# Event Dissemination in Mobile Wireless Sensor Networks

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## Abstract

*Sensor networks are composed of a large number of densely deployed sensors/actuators. Routing protocols are faced with the challenge of delivering data to sinks through multihop routes, in the presence of energy constrained sensor nodes. In this paper we present an energy-aware event dissemination protocol for mobile wireless sensor networks. In our proposed model each sink pro-actively constructs a redundant tree in the network to provide reliable delivery of events in the face of dynamic changes and mobility. Scalability is achieved by minimizing the number of participating nodes on the tree, while maintaining high coverage.*

## 1. Introduction

Continuing advances in semiconductor fabrication technologies in accordance with Moore's law are enabling the creation of tiny computational devices equipped with microelectromechanical sensors and actuators. These devices are capable of communicating with each other using radio to form wireless sensor networks (WSNs). Although the limited processing, storage and communication capabilities of nodes in WSNs create difficulties at all levels of the design process, the key design goal for WSNs is energy efficiency. Routing protocols for WSNs that deliver data to sinks via multihop routes must also contend with frequent topology changes and node movements. We also note that data may be forwarded to multiple nodes at no extra cost to the sender, due to the fact that nodes communicate using broadcast, and node densities are typically high. We exploit these characteristics in order to create a reliable, scalable and energy-aware event dissemination protocol for WSNs.

## 2 Related Work

Our work leverages ideas from ad hoc wireless multicast protocols. Several tree based protocols have been suggested in the literature, such as AMRoute and AMRIS[4, 7]. However, these perform poorly under dynamic conditions[6]. ODMRP [5] is a favorable mesh-based multicast protocol in ad hoc networks. It is, however, unfit for WSNs, since it relies on node IDs and degrades in performance when there are one (or few) sink node(s) present in the network. Directed Diffusion [3] and GRAB [1] are two well known gradient based protocols for WSNs. They, however, provide little scalability and mainly consider static networks. In TTDD [8], the source builds a virtual grid of dissemination nodes and queries from sinks are locally flooded to reach the nodes on the grid. It is not energy-aware as nodes on the grid are greedily forced to forward packets. In addition, it only supports sink mobility and relies on a-priori geographical knowledge for routing. Our approach is very similar to TTDD, but can also cope with these problems.

## 3. Model

Each sink pro-actively constructs a redundant tree in the network, in parallel to its interests dissemination phase, to enable reliable and efficient delivery of events in the face of dynamic changes and mobility. Only a small portion of the nodes form the redundant tree to reduce maintenance overhead and enhance scalability, while the remaining nodes flood data locally using a probabilistic forwarding algorithm to provide robustness. The redundant tree forms a suitable basis for cheaply maintaining routing paths between sources and sinks, eliminating flooding and route discovery mechanisms often employed in similar efforts to address the dynamic nature of WSNs.

In the following sections, for simplicity, we describe our protocol for the simplest case of one sink in the network.

### 3.1. Tree Construction

Sinks disseminate *interest messages* that outline the data requirements of the application in the network. Contents of the interest packet are as follows:

| |
|---|
| Tree ID (randomly generated by sink) |
| Event Topic(s) |
| Event Filters for each Event Topic |
| Sequence Number |
| Time Expiry period |
| CP-bit (one bit per event topic) |
| Tree-bit |

The sequence number is an indication of the hop count distance from a sink. The time expiry period signifies the duration of sink's interest in the specified events. The CP-bits are used to handle the presence of multiple sinks with similar event topics in the network, which are not detailed here due to the limited space. The tree is rooted at the sink with its branches distributed among sensor nodes in the network. While the tree aims to provide maximum coverage, it is only composed of a small portion of the nodes in the system. This reduces the cost of tree maintenance, and improves scalability. The redundant branches of the tree ensure multiple paths to the sink are available. Following reception of the interest message by nodes, each node makes a local decision on whether to volunteer to be a part of the tree or not. The decision is influenced by four parameters:

**Vital Resources** This is the amount of battery power, or vital resources[1] that a node has available. Other available local information can also be encoded into this parameter, such as stability, or steadiness.

**Number of parents** A node becomes aware of the number of parents[2] by the number of interest messages it has received with sequence numbers one less than its own sequence number.

**Number of parents on the tree** Number of parents that are on the redundant tree. Packets from such nodes would have a tree-bit set.

**Number of partners** Number of nodes with the same sequence number as the local node that have volunteered to be part of the tree, and whose broadcasts have been received by the local node.

Every node makes a probabilistic decision to be on the tree linearly proportional to the amount of *vital resources*, and inversely related to the *number of parents*, *number of parents on the tree* and *number of partners*. The probability function is a variable quantity from the moment that the node receives the first packet from a parent and when all neighbors have broadcast their interest messages. Thus, a node sleeps for a random duration after it has received the first packet from a parent prior to computing the probability function. Nodes that volunteer to form a part of the tree re-transmit the interest message with the tree-bit set.

