Applied Soft Computing 29 (2015) 12–25

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

# Heuristic routing with bandwidth and energy constraints in sensor networks

S. Kavi Priya [a,*], T. Revathi [b], K. Muneeswaran [c], K. Vijayalakshmi [d]

[a] Mepco Schlenk Engineering College (Autonomous), Sivakasi, India
[b] Department of IT, Mepco Schlenk Engineering College (Autonomous), Sivakasi, India
[c] Department of CSE, Mepco Schlenk Engineering College (Autonomous), Sivakasi, India
[d] Department of CSE, Ramco Institute of Technology, Rajapalayam, India

ARTICLE INFO

*Article history:*
Received 20 August 2011
Received in revised form 15 October 2014
Accepted 15 December 2014
Available online 29 December 2014

*Keywords:*
Sensor networks routing
Bandwidth constraint
Energy constraint
Nearest neighbor tree
Distributed algorithm
Maximum lifetime

ABSTRACT

Most of the routing algorithms devised for sensor networks considered either energy constraints or bandwidth constraints to maximize the network lifetime. In the real scenario, both energy and bandwidth are the scarcest resource for sensor networks. The energy constraints affect only sensor routing, whereas the link bandwidth affects both routing topology and data rate on each link. Therefore, a heuristic technique that combines both energy and bandwidth constraints for better routing in the wireless sensor networks is proposed. The link bandwidth is allocated based on the remaining energy making the routing solution feasible under bandwidth constraints. This scheme uses an energy efficient algorithm called nearest neighbor tree (NNT) for routing. The data gathered from the neighboring nodes are also aggregated based on averaging technique in order to reduce the number of data transmissions. Experimental results show that this technique yields good solutions to increase the sensor network lifetime. The proposed work is also tested for wildfire application.



## 1. Introduction

Wireless sensor network consists of large number of tiny sensor nodes connected via wireless communication channels. These are suitable for lots of applications such as military surveillance, temperature monitoring, wildfire detection, disaster warning, etc. In particular, sensors are deployed to monitor the regions where the human cannot intervene. For instance, sensors deployed for wildfire detection in the forest region continuously monitors the environment to detect the changes in temperature. When the temperature value crosses the threshold value say 40 °C (event detection), sensor routes the data to sink node (typically a base station or a sensor/actuator node or a gateway to larger network with high computing power and energy where information is required) in the remote location through the multi-hop routing algorithms. Therefore, the sink collects the data from all the sensor nodes to derive useful information about the event (for example the geographical map of the wildfire can be plotted) detected. Fig. 1 shows the model of wireless sensor networks used in the proposed work. According to the characteristics of sensor network, the sensor nodes perform sensing, preprocessing, aggregation and transmission of data on its neighboring nodes within the transmission range. Hence, the total data rate increases suddenly in the sensor networks when it detects the event. The sensor data cannot be further forwarded to the neighboring node, if the sensor node runs out of energy or due to network congestion. The sensor network starts to congest when the total link bandwidth between the sensor nodes is smaller than the data rate of the network. Hence the wireless sensor networks are considered as resource scarce, which is manifested in terms of energy, link bandwidth, computing power, etc. In most of the previous works related to sensor networks, the authors tried to increase either energy efficiency through different routing techniques [1–10] or optimize wireless link bandwidth as in [11,12]. The classical routing algorithms like minimum spanning tree [13,14], requires calculation of routing path at every node and results in high computing power to find the optimal path. The use of the distributed algorithm to find the best optimal nearest neighbors for packet forwarding will increase the network's lifetime. The network lifetime is considered as the time until which the first node in the sensor network drains out of energy. When every sensor node is allowed to forward data only to the nearest next neighboring node with optimal performance factor (energy or bandwidth efficiency) along with data aggregation (that converges number of data received from various sources into few messages), the sensor network's lifetime will be maximized as discussed in [15–17]. In [18], the authors have devised a routing technique with both energy and link constraints which will have performance degradation since it is executed in a centralized fashion. In some of the recent works [22–24], energy efficiency is attained by increasing the network coverage (resulted in increased hardware cost), standby cluster head (suffered due to central point of failure if cluster node is dead) and efficient location discovery respectively. The researchers also concluded that the distributed routing algorithm may increase the sensor network's lifetime. The works proposed in [2,5,9,15,17], suggests that using data aggregation in sensor network can utilize bandwidth efficiently. The survey of the papers [25–27] reveals that the performance of the sensor network may also depend on the type of application for which it is used. Therefore, this work proposes a model to tackle bandwidth constraints using link rate allocation and energy constraints using distributed NNT algorithm along with data aggregation considering the issues in the wireless sensor network wildfire application.

