Data Fusion and Topology Control in Wireless Sensor Networks

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Abstract: The design of large-scale sensor networks interconnecting various sensor nodes has spurred a great deal of interest due to its wide variety of applications. Wireless sensor networks allow distributed sensing and signal processing while collaborating during energy efficient operations. Wireless sensor networks are battery powered; therefore prolonging the network lifetime through an energy aware node organization is highly desirable. This paper highlights the advantages of data fusion and topology control in wireless sensor networks. Our aim is to provide a better understanding of the current research issues in this field. The paper provides a more detailed look at some existing data fusion and topology management algorithms.

Key words: Wireless sensor networks, Data aggregation, Topology control, Protocols.

1. Introduction

Recent advances in micro-fabrication and wireless communication technologies have spurred a great deal of interest in the use of large-scale wireless sensor networks. Wireless sensor networks consist of a large number of sensor nodes that may be randomly and densely deployed. These tiny sensor nodes, which consist of sensing, data processing, and communicating components, leverage the idea of sensor networks based on collaborative effort of a large number of nodes. Sensor nodes use their processing abilities to locally carry out simple computations and transmit only the required and partially processed data. The above-described features ensure a wide range of applications for sensor networks. Some of the application areas are health, military and security. Although many protocols and algorithms have been proposed for traditional wireless and adhoc networks, they are not well suited for the unique features and application requirements for sensor networks. These are due to following reasons: -

Since sensor nodes are randomly deployed, so they do not fit into any regular topology. Once deployed, they usually don't require any human intervention. Therefore, all routing and maintenance algorithms need to be distributed.

Sensors rely on battery for power, which is difficult to be replaced or recharged. So, energy efficient protocols should be designed.

Sensor networks should adapt itself to frequent topological changes which may be due to failure of nodes. The routing protocols should be to dynamically include or avoid such nodes in their paths.

Since sensor networks are dense, neighbor nodes may be very close to each other. Hence, multihop communication is expected to consume less power than the traditional single hop communication.

As these sensor nodes are typically energy constrained, it is desirable to minimize the number of messages relayed because radio transmissions can quickly consume battery power. A reduction in communication and energy costs is possible if collected sensor data is aggregated prior to relaying. Data fusion is a

process of combining data or information to estimate or predict entity states. A number of research efforts are currently underway to address the issues on collaborative signal and information processing in distributed micro sensor networks.
Several nodes in the network can collect data from neighboring nodes, aggregate the data into one packet and then transmit that packet to the management station. It is also possible to have node process management data. By doing this, the nodes can determine what data is critical and should be forwarded, thus eliminating the necessity to forward a lot of extraneous data. Management data can be compressed before transmission of less data and conserving both energy and bandwidth.
Saving energy can be done at many different levels and in many different ways.
Choosing the approach to selectively switching of the radio of sensor nodes based on the availability of alternate routing paths is another way of optimizing the energy consumption in a wireless sensor networks. Switching off the radio of the sensor nodes is only possible if the topology is configured in such a way that the network is not partitioned due to those inactive nodes. Thus effectively controlling the topology of the network emerges as a solution to the problem of energy conservation for wireless sensor networks.
Energy is one of the constrained resources that need to be optimized in order to prolong the life of wireless sensor networks. A classification and comprehensive survey of data fusion and topology control protocols in wireless sensor networks is presented.

2.Energy efficiency requirements in wsn

Optimizing energy consumption has been the focus of recent research in sensor networks. This can be done by having energy awareness in every aspect of design and operation. Fig. 1 shows the schematic diagram of sensor node components. A typical sensor network is generally composed of four components: power supply unit, a sensing unit, a computing / processing unit, and a communicating unit [1].

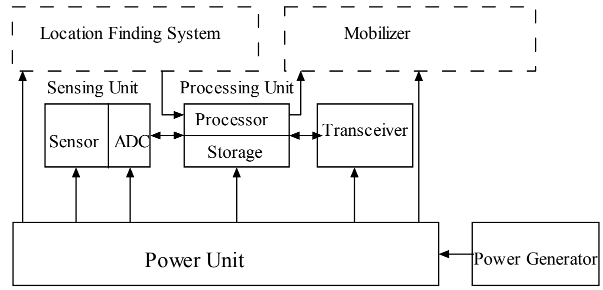

Fig.1 Components of a sensor node.

