Energy conservation approach to enhance the lifetime of wireless sensor network in different layers of communication protocols

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Abstract

Wireless sensor networks(WSN), are similar to wireless ad hoc network_in the sense that they rely on wireless connectivity and spontaneous formation of networks so that sensor data can be transported wirelessly. The unique network characteristics present several challenges in the design of sensor networks that involve limited battery capacity, limited hardware resources, massive and random deployment, dynamic and unreliable environment. Out of these, one of the challenging issues is to conserve the energy of nodes as much as possible to increase the lifetime of the node. Recent advances in WSNs have led to many new protocols where energy awareness is an essential consideration. Attention has been given to the network layer protocols to find ways for energy efficient and reliable route a setup to maximize network lifetime. Energy efficiency and lifetime of a network are challenging issues in WSNs. Number of protocols based on energy conservation have been proposed in literature but only few consider Quality of Service (QoS) parameters along with energy efficiency. Additionally two protocols, Improved Breadth First Search (IBFS) and Enhanced BFS (EBFS) on stable and optimal route formation based on graph theory have been proposed. Along with this, a pre deployment non-uniform node distribution strategy for enhancing the lifetime of the network for sector based network is proposed. Results have been evaluated theoretically as well as through simulations. It has been analyzed that the proposed hierarchical protocols achieve significant improvement in terms of delay, energy consumption, stability and network lifetime over other popular existing protocols like LEACH, PEGASIS, WCA and IWCA etc.

Keywords

WSN, LEACH, QoS, ADC, PRRP.

1.Introduction

Wireless sensor technology is playing a vital role in many of the commercialized industrial automation processes and various other real life applications. It is particularly suitable for harsh environment applications where deploying of other network infrastructure is difficult and/or almost impossible such as in battlefield, in hazardous chemical plant, and in high thermal environment. It is not uncommon to see that most of the crucial surveillance and security applications also rely on sensor based applications. Sensors which are tiny in size and cheap in cost have the capabilities to be deployed in a range of applications. Essentially all sensor networks comprise some forms of sensing mechanism to collect data from an intended physical environment either by a time driven approach or by event triggering approach. By these approaches a sensor will convey the sensed data to a destination or sink (multiple destinations/sinks are also possible) via some kinds of routing algorithm such as Minimum Cost Forwarding Algorithm (MCFA), Directed Diffusion Routing Protocol (DDRP), or one of the cluster-based routing protocols. Being very small in size, sensor nodes are built with limited computational capacity, small storage memory, and finite battery power capacity.

The structure of a typical WSN node consists of four main components: a sensing element, normally used for sensing a physically measureable parameter; an Analog-to-Digital Converter (ADC), used for converting analog signals to some digital formats; a processing unit, providing simple/basic data processing and computation capabilities; and a power unit, responsible for sensor node’s operation life span. It is a known fact that WSN is a resource constrained network in which energy efficiency is always the main issue since the operation of WSN depends heavily on the life span of the sensor nodes’ battery. The most energy consuming operation in WSN is the data packet routing activity. The characteristics of the WSN are different from the conventional networks. These unique characteristics are often taken into account for addressing the issues and challenges related to network coverage, runtime topologies management, node distribution, node administration, node mobility energy efficiency/consumption, network deployment, application areas/environment, and so forth.

Nodes in a WSN are generally energy, computation, and memory constrained. Consequently, there is a need for research and development into low-computation resource-aware algorithms for WSNs, targeting at small, highly resource constrained embedded sensor nodes. Energy consumption is of prime importance in WSNs and thus some algorithms and hardware were designed with energy efficiency or energy awareness as a central focal point of interest. Enhancing energy efficiency of WSN with respect to the communication routing protocol is the primary concern of this research. We propose a new routing protocol entitled “Position Responsive Routing Protocol (PRRP)” and compare its performance with the well-known LEACH and CELRP protocols. The simulation results show a significant improvement over the a fore mentioned protocols in terms of energy efficiency and the overall performance of the WSN. Most current energy minimization approaches consider WSNs in terms of network layers: (1) the operating system, (2) the physical layer, (3) the MAC layer, (4) the network layer, (5) the application layer. In this section we review related efforts in the minimisation of energy consumption at each layer.

