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Energy-efficient Communication Methods in Wireless Sensor Networks: A Critical Review

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ABSTRACT
A Wireless sensor network (WSN) has important applications such as remote ecological monitoring and target tracking. This has been enabled by the availability, particularly in recent years, of sensors that are smaller in size and smart. These sensors are equipped with wireless interfaces with which they can communicate with one another to form a network. Wireless sensor networks consist of sensor nodes with sensing and communication capabilities. As sensor nodes are generally battery-powered devices, the critical aspects to face concern how to reduce the energy consumption of nodes, so that the network lifetime can be improved to reasonable times. In this paper we first describe the energy consumption for components of a typical sensor node, and discuss the main directions to energy saving methods in wireless sensor networks. Then we present a methodical and comprehensive taxonomy of the energy optimization methods in wireless sensor networks. The main goal of energy optimization methods is to collect and aggregate data in an energy efficient manner so that network life time is enhanced. We conclude with possible future research directions.

Keywords
Wireless sensor network (WSN), Multiple-input Multiple-output, Energy efficiency, Alamouti diversity schemes.

1. INTRODUCTION
Wireless sensor networks (WSNs) have gained world-wide consideration in recent years, particularly with the proliferation in Micro-Electro-Mechanical systems (MEMS) technology which has facilitated the development of intelligent sensors. These sensors are small, with limited processing and computing resources. These sensor nodes can sense, measure, and collect information from the environment and, based on some local decision process, they can transmit the sense data to the users. The sensors nodes consist of sensing, data processing, and communicating component, leverage the idea of sensors networks. A sensors network [1] is composed of a large number of sensor nodes that are densely deployed either inside the phenomenon or very close to it. Intelligent sensor nodes are low power devices equipped with one or more sensors, a processor, memory, a power supply, a radio and an actuator. A variety of mechanical, thermal, biological, chemical, optical, and magnetic sensors may be attached to the sensor node to measure properties of the atmosphere. Since the sensor nodes have limited memory and are typically deployed in difficult-to-access locations, a radio is implemented for wireless communication to transfer the data to the base station. Battery is the main power source in a sensor node. Secondary power supply that harvests power from the environment such as solar panels may be added to the node depending on the appropriateness of the environment where the sensor will be deployed. In some cases it is possible to scavenge energy from the external environment [2] (like solar cells as power source). However, external power sources often exhibit a non-continuous behavior so that an energy buffer (a battery) is needed as well. In any case, energy is a very vital resource. Therefore, energy conservation is a key issue in the design of systems based on wireless sensor networks.

In this paper we will refer mainly to the sensor network model as shown in Figure 1 and consisting of one sink node or base station and a large number of sensor nodes deployed over a large geographic area or sensing field. Data are transferred from sensor nodes to sink through multi-hop communication model [3]. Experimental measurements have shown that generally data transmission is very costly in terms of energy consumption, while data processing consume significantly less [4]. The energy expenditure of transmitting a single bit of information is approximately the same as that needed for processing a thousand operations in a typical sensor node [5]. The energy consumption of sensing subsystem depends on specific sensor category. In many cases it is insignificant with respect to the energy consumed by the processing and, above all, the communication subsystem. In other cases, the energy expenditure for data sensing may be comparable to, or even greater than, the energy needed for data transmission. In general, energy-saving techniques focus on two subsystems: the networking subsystem (i.e., energy management is taken into account in the operation of each single node, as well as in the design of networking Protocols), and the sensing subsystem (i.e. techniques are used to decrease the amount or frequency of energy-expensive sample). The lifetime of a sensor network can be extended by jointly applying different techniques [6-8]. For example, energy efficient protocols [9] are designed at minimizing the energy consumption during network activities. On the other hand, a large amount of energy is consumed by node components (CPU, radio, etc.) even if they are inoperative. Power management methods [10] are thus used to switch off node components that are not momentarily needed.

