Survey on routing techniques in wireless Sensor networks

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Abstract: Wireless Sensor Networks (WSNs) consist of small nodes with sensing, computation and wireless communications capabilities. These nodes are limited with respect to energy supply restricted computational capacity and communication bandwidth & are primarily designed for monitoring and reporting events. Routing protocols for wireless sensor networks are responsible for maintaining the routes in the network and have to ensure reliable multi-hop communication under these conditions so many routing power management and data dissemination protocols have been specially designed for WSNs where energy awareness is an essential design issue. The focus however has been given to the routing protocols which might differ depending on the application and network architecture because each routing protocol has its merits and shortcomings, also sensor nodes are application dependent so a single routing protocol cannot be efficient for sensor networks across all applications. The lifetime will end when the working routing protocol can no longer support the whole wireless sensor network. To prolong the lifetime of the sensor nodes designing of efficient routing protocols is critical. In this paper, we present a survey of the state-of-the-art routing techniques in WSNs. We first outline the design challenges for routing protocols in WSNs followed by a comprehensive survey of different routing techniques. The paper concludes with possible future research areas.

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1. Introduction

Wireless sensor network (WSN) is widely considered as one of the most important technologies for the twenty-first century [1]. In the past decades, it has received tremendous attention from both academia and industry all over the world. A WSN typically consists of a large number of low-cost, low-power, and multifunctional wireless sensor nodes, with sensing, wireless communications and computation capabilities [2, 3]. These sensor nodes communicate over short distance via a wireless medium and collaborate to accomplish a common task, for example, environment monitoring, military surveillance, and industrial process control [4]. The basic philosophy behind WSNs is that, while the capability of each individual sensor node is limited, the aggregate power of the entire network is sufficient for the required mission. In many WSN applications, the deployment of sensor nodes is performed in an ad hoc fashion without careful planning and engineering. Once deployed, the sensor nodes must be able to autonomously organize themselves into a wireless communication network. Sensor nodes are battery-powered and are expected to operate without attendance for a relatively long period of time. Due to the severe energy constraints of large number of densely deployed sensor nodes, it requires a suite of network protocols to implement various network control and management functions such as synchronization, node localization, and network security. The traditional routing protocols have several shortcomings when applied to WSNs, which are mainly due to the energy-constrained nature of such networks [4]. Furthermore, these inconveniences are highlighted when the number of nodes in the network increases. A large number of research activities have been carried out to explore and overcome the constraints of WSNs and solve design and application issues. In this paper various routing protocols for wireless sensor network are discussed and compared. Section 2 of the paper discusses routing challenges and design issues in WSNs. In Section 3, various routing protocols are discussed. Section 4 concludes the paper & future scope.

2. Routing challenges and design issues in wsns

Despite the innumerable applications of WSNs, these networks have several restrictions, e.g., limited energy supply, limited computing power, and limited bandwidth of the wireless links connecting sensor nodes. One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation by employing aggressive energy management techniques. The design of routing protocols in WSNs is influenced by many challenging factors. These factors must be overcome before efficient communication can be achieved in WSNs. In the following, we summarize some of the routing challenges and design issues that affect routing process in WSNs.

Node Deployment: Node deployment in WSNs is application dependent and affects the performance of the routing protocol. The deployment can be either deterministic or randomized.

Energy Consumption without losing Accuracy: sensor nodes can use up their limited supply of energy performing computations and transmitting information in a wireless environment.

Data Reporting Model: Data reporting can be categorized as either time-driven continuous), event-driven, query-driven, and hybrid [5].

Node/Link Heterogeneity: In many studies, all sensor nodes were assumed to be homogeneous, i.e. having equal capacity in terms of computation, communication, and power. However, depending on the application a sensor node can have different role or capability.

Fault Tolerance: Some sensor nodes may fail or be blocked due to lack of power, physical damage, or environmental interference. The failure of sensor nodes should not affect the overall task of the sensor network.

Scalability: The number of sensor nodes deployed in the sensing area may be in the order of hundreds or thousands, or more. Any routing scheme must be able to work with this huge number of sensor nodes.

