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Different Energy Saving Schemes in Wireless Sensor Networks: A Survey

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Abstract

Wireless sensor networks (WSNs) are one of the very active research area. They have many applications like military, health care, environmental monitoring and industrial monitoring. The sensor nodes have limited energy source. Since in many cases the nodes are deployed in unreachable areas, hence recharging or replacing the battery of the sensor nodes is not an option. Therefore, one must employ techniques to conserve the energy by reducing the energy consumption by the nodes. In this paper, we discuss about the different energy saving schemes investigated by different research community in WSNs to reduce the energy consumption of the nodes and thereby improving the lifetime of the overall network. Energy saving protocols such as duty cycle, energy efficient routing, energy efficient medium access control (MAC), data aggregation, cross layer design and error control code (ECC) are discussed. Sleep/wake up method is adopted by the duty cycle approach to reduce the active time of the nodes and conserve their energy. The routing and MAC protocols use suitable energy efficient algorithms for saving energy. The data aggregation aims to save energy by reducing the number of transmissions. On the other side, cross layer approach looks for a cross layer optimization solution to improve the energy efficiency of the network. ECC reduces energy consumption by virtue of coding gain it offers which allows lower signal-to-noise ratio (SNR) to achieve the same bit error rate (BER) as an uncoded system. Some techniques such as use of directional antennas, topology control and transmission power control which have been widely investigated for other ad-hoc networks for energy conservation are also discussed in brief in this paper.

Keywords Energy conservation · Energy saving schemes · Lifetime · Survey · Wireless sensor networks

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1 Introduction

Wireless sensor network (WSN) has become a promising research area in recent years. It has many applications such as medical, military, environment monitoring, security and industry. Many research challenges are there in the design of WSN. Among them reduction of energy consumption of the sensor nodes and the overall network to prolong the lifetime of WSNs is of paramount importance. The reason is the sensor nodes are energy constraint and they have limited power capability. Also recharging or replacing the battery in the sensor nodes is not possible in many cases. Therefore, it is necessary to find suitable techniques to conserve the energy of these nodes. Sensing, processing and communication are the three major sources of energy consumption in sensor nodes. Among these three operations, communication expends more energy compared to the other two. Several methods of reducing the energy consumption and improving the lifetime of a WSN is presented in the literature. In this paper, we discuss the various energy saving schemes proposed by different researchers to increase lifetime of wireless sensor networks. Along with WSN, we also highlight some energy saving schemes adopted by other ad-hoc networks.

The rest of the paper is organized as follows. Section 2, presents lifetime study related works in WSN. Various energy saving protocols for WSN are discussed in Sect. 3. In Sect. 4, we present some energy saving schemes for other ad-hoc networks and finally the paper is concluded in Sect. 5.

2 Lifetime in WSN

As mentioned earlier sensor nodes are energy constrained and preserving their energy is very important as the lifetime of the network is limited by the energy dissipation by these nodes. Several authors have studied the lifetime in wireless sensor networks [1–17].

In [18], the authors have derived fundamental upper bound for lifetime of wireless sensor network considering a linear network. They have considered only a single source and the intermediate nodes simply acts as relay and forwards the data towards the sink. Also they have considered only the energy consumption associated with transmitting and receiving of information. However they have not considered the start-up energies of the transmitting and receiving nodes. The authors have derived the expression for characteristic distance. In [19], the authors have considered both optimal spacing and equal spacing of sensor nodes to study the lifetime of linear many-to-one WSN. Effect of coding and medium access control on lifetime of WSN is discussed. The authors have found that optimal spacing of nodes can improve the lifetime of WSN. They have also found that for a low bit error probability (BEP) short hop distance is more efficient, whereas for high BEP longer hops are more energy efficient.

In [20], the authors have studied the relationship between radio range and traffic for linear WSN. They have shown that about half the power can be saved by properly adjusting the radio range rather than using equal radio range. The authors have considered energy consumption for transmitting and receiving. However, start-up energies of transmitting and receiving nodes are not considered in their analysis. In [21], the authors have proposed an equal energy dissipation scheme for the sensor nodes to improve the lifetime of the WSN. They have considered fixed node placement and random node placement on a linear array to validate their results. The proposed scheme also ensures minimum residual energy for the nodes to gain maximum lifetime for the network. Similar result is seen in [22] where the author has investigated equal energy dissipation for sensor nodes for both linear array and Y-shaped array. Compared to the other reported schemes in the literature, his proposed scheme is found to double the network lifetime. It also ensures that the sensor nodes run out of energy almost simultaneously.