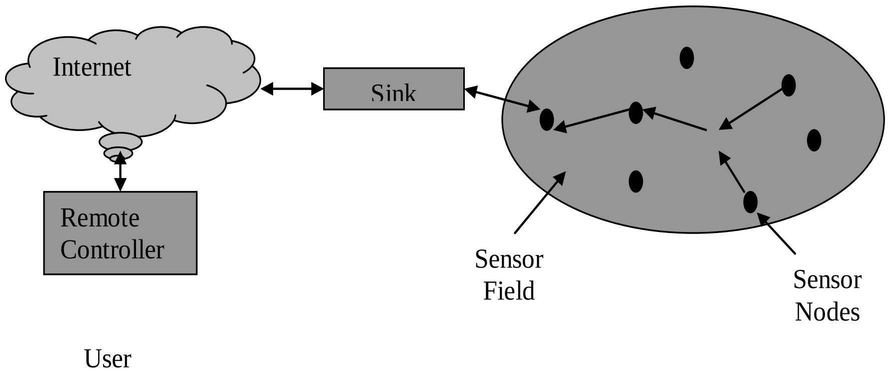

Fig 1: Wireless Sensor Network Model

Wireless sensor networks are principally two types: structured and unstructured. In a structured WSN all or some of the sensor node are deployed in a pre-planned approach. The advantage of a structured network is that fewer nodes can be deployed with lower network maintenance and management expenditure. Fewer nodes can be deployed now since nodes are placed at specific locations to provide coverage while ad hoc deployment can have uncovered regions. An unstructured WSN is one that contains a dense group of sensors nodes. Sensors node may be deployed in an ad hoc manner into field. In ad hoc deployment, sensor may be randomly placed into field. Once deployed, the network is left unattended to perform monitoring and reporting functions. In an unstructured WSN, network maintenance such as managing connectivity and detecting failures is difficult since there are several nodes.

Wireless sensor networks have great potential for many applications in scenarios such as military target tracking and surveillance [2,3], natural disaster relief [4], biomedical health monitoring [5,6], and hazardous environment exploration and seismic sensing [7] . In military target tracking and surveillance, a WSN can help in intrusion detection and identification. With natural disasters, sensor nodes can sense and detect the atmosphere to forecast disasters before they occur. In biological medical application, surgical implants of sensors can help monitor a patient's health. For seismic sensing, ad hoc deployment of sensors along the volcanic area can detect the development of earthquakes and eruptions. Wireless sensor network has its own design and resource constraints. Resources constraints include a limited amount of energy, short communication range, low bandwidth, and limited processing and storage capacity in each node.

The rest of the paper is organized as follows: In Section 2, design issues of energy constrained wireless sensor networks is described. Different energy saving methods in wireless sensor networks is investigated in section 3. In Section 4, we describe the energy optimization techniques that increase the lifetime of wireless sensor networks. Finally section 5, we provide some concluding remarks and upcoming research directions.

2. DESIGN ISSUES OF ENERGY CONSTRAINED WIRELESS SENSOR NETWORKS

A sensor node as shown in Figure 2 is made up four basic components:

[i] Sensing unit

[a] Sensors

[b] Analog-to-Digital Converter (ADC)

[ii] Processing unit

[iii] Transceiver unit

[iv] Power unit

Sensor node as shown in Figure 2 may also have additional application dependent components such as a location finding system, power generator and mobilizer. The analog signals produced by the sensors based on the observed phenomenon are transformed to digital signals by ADC, and then fed into the processing unit. The processing unit, which is generally associated with a small storage unit, manages the events that make the sensor node collaborate with other nodes to carry out the assigned sensing tasks. A transceiver unit connects the node to the network. The main job of sensor node in a sensor field is to detect the events, perform quick local data processing, and broadcast the data. Energy consumption is a key issue in wireless sensor networks (WSNs). In a sensor node, energy is consumed by the power supply, the sensor, the computation unit and the broadcasting unit. The wireless sensor node, being a microelectronics device, can only be equipped with a limited power source (≤0.5 Ah, 1.2 V).