The sensing node is powered by a limited battery, which is impossible to replace or recharge in most application scenarios. Except for the power unit all other components will consume energy when fulfilling their tasks. Extensive study and analysis of energy consumption in wireless sensor networks are available [2,3].
The majority of the consumed power is in communication. The communicating energy is determined by the total amount of communication and the transmission distance. As reported in [4] processing data locally to reduce the traffic amount may achieve energy savings. Moreover, according to Rappaport [5], signal propagation follows as exponential law to the transmitting distance. Therefore, minimizing the amount of data communicated among sensors and reducing the long transmitting distance into a number of short ones are key elements to optimizing the communicating energy; numerous efforts have focused on these objectives. Several approaches have been devised in order to reduce data communication. For instance,
(a) Data Aggregation.
(b)Collaborative Signal and Information Processing (CSIP)
(c) Negotiation - based protocols.

2.1 Data aggregation

Data aggregation has been proposed as one of the most important techniques for conserving energy [6]. Data aggregation can be perceived as a set of automated methods of combining the data that comes from many sensor nodes into a set of meaningful information [7]. With this respect, data aggregation is known as data fusion

[8]. Data aggregation has been applied to eliminate redundancy in neighboring nodes [9,10]. It applies a novel data-centric approach to replace the traditional address-centric approach in data forwarding [6].
Several data aggregation algorithms have been reported in the literature. The most straight forward is duplicate suppression i.e. if multiple sources send the same data, the intermediate node will only forward one of them. Using a maximum or minimum function is also possible. Heinzelman et al. [7] and Julik & colleagues [11] proposed SPIN to realize traffic reduction for information dissemination using metadata negotiations between sensors to avoid redundant and/ or unnecessary data propagation through the network. The greedy aggregation approach [12] can improve path sharing and attain significant energy savings when the network has higher node densities compared with the opportunistic approach. Krishnamachari and colleagues [6] described the impact of source-destination placement on the energy costs and delay associated with data aggregation. They also investigated the complexity of optimal data aggregation.

2.2 Collaborative signal and information processing

Collaborative signal and information processing (CSIP) schemes are also powerful in reducing the amount of traffic transmitted and thus result in energy efficiency in wireless sensor networks. CSIP can be implemented through coherent signal processing on a small number of nodes in a cluster or through noncoherent processing across a larger number of nodes when synchronization is not a strict requirement [13]. CSIP algorithms can be classified [14] as
(i) Information driven schemes [15,16];
(ii) Mobile-agent based schemes [17] which attempt to reduce the system traffic by employing an agent, thus transmitting the integration process to the data sites instead of moving original data directly; and
(iii) Relation- based schemes [18] which use a top -down approach to select the sensor nodes to sense and communicate based on a high- level description of the task.

2.3 Negotiation based protocols

Negotiation based protocols have been introduced to reduce unnecessary replicated data [7,11]. Similarly, in order to decrease signal transmission distance, multihop communication and clustering-based hierarchies have been proposed to forward data in the network [19,20,21,22,23].
(i) LEACH: In reference [7,20], the authors proposed a distributed LEACH. LEACH is a well developed clustering- based protocol dedicated for continuous energy-efficient information collection in wireless sensor networks. However, it is used for proactive application scenarios and does not take the energy consumption for idle sensing of the channel into account, the formation of clusters is not energy aware. Therefore, some efforts have been made to improve its performance further.
(ii) TEEN: Manjeshwar and Agrawal [21] proposed the threshold-sensitive energy-efficient sensor network (TEEN) protocol. TEEN adopts the cluster formation method of LEACH, but uses thresholds to achieve enhanced control on sensor nodes. This scheme can also save energy consumption due to idle sensing. It is suitable for time-critical data delivery in reactive application scenarios.
(iii) APTEEN: Adaptive periodic TEEN (APTEEN) is proposed in [22] to fit in the requirements of hybrid application scenarios using enhanced query management and a modified TDMA MAC protocol. In TEEN and APTEEN the concept of multilevel clustering is used.
(iv) PEGASIS: A chain-based protocol called power efficient gathering in sensor information systems (PEGASIS) is presented in [24]. Instead of sending data packets directly to cluster heads, as is done in the LEACH protocol, each node forwards its packets to the destination through its closet neighbors.
(v) Utilizing the features of randomized creation and rotation of cluster heads as proposed in LEACH, as well as the advantages of multihop clustering algorithms, Bandyopadhyay and Coyle [25] introduced a new energy-efficient, single-level, mulitihop-clustering algorithm.
(vi)Several authors have studied the problem of energy- balanced data propagation in wireless sensor networks [26,27]. In reference [28],

