Report on Wireless Communication Project 14
Routing in Sensor Networks

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1. Surveys on sensor networks

1.1. Introduction

A sensor network can be literally defined as a sensor community networked through wirelesss links or the Internet. Due to the development in sensor technology and wireless communication, sensor networks have come to be of paramount importance for information collection and distribution in special application contexts, such as tracking contamination in hazardous environments, surveillance in military secret missions, habitat monitoring in the nature preserves, etc. Furthermore, as a result of the advances of related technologies, for instance, the microelectronmechanical system (MEMS), cheap, small, smart and networked devices with multiple onboard sensors can be deployed in large numbers and make many sorts of applications feasible. In a word, there are unprecedented opportunities in the research of sensor networks.

Among the existing network models, Mobile Ad Hoc Networks (MANETs) are the cloest to sensor network, sharing many characteristics such as

- The network topology changes very frequently.
- Nodes in the network are limited in power.
- Wireless communication links are applied for nodes connection.

However, sensor networks distinguish themselves from other networks especially those in an ad hoc manner like MANETs, by the following characteristics.

- Besides power limitation, sensor nodes are further confined with computational capacities and memory than their MANET counterparts due to their low cost.
- Sensor nodes are densely deployed, and the number of sensor nodes in a sensor network can be several orders of magnitude higher than the nodes in an ad hoc network.
- Sensor nodes may not have global identification due to the large amount of overhead and large number of sensors.
- Usually, sensors are deployed once in their lifetime, while nodes in MANET move really in an ad hoc manner.
- Sensor nodes mainly use a broadcast communication paradigm, whereas most ad hoc networks are based on point-to-point communications.
- Usually, the data in sensor networks are bound either downstream to nodes from a sink or upstream to a sink from nodes, while in MANET, the data flows are irregular.

Thus, because of these distinguishing characteristics, the protocols and techniques developed for MANETs cannot be directly applied to routing in sensor networks. Moreover, this fact determines crucial features that must be considered during the design and implementation of routing protocols for sensor networks, which will introduced in Section 2.

1.2. The evolution of sensor networks

As with many technologies, defense application have been the initial motivation for research and development in sensor networks, especially during the Cold War. At this period, sensor networks were mainly studied for and applied in enemy tracking in battlefield environments, such as the Sound Surveillance System (SOSUS) which was deployed at strategic on the ocean bottom to detect and track quiet Soviet submarines. These sensor networks generally adopt a hierarchical processing structure, and in many cases, human operators play a key role in the system. These initiatives provided some key processing technologies for modern sensor networks. At the next stage of their evolution, sensor networks hava gradually adopted a distributed architecture. Many related programs are involved with this trend, like the Distributed Sensor Networks (DSN) program at the Defense Advanced Research Projects Agency (DARPA) which was started around 1980. Moreover, to develop a network operating system that allows flexible, transparent access to distributed resources needed for a fault-tolerant DSN, was focused by researchers at Carnegie Mellon University (CMU), Pittsburgh, PA. They managed to develop a communication-oriented operating system called Accent, whose primitives support transparent networking, system reconfiguration, and rebinding. In further development of sensor networks, planners of military systems recognized the benefits of sensor networks, which become a crucial component of network-centric warfare. In network-centric warfare, sensors do not necessarily belong to weapons or platforms, in contrast to which platform-centric warfare used to be. Instead, they collaborate with each other over a communication network, and information sent to the appropriate ”shooters”. In recent technology trend, commercial companies such as Ember, Crossbow, and Sensoria are now building and deploying small sensor nodes and systems. These companies provide a vision of how our daily lives will be enhanced through a network of small, embedded sensor nodes. In addition, IEEE has defined the IEEE 802.15 standard for personal area networks (PANs), with ”personal networks” defined to have a radius of 5 to 10 m. Networks of short-range sensors are the ideal technology to be employed in PANs.

1.3. New applications of sensor networks

The research and development in sensor networks was initially introduced to serve for defense and military purposes. However, it has been identified as one of the most important technologies for 21st century, and there are many interesting new applications emerged in this area. The following are a few examples.