* Corresponding author at: Mepco Schlenk Engineering College (Autonomous), Sivakasi, Tamil Nadu, India. Tel.: +91 9842295563; fax: +91 04562235111.
*E-mail addresses:* urskavi@mepcoeng.ac.in (S. Kavi Priya), trevathi@mepcoeng.ac.in (T. Revathi), kmuni@mepcoeng.ac.in (K. Muneeswaran), vijayasrini9701@gmail.com (K. Vijayalakshmi).

http://dx.doi.org/10.1016/j.asoc.2014.12.019
1568-4946/

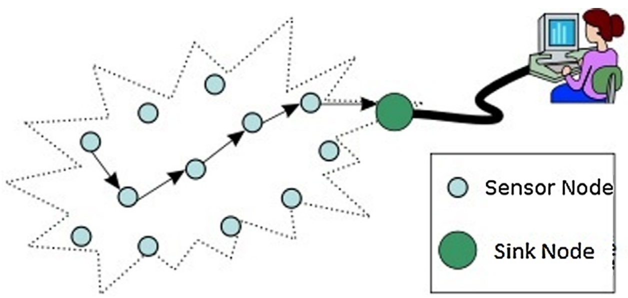


**Fig. 1.** Model of wireless sensor networks.

The rest of the paper is outlined as follows: Section 2 describes some of the research woks in the related area and their significance. Section 3 narrates the various constraints and modules used in the proposed work. Section 4 addresses the overall design of the proposed scheme and the various algorithms used in this work. Section 5 shows the simulation results and performance of the modeled system. Section 6 gives the application details of the proposed work in a model sensor network. Section 7 concludes the paper.

## 2. Related research works

Chang and Tassiulas [1] reduced the sensor network traffic by routing the sensed data only based on the sensor node's remaining energy. The authors conclude that this type of routing saves ad hoc network lifetime unlike the other algorithms which try to minimize the absolute consumed power. Schurgers and Srivastava [2] derived a practical routing guideline called gradient based routing based on the energy histogram for uniform resource utilization in the network. They also suggested that robust aggregation of packet streams will reduce the sensor node energy consumption by a factor of two or three. The algorithms proposed in [1,2] did not consider the number of messages transmitted between the neighbors that may result in increased communication cost.

Bhardwaj et al. [3] proposed a model for bounding the lifetime of the sensor node to formulate energy constraints. The authors assumed that there was sufficient bandwidth and only one node could act as a source in the sensor network. But in some sensor applications like wild fire monitoring, poisonous gas leakage management system, etc. there is only limited bandwidth and many nodes can simultaneously send data at a particular time. Younis et al. [4] modeled a gateway-based routing technique that finds the optimal path in the network. In this scheme, a central network manager between the sensor clusters is responsible for routing. Chamam and Pierre [14] implemented a centralized tabu search heuristic to tackle the exponentially increasing computation time which is addressing the optimal planning of sensor states for cluster based sensor networks. Senthilkumar et al. [23] discussed honeybee technique for re-election of cluster heads to increase the energy efficiency of sensor networks. In this scheme, when a cluster head goes down, immediately the standby node becomes the cluster head. Thus the sensor network works continuously without any delay in order to choose the next cluster. These techniques are less suitable for sensor networks for two reasons: (i) It needs more computing power (ii) When the central manager node dries out of battery power; the entire network is out of control.