authors have highlighted a scheme for monitoring residual energy distributions at different parts of the network through a mechanism called energy- centric scale, which is then used to perform optimal as well as approx. energy-centric routing in wireless sensor networks with the objective of maximizing the network lifetime. The paper in reference [29], describes a scalable key management and clustering scheme for secure group communications in adhoc and sensor networks. The scalability problem is solved by partitioning the communicating devices into subgroups, with a leader in each subgroup, and further organizing the subgroups into hierarchies. A load-balancing clustering approach for heterogeneous sensor networks is introduced in [30]. Qing et al. [31] have studied the performance of the clustering algorithms in saving energy for heterogeneous wireless sensor networks.

(vii) Directed diffusion A family of energy-efficient information dissemination protocols have been proposed in literature for instance, Directed diffusion [9,10] incorporates in-network data aggregation, data caching, and data-centric dissemination while enforcing adaptation to the empirically best path.

3.Existing Topology Control Algorithms

The topic of topology control in general adhoc networks has been studied extensively. The purpose of traditional topology control has been to balance two contradictory goals - reducing energy consumption and maintaining high connectivity.

Most early topology control protocols adjusted radio settings e.g., transmission power [32], beam forming patterns [33] to maintain connectivity with an optimal set of neighbors. Because it is often power-efficient to relay packets over several short hops than a single long hop, reducing transmission power is an effective means for reducing overall energy consumption. These methods may be very effective in sensors networks where energy consumption is dominated by the energy consumed in transmitting data packets. However, typical power models considered for sensor networks show that receive power and idle power are comparable to transmit power [34]. Based on this observation, further savings can surely be achieved by not only reducing transmission power, but also setting the sensors radios into a sleep state whenever possible.

Topology control protocols can be classified into two groups depending on which network layer information is used for identifying redundant nodes.

(i) Protocols like PAMAS [35], STEM [36] use MAC layer information to identify redundancy in the network.

(ii) Protocols like CEC, GAF [37], ASCENT [38], LEACH [7]-use information from the routing layer and above for identifying redundant nodes.

(a) ASCENT: Protocols like ASCENT which use application level information display high energy savings. In ASCENT, neighbor density and packet loss information is used to determine local connectivity and thereafter choose redundant nodes.

(b) LEACH: It is a clustering based routing protocol that uses randomized rotation of cluster-heads to evenly distribute the energy load among the sensors in the network. In order to avoid the energy drainage of cluster-heads in LEACH, the cluster-head positions are not fixed and are re-elected periodically. LEACH selects routing paths based on the total path energy.

(c) PAMAS: It uses a second radio channel to monitor neighbor traffic to determine the duty cycle of its main radio channel.

(d) AFECA: The AFECA [39] trades off energy consumption and the quality of the message delivery based on the application requirements.

(e) GAF: GAF [37] is another power- saving scheme that saves energy by powering off the redundant nodes. GAF identifies the redundant nodes by using the geographic location and a conservative estimate of the radio ranges. It superimposes a virtual grid proportional to the communication radius of the nodes on to the network. Because the nodes in one grid are equal from the routing perspective, the radios of the redundant nodes within a grid can be turned off. The nodes awake within a grid rotate to balance their energy.

(f)There are also a number of research efforts that trade off between latency and energy consumption. The power management approach presented in Kravets and Krishnan [40] selectively chooses short periods of time to suspend and shut down the communication unit, they queue the data before suspending the communication.

(g) STEM is a power saving-strategy that does not try to preserve the capacity of the network. STEM works by putting an increasing number of nodes into sleep node, and then encountering the latency to setup a multihop path. Nodes in STEM must have an extra low power radio (paging channel) that does not go into sleeping mode and constantly monitors the network to wake up the node in case of an interesting event.

4. Conclusions

Wireless sensor networks are networks consisting of many sensor nodes, which are constrained by power and energy. Energy aware computation and communication is the key to achieve long lifetime in WSN. This paper in general emphasizes on energy conservation for wireless sensor networks using collaborative signal and information processing and topology control. Sensor networks designed with such provisions having built in energy awareness and scalable energy consumption will achieve maximal system lifetime in the most challenging and diverse environment.

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