International Journal of Information Technology and Knowledge Management
January June 2009, Volume 2, No. 1, pp. 97-101

HIERARCHICAL ROUTING PROTOCOLS IN WIRELESS SENSOR NETWORK

Dinesh Anand* & Sanjay Kumar**

As the scale of the network increases, especially wireless and mobile networks come into fashion. Recent advances in wireless sensor networks have led to many new protocols specifically designed for sensor networks where energy awareness is an essential consideration. In this paper, the emphasis is on the study of Hierarchical routing protocols in wireless sensor networks (WSNs) since they might differ depending on the application and network architecture. We review the routing protocols such as LEACH, PEGASIS, TEEN and APTEEN.

Keywords: Hierarchical, Routing Protocols, Wireless Sensor Network

INTRODUCTION

Wireless sensor network (WSN) is a significant technology attracting considerable research attention in recent years. This network consists of large numbers of sensors, which are tiny, low-cost low-power radio devices dedicated to performing certain functions such as collecting various environmental data and sending them to infrastructure processing nodes [3]. Due to these characteristics, a sensor can not hold the whole wireless network information.

Communication in WSNs usually occurs in ad hoc manner, and shows similarities to wireless ad hoc networks. Likewise, WSNs are dynamic in the sense that radio range and network connectivity changes by time. Sensor nodes dies and new sensor nodes may be added to the network. However, WSNs are more constrained, denser and may suffer (or take advantage) of redundant information. WSN architectures are organized in hierarchical and distributed structures as shown in Figure 1.

HIERARCHICAL WSNs (HWSN)

There is a hierarchy among the nodes based on their capabilities: base stations, cluster heads and sensor nodes. Base stations are many orders of magnitude more powerful than sensor nodes and cluster heads. A base station is typically a gateway to another network, a powerful data Processing/storage center, or an access point for human interface. Base stations collect sensor readings, perform costly operations on behalf of sensor nodes and manage the network. In some applications, base stations are assumed to be trusted and temper resistant. Thus, they are used as key distribution centers. Sensor nodes are deployed around one or more hop neighborhood of the base stations. They form a dense network where a cluster of sensors lying in a specific area may provide similar or close readings. Nodes with better resources, named as cluster heads, may be used collect and merge local traffic and send it to base stations. Transmission power of a base station is usually enough to reach all sensor nodes, but sensor nodes depend on the ad hoc communication to reach base stations.

Data flow in such networks can be:

(i) pair-wise (unicast) among sensor nodes
(ii) group-wise (multicast) within a cluster of sensor nodes
(iii) network-wise (broadcast) from base stations to sensor nodes.

DISTRIBUTED WSNs (DWSN)

There is no fixed infrastructure, and network topology is not known prior to deployment. Sensor nodes are usually randomly scattered all over the target area. Once they are deployed, each sensor node scans its radio coverage area to figure out its neighbors. Data flow in DWSN is similar to data flow in HWSN with a difference that network-wise (broadcast) can be sent by every sensor nodes.

A solution to the above problem is to introduce a hierarchical topology to the network architecture [2]. Network information, such as routing tables, can be reduced by using this structure, because multiple sensors and links are aggregated to one sensor and link. Therefore, topology aggregation becomes a focused question in recent research within the large-scale networks.

ROUTING PROTOCOLS IN WSNs

In general, routing in WSNs can be divided into flat-based routing, hierarchical-based routing, and location-based

* Department of Computer Applications, BGIMT, Sangrur, Punjab, India, *E-mail: bgimtdinesh@gmail.com*

** Department of Computer Science & Engg., Kurukshetra Inst. of Tech. & Mngt, Kurukshetra, *E-mail: skm_09@rediffmail.com*