[1] we classify any resource that a node's survival depends upon as a *vital resource* such as battery power

[2] nodes accessible that are one hop closer to the sink

### 3.2. Notification Service

Notification of an event from a source (potentially any sensor in the system) to the sink(s) is routed by multi-hop forwarding. We exploit the symmetrical nature of radio propagation in the wireless media as a source of *passive acknowledgments* to ensure reliability of packet forwarding in the system. Passive acknowledgment is where the sender overhears the re-transmission of the packet by one of its recipients, and thus is assured that one of its recipients has forwarded the packet. The source assigns a randomly generated ID to each of its event packets to allow the sink or other nodes in the system to drop duplicate packets.

### 3.3. Routing Algorithms

Packets are routed according to two schemes in the system:

- Forwarding through tree nodes
- Probabilistic forwarding through nodes not on the tree

Once a node on the tree receives a packet, it simply rebroadcasts the packet, with its own sequence number and the tree-bit set. This packet is then expected to be rebroadcast by a node higher in the tree. The tree-bit ensures that no other node apart from the ones on the tree shall forward the packet, and the sequence number is used to ensure propagation towards the sink.

Probabilistic forwarding takes place when a node receives a packet with its tree-bit unset. The node probabilistically makes a decision on forwarding the event. The approach resembles 'contention-based forwarding' proposed by Fler et al in [2]. While they discuss the suppression strategies in detail, we highlight parameters that influence the local decision made by a node to forward the packet. They are as follows:

**Local Energy** As an energy-aware strategy, the amount of energy or battery power left in a node plays a critical role in the decision-making process.

**Local Sequence number** A lower sequence number would suggest that this node is closer to the sink than the one who has just broadcast this packet. This increases the probability of forwarding.

**Freshness of the Sequence Number** The freshness of the sequence number is a weighting factor for determining its influence on the decision-making process. As time passes the sequence number becomes less reliable.

**Number of forwards** If the node receives a second broadcast of the packet, as a sign that another node has made the decision to re-broadcast the packet, it will drop the packet.

Cheap suppression strategies reduce duplicate forwarding of packets, but do not completely eliminate this phenomenon. Convergence of the tree branches towards the root is another means of eliminating the duplicate packets in the network. All nodes maintain a buffer table of recent event IDs sent or received. This is used for eliminating duplicate deliveries as well as reverse tree path construction.

### 3.4. Branch Reconstruction

Tree nodes periodically reconstruct their branches. This process is initiated when the expiry time is reached, or packets have been received with tree-bit unset (i.e. they have been forwarded through the probabilistic scheme). The first is to account for mobility, and to balance energy dissipation in the area, by re-electing new tree nodes. The second is to reactively maintain a connected tree, covering the sink and the source nodes.

## 4. Performance Evaluation

While we believe that the choice of the probabilistic function for tree construction is largely application dependent, we evaluated the scalability of the model by analyzing the relationship between the proportion of nodes on the tree and the coverage of the tree through a simple form of the function. The physical platform of the evaluation model was designed as a two dimensional grid matrix, 300 points in length and width. All sensors have a fixed range of transmission on the grid, which results in a circular coverage. The probability function used for the tree construction was as follows.

$$Pr = \begin{cases} 0, & \text{when } parents > 2; \\ 0, & \text{when } partners > 3; \\ 1 & \text{otherwise.} \end{cases}$$

| com\den | 10% | 20% | 30% | 40% |
|---|---|---|---|---|
| 10 pts range | 95% cov 20% tree | 96% cov 10% tree | 97% cov 7.4% tree | 95% cov 5.5% tree |
| 20 pts range | 97% cov 5.8% tree | 96% cov 3.1% tree | 96% cov 2% tree | 95% cov 1.5% tree |
| 30 pts range | 97% cov 2.9% tree | 96% cov 1.4% tree | 96% cov 0.9% tree | 95% cov 0.7% tree |

The table above presents two figures for combinations of densities and communication ranges in the evaluation model. The first figure illustrates the coverage of the tree in the network. This is the percentage of nodes that are within a one hop distance from a node on the tree. The second figure is an indication of the percentage of the nodes that are part of the tree. High coverage at the expense of employing low percentage of tree nodes illustrate the scalability of the model. As expected, the ratio of the nodes on the tree decreases as the communication range and density increase. In practice the probabilistic function should be tuned to fit the application model. How the choice of different parameters and operations effect the function will be the subject of future work.

## 5. Conclusions

The energy-aware event dissemination protocol outlined in this paper exploits the high density of nodes, and wireless nature of the sensor networks to construct redundant trees in the network. The redundant tree provides multiple available paths for reliable delivery of events in the face of failures or dynamics, and is highly scalable - employing a small portion of the nodes as forwarding tree nodes in the WSN. It also provides a high coverage platform to cheaply maintain routing paths between the source and sink nodes.

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