In [23], the authors have studied lifetime of WSN for many-to-one network. They have employed a load balancing technique to improve the lifetime of WSN. The work considered a grid topology with uniform deployment of stationary nodes. They have investigated the energy consumption of the nodes by placing the base station (BS) at the corner and at the centre of the grid topology. It is found that placing BS at the centre results in significantly lower energy consumption. Several authors have proposed schemes to improve the lifetime of WSN through the use of mobile sinks [15, 24–28]. Some researchers have suggested the use of mobile relay nodes to improve the lifetime of WSN [29–32]. Use of mobile cluster heads [33, 34], mobile wireless sensor networks [35] are also proposed by some researchers to improve the lifetime of WSN.

3 Different Energy Saving Protocols for WSN

Lifetime of WSN can be improved by reducing the energy consumption of the sensor nodes. Energy efficiency in wireless sensor network is studied by many researchers [36–39]. The various approaches to reduce the energy consumption of the sensor nodes and the overall network are presented below.

3.1 Duty Cycle Approach

One of the most effective way of conserving energy in WSN is putting the radio transceiver in sleep mode whenever communication is not needed, i.e. when there is no data to transmit or receive. As soon as no data is there to either transmit or receive, the radio transceiver should be switched off and should be switched on the moment data is available. This act of switching between active and sleep mode depending upon network activity is usually referred to as duty cycling. The fraction of time nodes are active during their lifetime is termed as the duty cycle. Sensor nodes need to coordinate their sleep or wake-up times as they perform cooperative tasks. Therefore, any duty cycling scheme should be accompanied with a sleep/wake-up time scheduling algorithm. The algorithm is typically a distributed one based on which the nodes decides to switch between active and sleep modes. It allows the nodes in neighbouring region to remain active at the same time. This makes packet exchange feasible even for low duty cycle operation of nodes.

Duty cycle and scheduling in WSN has been studied by several researchers [40–52]. In [40], the authors have proposed a scheduling scheme to extend the lifetime of WSN. The scheme determines how many and which nodes should be put into sleep mode without losing coverage and connectivity. In [47], a distributed energy efficient sleep scheduling and routing scheme is proposed by the authors.

3.2 Routing

Routing is costly and significant phenomenon which is a great source of energy consumption in multi-hop communication. Since sensor nodes are energy constrained and the goal is to design an energy efficient network to improve the lifetime of WSN, routing protocols must be energy efficient. Several authors have proposed different routing protocols to extend the lifetime of the WSN [53–63].

Routing protocols in WSN can be classified in different ways as shown in Fig. 1. Path based routing protocols can be proactive, reactive or hybrid. Proactive routing protocol maintains an updated list of destination and their routes in the form of table. This is achieved by a periodic distribution of the updated routing tables throughout the network. For maintenance relevant amount of data is needed and also this protocol has slower reaction on reorganisation and failures. In reactive protocols, routes are formed on demand basis. This protocol can suffer from high latency and network congestion due to excessive flooding of route request packets. Hybrid protocols are combination of both proactive and reactive protocols. In this protocol routes are established based on proactive approach and then demand are made through other activated nodes by reactive flooding. The efficiency of this protocol depends on the number of other nodes activation.

Based on network structure routing protocols can be flat, hierarchical or location based. In flat based protocol, the base station sends query to a specific group of sensor nodes and waits for their response. In this protocol, all nodes share the same responsibilities and it is a data centric routing approach. Initial routing table is formed by flooding. This protocol suffers from high latency and low energy efficiency. In hierarchical routing, cluster is formed where nodes with higher energy are chosen as the cluster heads (CHs) and the low energy nodes sense the data and send to the cluster heads. In this type of routing protocol, one can control the data transmission by varying the two threshold levels. The drawback