2.Background and related work

The main operational sustainability concern in WSN is its energy resource constraint. This brings along in recent years that a great number of energy efficient routing protocols have been proposed for WSNs based on the network organization and the routing protocol operations. Some of these focused on minimizing the communication distance to reduce the energy consumption and a handful of them focused on fair energy distribution to avoid the routing hole (hot spot) problems. These protocols are suitable in certain situations; however they may not be applicable in cases where mobility is not feasible such as earthquake, forest fire, and disaster management. Mobility techniques do have other challenges like increased energy overhead owing to frequent network topology changes and data packet drops due to high latency. Many researchers pay attention to the WSN energy issue by designing different routing techniques and MAC-layer protocols to raise the energy level in WSN. Our literature review reveals that a range of different energy efficient routing protocols in the recent past were designed mostly based on the network structure such as hierarchical routing, location routing, and flat based routing. Our extensive literature review also reveals that the existing routing protocols are still facing energy efficiency limitation issues. Critical analyses of some of the popular existing energy efficient routing protocols are presented in this section. The literature review referred to the fact that the main advantage of flat based routing protocol is its simplicity in operation and it had a direct communication mechanism with the base station in which all nodes are allowed to participate during the routing operation. For its simplicity, the nodes only need information about their closest neighbours. However, the major disadvantage is that nodes spread out in a flat manner and all nodes are attempting to participate equally thus causing the nodes closer to the sink to deplete their power sooner than those located further away from the sink. This is mainly due to the heavy data transmission load. This is badly affecting the nodes closer to the sink for keeping them alive longer. Therefore the nodes further away may be unable to communicate with the base station after some time due to network isolated segmentation problem in the WSN. Consequently many of the nodes are not able to participate in routing thus not utilizing their entire energy effectively. More research works are deemed necessary to address the WSN energy efficiency in this aspect. In addition, flat routing is still having issues in data collision overhead, links formed on the fly without synchronization, energy dissipation depending on traffic patterns, and fairness being not guaranteed.

(a)Reservation Based Power-Aware MAC

Tries to avoid collisions in the MAC layer, since collisions may result in retransmissions, leading to unnecessary power consumption. Although EC-MAC was originally constructed for networks with base stations serving as access points, its definition could be extended to ad hoc networks, where a group of nodes may select some type of coordinator to perform the functions of a base station. Furthermore, because the coordinator’s in which coordinators are rotated among network nodes. role consumes the resources of certain nodes, a group of schemes were proposed.

(b)Switching off Power-Aware MAC: Tries to minimize the idle energy conservation by forcing nodes to enter the doze mode. For example, PAMAS allows a station to power its radio off but has to keep a separate channel on which the RTS/CTS packets are received. Similarly, Chiasserini allows a station to go to sleep, but a special hardware is required to receive wakeup signals. The geographical area is partitioned into smaller grids in each of which only one host needs to remain active to relay packets.

(c)Transmission Power Control: Came about because the maximum power is consumed during the transmission mode. According to the path-loss radio propagation model there is a non-linear relation between the transmission power and the transmission distance. It is more energy conserving (considering only transmission energy) to send the detain a multihop fashion using relay nodes rather than sending it directly to the destination. A simple power control scheme for the 802.11 protocol should adjust the transmission energy for data and control frames (RTS/CTS) according to the distance between the sender and the relay node.

Physical layer-physical layer Communication between wireless sensor nodes needs a radio connection as a physical layer in which energy is consumed when the radio sends or receives data. The physical layer involves modulating and coding data in the transmitter, and then in the receiver this layer must optimally decode the data. The radio channel has three modes: idle, sleep important to minimise the time and energy to switch between different modes and transmit and receive states [1]. Furthermore, a low-power listening approach may operate at the physical layer, in which the basic idea is to periodically turn on the receiver to sample the incoming data. This duty-cycle approach reduces the idle listening overhead in the network [2]. Moreover, the energy consumption of the radio channel for sending and receiving data is equal; consequently, energy efficient MAC protocols have to maximise the sleep time of sensors [3]. Due to real-time monitoring and interaction with different parts of a sensing node, the operating System (OS) is probably the best place to optimise and manage energy consumption of a WSN at the node level. Perhaps one of the best known techniques at the OS kernel level for minimising energy consumption in the anode is processing unit scheduling by Dynamic Voltage-Frequency Scaling (DVFS). This technique allocates CPU time to tasks and manipulates the CPU power states [4]. In other words, tasks are executed at different frequencies, where lower frequencies mean less power consumption, and the CPU is moved to the lowest power state when there is no task to execute. Parallel thread processing techniques can be useful to reduce the energy usage of a nodes processor; for instance, in a WSN with cluster-based infrastructure, cluster heads become responsible for collecting data and executing the necessity computation operations. As addressed in [5], partitioning a computation, resulting in creating a greater allowable latency per computation, saves more energy through DVFS. Such partitioning makes a considerable improvement in energy dissipation by altering task scheduling algorithms, sequence of tasks execution, and communication scheduling among sensors. In [6] a task mapping technique followed by a scheduling solution for WSN applications was proposed to improve the partitioning technique.