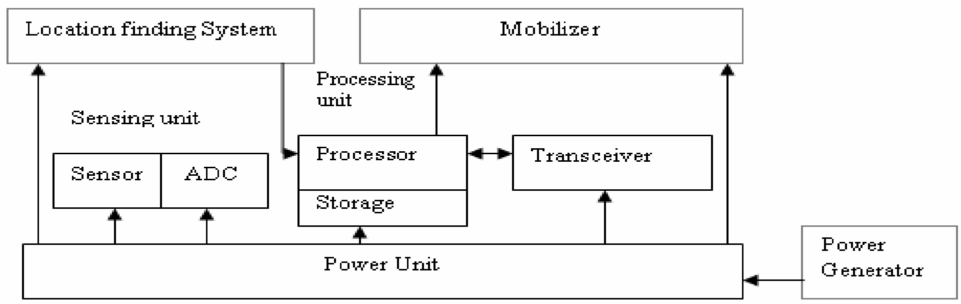

Fig 2: Components of a sensor node

Sensor node life time, therefore, shows strong dependence on battery life. Power consumption can hence be dividing into three domains: sensing, communication, and information processing. The total average power consumption along the signal path as shown in Figure 3 and Figure 4 can be divided into two main components: the power consumption of all the power amplifiers P_{PA} and power consumption of all other circuit blocks P_c .The power consumption of the power amplifiers can be approximated by

$$P_{PA} = (1+\alpha)P_{Out} \quad (1)$$

Where $\alpha = (\xi - \eta)/\eta$ with η the drain efficiency of the power amplifier and ξ the peak to average ratio (PAR) which is dependent on the modulation scheme and the associated constellation size. When the channel only experiences a square law path loss we have

$$P_{Out} = E_b R_b (4\pi d)^2 M_l N_f / G_t G_r \lambda^2 \quad (2)$$

Where E_b is the required energy per bit at the receiver for a given BER requirement, R_b is the bit rate, d is the transmission distance, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, and λ is the carrier wavelength, M_l is the link margin, and N_f is receiver noise figure. The second term P_c in the total power consumption is given by

$$P_c \approx Mt\,(P_{DAC} + P_{mix} + P_{filt}) + 2\,P_{syn} + M_r\,(P_{LNA} + P_{mix} + P_{IFA} + P_{fltr} + P_{ADC}) \quad (3)$$

Where P_{DAC}, P_{mix}, P_{LNA}, P_{IFA}, P_{fltr}, P_{ADC} and Psyn are the power consumption values for the Digital to Analog Converter (DAC), the mixer, the Low Noise Amplifier (LNA), the Intermediate Frequency Amplifier (IFA), the active filters at the transmitter side, the active filters at receiver side, the Analog to Digital Converter (ADC), and the frequency synthesizer, respectively. To estimate the values of P_{ADC}, P_{DAC} and P_{IFA} , we use the model introduced in [6]. Finally, the total energy consumption per bit for a fixed rate system can be obtained as

$$E_{bt} = (P_{PA} + P_C)/R_b \quad (4)$$

The total energy consumption is determined by multiplying E_{bt} by the number of bits to be transmitted.

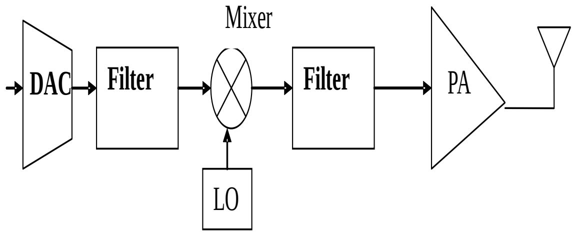

Fig 3: Transmitter Block Diagram

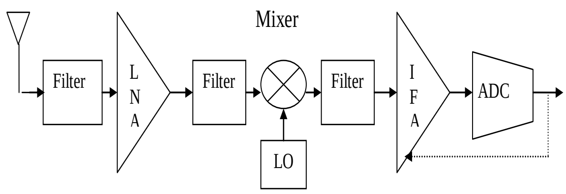

Fig 4: Receiver Block Diagram

For a sensor network with total non-rechargeable initial energy E_0, the expected network life E[£], measured as the average amount of time until the network is considered nonfunctional is given as

$$E[\ell] = \frac{E_0 - E[E_w]}{P_c + \lambda E[E_r]} \quad (5)$$

Where P_c is the constant continuous power consumption of all sensors in the network, E $[E_w]$ is the expected wasted energy (i.e. the total unused energy in the network when it is dies), λ is the expected sensor reporting rate defined as the number of data collections per unit time, and $E[E_r]$ is the expected reporting energy consumed by all sensors in a randomly chosen data collection. Network life time is defined as the number of data-aggregation round until α percent of sensor die where α percent is specified by the system designer.

3. DIFFERENT ENERGY SAVING METHODS IN WIRELESS SENSOR NETWORKS

The power consumption mainly depends on the specific node. In [11-12] it is shown that the power characteristics of a Mote-class node are completely different from those of a strargate node. However, subsequent remarks generally hold [16]

1. The communication subsystem has energy consumption much higher than the computation subsystem. It has shown that transmitting one bit may consume as much as executing a few thousands instructions [11]. Therefore, communication should be traded for computation in wireless sensor networks.