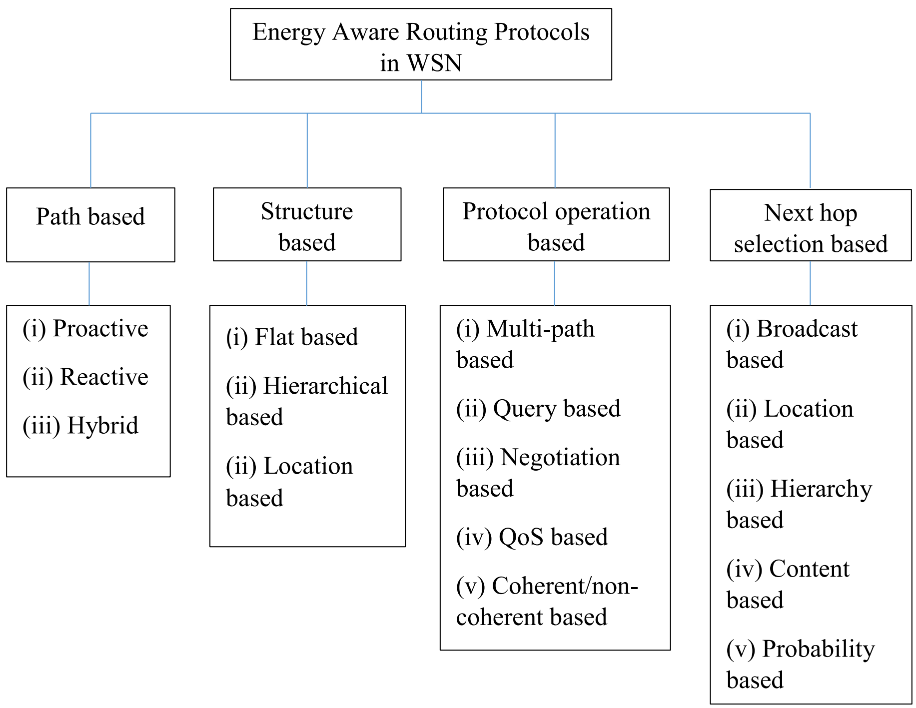

Fig. 1 Classification of energy aware routing protocols in WSNs [39]

of this scheme is that nodes will not communicate unless the thresholds are met and also there will be data loss if CHs cannot communicate with each other. Instead of routing link information, the location information of the nodes is used in location based routing protocol. This protocol enhances the network lifetime by saving energy. It also maintains routing fidelity. However, this protocol cannot predict large traffic injection and delay.

Based on protocol operation, routing are classified as: multipath, query, negotiation, QoS and coherent or non-coherent based. In multipath protocol, multipath selection is used to reduce delay in reaching destination. However, this scheme suffers from high energy consumption as periodic messages needed to be sent to keep the network paths alive. This type of routing protocol is not suitable for topologies where time is varying. In case of query-based protocol, the destination node sends query for data from a node through the network. The node that matches this data sends it to the node which initiated the query. Queries may lead to extra overhead which can increase energy consumption. Negotiation based protocol uses negotiation to reduce redundant data transmission. In QoS based routing protocol, routing decision are taken based on three parameters: energy resource, QoS of the path and priority level of the packet. Reliability, delay, bandwidth, jitter determine the QoS metric. This protocol suffers from overhead as it is required to maintain routing table and states at each node. In coherent routing nodes forward the data to the aggregator after minimum processing which includes operation such as time-sampling and elimination of redundancy. In non-coherent routing, the nodes process the raw data locally and then send to the aggregator for further processing. In both coherent and non-coherent protocols, the nodes are elected based on their computation capability and energy reserves. Energy consumption can be minimized with the help of a minimum-hop spanning tree that completely covers the network. However, these two protocols suffer from higher overhead, longer delay and lower scalability.

Based on next hop selection, routing protocols can be categorized into broadcast based, location based, hierarchy based, content based and probability based. In broadcast based protocol, whether to forward the message or not is decided by each node individually. If it decides to forward, it will simply re-broadcast the message else the message will be dropped. In this protocol, nodes can become bottleneck due to long delay and rebroadcasting. In location based the decision for the next hop en route to destination is made on basis of known location of neighbours and destination known as centroid of the region. Although this protocol can avoid communication overhead caused by flooding but neighbours position calculation may cause extra overheads. In hierarchical based routing all nodes forwards their data to the aggregator. Communication overhead can be reduced due to aggregation of the data which in turn will reduce the energy consumption. This will result in improved lifetime of the network. Content based routing protocol decides next hop purely based on the content of the query. This routing protocol is compatible to WSN architecture since only data is requested by the base station irrespective of its origin. Probability based routing protocols chose next hop arbitrarily. In this protocol, selection and maintenance of a set of path is done based on a probability which is dependent on how much energy consumption can be lowered for each path.

3.3 Medium Access Control (MAC) Protocols

To reduce the energy consumption and extend the lifetime of WSN along with routing protocols the MAC protocols must also be energy efficient. The four main source of energy wastage in MAC comes from collision, overhearing, idle listening and control packet overhead.

