The Challenge of Mesh Routing in Ubiquitous Sensor Networks

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Abstract: This informative paper describes the harsh environment in which sensor networks operate, explains challenges of routing in sensor networks and provides an overview of existing approaches of multi-hop routing.

1. Introduction

Ubiquitous sensor networks (USN) are formed by potentially very large numbers of sensor devices, which are distinguished by their reliance on battery-operation, low bandwidth, short transmission range, scarce memory capacity, limited processing capability and other attributes of inexpensive hardware. These characteristics enable a whole new spectrum of applications and service scenarios [1]; but they also create numerous new challenges on obtaining robust and reliable mesh routing.

In order to enable communication between devices that are out of mutual radio reception range, multi-hop routing through intermediate nodes is required. However, traditional routing protocol design does not satisfy the requirements of sensor networks because of the sensor nodes' limited resources and their often very application-specific patterns of communication. In addition, existing ad hoc networking protocols are often based on assumptions that do not hold true in sensor network environments, such as trusting the link layer of providing stable communication and bidirectional links. But in sensor networks links are often unreliable, variable or even unidirectional due to close coupling to the physical world and its inherent unpredictability.

This paper is organized as follows: Chapter 2 gives a short overview about previous work on mesh routing in sensor networks, Chapter 3 lists its challenges and Chapter 4 summarizes the international standardization efforts. Chapter 5 concludes this paper.

2. Existing Approaches to Mesh Routing

Research efforts in the area of sensor networking have put forth a large variety of multi-hop routing algorithms [2]. Most related work focuses on optimizing routing for specific USN application scenarios, which can largely be categorized into the following models of communication:

- Data Gathering (many-to-one)
- Data Dissemination (one-to-many)
- Triggering (point-to-point)

In sensor networks, data is often gathered from numerous sensor sources to one or more sinks, in which case end-to-end connectivity is not necessary. For instance, Flooding is maybe the most widely known mechanism for a sink node to query a sensor network. But especially in low-power networks, Flooding causes too much overhead and alternative protocols, such as Gossiping [3] or Rumor Routing [4] have been proposed. For finding routes from multiple sources to a single destination with in-network consolidation of redundant data, data-centric routing schemes have been designed, such as Directed Diffusion [5] or Dissemination via Negotiation (SPIN) [6].

In order to make measured data more meaningful, it is often required to have corresponding location information available. But GPS receivers are too big and expensive for being deployed in sensor networks, and they do not function properly under heavy foliage and in urban canyons. Several geographical routing mechanisms have been suggested for sensor networks in the absence of precise location information, such as Greedy Perimeter Stateless Routing (GPSR) [7].

3. Mesh Routing Challenges

This section discusses the challenges of mesh routing in wireless sensor networks. Related studies have been done on the design space of wireless sensor networks [1], but mesh routing on wireless sensor networks itself has many challenging issues. This paper is an attempt to specify important issues and technical considerations on mesh routing for wireless sensor networks.

3.1 Reliability and Robustness

The low-performance properties of common sensor devices and their usual random deployment causes significantly higher loss rates compared to manually established or even wired networks. Heavy interference in densely deployed networks, sudden congestion by event-triggered traffic bursts, or multipath signal propagation in complex outdoor or indoor environments create additional complexity for obtaining reliable communication in sensor networks.

3.2 Power Conservation

No matter in which type of sensor network, saving energy is crucially important to devices that are not mains-powered but have to rely on a depleting source, such as a battery. The lifetime of a sensor node depends on the energy it can store and harvest through energy scavenging [8], for example by using a solar panel.

Compared to functions such as computational operations or taking sensor samples, radio communications is a very dominant factor of power consumption. Therefore, the optimization of multi-hop routing protocols in terms of achieving a minimal number of control messages is essential for the longevity of battery-powered nodes and the network as a whole. Routing overhead must be minimized in order to prevent frame fragmentation on underlying network layers, thereby reducing the energy required for transmission and preventing additional spending of energy for packet reassembly.

Power-aware routing is a non-trivial task, because it is affected by many mutually conflicting goals. The most prominent target is to create multi-hop routing schemes, which minimize the total energy consumed within the sensor network by finding shortest paths in terms of energy consumption. Heavy traffic over the same energy-optimal paths might however cause fast battery depletion of nodes on these more frequently chosen routes, and this can lead to network disconnectivity. Thus, an alternative goal is often the maximization of the time until a network partition happens.

In order to select energy-optimal paths, sensor network mesh routing protocols often try to minimize power consumption by utilizing a combination of the link quality indication (LQI) provided by the MAC layer and other measures, such as path length, packet loss rates, delay, bandwidth, traffic load, etc. Minimum Expected Transmissions (MT) is an example of such a sophisticated routing measure [9].

3.3 Low Protocol Complexity

A routing protocol of low complexity indirectly assists to achieve the previously described goal of reducing power consumption. It is an additional challenge to design mesh routing algorithms that fit within the restricted memory of sensor devices and have low computational and algorithmical complexity.

In large and dense sensor networks, keeping routing and neighbor management tables can easily exceed the capacity of a node, so that old or rarely used entries have do be discarded in favor of more recent information.

3.4 Topology Control

In order to save energy, sensor network nodes are often scheduled to periodically hibernate by periodically shutting off their transceiver activity. Such mechanisms occur at the level of media access control and might not be perceivable by a higher-layer routing protocol. Therefore, mesh routing protocols must be able to ensure robust packet delivery despite of nodes frequently switching to a sleep state, for instance by allowing link-layer feedback to the routing protocol.

4. Standardization Efforts

The main challenge of specifying an all-purpose multi-hop routing protocol for sensor networks is the participating devices' lack of system resources to meet all the requirements posed by the huge variety of possible application scenarios. This difficulty of creating a balance between protocol simplicity and robust multi-hop routing, covering all conceivable types of sensor networks, is currently a hot topic within various standardization bodies, such as IETF , ITU-T and IEEE.

A prominent standard on sensor networks is IEEE 802.15.4, which provides a solid PHY and MAC foundation. But it does not specify how multi-hop routing is to be carried out. For these issues, the IEEE 802.15.5 Working Group has been charted.

In IETF, the 6lowpan Working Group has defined an adaptation layer for IPv6 header compression, reducing the overhead caused by redundant information in IP, UDP and TCP headers. It is now being discussed how to support IP-based sensor networks by multi-hop routing.

ITU-T has started to work on sensor network issues over the Next Generation Network (NGN), and ITU-T's study group SG13 Q.1 has considered to include Ubiquitous Sensor Networking (USN) services into their NGN Services Release 2 document.

5. Conclusion

A great number of research efforts on mesh routing in wireless sensor networks were designed for specific application purposes. But the necessity to build a general-purpose mesh routing mechanism has risen as the use of sensor networks has spread into the broad area of pervasive networking. This paper discussed challenges of mesh routing in the perspective of sensor networking services. Although there are many important factors to design mesh routing mechanism on wireless sensor networks, we tried to justify our view to clarify these issues.

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