1. *Infrastructure security*

   Critical buildings and facilities such as power plants and communication centers have to be protected form potential terrorists. Networks of video, acoustic, and other sensors can be deployed around these facilities. Sensor networks can also be used to detect biological, chemical, and nuclear attacks.

2. *Environment and habitat monitoring*

   Environment and habitat monitoring is a natural candidate for applying sensor networks. There are various nature study contexts which need sensor networks to collection precious source information. For example, environmental sensors are used to study vegetation response to climatic trends and diseases, and acoustic and imaging sensors can identify, track, and measure the population of flocks, etc.

3. *Industrial sensing*

   Sensor networks can also be applied in industry to lower cost and improving machine performance and maintainability, which actualize highly automated production, sophisticated on-line quality control, and thus enable factories to maintain compliance with the state’s safety regulations while keeping installation costs low.

4. *Traffic control*

   The application of sensor networks in traffic control is really self-explain, and it has been used for quite a while. Due to development of the sensor network technology, the landscape of traffic monitoring and control can be totally changed. Cheap sensors with embedded networking capability can be deployed at every road intersection to detect and count vehicle traffic and estimate its speed. Well networked sensor nodes can communicate with each other and depict a ”global traffic picture” which can be queried by human operators or automatic controllers to generate control signals.

2. Surveys on routing protocols for sensor networks

2.1. Introduction

The routing protocol is basically a mechanism which provides feasible and reliable communication of nodes in a network. Given the the architecture and requirements of sensor networks we introduced in Section 1.1, their subset in the sensor network environment are mainly designed for implementing convenient and energy-saving communication and information exchange between sensor nodes in the network.

2.2. Classification of Routing Protocols

There are actually several criteria we can refer to to classify routing protocols in sensor networks.

1. Depending on how the sender gains a route to the receiver, routing protocols can be classified into three categories.

   proactive protocols All routes are computed before they are really needed.

   reactive protocols All routes are computed on demand.

hybrid protocols Use a combination of these two above ideas.

Since proactive protocols are resource-consuming in holding huge routing tables while sensor nodes are poor in computational capacity and memory, reactive and hybrid routing protocols are preferred in sensor networks.

2. According to nodes' participating style, routing protocols can be classified into another three categories.

   direct communication protocols A sensor node sends data directly to the sink.

   flat protocols All nodes in the network are treated equally and a node send data to the sink through hops.

   clustering protocols Nodes in the networks are organized into clusters.

   Under direct communication protocols, if the coverage of the network is large, the power of sensor nodes will be drained very quickly. Moreover, collision can be more and more significant in undermining the quality of data transmission, as the sensor nodes increases. Thus networks are not scalable under direct communication protocols. However, flat protocols suffer from energy-consuming problems as well. Since it use a by-hop way to build up the connection between nodes and the sink, and it is probably that most participating nodes are around the sink. As a result of this phenomenon, those nodes in the vicinity of the sink could run out of power soon. Compared to the previous two types of protocols, cluster protocols are not only scalable but also energy efficient in finding a feasible route and easy to manage the sensors and routes.

3. Depending on whether a routing protocol is location aware or not, routing protocols can be classified into **location aware** and **location-less** routing protocols.

3. Related work in routing protocols for sensor networks

There is actually a lot work done in routing protocols for sensor networks. We will have a survey into the existing routing protocols, and then summarize the desirable features of would-be-good routing protocols for sensor networks.

3.1. Existing routing protocols

1. *Low Energy Adaptive Clustering Hierarchy (LEACH)*

   LEACH is a clustering-based protocol that utilizes randomized rotation of the cluster-heads to evenly distribute the energy load among the sensor nodes in the network.
   It is mainly based on the following **assumption**:

   - The base station is fixed and located far from the sensors.
   - All nodes in the network are homogeneous and energy-constrained.

   And it's characterized by the following **features**:

   - It employs localized coordination to improve the scalability and robustness.
   - It uses data fusion to reduce the amount of information transmitted between sensor nodes and a given sink.
   - It uses dynamic cluster-heads mechanism to avoid the energy depletion of selected cluster-heads

   In sum, the combination of data compression and routing brings the energy saving feature to LEACH. However, it suffers from several **problems** as follows.