Collision occurs when a third party starts transmitting when a transmission between two nodes is already going on. This mainly occurs due to hidden terminals (node which is within the range of intended destination but out of range of the sender). Collision necessitates retransmission of packets which wastes energy of both transmitter and receiver. The hidden terminal problem that occurs in carrier sense multiple access (CSMA) can be avoided with time division multiple access (TDMA). In TDMA, the time frame is divided into timeslots and assigned to nodes exclusively. Another reason of energy wastage in MAC is overhearing. Overhearing occurs when a nodes receives a packet which was not intended for it. Idle state energy consumption is another form of energy wastage. A node is said to be in idle state when it does not actually receive anything even though it is ready to receive. The energy consumption in idle state is quite significant with respect to the receive energy. The idle state energy consumption can be avoided by employing duty cycle approach. The Control packet overhead is also responsible for energy wastage in MAC protocols. Number of control packets for transmission should be minimized to conserve energy of the sensor nodes. Apart from these over emitting also results in energy wastage. Over emitting happens when transmitter sends data but receiver is not ready to receive or transmission rate is higher than the receiving rate.

Several authors have investigated and studied different energy efficient MAC protocols in WSN [64–76]. Some of the reported MAC protocols for WSNs in the literature are SMAC, PMAC, GMAC, ZMAC, RMAC, X-MAC, TMAC, U-MAC, SWMAC, DMAC, TRAMA, SCP-MAC etc. MAC protocols can be broadly categorized into two types: centralized and distributed. The centralized MAC can be further categorized as scheduled based and contention based. Scheduled based protocols are generally suited for static topologies. In this protocol, the clock of each node is needed to be time synchronized. The scheduled based protocols are collision free, has low idle listening and low overhearing overheads. Thus, scheduled based MAC protocols are energy efficient. However, it suffers from low throughput and high latency problem. Also it has poor adaptability to changes of the network. Contention based protocols are the most investigated MAC protocols for WSN. In these protocols nodes compete in probabilistic coordination. These protocols are simple and unlike scheduled protocols do not require time synchronization. Also these protocols has good adaptability to network changes. However, contention based protocols have high idle listening and overhearing overheads which makes them energy inefficient.

3.4 Data Aggregation

Another technique which can reduce energy consumption in WSN is data aggregation. In WSN, the nodes deployment is quite dense and thus the data sensed by these nodes are highly correlated. Therefore, there exists high redundancy in the sensed data. Data aggregation aims to reduce the redundant data before transmission. This will result in less number of transmissions which in turn reduces the energy consumption by the energy constrained nodes. Generally data aggregation technique is combined with some other techniques such as clustering and scheduling to further reduce the energy consumption.

Several data aggregation approaches are reported in the literature. Figure 2 shows different data aggregation approaches for WSN. In centralized approach, all the nodes send their data to a central node. This node is the most resourceful in terms of energy and computational capability. The central node aggregates the received data and then send it to the base

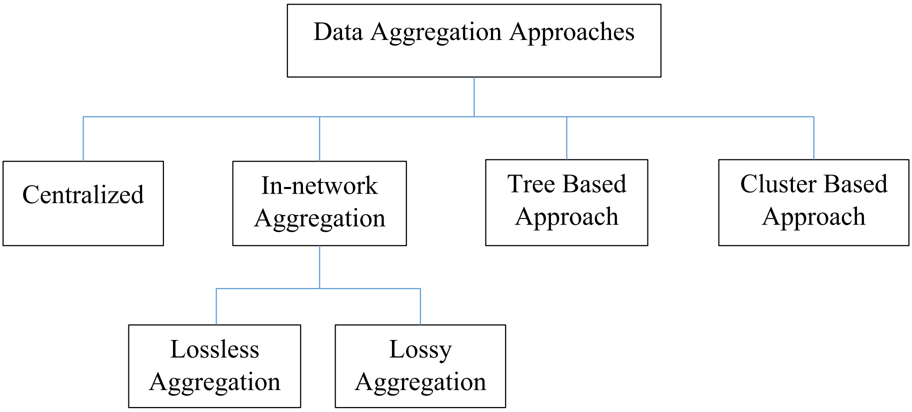

Fig. 2 Data aggregation approaches [77]

station. An address based routing is used in this data aggregation approach. This approach suffers from high traffic problems. In in-network aggregation scheme, aggregation of data is done at all the intermediate nodes. In this scheme, energy saving is achieved by reducing the energy consumption at all the intermediate nodes. In-network aggregation have two approaches: lossless and lossy. In lossy aggregation scheme, packet size is reduced by using some techniques whereas in lossless scheme, the packet size remains unchanged.

