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Survey on Energy Conservation in Wireless Sensor Networks

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Abstract: ***Wireless sensor networks (WSNs) are networks of autonomous nodes used for monitoring an environment. Developers of WSNs face challenges that arise from communication link failures, memory and computational constraints, and limited energy. Particle swarm optimization (PSO) is a simple, effective and computationally efficient optimization algorithm. The energy conservation techniques and algorithms for computing the optimal transmitting ranges in order to generate a network with desired properties while reducing sensors energy consumption are discussed and compared through simulations. We describe a new clustering based approach that utilizes the periodical coordination to reduce the overall energy usage by the network.***

Keywords: ad hoc network, energy conservation protocol

1. Introduction

An ad hoc network is a wireless decentralized structure network comprised of nodes, which autonomously set up a network. No external network infrastructure is necessary to transmit data – there is no central administration. Freely located network nodes participate in transmission. Network nodes can travel in space as time passes, while direct communication between each pair of nodes is usually not possible. Generally, ad hoc network can consist of different types of multi functional.

Wireless sensor network (WSN) is most often set up in ad-hoc mode by means of small-size identical devices grouped into network nodes distributed densely over a significant area. These devices, each equipped with central processing unit (CPU), battery, sensor and radio transceiver networked through wireless links provide unparalleled possibilities for collection and transmission of data and can be used for monitoring and controlling environment, cities, homes, etc. In most cases WSNs are stationary or quasi-stationary, while node mobility can be ignored. There is no prearrangement assumption about specific role each node should perform. Each node makes its decision independently, based on the situation in the deployment region, and its knowledge about the network. In the case of net-works comprising several hundreds or thousands of nodes, it is necessary to choose an architecture and technology which will enable relatively cheap production of individual devices. For this reason, WSNs need some special treatment as they have unavoidable limitations, for example, limited amount of power at their disposal. Each battery powered device, participating in WSN needs to manage its power in order to perform its duties as long, and as effective as possible. Wireless sensors are thus characterized by low processing speed, limited memory and communication range.

Wireless sensor network can be used in different environments and situations and perform tasks of different kinds. Their application will condition the network topology and the choice of technology for its production. The network protocols used in the case of networks whose operating range covers a single building will differ from those operating within large space areas. The construction of a network capable of performing its task requires obtaining information on the devices (nodes) it comprises. The crucial data is the following: geographical location of network nodes, admissible power of radio transmitter and options for control of signal power, estimated number of network nodes, and number of nodes that can be lost before the network is declared non-operational, assumed network functionality (maximization of nodes operational time, maximization of throughput, etc.).In our paper we discuss the approaches to design the optimal w.r.t. minimal energy consumption WSN topologies. The short description of communication methods, energy conservation techniques (power save protocols) and algorithms for computing the optimal transmitting ranges in order to generate a network with desired properties while reducing sensors energy consumption (topology control protocols) is provided.

Power save protocols attempt to save nodes energy by putting its radio transceiver in the sleep state. Topology control protocols are responsible for providing the routing protocols with the list of the nodes 'neighbors, and making decisions about the ranges of transmission power utilized in each transmission. We analyze the properties of two location based distributed topology control protocols, and report the results of simulation experiments covering a wide range of network system configurations. Finally, we discuss the idea of our novel location based power save scheme utilizing hierarchical structure with periodic coordination of network nodes activity.

2. Topology Control

Transmission of data package between two network nodes xi and xj requires power proportional to d2i j, where di j denotes the Euclidean distance between sender and receiver. Let's assume that instead of performing direct transmission, a relay node xk is used. In such case two transmissions need to be performed: from a source node xi to a relay node xk (distance dik) and from the node xk to the destination node xj (distance dk j). Let's consider a triangle xixkxj let a be an angle at vertex xk. By elementary geometry we have: d2i j = dik2 +dk j2 − GLNGN MFRV ZKHQ FRVD≤ 0, total amount of energy spent to transmit a data package is smaller when a relaynode is used Generally, short transmissions in the network are desired. They involve smaller power consumption and cause less interference in a network, simultaneously affected, trans-missions, thus increasing the network throughput. In general, the goal of topology control (TC) [3] is to identify the situation when the using of the relay node is more energy-efficient than direct transmission and create the network topology accordingly. Topology control assumes that the nodes have impact on the power used to transmit a message. The basic task of TC algorithm consists in attributing the level of power used to send messages to every node in order to minimize the amount of power received from the power source, while at the same time maintaining the coherence of the network.