Network Dynamics: Most of the network architectures assume that sensor nodes are stationary. However mobility of BS's and sensor nodes is sometimes necessary in many applications [6].

Transmission Media: In a multi-hop sensor network, communicating nodes are linked by a wireless medium.

Connectivity: High node density in sensor networks precludes them from being completely isolated from each other.

Coverage: In WSNs, each sensor node obtains a certain view of the environment. A given sensor's view of the environment is limited both in range and in accuracy.

Data Aggregation: Since sensor nodes may generate significant redundant data, similar packets from multiple nodes can be aggregated so that the number of transmissions is reduced.

Quality of Service: In some applications, data should be delivered within a certain period of time from the moment it is sensed; otherwise the data will be useless.

3. Routing protocols in wsns

Routing in wireless sensor networks differs from conventional routing in fixed networks in various ways. There is no infrastructure, wireless links are unreliable, sensor nodes may fail, and routing protocols have to meet strict energy saving requirements [7]. Many routing algorithms were developed for wireless networks in general. We review sample routing protocols of different categories in preceding sub-section.

3.1 Location-based Protocols

In location-based protocols, sensor nodes are addressed by means of their locations. Location information for sensor nodes is required for sensor networks by most of the routing protocols to calculate the distance between two particular nodes so that energy consumption can be estimated. In this section, we present a sample of location-aware routing protocols proposed for WSNs.

3.1.1 Geographic Adaptive Fidelity (Gaf)

GAF [8] is an energy-aware routing protocol primarily proposed for MANETs, but can also be used for WSNs because it favors energy conservation. The design of GAF is motivated based on an energy model [9, 10] that considers energy consumption due to the reception and transmission of packets as well as idle (or listening) time when the radio of a sensor is on to detect the presence of incoming packets. GAF is based on mechanism of turning off unnecessary sensors while keeping a constant level of *routing fidelity* (or uninterrupted connectivity between communicating sensors).

3.1.2 Geographic and Energy-Aware Routing (gear)

GEAR [11] is an energy-efficient routing protocol proposed for routing queries to target regions in a sensor field, In GEAR, the sensors are supposed to have localization hardware equipped, for example, a GPS unit or a localization system [12] so that they know their current positions. Furthermore, the sensors are aware of their residual energy as well as the locations and residual energy of each of their neighbors. GEAR uses energy aware heuristics that are based on geographical information to select sensors to route a packet toward its destination region. Then, GEAR uses a recursive geographic forwarding algorithm to disseminate the packet inside the target region.

3.1.3 Trajectory-Based Forwarding (TBF)

TBF [13] is a routing protocol that requires a sufficiently dense network and the presence of a coordinate system, for example, a GPS, so that the sensors can position themselves and estimate

distance to their neighbors. The source specifies the trajectory in a packet, but does not explicitly indicate the path on a hop-by-hop basis. Based on the location information of its neighbors, a forwarding sensor makes a greedy decision to determine the next hop that is the closest to the trajectory fixed by the source sensor. Route maintenance in TBF is unaffected by sensor mobility given that a source route is a trajectory that does not include the names of the forwarding sensors. In order to increase the reliability and capacity of the network, it is also possible to implement multipath routing in TBF where an alternate path is just another trajectory.

3.1.4 Bounded Voronoi Greedy Forwarding [BVGF]

BVGF [14] uses the concept of Voronoi diagram [15] in which the sensors should be aware of their geographical positions. In BVGF, a network is modeled by a Voronoi diagram with sites representing the locations of sensors. In this type of greedy geographic routing, a sensor will always forward a packet to the neighbor that has the shortest distance to the destination. The sensors eligible for acting as the next hops are the ones whose Voronoi regions are traversed by the segment line joining the source and the destination. The BVGF protocol chooses as the next hop the neighbor that has the shortest Euclidean distance to the destination among all eligible neighbors. It does not help the sensors deplete their battery power uniformly. Each sensor actually has only one next hop to forward its data to the sink. Therefore, any data dissemination path between a source sensor and the sink will always have the same chain of the next hops, which will severely suffer from battery power depletion. BVGF does not consider energy as a metric.