In tree based approach, a tree is formed where the root nodes act as the base station and the leaf nodes are the source node. Here the intermediate nodes acts as parent nodes. The tree is a minimum spanning tree. The energy is saved by forming an energy efficient tree. In cluster-based approach, the nodes are divided into clusters where one node acts as the cluster head (CH). The nodes within the same cluster sends their data to CH node rather than sending it to the base station directly. The CH node of each cluster aggregates the received data and then sends to the base station. A threshold energy limit is set for CH node selection involved in data aggregation. Periodic monitoring of the residual energy of the current CH node is done. If the residual energy reaches below the threshold level then the nodes with the highest energy within the same cluster is chosen as the new CH node replacing the old one. Energy is saved as only the aggregated result is transmitted by the CH node to the sink. Energy efficient data aggregation for WSN has been studied by several authors [78–87].

3.5 Cross Layer Design

The conventional layered protocol design does not give optimal performance. Network performance including energy efficiency can be significantly improved by a cross layer design. A cross layer design can be of two types: loosely coupled or tightly coupled cross layer design. In case of loosely coupled cross layer design, one protocol layer is focussed and optimization is done without crossing layer. In this scheme, information from other layers are taken into consideration to improve the performance of this layer. For example, physical layer can pass the information about channel quality to TCP layer so that it can differentiate between packet loss and congestion and thus can deal with congestion control in a better way. In tightly coupled cross layer design scheme, mere information passing is not enough. Here the algorithms of different layers are optimized as single optimization problem. Tightly coupled cross layer design gives better performance improvement. However, loosely coupled cross layer design scheme has the advantage that it does not completely abandon the transparency between protocol layers. Cross layer analysis for WSN has been studied by many researchers [88–98].

In [89], the authors have proposed a cross layer strategy to maximize the network lifetime of WSN while guaranteeing end-to-end success probability. They have designed a cross layer strategy by taking into consideration of the power control in physical layer, ARQ control in MAC layer and routing protocol in network layer jointly. Their proposed scheme minimizes the energy consumption along with controlling the reliability of the network. The results also show that, if the link distance is short then retransmission control is not helpful for energy efficiency. The authors in [95], have proposed a cross layer collision aware routing scheme to increase the lifetime of WSN. They have chosen collision degree and energy level as the routing metric instead of the traditional hop-count to reduce the energy consumption of the network. Residual and initial energy are used to calculate the energy level and then nodes with highest residual energy are used as relay nodes. They have compared their scheme with AODV and have found that their proposed scheme outperforms the AODV scheme in terms of packet loss, average delay and energy efficiency. In [96], the authors have jointly optimized three layers: physical, MAC and routing layer to improve the lifetime of the WSN through optimal gathering of correlated data.

3.6 Error Control Code (ECC)

Reliability is important for any communication system. Any radio signals get affected by random noise and channel fading [99, 100]. Therefore some form of error control mechanisms need to be employed to counter these effects and improve the reliability of the system. ECC can also help in conserving energy of the sensor nodes. ECC supports lower signal-to-noise ratio (SNR) to achieve the same bit error rate (BER) as an uncoded system. This advantage is exploited in saving the energy consumption and designing an energy efficient WSN.

3.6.1 Different Error Control Strategies

Various error control strategies are employed in a communication system to combat the channel noise and improve the reliability of communication. Figure 3 shows the classification of different error control strategies used in communication system.

3.6.1.1 Automatic Repeat Request (ARQ) In this scheme, when error is detected at the receiver end the receiver sent a retransmission request to the transmitter. This process repeats until the receiver receives an error free message. Two types of ARQ system are there: stop-and-wait ARQ and continuous ARQ.

Stop-and-wait ARQ In stop-and-wait ARQ, after transmitting a message the transmitter waits for a positive acknowledgement (ACK) or negative acknowledgement (NAK) from the receiver. If the transmitter receives ACK, it means that receiver has received error free message and the transmitter proceed with the transmission of the next message. In case, the transmitter receives a NAK which means error is detected, the transmitter resends the preceding message. In very noisy channel, several retransmission may be needed before the receiver receives the message correctly.