2.1. Topology Control Protocols

Topology control protocols are responsible for providing the routing protocols with the list of nodes' neighbors, and making decisions about the ranges of transmission power utilized in each transmission. The open systems interconnection (OSI) network model assumes that routing task is dealt with the network layer. On the other hand all functions and procedures required to send data through the network are stored in the OSI data link layer. Therefore the topology control layer is placed partially in the OSI network layer and the OSI data link layer.

We can divide these protocols into several groups.

- **Homogeneous topology controls protocols** assume that each node uses the same value of transmission power, which reduces the problem to simpler task of finding the minimal level of transmit power such that certain network property is achieved.
- **Location based topology control protocols** utilize the information about geographical location of nodes in the deployment area.
- **Neighbor based topology control protocols** assume that no information about location of nodes is available but each node can determine set of its neighbors and build an order on this set. Order may be based on round trip time, link quality or signal strength.

2.2. Location Based Protocols

We implemented and tested two location based protocols: R&M developed by Rodoplu and Meng, described in [6] and LMST (local minimum spanning tree) proposed by Li, Wang and Song in [7]. The short description of these techniques is provided.

The R&M and LMST Protocols: Let N be a set of n wireless nodes deployed in the certain region and forming WSN. Assuming that Ri denotes the maximal transmission range assigned to ith node we can generate the communication graph G = (N,E) induced by R on a given WSN. The E denotes a set of directed edges, and the directed edge [xi,xj] exists if xi and xj are neighbors, i.e., di j ≤ Ri, where di j denotes the Euclidean distance between sender and receiver. The communication graph G obtained when all the nodes transmit at maximum power is called max-power graph.

Let us consider the situation when all nodes transmit the collected data to one (or more) master node(s) xm – a base station(s). We can formulate the minimum energy all-to-one communication problem of calculating the optimal reverse spanning tree T of maxpower graph G rooted at Xm:

P IQ7 [L∈N,i6=mC(xi,PredT (xi)), (2)

where PredT (xi) denotes the predecessor of ith node in the spanning tree T and C(•) the energy cost of transmission from xi to its predecessor.

The R&M protocol calculates the most energy-efficient path from any node to the master node. It is composed of two phases.

Phase 1: The goal is to compute the enclosure graph of all nodes in WSN. Each node sends a broadcast message, at maximum power, containing its ID and location information. As such message is received by xi from any neighbor node, xi identifies the set of nodes locations for which communicating through relay node is more energy efficient than direct communication (the relay region of xi). Next, xi checks if the newly found node is in the relay region of any previously found neighbors. A node is marked dead if it lays in the relay region of any neighbor of xi, and alive otherwise. After receiving broadcast messages from all neighbors, the set of nodes marked with alive identifier creates the enclosure graph of xi.

Phase 2: In the second phase the optimal, i.e., minimum-energy reverse spanning tree rooted at the master node is computed. The Bellman-Ford algorithm [8] for shortest path calculation is used on the enclosure graph that was determined in the phase 1. Each node computes the minimal cost, i.e., minimal energy to reach the master node given the cost of its neighbors, and broadcasts the message with this value at its maximum power. The operation is repeated every time a message with a new cost is received. After all nodes determine the minimum energy neighbor link, the optimal topology is computed. The second considered protocol LMST can be used toWSN with nodes equipped with transceivers with the same maximum power. LMST operates in three phases.

Phase 1: Each node sends a broadcast message; at maximum transmit power, containing its ID and location information to its one hop neighbor in the maxpower graph.

Phase 2: The topology is generated. Each node determines a set of its neighbors, calculates Euclidean distance to every neighbor, and finally creates a minimum spanning tree based on its neighbors and computed distances (edge weights in the MST). Final network topology is derived from local MST created by all nodes. Neighbor set of each node consists of nodes, which are its direct neighbors in its local MST. Unfortunately, created topology may contain unidirectional links. Two approaches are proposed to solve this problem: it is assumed that all of them are bidirectional links or all unidirectional links are removed.

Phase 3: Transmission power required to reach every neighbor in a given topology is calculated based on the broadcast messages transmitted in the first phase. Based on the measurements of power of the broadcast messages and knowledge about power level used when transmitting the message, it is possible to compute power level needed to reach the target neighbor.