3.1.5 Minimum Energy Communication Network (MecN)

MECN [16] is a location-based protocol for achieving minimum energy for randomly deployed ad hoc networks, which attempts to set up and maintain a minimum energy network with mobile sensors. It is self-reconfiguring protocol that maintains network connectivity in spite of sensor mobility. It computes an optimal spanning tree rooted at the sink, called minimum power topology, which contains only the minimum power paths from ach sensor to the sink. It is based on the positions of sensors on the plane. Each sensor broadcasts its cost to its neighbors, where the cost of a node is the minimum power required for this sensor to establish a directed path to the sink.

3.2 Data Centric Protocols

Data-centric protocols differ from traditional address-centric protocols in the manner that the data is sent from source sensors to the sink. In address-centric protocols, each source sensor that has the appropriate data responds by sending its data to the sink independently of all other sensors. However, in data-centric protocols, when the source sensors send their data to the sink, intermediate sensors can perform some form of aggregation on the data originating from multiple source sensors and send the aggregated data toward the sink. This process can result in energy savings because of less transmission required to send the data from the sources to the sink. In this section, we review some of the data-centric routing protocols for WSNs.

3.2.1 Sensor Protocols for Information Via Negotiation (SpiN)

SPIN [17, 18] protocol was designed to improve classic flooding protocols and overcome the problems they may cause, for example, implosion and overlap. The SPIN protocols are resource aware and resource adaptive. The sensors running the SPIN protocols are able to compute the energy consumption required to compute, send, and receive data over the network. Thus, they can make informed decisions for efficient use of their own resources. The SPIN protocols are based on two key mechanisms namely negotiation and resource adaptation. SPIN enables the sensors to negotiate with each other before any data dissemination can occur in order to avoid injecting non- useful and redundant information in the network.

3.2.2 Directed Diffusion

Directed diffusion [19, 20] is a data-centric routing protocol for sensor query dissemination and processing. It meets the main requirements of WSNs such as energy efficiency, scalability, and robustness. Directed diffusion has several key elements namely data naming, interests and gradients, data propagation, and reinforcement. A sensing task can be described by a list of attribute-value pairs. At the beginning of the directed diffusion process, the sink specifies a low data rate for incoming events. After that, the sink can reinforce one particular sensor to send events with a higher data rate by resending the original interest message with a smaller interval. Likewise, if a neighboring sensor receives this interest message and finds that the sender's interest has a higher data rate than before, and this data rate is higher than that of any existing gradient, it will reinforce one or more of its neighbors.

3.2.3 Rumour Routing

Rumor routing is a logical compromise between query flooding and event flooding app schemes [21]. Rumor routing is an efficient protocol if the number of queries is between the two intersection points of the curve of rumor routing with those of query flooding and event flooding. Rumor routing is based on the concept of agent, which is a long-lived packet that traverses a network and informs each sensor it encounters about the events that it has learned during its network traverse. An agent will travel the network for a certain number of hops and then die. Each sensor, including the agent, maintains an event list that has event-distance pairs, where every entry in the list contains the event and the actual distance in the number of hops to that event from the currently visited sensor. Therefore, when the agent encounters a sensor on its path, it synchronizes its event list with that of the sensor it has encountered. Also, the sensors that hear the agent update their event lists according to that of the agent in order to maintain the shortest paths to the events that occur in the network.

3.2.4 Active Query Forwarding in Sensor Networks (AcquiRe)

ACQUIRE [22] is another data centric querying mechanism used for querying named data. It provides superior query optimization to answer specific types of queries, called one-shot complex queries for replicated data. ACQUIRE query (i.e., interest for named data) consists of several sub queries for which several simple responses are provided by several relevant sensors. Each sub-query is answered based on the currently stored data at its relevant sensor. ACQUIRE allows a sensor to inject an active query in a network following either a random or a specified trajectory until the query gets answered by some sensors on the path using a localized update mechanism. Unlike other query techniques, ACQUIRE allows the querier to inject a complex query into the network to be forwarded stepwise through a sequence of sensors.