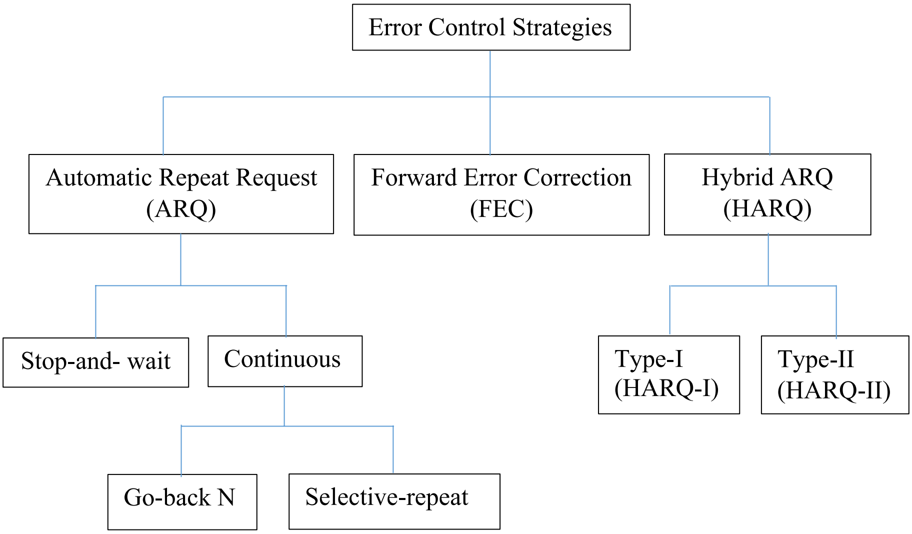

Fig. 3 Different error control strategies used in communication system

Continuous ARQ In continuous ARQ, the transmitter sends message continuously and also receives acknowledgements continuously. When the transmitter receives a NAK, it starts a retransmission. Continuous ARQ can be of two types: go-back N ARQ and selective-repeat ARQ. In go-back N ARQ, the transmitter can back-up the erroneous message and sends that message along with the next N-1 messages that follows it. Whereas, in selective-repeat ARQ, the transmitter resends only the messages which are acknowledged negatively. Although selective-repeat is more efficient but it requires more logic and buffering.

Continuous ARQ is generally employed for a system where the transmission rate is high and round trip delay is long. Whereas, stop-and-wait ARQ is employed for a system where time taken for transmitting a message is longer than the time taken for receiving acknowledgement.

3.6.1.2 Forward Error Correction (FEC) In FEC scheme, some redundancy is added to the packet before transmission so that the receiver can receive an error free message even if some bits received erroneously. FEC schemes incur additional communication overhead due to the transmission and reception of redundant bits along with encoding and decoding of packets.

Error detection requires much simpler circuit compared to error correction, which is the major advantage ARQ has over FEC scheme. Also in ARQ system, retransmission is only needed when there is error in received message. However, in very noisy channel ARQ will increase the number of retransmission which in turn will reduce the throughput of the system. Therefore, when the channel is bad (i.e. channel error rate is high) FEC is more efficient than the ARQ scheme. Also when the channel is bad ARQ scheme will consume more energy due to the increased number of retransmissions. In very noisy channel, FEC scheme can be more energy efficient compared to ARQ provided that the additional energy consumption due to extra bit transmission (redundant bits), encoding and decoding operation for the ECC employed is less than the power saving due to coding gain.

3.6.1.3 Hybrid ARQ (HARQ) Both ARQ and FEC schemes have some advantages as well as some drawbacks. The drawbacks of both these schemes can be overcome by using a proper combination of these two schemes. Hybrid ARQ is a technique which exploits the advantages of both ARQ and FEC schemes. It is basically consists of an FEC subsystem within an ARQ system. The most frequently occurred error patterns are corrected by FEC which in turn reduces the frequency of retransmission. This improves the throughput of the system. On the other hand, in case of less frequent error patterns, retransmission is requested by the receiver. This improves the reliability of the system. Thus, a hybrid ARQ provides higher reliability than the system with FEC alone and provides higher throughput than the system which employs ARQ only. Two types of HARQ mechanism is there: type I (HARQ-I) and type II (HARQ-II).

HARQ-I In this scheme, at first the transmitter sends an uncoded packet or a packet encoded with code of lower error correcting capability and waits for the acknowledgement. If a NAK is received, the transmitter then resends the packet encoded with code of stronger error correcting capability. This process continues until the receiver receives an error free message or successfully decode the message. HARQ-I does not require to store the previously sent packet.

HARQ-II In HARQ-II scheme, two codes are used; one is high rate code C_1 which only detects error and the second one is an invertible half-rate code C_2 which is capable of both error detection and correction. A code which can determine the information digit uniquely by an inversion process just from the knowledge of parity-check digits is known as invertible code [101]. In HARQ-II, first the message is encoded with C_1 and is transmitted. At the same time the transmitter computes the parity-check bits for C_2 and stores it into retransmission buffer for later use. If error is detected at the receiver, the receiver stores the received message and sends a negative acknowledgement NAK to the transmitter. When the transmitter receives NAK, it sends the redundant bits by encoding the stored parity-check digits into code vector based on C_1. If the received code vector is error free, the original message is recovered from previously stored erroneous message by inversion. If error is detected in the received vector, then invertible half rate code C_2 is used to correct the error using this received vector and previously stored erroneous message. If the receiver fails to correct errors, then NAK is send to the transmitter and the process continues. HARQ implementation cost is less than HARQ-I. However, HARQ-II reduces the bandwidth utilization of the protocol.