Simulation Results: The performance of R&M and LMST in terms of energy conservation was investigated through simulation. We carried out a set of experiments for various wireless sensor network topologies. It was assumed that all data collected in sensors were transmitted to one base station. We compared the results obtained using both algorithms with those when energy consumption was not considered while routing calculation. The key metric for evaluating the listed methods was the energy consumption used for data transmission. All experiments were conducted using the popular software for network simulation – ns-2 [9]. We implemented R&M and LMST protocols based on modules provided in ns-2 library of classes. The sensor networks with 50 – 300 nodes simulating the commercially available MICA2 sensors [10] with randomly generated positions in square regions 400×400 to 3000×3000 were considered in our experiments. The technical parameters of sensors were taken from [11], i.e., the radio power consumption for transmission was from 8.6 mA (RF transmission power −20 dBm) to 25.4 mA (RF transmission power 5 dBm), the initial energy resource of each node was assumed to be equal to 21 kJ. 70 Comparative Study of Wireless Sensor Networks Energy-Efficient Topologies and Power Save Protocols The objective of the first series of simulations was to compare the topologies calculated using described algorithms.

3. Energy Conservation

3.1. Power Consumption

The handling of the wireless transceiver contributes significantly to the node’s overall energy consumption. Depending on the state of the transceiver, different levels of power consumption is being observed. Table 2 summarizes the sample power consumption of some 802.11 wireless interfaces. In order to extend the working time of individual devices, it is frequent practice that some node elements are deactivated, including the radio transceiver. They remain inactive for most time and are activated only to transmit or receive messages from other nodes. Radio transceiver in WSN network node can operate in one out of four modes, which differ in the consumption of power necessary for proper operation: transmission – signal is transmitted to other nodes (greatest power consumption), receiving message from other node is received (medium power consumption), Stand-by (idle) – transceiver inactive, turned on and ready to change to data transmission or receiving (low power consumption), sleep radio transceiver off.

3.2. Power Save Protocols

The power-saving protocols used in sensor networks impose reduced consumption by putting the radio transceiver into the sleep mode. The use of such protocols involves the limitation of accessible band, and can also interrupt the data transfer in the network. Adequate choice of radio transceiver’s switch-off time introduces further difficulty in the implementation of network protocols. The literature (e.g., [3]) present algorithms designed to limit the power consumption while simultaneously minimizing the negative impact on the network throughput and on the efficiency of data transmission routing. Different types of protocols are used depending on the application of the network. Two categories can be distinguished.

Synchronous power save protocols, where it is assumed that nodes periodically wake up to exchange data packets. The sleep cycles of all nodes are globally synchronized. The main issue is to adjust length of sleep and wake phases that will minimize energy consumption and impact on a given network’s throughput.

Topology based power save protocols, where a subset of nodes which topologically covers whole network is selected. Nodes belonging to this set are not allowed to operate in the sleep mode. Other nodes are required to be periodically awake in order to receive incoming traffic. Power save protocols should be capable of buffering traffic destined to the sleeping nodes and forwarding data in partial network defined by the covering set. The covering set membership needs to be rotated between all nodes in the network in order to maximize the life time of the network.

It was observed that grouping sensor nodes into clusters can reduce the overall energy usage in a network. Clustering based algorithms seems to be the most efficient routing protocols for wireless sensor network clustering schemes. We developed a new clustering based power save protocol that utilizes the periodical coordination mechanism to reduce the energy consumption of a network. The proposed algorithm is an extension of the popular geographic adaptive fidelity (GAF) protocol.

The GAF Protocol: The GAF protocol described in [17] is a power save protocol that utilizes the information about the geographical location of the nodes. It relies heavily on the concept of node equivalence. The nodes A and B are equivalent with regard of data transmission between nodes C and D if and only if it is possible to use either node A or node B as a relay for the transmission between nodes C and D. The node equivalence is a feature that is not easily discovered. It is easy to notice, that nodes A and B, equivalent with regard of data transmission between nodes C and D do not have to be equivalent with regard of transmission between nodes D and E. In order to solve this problem, the GAF protocol partitions the network using a geographic grid. The grid size r is defined such that each node in one grid square is in transmission range of all nodes within adjacent grid squares. The sample construction of such a grid is depicted in Fig. 1. With elementary geometry we have grid size of $R/\sqrt{5}$, where R denotes the maximal transmission range assigned to each node. The construction of such a grid allows the GAF protocol to preserve the original network connectivity. The sole concept of the GAF protocol is to maintain only one node with its radio transceiver turned on per grid square. Such a node is called an active node and is responsible for relaying all the network traffic on behalf of its grid square. When there are more nodes in a grid square, the function of an active node is rotated between all the nodes in a grid square. The full graph of state transitions in the GAF algorithm is depicted in Fig.

1. Each node starts operation in the discovery mode, meaning the node has its radio transceiver turned on and is pending to switch to active state. The node spends a fixed amount of time TD in discovery state, when the time has passed; the node switches to the active state. After spending a fixed amount of time TA in active state, the node switches back to the discovery state.

