considered a significant routing approach for being dissimilar from former proposals in term of immunizes

the network from sink isolation and reducing the rate of autorouting by efficient load switching between trees.

Also, this approach is considered competitive to cluster approach in term of no power consumption due to the continuous iteration for clustering phase and re-cluster head selection (CH). In addition to that, it eliminates the need for a large address space to construct topology specifically in large scale WSNs with multiple sinks.

The current work is on progress to simulate the proposed model as well as compare its efficiency with some former studies such as LEACH. In addition to that, a proper metric of power consumption at the hotspot zone that copes with this model will be designed. This study has extensively surveyed a number of research proposals on Wireless Sensor Networks (WSN) and summarizes some of their shortcomings. Prolong lifetime of the WSN with multiple sink is one of the still open research issue. Accordingly, we proposed a new approach that handles this challenge. Work is currently ongoing to simulate the proposed model and to determine whether an appreciable saving in terms of network lifetime can be made and that it is longer than some other mechanisms. Also, an energy aware-sink hotspot zone that copes with this model will be designed.

## 5. References

1. Arampatzis T, Lygeros J. A survey of applications of wireless sensors and wireless sensor networks. *Proceedings of the IEEE International Symposium on Mediterrean Conference on Control and Automation*. 2005; 1:719–24.
2. Palsapi AAKM. Comparative performance study of routing protocols in wireless sensor network. M.Sc., dissertation, University College Dublin, Ireland; 2012.
3. Buratti C, Verdone R. Tree-based topology design for multi-sink wireless sensor networks. *The 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*; 2007. p. 1–5. <https://doi.org/10.1109/PIMRC.2007.4394655>.
4. Sendra S, Lloret J, García M, Toledo JF. Power saving and energy optimization techniques in WSN. *Journal of Communications*. 2011; 6(6):439–59. <https://doi.org/10.4304/jcm.6.6.439-459>.
5. Hao J, Zhang B. Routing protocols for duty cycled wireless sensor networks: A survey. *IEEE, Communications Magazine*. 2012; 50(12):116–23. <https://doi.org/10.1109/MCOM.2012.6384460>.
6. Bista R, Chang J. Energy efficient data aggregation for wireless sensor networks. *Sustainable Wireless Sensor Networks*. Seah W, Tan YK; 2010. <https://doi.org/10.5772/13708>.
7. Cipollone E, Cuomo F. Event detection capabilities of IEEE 802.15.4 Multi-Sink Wireless Sensor Networks. *GTTI, Rome*; 2007.
8. Wang C, Wu W. A load-balance routing algorithm for multi-sink wireless sensor networks. *Proceedings of International Conference on Communication Software and Networks*; 2009. p. 380–4. <https://doi.org/10.1109/ICCSN.2009.148>.
9. Venugopal M, Abeera P. Geographic location based STR protocol in wireless Zigbee networks. *International Journal of Advanced Trends in Computer Science and Engineering*. 2014; 3(4):7–13.
10. Chen S, Coolbeth M, Dinh H, Kim YA, Wang B. Data collection with multiple sinks in wireless sensor networks. *4th International Conference Wireless Algorithms, Systems, and Applications*; 2009. p. 284–94. [https://doi.org/10.1007/978-3-642-03417-6\\_28](https://doi.org/10.1007/978-3-642-03417-6_28).
11. Kim H, Seok Y, Choi N, Choi Y, Kwon T. Optimal multi-sink positioning and energy-efficient routing in wireless sensor networks. *Lecture Notes in Computer Science*, Springer Berlin. 2005; 3391:264–74. [https://doi.org/10.1007/978-3-540-30582-8\\_28](https://doi.org/10.1007/978-3-540-30582-8_28).
12. Agarkhed J, Biradar GS, Mytri VD. Cluster based energy efficient QoS routing in multi-sink wireless multimedia sensor networks. *International Journal of Computer Science and Network Security*. 2012; 12(5). <https://doi.org/10.1109/ICIEA.2012.6360821>.
13. Vincze Z, Vida R, Vidacs A. Deploying multiple sinks in multi-hop wireless sensor networks. *Pervasive Services*. 2007. <https://doi.org/10.1109/PERSER.2007.4283889>.
14. Forster A, Murphy AL. FROMS-feedback routing for optimizing multiple sinks in WSN with reinforcement learning. *Proceedings 3rd International Conference on Intelligent Sensors, Sensor Networks and Information Processing*; 2007. p. 371–6. <https://doi.org/10.1109/ISSNIP.2007.4496872>. PMID:17182736 PMCID:PMC3043851.
15. Oyman EI, Ersoy C. Multiple sink network design problem in large scale wireless sensor networks. *IEEE International Conference Communications*; 2004. p. 3663–7. <https://doi.org/10.1109/ICC.2004.1313226>.
16. Eslaminejad M, Razak SA, Ismail AH. EEDARS: An energy-efficient dual-sink algorithm with role switching mechanism for event-driven wireless sensor networks. *KSII*

- Transactions on Internet and Information Systems. 2012; 6(10).
17. Chen Y, Chan E, Han S. Energy efficient multipath routing in large scale sensor networks with multiple sink nodes. 6th International Conference on Advanced Parallel Processing Technologies; 2005. p. 390–9. [https://doi.org/10.1007/11573937\\_42](https://doi.org/10.1007/11573937_42).
  18. Chang CY, Lu YJ, Sheu JP. Adaptive route-sharing protocol for data collection in wireless sensor networks. International Journal of Ad Hoc and Ubiquitous Computing. 2012; 9(3):184–95. <https://doi.org/10.1504/IJAHUC.2012.046956>.
  19. Feldman M, Feldman S. Tree-based organization for very large scale sensor networks. The Fifth International Conference on Sensor Technologies and Applications, SENSORCOMM, Saint Laurent du Var, France; 2011. p. 45–50.
  20. Uppal RS, Kumar S, Singh H. Reliable and energy saving multipath routing in multisink wireless sensor networks. Global Journal of Computer Science and Technology Network, Web and Securit. 2013; 13(13).