Network layer-The network layer consists of a few parts, each one involving different techniques to reduce energy consumption of the network and ultimately improve its lifetime; this section studies these strategies. Briefly, there are a few easy techniques to reduce communication load and therefore consume less energy: among them are decreasing the amount of transmitted data, reducing the number of reporting sensors, and shortening the comm[7]nication range [8], to name a few. Since there are different types of nodes in a network and each one has its own energy requirement, assigning energy according to requirement makes it possible to avoid the wastage of residual energy. Non-uniform energy assignment achieves a balance between energy efficiency and energy balance simultaneously [9]. Despite its benefit, monitoring the energy requirement of each node and assigning an appropriate task is very difficult. Generally, sensors have a high degree of cooperation in nature, and the authors of one study [10] employed this behaviour to propose a data transmission policy called energy-efficient cooperative communication (EECC).

Routing- Since routing is a significant and costly task in WSNs, routing protocols should be energy efficient to increase the network lifetime. Al-Karaki and Kamal discussed types of networks, topologies and protocols and their influences on the energy cost. In homogenous sensor networks, all nodes are the same and the routing tasks are assigned equally among the nodes, while in heterogeneous networks the nodes have different capabilities. Nodes with high capability may be assigned more responsibility and overall energy consumption can be reduced by optimising arrangements. Routing protocols operate on topologies such as tree, mesh, clustered, etc to deliver data to the destination. Different methods use different techniques to extend the lifetime of the sensor. SPIN 33 (Sensor Protocols for Information via Negotiation) is a routing technique based on node advertisements in which nodes only need to know their one-hop neighbours. The technique is, however, not suitable for applications that require reliable data delivery. LEACH (Low-Energy Adaptive Clustering Hierarchy) is a clustered routing algorithm where the cluster-heads are responsible for relaying data and controlling the cluster. Although LEACH is an effective technique for achieving prolonged network lifetime, scalability, and information security, LEACH does not guarantee optimum routes. Directed Diffusion technique is a data centric, localised repair, multi-path delivery for multiple sources, sinks and queries [5] aiming to find optimal paths.