   - The nodes on the route from a hot spot to the base station might drain their battery very soon, which is known as "hot spot" problem.
   - It can not be deployed in time critical applications.
   - The assumption about the sink may not be practical.

2. *Power-Efficient Gathering in Sensor Information Systems (PEGASIS)*

   PEGASIS is a chain-based power efficient protocol based on LEACH.
   It is a near optimal protocol under the following **assumptions** about the network.

   - All nodes have location information about all other nodes and each of them has the capability of transmitting data to the base station directly.
   - Sensor nodes are immobile.
   - LEACH's assumptions in Section 3.1-1.

As the a near optimal protocol, PEGASIS outperforms LEACH with the following **characteristics**.

- Under the condition that each node knows the global topology of the network, the routing chain can be constructed easily by using a greedy algorithm.
- Each node in the chain takes turn to be the leader, which eliminates the overhead of dynamic cluster formation, minimizes the sum of distances that non-leader nodes must transmit, and limits the number of transmissions sum.

It is also recognized to be **problematic** in the following aspects.

- It suffers from the same problems described in Section 3.1 as LEACH does.
- Its requirement that global information of the network needs to be known by each sensor node, make the network not scale well and difficult for nodes to obtain such global knowledge due to their limitation in resource.

3. *Threshold sensitive Energy Efficient Sensor Network protocol (TEEN)*

   TEEN is a cluster-based routing protocol based on LEACH.
   It introduces two definitions, namely, Hard Threshold and Soft Threshold.

   Hard Threshold (H_T) The absolute value of the attribute beyond which, the node sensing this value must switch on its transmitter and report it.

   Soft Threshold (S_T) A change in the value of the sensed attribute which triggers the node to switch on its transmitter and report sensed data.

   It is based on the following **assumptions**.

   - The network is composed of a base station and sensor nodes with the same initial energy.
   - The base station has a constant power supply and can transmit with high power to all the nodes directly.

   All the unaddressed issues by LEACH are left unaddressed by TEEN as well. In addition to LEACH's drawbacks, TEEN suffers from the following **disadvantages**:

   - Cluster heads have to leave their transmitters on all the time and wait for data sent from other nodes, which worsen the poor resource-possess situation.
   - A node's time slot is wasted if it does not have data to send, while other nodes have to wait for their time slots.
   - There is no such a mechanism that could guarantee that the nodes that do not sense the S_T can be distinguished from the ones that are failed.

4. *Sensor Protocols for Information via Negotiation (SPIN)*

   SPIN is a family of protocols that efficiently disseminate information among sensor nodes in an energy constrained sensor network.
   It **assumes** that all of them are potential sinks.
   It has many novel **features**, namely, using metadata to name their data, using negotiations to eliminate the redundancy throughout the network. Furthermore, every node makes communication decisions based on both application-specific knowledge of the data and knowledge of the resources available to it, which enables efficient data distribution with limited energy. Due to these features above, SPIN manages to solve three problems in conventional data dissemination approaches, namely, implosion, overlap, and resource blindness.
   Here are some **drawbacks** within SPIN.

   - It's not scalable.
   - The nodes around a sink could deplete their battery quickly if the sink is interested in too many events.
   - Events are always sent throughout the network.

5. *Directed Diffusion*

   Directed Diffusion is a data-centric routing algorithm in which all communication is for named data.
   It consists of four elements: interests, data messages, gradients and reinforcements.

   Interest is a task description which is named by, for instance, a list of attribute-value pairs that describe a task.

   Data are named using attribute-value. pairs.

   gradient specifies both data rate and the direction along which events should be sent.

Reinforcement is used to select a single path from multiple paths.

Direct Diffusion networks are **classified** as application ware, and they can achieve energy saving by selecting good paths empirically by catching and processing data in-network.
The problems within this type of protocols are:

- To implement data aggregation, it employs time synchronization technique, which is not easy to realize in a sensor network.
- The overhead involved in recording information in data aggregation.