Krishnamachari et al. [5] used Greedy Incremental Tree (GIT) heuristic scheme for data aggregation. In this scheme, the aggregation tree was built sequentially that will consume more time when compared to distributed schemes. Cui et al. [6] emphasized that the energy efficiency in a multi-hop routing environment must be supported across all layers of the protocol stack. They devised a cross-layer design based on variable-length TDMA schemes where the slot length is optimally assigned according to the routing requirement of each sensor node. But this technique may not be suitable for large scale sensor networks.

Ambühl [7] proposed an approximation algorithm that constructed minimum spanning tree based on the Euclidean distance to reduce the battery power consumption. Ok et al. [8] introduced a new metric for energy cost considering sensor node's remaining energies as well as energy efficiency. This metric gave rise to the distributed energy balanced routing (DEBR) algorithm that increased the life span of sensor network. Misra and Dias Thomasinous [9] suggested a simple, least-time, energy-efficient routing protocol with one-level data aggregation that ensured increased lifetime, reliability and congestion avoidance in sensor networks. Qiu et al. [10] formulated enhanced tree routing (ETR) strategy based on sensor node address assignment schemes. In addition to the parent–child links, ETR also used links to other one-hop neighbors that will lead to a shorter path. It is shown that such a decision can be made with minimum storage and less computing cost. The works in [7–10] considered only the energy efficiency leaving behind the bandwidth efficiency for data forwarding in the sensor network. Hence, the number of network communications is increased whereas the sensor network's lifetime is reduced.

Madan and Lall [11] proposed a linear programming and subgradient distributed algorithm for routing and maximized the sensor network's lifetime. Chang and Tassiulas [12] formulated a shortest path routing algorithm using sensor link costs. The link costs reflect both the communication energy consumption rates and the residual energy levels between the sensor nodes. This work helps to derive energy constraints that can maximize the sensor node lifetime. But the overhead in executing the algorithm is slightly high and is well suited only for small scale sensor networks. Li et al. [13] proposed a new localized routing algorithm called Incident MST (minimum spanning tree) for broadcasting in wireless adhoc networks. The author concluded that if the total link power was deterministic, then the algorithm might result in high energy efficiency. Cheng et al. [18] discussed the sufficient bandwidth and energy constraints for the sensor nodes to maximize the sensor network's lifetime. The authors proved that ignoring bandwidth constraints on energy efficient algorithms may lead to infeasible routing solutions. They also aggregated received data in order to minimize the number of wireless transmissions between the sensor nodes. These works confirmed that the link bandwidth is also needed for efficient routing in sensor networks.

Luo et al. [15] focused on optimizing both data transmission and aggregation costs by dynamically adjusting the route structure when the sensor nodes joined or leaved the network. This algorithm was slightly deviated from real network energy consumption for complex applications. Gallager et al. [16] designed a distributed algorithm that constructed the minimum-weight spanning tree. The sensor network was implemented as a connected undirected graph with distinct edge weights. The nearest neighbor tree algorithm was proposed based on the above scheme. Khan et al. [17] presented NNT algorithms ex the complete graph model where the maximum transmission range of the nodes were large enough so that any pair of nodes could communicate directly with each other. The authors proposed two NNT algorithms: Random-NNT and Coordinate-NNT based on types of ranking the sensor nodes for single hop wireless network. They also modeled UDGNNT (undirected graph NNT) for multi-hop wireless networks and proved that (1) the tree produced by such a distributed algorithm will be of low cost; (2) the NNT paradigm can be used to design a simple dynamic algorithm and (3) the time, message and work complexities of the NNT algorithms are close to the optimal energy constraint for routing.

Konstantinidis and Yang [22] show that better energy efficiency can be achieved in a short period when solved in parallel as a multi objective evolutionary problem based on decomposition. The