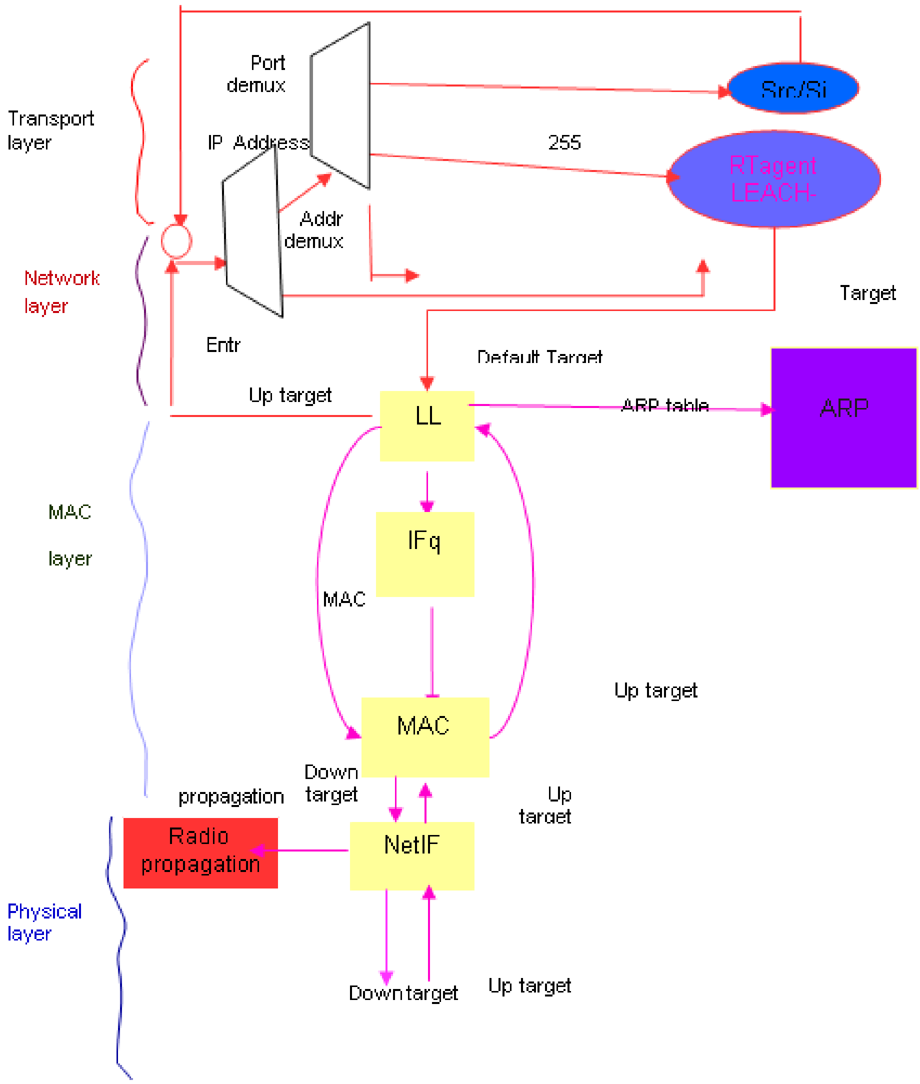

Figure 1 Details network layers of sensor node

Transport layer-Transport layer ensures the reliability and the quality of data at the sender and the receiver. Transport protocols in WSNs should support multiple applications (industrial process monitoring and control, machine health monitoring, environment and habitat monitoring, health care applications, home automation, and traffic control) and provide variable reliability level, packet loss recovery and congestion control mechanism. We can distinguish between two types of data in WSNs: 1) Data sent by sensor network to the base station (Sink), 2) Data sent by the base station to one or a subset of sensor nodes for different purposes (control, management, re-tasking, reprogramming). The development of a transport protocol should be generic and independent. It should provide various reliability levels for different applications. WSNs suffer from a high loss rate. Packet loss may be due to bad radio communication, congestion, packet collisions, full memory capacity, and node mobility or fail. Thus, transport protocol should provide two functions: reliable data transport and congestion control. A reliable application requires that all segments sent by a source arrive to the destination. Missing segments that may be lost in the WSN should be recovered by reliable schemes. Congestion happens when the data packets generated by sensor nodes exceed the network capacity. When the networks get congested, intermediate sensor nodes may drop packets. This leads to retransmissions of the dropped packets and thus a waste of energy that is a very important factor in wireless sensor network. In the following, we present a summary of recent transport protocol proposed for WSNs.

3.Reliable multi-segment transport

The first transport layer with hop-by-hop recovery scheme using caching mode as additional control traffic for Direct Diffusion. The main goal of RMST is to minimize the cost of end-to-end retransmissions. RMST protocol provides two transmission modes: caching mode (with hop-by-hop recovery) and non-caching mode (with end-to-end recovery). In non-caching mode, only sources and sinks maintain a cache, and only sinks set timers to detects loss. In caching mode, RMST protocol assumes that each sensor node has a cache memory where recently received segments can be saved. RMST protocol reduces end-to-end retransmissions by introducing hop-by-hop retransmissions from caches of neighbour nodes. In link layer, lost packets are retransmitted using Automatic Repeat request (ARQ). The RSMT receivers are responsible for detecting losses and for trigger the recovery of the missing segments through the generation of Negative Acknowledgments (NACKs). The RSMT receivers are not only sinks, but also intermediate nodes. To handle losses, an RSMT intermediate node should store data traffics and constructs a map of received segments. When an out-of order segment is received, an RSMT receiver sends a NACK requesting the retransmissions of the lost messages. Firstly, the one-hop neighbours process NACKs. Then, if one of the neighbours finds the missing segments in cache, it suppresses the NACK message and retransmits the missing segments to the sink. Else, the NACK message is relayed to the next node toward the source. RSMT protocol provides 100% reliability even for applications that do not require total reliability. Moreover, RMST does not include real time guarantees or congestion control mechanisms. Require that each node has enough memory to store all received segments is a very strong condition difficult to be satisfied with memory-constraint wireless devices.