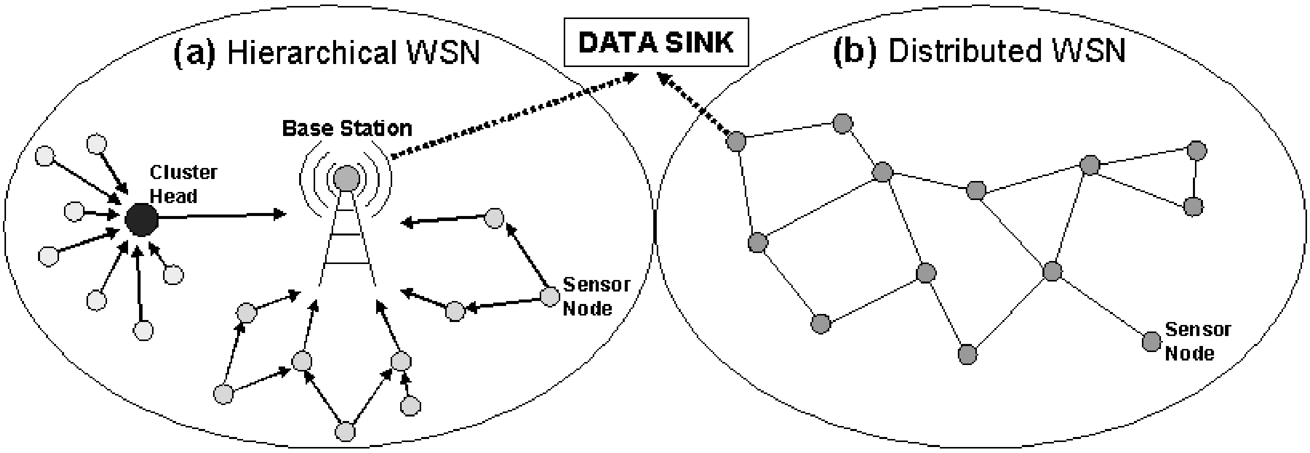

Figure 1: Network Models: Hierarchical and Distributed Wireless Sensor Networks

routing depending on the network structure. In flat-based routing, all nodes are typically assigned equal roles or functionality. In hierarchical-based routing, however, nodes will play different roles in the network. In location-based routing, sensor nodes' positions are exploited to route data in the network. A routing protocol is considered adaptive if certain system parameters can be controlled in order to adapt to the current network conditions and available energy levels. Furthermore, these protocols can be classified into multipath -based, query-based, negotiation-based, QoS-based, or coherent-based routing techniques depending on the protocol operation. In addition to the above, routing protocols can be classified into three categories, namely, proactive, reactive, and hybrid protocols depending on how the source finds a route to the destination.

(a) Proactive/Table Driven Routing Protocols

In proactive routing protocols, each node maintains routing information to every other node or nodes located in a specific part of the network. This routing information is kept in a number of routing tables. These tables are periodically updated and/or if the network topology changes. The limitation is that such protocols incur substantial signaling traffic and power consumption. Examples of table driven routing protocols are OLSR, FSR and DSDV.

(b) Reactive/On Demand Routing Protocols

The reactive routing protocols maintain information for active routes only i.e. routes are determined and maintained for nodes that require to send data. When a source has a packet to transmit it invokes a route discovery mechanism to find the path to the destination. The problem arises when a source node moves or a hop on the route to the destination node becomes unreachable. In such cases route discovery from source node to the destination node must be reinitiated. Examples of on-demand routing protocols are DSR and AODV.

(c) Hybrid Routing Protocols

The hybrid routing protocols share the ideas of table driven as well as on-demand protocols. Examples of hybrid routing protocols are Zone Routing Protocols.

When sensor nodes are static, it is preferable to have table driven routing protocols rather than using reactive protocols. A significant amount of energy is used in route discovery and setup of reactive protocols. Another class of routing protocols is called the cooperative routing protocols. In cooperative routing, nodes send data to a central node where data can be aggregated and may be subject to further processing, hence reducing route cost in terms of energy use. Many other protocols rely on timing and position information. We use a classification according to the network structure and protocol operation (routing criteria).

Classification of Routing Protocols

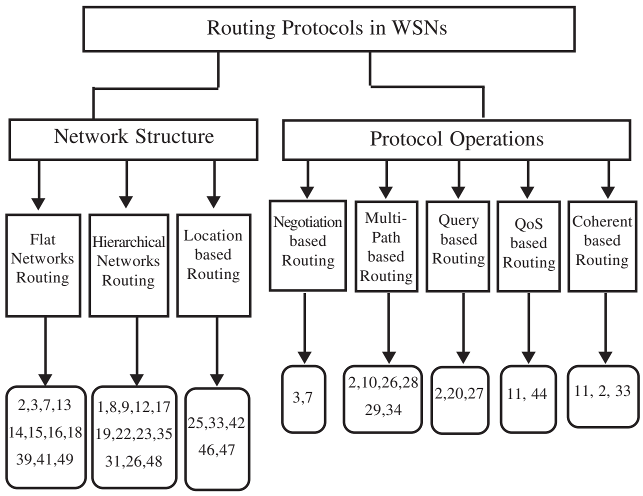

Figure 2: Classification of Routing Protocols in WSNs

Network Structure Based Protocols

The underlying network structure can play significant role in the operation of the routing Protocol in WSNs.

Flat Routing

In flat networks, each node typically plays the same role and sensor nodes collaborate together to perform the sensing task. Due to the large number of such nodes, it is not feasible to assign a global identifier to each node. This consideration has led to data centric routing, where the BS sends queries to certain regions and waits for data from the sensors located in the selected regions. Since data is being requested through queries, attribute-based naming is necessary to specify the properties of data. In data-centric protocols, two protocols SPIN, Directed diffusion to save energy.