6. *Minimum Cost Forwarding Algorithm for Large Sensor Networks*

   The minimum cost forwarding approach takes advantage of the fact that most data flows are in single direction in sensor networks (i.e. from data sources to a sink).
   It **assumes** that all nodes including sinks are stationary. It has such a **feature** that provides us with the flexibility by allowing the cost to be measured in terms of energy or hops. However, it has the following drawbacks.

   - It has to consider non-negligible delays, channel errors, and node failures while implementing it, which adds additional complexity to the algorithm.
   - The number of sinks should be kept small; otherwise, nodes have to store large amount of cost information related to those sinks.
   - The time to set the cost field is directly proportional to the size of the network. It could be intolerable when the network size becomes too large.
   - Load is not balanced. Nodes with lower cost to the sink may deplete their energy very soon.

7. *Two-Tier Data Dissemination Model (TTDD)*

   TTDD provides scalable and efficient data delivery to multiple mobile sinks. Its main **characteristic** is that each data source proactively builds a grid structure which enables a mobile sink to receive data continuously while moving by flooding queries within its local cell only.
   The **assumptions** in its algorithm are:

   - Sensor nodes are stationary and location-aware, whereas sinks may change their locations dynamically.
   - Once a stimulus (interest) appears, the sensors surrounding it processes the signal and one of them becomes the source to generate data reports.
   - Sensor nodes are aware of their missions which change only infrequently.

   The main **drawbacks** of TTDD are that sensor nodes are confined to be stationary in the network, and location information is required to set up the grid structure. The length of a forwarding path in TTDD is at most $\sqrt{2}$ times the length of the shortest path.

8. *Routing Protocols with Random Walks*

   As its name suggests, random walks approach is claimed to be the first algorithm that achieves true multi-path routing as well as some kind of load balancing in a statistical sense.
   Its design is based on the following **assumptions.**

   - Only large scale networks are considered.
   - Once nodes are deployed, their mobility is very limited. But they can be turned on or off at random times.
   - Each node has a unique identifier but no location information is needed.
   - Each node lies exactly on one crossing point of a regular grid on a plane, and the topology could be irregular.

   Its **advantages** are:

   - Little state information needs to be kept by nodes.
   - It balances routing or communication load.
   - Different routes are chosen at different time even for the same pair of source and destination.

   while its main **drawback** is the topology of the network in the assumption of the algorithm may not be practical.

9. *Rumor Routing*

   Rumor Routing [7] combines query flooding and event flooding protocols in a random way.
   The authors make the following **assumptions**.

   - The network is composed of densely distributed nodes.
   - No unidirectional links exist.

- Only short distance transmissions are allowed.
- Nodes are immobile.

Thus, through the overview and comparison the existing routing protocols for sensor networks, we can summarize the desirable features that a well-developed routing protocol for sensor networks must be equipped with as follow.

- Low power consumption
    - Dynamic clustering architecture. It prevents cluster heads from depleting their power soon, and hence extends the network's lifetime.
    - Data fusion. If nodes could classify and aggregate data, it helps in efficient query processing, and decreases network overhead dramatically. This saves energy.
    - Thresholds for sensor nodes to transfer sensed data. Given good thresholds, it may solve "hot spot" problem and save energy by limiting unnecessary transmissions.
    - Thresholds for sensor nodes to relay data. Determining appropriate thresholds of energy and time delay to relay data would help in elongating nodes' lifetime.
- Low lost and good fault-tolerance
    - Randomizing path choice. If a routing algorithm can support multiple paths to a destination with low overhead, it could help in balancing the network load and tolerating the failure of nodes.
- Flexible scalability
- High security
- Low message latency

4. Conclusion

The sensor network are promising technology front in the 21st century. Due to the architecture and requirement of sensor networks, their routing protocols are distinguishing from those developed for ad hoc networks. Routing protocols for sensor networks must concern issues like energy saving, scalability, etc. With better developed routing protocols the sensor network technology can be more versatile and make our world better.

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