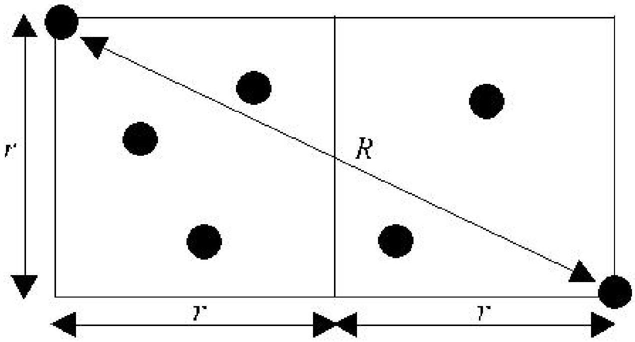

Figure 1: Network grid construction for GAF protocol

Whenever a node changes state to discovery or active, it sends a broadcast message containing node ID, grid ID and the value of a ranking function. If a node in discovery or active state receives a message from a node in the same grid and a higher value of the ranking function, it is allowed to change its state to sleep and turn its radio transceiver off for TS. The ranking function and timers TD, TA, TS can be used to tune the algorithm. Usually the ranking function selects nodes with "longest ex- Fig. 1. State transitions in GAF protocol. The GAF protocol can be easily adapted to mobility scenarios; in such a case the ranking function utilizes information about the time, when a node will leave the grid square.

The Coordination-Based Power Save Protocol (CPSP):

The typical wireless sensor network consists of large quantity of sensor nodes and a base station – a dedicated node which serves as a destination for messages generated by the sensor nodes. The base station is responsible for relaying information gathered by the network to the network operator. It can be assumed that the base station has significantly more resources than the sensor nodes and is directly connected to the power grid.

The wireless sensor network is utilized to deliver messages generated by the sensor nodes to the base station. From the operator's point of view there is no difference between not having any nodes in the network and the nodes not being able to deliver their messages to the base station. We propose to utilize the dedicated network node (or nodes) as a network coordinator (or coordinators) in order to ensure that the base station is able to receive messages from the network nodes for as long period of time as possible. The base station is a natural candidate to play a role of the coordinator. Our protocol assumes that the network is partitioned by a geographical grid in the same manner as in the GAF protocol. In addition we assume that not every network grid needs to maintain an active node. The cells that do not need to establish an active node are determined by the coordinator. The grids that must maintain an active node operate similarly to the grids in the GAF protocol. In remaining grids all nodes are put to sleep state until the next topology update. The coordinator views the network grids as a graph. The nodes periodically send to the coordinator information about amount of power available to them, which enable the coordinator to assign weights to the edges in the graph. Periodically, the coordinator calculates minimum spanning tree on the graph with itself as the root of the tree. The leaves of the tree are network grids that do not need to maintain an active node. The structure of spanning tree was chosen in order to preserve the original network connectivity. The calculated network topology is sent to all network nodes using a dedicated broadcast algorithm.

The CPSP Broadcast Algorithm: The CPSP broadcast algorithm relies heavily on the structure of the network and the information it is supposed to deliver to all network nodes. In order to perform the broadcast transmission, extended GAF discovery messages are utilized. Each discovery message contains the sequence number of latest transmitted network map. Since each network grid is able to receive discovery messages originating from neighboring grids, it is able to determine whether it is necessary to broadcast the latest received packet. If the grid determines that the neighboring grid has newer information, it sends a discovery message for neighboring grids to hear it. The size of broadcasted messages is kept as small as possible, information which cells should maintain an active node is sent as a bitmap – one bit represents one network grid.

Simulation Results: The coordinated power save protocol was implemented in the environment of the ns-2 network simulator [9]. The proposed protocol was compared with the plain GAF protocol and a network with no power save capabilities at all.

CPSP broadcast and GAF comparison. The initial energy resource of each node was assumed to be 21 kJ. Additionally it was assumed that the nodes utilize standard 802.11 radio transceiver. The traffic scheme utilized during simulation assumed random nodes sending messages to the base station at random moments of time. The messages sent to the base station were batches of 512 byte packets. The map of the network and the traffic scheme were generated using standard utilities shipped with the ns-2 network simulator. The metric for evaluating the GAF and CPSP methods was the average amount of energy left in the node during the time of simulation. Although the main objective of CPSP algorithm is to optimize the lifetime of the network and the utilized metric does not directly show the performance of protocols in that area.