(1) SPIN (Sensor Protocols for Information via Negotiation)

(2) Directed-Diffusion

In this paper, the emphasis is on the study of Hierarchical routing protocols in WSNs.

Hierarchical Routing Protocols

Hierarchical or cluster-based routing, originally proposed in wire-line networks, are well-known techniques with special advantages related to scalability and efficient communication. The concept of hierarchical routing is also utilized to perform energy-efficient routing in WSNs. In a hierarchical architecture, higher energy nodes can be used to process and send the information while low energy nodes can be used to perform the sensing in the proximity of the target. This means that creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS. Hierarchical routing is mainly two-layer routing where one layer is used to select cluster heads and the other layer is used for routing.

LEACH

Low-Energy Adaptive Clustering Hierarchy (LEACH) [6] is one of the most popular hierarchical routing algorithms for sensor networks. The idea is to form clusters of the sensor nodes based on the received signal strength and use local cluster heads as routers to the sink. This will save energy since the transmissions will only be done by such cluster heads rather than all sensor nodes. Optimal number of cluster heads is estimated to be 5% of the total number of nodes. All the data processing such as data fusion and aggregation are local to the cluster. Cluster heads change randomly over time in order to balance the energy dissipation of nodes. This decision is made by the node choosing a random number between 0 and 1. The node becomes a cluster head for the current round if the number is less than the following threshold:

$$T(n) = \begin{cases} \dfrac{p}{1 - p * (r \bmod \frac{1}{p})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

where p is the desired percentage of cluster heads (e.g. 0.05), r is = the current round, and G is the set of nodes that have not been cluster heads in the last $1/p$ rounds.

LEACH achieves over a factor of 7 reduction in energy dissipation compared to direct communication and a factor of 4-8 compared to the minimum transmission energy routing protocol. The nodes die randomly and dynamic clustering increases lifetime of the system. LEACH is completely distributed and requires no global knowledge of network. However, LEACH uses single-hop routing where each node can transmit directly to the cluster-head and the sink. Therefore, it is not applicable to networks deployed in large regions. Furthermore, the idea of dynamic clustering brings extra overhead, e.g. head changes, advertisements etc., which may diminish the gain in energy consumption.

PEGASIS & Hierarchical-PEGASIS

Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [7] is an improvement of the LEACH protocol. Rather than forming multiple clusters, EGASIS 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). Gathered data moves from node to node, aggregated and eventually sent to the base station. The chain construction is performed in a greedy way. As shown in Fig. 3 node c0 passes its data to node c1.

c0→c1→c2→c3→c4

↓

Base Station

Figure 3: Chaining in PEGASIS

Node c1 aggregates node c0's data with its own and then transmits to the leader. After node c2 passes the token to node c4, node c4 transmits its data to node c3. Node c3 aggregates node c4's data with its own and then transmits to the leader. Node c2 waits to receive data from both neighbors and then aggregates its data with its neighbors' data. Finally, node c2 transmits one message to the base station.

The difference from LEACH is to use multi-hop routing by forming chains and selecting

only one node to transmit to the base station instead of using multiple nodes. PEGASIS has been shown to outperform LEACH by about 100 to 300% for different network sizes and topologies. Such performance gain is achieved through the elimination of the overhead caused by dynamic.

TEEN and APTEEN

Threshold sensitive Energy Efficient sensor Network protocol (TEEN)[8] is a hierarchical protocol designed to be responsive to sudden changes in the sensed attributes such as temperature. Responsiveness is important for time-critical applications, in which the network operated in a reactive mode. TEEN pursues a hierarchical approach along with the use of a data-centric mechanism. The sensor network architecture is based on a hierarchical grouping where closer nodes form clusters and this process goes on the second level until base station (sink) is reached. The model is depicted in Fig. 4, which is redrawn from [8].