Pump Slowly, Fetch Quickly

PSFQ is based on slowly injecting packets into the network “pump operation” and performing aggressive hop-by-hop recovery in case of packet losses “fetch operation”. Like RSMT, PSFQ provides a hop-by-hop error recovery mechanism in which intermediate nodes take the responsibility of loss detection and recovery. To enable a hop-by-hop loss recovery and in-sequence data delivery, a data cache is created and maintained at intermediate nodes. The PSFQ “pump operation” consists in a timely controlled data forwarding. In intermediate nodes, when a packet is received in an out-of-order sequence, it is stored. However, instead of forwarding it, the immediate node requests retransmission of the missing segment.

Event-to-Sink Reliable Transport protocol- ESRT is a transport protocol that seeks to achieve reliable event direction with minimum energy expenditure and congestion resolution. The main goal is to configure the reporting frequency rate to achieve the desired event detection accuracy with minimum energy expenditure. In fact, a sensor node in ESRT sends messages with an announced reporting frequency to the base station. An ESRT base station regulates the reporting rate of sensors in response to a congestion detected in the network. Congestion control mechanism is implemented in the base station, which informs all sensor nodes using a different technology about the new reporting frequency. An ESRT node monitors its local buffer level and sets a congestion notification bit in the packets it forwards to base station if the buffer overflows. If the base station receives a packet with the congestion notification bit set, it broadcasts a control signal informing all source nodes to slow down their common reporting frequency. The ESRT base station must broadcast this control signal at high energy so that all sources can hear it or use another technology.

4.Distributed transport for sensor networks

Distributed Transport for Sensor Networks is an energy-efficient hop-by-hop reliable transport protocol using both ACK and NACK message for delivery confirmation. A DTSN node analyzes the sequence numbers of received packets and detects losses by finding gaps. Every source node sends an Explicit Acknowledgment Request (EAR) every one Acknowledgment Window (AK) to ask for an ACK or a NACK. The sink node replays by an ACK message if no gap is detected or by a NACK message containing the sequence numbers of missing segments. DTSN protocol is a hop-by-hop recovery protocol; all intermediate node caches received packet in their cache. Upon reception of an ACK message, intermediate node deletes acknowledged segment. Otherwise (i.e. reception of NACK message) an intermediate node checks if its cache contains one of the missing segment. DTSN node retransmits missing segments and updates the NACK message. DTSN offers two types of service: total reliability service and differentiated reliability service. The difference between the two types of service is the probability of caching a segment in an intermediate node. For example, in full reliability scenario, all segments are cached in intermediate nodes. DTSN algorithm does not threat congestion detection and control.

Rate-Controlled Reliable Transport protocol- Rate-Controlled Reliable Transport protocol is a multipoint-to-point reliable transport protocol for wireless sensor networks. RCRT uses an explicit end-to-end loss recovery and places all congestion detection, recovery and rate adaptation schemes in the base station (Sink). RCRT sink has three distinct logical components:

(a) End-to-end retransmission The main goal of RCRT is to achieve 100% reliability. The RCRT sink uses NACK-based end-to-end loss recovery to request the retransmissions of missing packets from the source. Each source (sensor node) has a retransmission buffer where is saved the not acknowledged segment. The sink node keeps a list of lost segments then sends a NACK feedback message to the source containing the sequence numbers of missing segments. Upon receiving a NACK, the source node retransmits the requested segments.

(b) Congestion detection To distinguish between congestion and transmission losses, RCRT congestion detection mechanism is based on the length of the losses. The sink node maintains a list of the out-of-order messages and computes the Time to recover loss.

5.Conclusion

To save energy in media access communication is an active research area. In this paper, we have surveyed the existing energy saving mechanisms for MAC protocols. Energy saving mechanisms are diverse in MAC protocols. Due to a wide range of sensor network applications, it is impossible that one particular type of mechanism is used universally. Many MACs use a variety of approaches to save energy and give optimum performance. LEACH protocol is a perfect example for this. It uses clustering, data aggregation, and in network processing to provide optimum performance. This leads to dissimilar advantages and disadvantages. Application scenario is also a major factor in MAC protocol performance and energy efficiency. In some scenarios, periodic low duty cycle-based hierarchical protocol may work better, and in some other cases cluster-based protocols can perform better. A MAC protocol needs to give optimum performance in the specific application area where it is used. Hence energy efficiency, though a primary requirement in a MAC protocol, depends on a particular network and application area. In our opinion, a hybrid approach would be a necessary development path for energy-efficient MAC protocols.

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