Since an HARQ schemes combines the advantages of both ARQ and FEC in a way that it uses FEC for more frequent error patterns and ARQ for the less frequent error patterns. Therefore, HARQ can be more energy efficient even in very noisy channels. Both FEC and HARQ scheme increases the error resiliency than ARQ. Hence both the schemes can support lower SNR to achieve the same BER.

Different error control mechanisms are investigated in wireless sensor networks by the research community. However, since sensor nodes are energy constrained, hence the employed energy control mechanism must be energy efficient. ECC provides many advantages in the design of WSN. ECC provides coding gain (defined as the difference between SNR of a coded and uncoded system to achieve the same BER) which results in transmitter energy saving. Also ECC improves the reliability of the channel. Several authors have investigated the effect and usefulness of different error control codes in wireless sensor network design under different conditions [94, 102–109].

In [110], the authors have shown that in lossy environments and high frequency situations benefits of ECC outweighs the cost. In the paper, the authors have derived an expression for critical distance (distance at which decoders energy consumption per bit equals transmitter energy saving per bit due to coding gain, compared to an uncoded system). In [111], the authors have shown that no convolutional code provides energy efficiency for probability of bit error, $P_b > 10^{-5}$ compared to an uncoded system. In [112], energy efficiency of Bose, Chaudhuri, and Hocquenghem (BCH) code and convolutional codes are compared to optimize packet size in WSN. It has been shown that BCH codes are more energy efficient than convolutional code, they outperform the most energy efficient convolutional code by 15%. The authors in [102], have reported a similar result where convolutional code is compared with block codes. They have shown that in terms of energy efficiency convolutional codes are inferior to block codes. In [113], the authors have analysed different modulation schemes and two BCH codes based on their energy consumption efficiency. However, the authors have considered only the energy consumption for the redundant bits as the overhead of the ECC without considering the decoding energy consumption. Moreover, in both [102, 113], only a single hop link is considered.

In [114], effect of different linear block codes on energy consumption in multi-hop WSN is investigated. The authors have shown that efficiency of different codes vary with channel conditions. The energy consumption is found to be lowest at a particular BER if the single hop distance matches the transceiver's characteristic distance. However, the authors in this paper have not considered the decoding energy consumption of the ECC. Also, the authors have considered only a single node transmitting scenario. However, in most useful scenario all the nodes will transmit their data simultaneously. The authors in [115], have studied the joint impact of error correction code and different modulation schemes on sensor node energy consumption. They have investigated the energy consumption with respect to Reed-Solomon (RS) code of different length and different error correcting capabilities beyond the crossover distance as below this distance the computational energy consumption outweighs the energy consumption in transmission. They have shown that RS codes with short codeword length along with BPSK modulation can save about 47% energy in WSN.

In [116], the authors have investigated and compared the energy consumption for RS, list decoded RS, multivariate interpolation decoded RS (MIDRS) and Hermitian codes in multi-hop WSN. The authors have focussed on using codes with less encoding complexities. Also they have assumed encoding only at the first node and decoding only at the base station to save energy at the node level. In [94], the authors have investigated ARQ, hybrid ARQ and FEC error control schemes in a cross layer analysis. It has been shown that FEC improves the error resiliency which can be exploited in two ways: by reducing the transmit power or by constructing longer distance. Trade-offs between different error control schemes in terms of energy consumption, end-to-end packet error rate and latency are investigated considering hop length extension and transmit power control. They have shown that in hop length extension technique, some FEC and HARQ scheme reduces both energy consumption and end-to-end latency compared to the ARQ scheme. On the other hand in case of transmit power control, significant reduction in energy consumption at the cost of increase in latency can be achieved with certain FEC.

In [104], the authors have investigated trade-off between transmission and processing energy consumption in WSN. They have employed convolutional code for their study. The authors have concluded that node and network lifetime of WSN can be significantly improved by using convolutional code for error correction, if optimized code complexity is applied at each hop. However, the saving in energy consumption is depended on network topology. In [117], energy efficiency of cyclic code, BCH code and ARQ scheme in IEEE 802.15.4 RF transceiver based sensor nodes are compared and BCH code is found to be more energy efficient than the other schemes. The authors have used codes with same coding gain to decide the optimum choice of ECC for IEEE 802.15.4 compliant WSN. In [105], RS, convolutional, Golay, Hamming and low-density parity-check (LDPC) codes with binary phase shift keying (BPSK) modulation are compared in an AWGN channel for WSN. Considering BER performance along with coding and decoding complexity the authors have concluded that RS code is the best choice for energy constrained WSN.