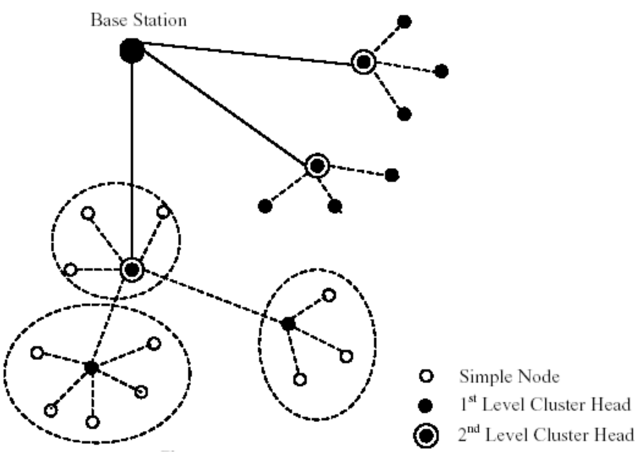

Figure 4: Hierarchical Clustering in TEEN & APTEEN

After the clusters are formed, the cluster head broadcasts two thresholds to the nodes. These are hard and soft thresholds for sensed attributes. Hard threshold is the minimum possible value of an attribute to trigger a sensor node to switch on its transmitter and transmit to the cluster head. Thus, the hard threshold allows the nodes to transmit only when the sensed attribute is in the range of interest, thus reducing the number of transmissions significantly. Once a node senses a value at or beyond the hard threshold, it transmits data only when the value of that attributes changes by an amount equal to or greater than the soft threshold. As a consequence, soft threshold will further reduce the number of transmissions if there is little or no change the value of sensed attribute. One can adjust both hard and soft threshold values in order to control the number of packet transmissions. However, TEEN is not good for applications where periodic reports are needed since the user may not get any data at all if the thresholds are not reached.

Hierarchical vs. Flat Topology Routing

Hierarchical Routing	*Flat Routing*
1. Reservation-based scheduling	1. Contention-based scheduling
2. Collisions avoided.	2. Collision overhead present
3. Reduced duty cycle due to periodic Sleeping.	3. Variable duty cycle by controlling sleeptime of nodes.
4. Data aggregation by cluster-head.	4. Node on multihop path aggregates incoming data from neighbors.
5. Simple but non-optimal routing	5. Routing can be made optimal but with an added complexity.
6. Requires global and local synchronization.	6. Links formed on the fly without synchronization.
7. Overhead of cluster formation throughout the network .	7. Routes formed only in regions that have data for transmission.
8. Energy dissipation is uniform.	8. Energy dissipation depends on traffic patterns.
9. Fair channel allocation.	9. Fairness not guaranteed.
10.Energy dissipation cannot be controlled.	10. Energy dissipation adapts to traffic pattern.

CONCLUSION

Routing in sensor networks is a new area of research, but rapidly growing set of research results. In this paper, we have examined the merit of hierarchical routing protocols with respect to extend the life time of sensor network, while not compromising data delivery Overall, the routing techniques are classified based on the network structure into three categories: flat, hierarchical, and location based routing protocols. We compare the performance between Hierarchical routing protocols and Flat routing protocols on various performance parameters such as scalability and efficient communication. The concept of hierarchical routing is also utilized to perform energy-efficient routing in WSNs

References

[1] Camtepe, S.A. and Yener, Bulent , Key Distribution Mechanisms for Wireless Sensor Networks: A Survey.

[2] Akyildiz, I., Su, W., Sankarasubramaniam, Y., and Cayirci, E. 2002. Wireless Sensor Networks: a Survey. Computer Networks.

[3] Chan, K. S., Pishro-Nik, H., and Fekri, F., "Analysis of Hierarchical Algorithms for Wireless Sensor Network Routing Protocols", *Wireless Communications and Networking Conference,* LA USA, 2005 *IEEE*, **3**, (March 13, 2005), 1830–1835.

[4] Benenson, Z., Gartner, F. C., and Kesdogan, D., "An Algorithmic Framework for Robust Access Control in Wireless Sensor Networks", *Proceeedings of the Second European Workshop on Wireless Sensor Networks*, Turkey, (Feb 2, 2005), 158–165.

[5] Al-Karaki, Jamal N. and E. Kamal, Ahmed "Routing Techniques in Wireless Sensor Networks": A Survey

[6] W. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks", *Proceedings of the 33rd Hawaii International Conference on System Sciences (HICSS'00)*, (January 2000).

[7] S. Lindsey and C. S. Raghavendra, "PEGASIS: Power Efficient GAthering in Sensor Information Systems," in the *Proceedings of the IEEE Aerospace Conference,* Big Sky, Montana, (March 2002).

[8] A. Manjeshwar and D. P. Agarwal, "TEEN: A Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks," In *1st International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Computing*, San Francisco, CA, (April 2001).

[9] A. Manjeshwar and D. P. Agarwal, "APTEEN: A Hybrid Protocol for Efficient Routing and Comprehensive Information Retrieval in Wireless Sensor Networks," *Parallel and Distributed Processing Symposium., Proceedings International*, IPDPS (2002), 195–202.

[10] Eugene Shih, *et al.*, "Physical Layer Driven Protocol and Algorithm Design for Energy-efficient Wireless Sensor Networks", in the *Proceedings of the 7th Annual ACM/IEEE International Conference on Mobile Computing and Networking* (Mobicom'01), Rome, Italy, (July 2001).

[11] L. Subramanian and R. H. Katz, "An Architecture for Building Self Configurable Systems," in the *Proceedings of IEEE/ACM Workshop on Mobile Ad Hoc Networking and Computing*, Boston, MA, (August 2000).