3.3 Hierarchical Protocols

Many research projects in the last few years have explored hierarchical clustering in WSN from different perspectives [2]. Clustering is an energy-efficient communication protocol that can be used by the sensors to report their sensed data to the sink. In this section, we describe a sample of layered protocols in which a network is composed of several clumps (or clusters) of sensors. Each clump is managed by a special node, called cluster head, which is responsible for coordinating the data transmission activities of all sensors in its clump.

3.3.1 Low-energy Adaptive clustering hierarchy (LeaCH)

LEACH [23] is the first and most popular energy-efficient hierarchical clustering algorithm for WSNs that was proposed for reducing power consumption. In LEACH, the clustering task is rotated among the nodes, based on duration. Direct communication is used by each cluster head (CH) to forward the data to the base station (BS). It uses clusters to prolong the life of the wireless sensor network. LEACH is based on an aggregation (or fusion) technique that combines or aggregates the original data into a smaller size of data that carry only meaningful information to all individual sensors. LEACH divides the a network into several cluster of sensors, which are constructed by using localized coordination and control not only to reduce the amount of data that are transmitted to the sink, but also to make routing and data dissemination more scalable and robust. LEACH uses a randomize rotation of high-energy CH position rather than selecting in static manner, to give a chance to all sensors to act as CHs and avoid the battery depletion of an individual sensor and dieing quickly. The operation of LEACH is divided into rounds having two phases each namely (i) a setup phase to organize the network into clusters, CH advertisement, and transmission schedule creation and (ii) a steady-state phase for data aggregation, compression, and transmission to the sink.

3.3.2 Power-Efficient Gathering in Sensor Information Systems (PeGasiS)

PEGASIS [24] is an extension of the LEACH protocol, which forms chains from sensor nodes so that each node transmits and receives from a neighbor and only one node is selected from that chain to transmit to the base station (sink). The data is gathered and moves from node to node, aggregated and eventually sent to the base station. The chain construction is performed in a greedy way. Unlike LEACH, PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the BS (sink) instead of using multiple nodes. A sensor transmits to its local neighbors in the data fusion phase instead of sending directly to its CH as in the case of LEACH. In PEGASIS routing protocol, the construction phase assumes that all the sensors have global knowledge about the network, particularly, the positions of the sensors, and use a greedy approach. When a sensor fails or dies due to low battery power, the chain is constructed using the same greedy approach by bypassing the failed sensor. In each round, a randomly chosen sensor node from the chain will transmit the aggregated data to the BS, thus reducing the per round energy expenditure compared to LEACH.

3.3.3 Hybrid Energy-Efficient Distributed Clustering (Heed)

HEED [25] extends the basic scheme of LEACH by using residual energy and node degree or density as a metric for cluster selection to achieve power balancing. It operates in multi-hop networks, using an adaptive transmission power in the inter-clustering communication. HEED was proposed with four primary goals namely (i) prolonging network lifetime by distributing energy consumption, (ii) terminating the clustering process within a constant number of iterations, (iii) minimizing control overhead and (iv) producing well-distributed CHs and compact clusters. In

HEED, the proposed algorithm periodically selects CHs according to a combination of two clustering parameters. The primary parameter is their residual energy of each sensor node (used in calculating probability of becoming a CH) and the secondary parameter is the intra-cluster communication cost as a function of cluster density or node degree (i.e. number of neighbors).

4. Conclusion

One of the main challenges in the design of routing protocols for WSNs is energy efficiency due to the scarce energy resources of sensors. The ultimate objective behind the routing protocol design is to keep the sensors operating for as long as possible, thus extending the network lifetime. The energy consumption of the sensors is dominated by data transmission and reception. Therefore, routing protocols designed for WSNs should be as energy efficient as possible to prolong the lifetime of individual sensors, and hence the network lifetime. In this paper, we have surveyed a sample of routing protocols. One important research related direction should receive attention towards and three-dimensional (3D) sensor fields when designing such protocols. Although most of research work on WSNs in particular is on routing, considered two-dimensional (2D) settings, where sensors are deployed on a planar field, there are some situations where the 2D assumption is not reasonable and the use of a 3D design becomes a necessity.

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