In [107], the authors have proposed a cross layered adaptive rate LDPC codes for reducing energy consumption of WSN. Coherence time, BER and SNR of physical layer and demanded date rate of routing layer is used to decide the data rate of the LDPC coder. Their proposed scheme changes the rate of the LDPC coder to maintain the QoS performance required. The authors have also calculated the energy consumption for transmitting and receiving *n* bits for μAMPS-1 mote. The authors in [108], have proposed a hybrid adapting coding and decoding scheme to improve the lifetime and reliability of multi-hop WSN. Internode distances, channel conditions and error correction codes performance is taken into consideration to decide coding and decoding technique. The authors have used RS and LDPC codes for error protection. Their proposed scheme is shown to be improve both energy efficiency and reliability of the multi-hop WSN.

4 Energy Saving Schemes in Other Ad-Hoc Networks

In the previous section, various energy saving schemes for WSN are discussed. Although ad-hoc networks and WSN are not exactly similar but they do share some common features. Similar to the sensor nodes, the nodes in ad-hoc networks also have limited energy source. Several energy efficient schemes of ad-hoc networks are also investigated in WSNs. In this section, we discuss about some of the energy saving schemes opted by other ad-hoc networks to conserve energy and improve its lifetime.

4.1 Use of Directional Antennas

In mobile ad-hoc networks (MANETs), many researchers have proposed the use of directional antennas to improve the energy efficiency of the network [118–123]. Omnidirectional antennas transmit signal equally to all directions. However, in most of the applications, communication is unicast and therefore significant amount of energy can be saved by the use of directional antennas. Also, the use of directional antennas can reduce the interference between radio streams and improve the SNR. Therefore, directional antennas can improve the reliability and reduce the number of retransmissions. However, use of directional antennas necessitates to find the right direction and parameters correctly and quickly.

4.2 Topology Control

Topology control is another approach through which energy can be conserved in a wireless ad-hoc network (WANET) or MANET. In this approach, nodes transmission power are adjusted without losing the connectivity. To form the topology it needs the information of location, neighbour, direction and so on. In topology control the primary target is to replace the long communication hops with the smaller hops which are energy efficient. Several researchers have investigated various energy efficient topology control in WANETs [124–132].

4.3 Transmission Power Control

Many researchers have proposed transmission power control to reduce the energy consumption in ad-hoc networks [133–138]. In this approach the transmission power is adjusted between communicating nodes. Many power control algorithms are presented in the literature. The range of coherently receiving a signal is determined by the transmission power. Therefore, the transmission power can be dynamically adjusted based on the estimated distance between the nodes. However, judicious power control in ad-hoc network is not very easy. Improper power control can lead to poor performance compared to even without any power control. For example, if the transmission power is reduced excessively then it can result in an unconnected network or may produce more delay.

5 Conclusion

Sensor nodes in WSNs have limited energy source. Since in many applications it is difficult to replace or recharge the battery therefore conserving nodes energy to prolong the network lifetime still remains one of the most challenging and most significant task. In this paper, we have discussed about the different energy saving schemes proposed in the literature to reduce the energy consumption to improve the lifetime of WSN. Each of these schemes have their own advantages. The Duty cycle approach or scheduling saves energy by putting nodes into sleep mode when there is no data receive or transmit. Data aggregation improves the energy efficiency by reducing the number of transmissions by eliminating redundant data. Implementing an energy efficient routing algorithms and MAC protocols are another way to conserve the energy of the sensor nodes. Several energy efficient routing and MAC protocols are proposed in the literature. Cross layer design can give more optimal energy efficiency than single layer optimization. ECC can improve both energy efficiency and error resiliency of a wireless sensor network. Because of improved error resiliency less SNR will be required to achieve the same bit error probability as an uncoded system. This results in saving of transmission power and in turn saves energy of the nodes. However, not all ECC are energy efficient. Several factors affects the energy efficiency of these codes. In good channels where the error rate is less ARQ is found to be more energy efficient than FEC. For an ECC to be energy efficient its coding gain must be greater than the extra energy consumption due the extra bits and encoding and decoding operation. Some hybrid energy conservation schemes where more than one energy saving schemes are combined together are also proposed by many researchers. Although there are several techniques proposed in the literature by the researchers to improve the lifetime of WSN, still there is need for new techniques to reduce the energy consumption further. Some researchers have suggested wireless power transfer and energy harvesting as means to improve WSN lifetime. However, a cost effective, reliable and efficient implementations of these techniques still remains a challenge.

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