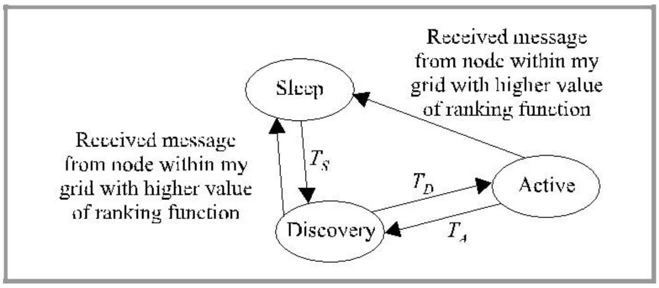

Figure 2: State transitions in GAF protocol

Wireless Sensor Networks Energy-Efficient Topologies and Power Save Protocols

4. Literature Survey

Prashant Dewan et. al.[1] The reputations of the nodes, based on their history of relaying packets, can be used by their neighbors to make sure that the packet will be relayed by the node. This paper introduces a reputation method for ad hoc networks. Instead of choosing the minimum distance path to the destination, the source node selects a path whose next hop node has the highest reputation. This policy, when used again and again, in the presence of 40% malicious nodes, changes in best way the throughput of the system to 65%, from 22% throughput provided by AODV.

V. Giri Babu et. al. [2] Each node in a MANET acts as a router, and communicates with each other. In a MANET (mobile ad hoc network), the mobility & resource constraints of mobile nodes may lead to network partitioning or performance degradation. Many data replication techniques have been proposed to minimize performance degradation. Maximum of them assume that all mobile nodes collaborate fully in terms of sharing their memory space. In reality, however, many nodes may selfishly decide only to cooperate selfishly, or not at all, with other nodes. These selfish nodes could then decrease the overall data accessibility in the network. In this paper, examine the impact of selfish nodes in a mobile ad hoc network from the perspective of replica allocation.

Raghavendra V. Kulkarni [3] His research interests include the development of wireless sensor network applications using computational intelligence tools. Wireless-sensor networks (WSNs) are networks of autonomous nodes used for monitoring an environment. Developers of WSNs face challenges that arise from communication link failures, memory and computational constraints, and limited energy. Many issues in WSNs are formulated as multidimensional optimization problems, and approached through bioinspired techniques. Particle swarm optimization (PSO) is a simple, effective, and computationally efficient optimization algorithm. It has been applied to address WSN issues such as optimal deployment, node localization, clustering, and data aggregation. This paper outlines issues in WSNs, introduces PSO, and discusses its suitability for WSN applications.

P. Santi [4] Topology Control (TC) is one of the most important techniques used in wireless ad hoc and sensor networks to reduce energy consumption (which is essential to extend the network operational time) and radio interference (with a positive effect on the network traffic carrying capacity). The goal of this technique is to control the topology of the graph representing the communication links between network nodes with the purpose of maintaining some global graph property (e.g., connectivity), while reducing energy consumption and/or interference that are strictly related to the nodes' transmitting range. In this article, we state several problems related to topology control in wireless ad hoc and sensor networks and we survey state-of-the-art solutions which have been proposed to tackle them. We also outline several directions for further research which we hope will motivate researchers to undertake additional studies in this field.

Anna Hac [5] Wireless sensor nodes deposited in various places provide light, temperature, and activity measurements. Wireless nodes attaches to circuits or appliances sense the current or control the usage. Together they form a dynamic, multihop, routing network connecting each node more powerful networks and processing resources. The emergence of compact, low-power, wireless communication sensors and actuators in the technology supporting the ongoing miniaturization of processing and storage, allow for entirely new kinds of embedded where they may not have been designed into a particular control path, and are often very dynamic.

V. Rodoplu and T. Meng [6] We describe a distributed position-based network protocol optimized for minimum energy consumption in mobile wireless networks that support peer-to-peer communications. Given any number of randomly deployed nodes over an area, we illustrate that a simple local optimization scheme executed at each node guarantees strong connectivity of the entire network and attains the global minimum energy solution for stationary networks. Due to its localized nature, this protocol proves to be self-reconfiguring and stays close to the minimum energy solution when applied to mobile networks. Simulation results are used to verify the performance of the protocol.

5. Conclusion

The paper provides the short overview of the energy conservation techniques and algorithms for calculating energy-efficient topologies for WSNs. The efficiency of four location based approaches, i.e., two schemes for topology control and two powers save algorithms are discussed based on the results of simulation experiments. The energy efficient method of introducing a coordinator to a WSN is presented. We show that our algorithm outperforms the results obtained for popular clustering based power save protocol GAF. In general, the simulation results presented in the paper show that topology control and power save protocols effect the scheduling transmissions in a wireless sensor network, and confirm that all discussed approaches to reduce the energy consumption improve the performance of this type of network.

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