2. The radio energy consumption is of the same order of magnitude in the reception, transmission, and idle states, while the power consumption drops of at least one order of magnitude in the sleep state. Therefore, the radio should be put to sleep (or turned off) whenever possible.

3. Depending on the specific application, the sensing subsystem might be another significant source of energy consumption, so its power consumption has to be reduced as well.

Based on the above power breakdown, several approaches have to be exploited, to reduce the power consumption in wireless sensor networks. Broadly, we recognize three main enabling techniques, namely, duty cycling, data-driven approaches, and mobility as shown in Figure 5.

3.1 Duty Cycling Approaches

Duty cycling approach is basically based on topology control and Power management. Duty cycling is defined as fraction of time nodes are active during their lifetime. Duty cycling is mainly focused on the networking subsystem. The most effective energy-conserving operation is putting the radio transceiver in the sleep mode whenever communication is not required. As sensor nodes execute a cooperative task, they need to coordinate their sleep/wakeup times.

3.1.1 Topology Control Protocols

The concept of topology control is strictly linked with that of network redundancy. Dense sensor networks typically have degree of redundancy. In many cases network deployment is done at random, e.g., by dropping a large number of sensor nodes from an airplane. Therefore, it may be convenient to deploy a number of nodes greater than necessary to cope with possible node failures occurring during or after the deployment. Topology control protocols are thus aimed at dynamically adapting the network topology, based on the application needs, so as to allow network operations while minimizing the number of active nodes (and, hence, prolonging the network life time) . In this regard, topology control protocols can be classified in the two sub categories for e.g. location driven protocols and connectivity driven protocols .

Location driven protocols describe which node to turn on and when, based on the location of sensor node which is assumed to be known. Connectivity driven protocols dynamically activate/deactivate sensor nodes so that network connectivity or complete sensing coverage [13, 14] is fulfilled. Span [15] is a connectivity-driven protocol that adaptively elects coordinators of all nodes in the network. Coordinators stay awake continuously and perform multi-hop routing. While the other nodes stay in sleeping mode and periodically check if it is needed to wake up and become a coordinator .To guarantee a sufficient number of coordinators, Span uses the following Coordinator eligibility rule: If two neighbors of a non-coordinator node can not reach each other, either directly or via one or more coordinators, that node should become a coordinator. However, it may happen that several nodes discover the lack of coordinator at the same time and, thus, they all decide to become a coordinator. To avoid such cases nodes that make a decision to become a coordinator defer their announcement by a random back off delay. Each node uses a function that generates a random time by taking into account both the number of neighbors that can be connected by a potential coordinator node, and its residual energy. The fundamental ideas are that (i) nodes with a higher expected life time should be more likely to volunteer to become a coordinator; and (ii) Coordinators should be selected in such a way to reduce their number. Each coordinator periodically checks if it can stop being a coordinator.

3.1.2 Power Management

Power management protocols can be implemented either as independent sleep /wakeup protocols running on top of a MAC protocol, or strictly integrated with the MAC protocol itself. Sleep /wakeup protocols can be further subdivided into three main categories [16]; on-demand, scheduled rendezvous, and asynchronous schemes. On-demand schemes are based on the idea that a node should be awaken just when it has to receive a packet from the neighboring node. This minimizes the energy consumption and, thus, makes on-demand schemes particularly suitable for sensor network applications with a very low duty cycle (e.g., fire detection, surveillance of machine failures and, more generally, all event-driven scenarios). In such scenarios sensor nodes are in the monitoring state for most of time. As soon as an event is detected, nodes transit to the transfer state. On-demand sleep/wakeup schemes are aimed at reducing energy consumption in the monitoring state while ensuring a limited delay for transitioning in the transfer state.

Scheduled rendezvous schemes need that all neighboring nodes wake up at the same time. Typically, nodes wake up periodically to check for potential communications. Then, they return to sleep until the next rendezvous time. The major advantage of such schemes is that when node is awake it is guaranteed that all its neighbors are awake as well. This allows sending broadcast messages to all neighbors [16]. The simplest way is using a fully synchronized pattern [17].

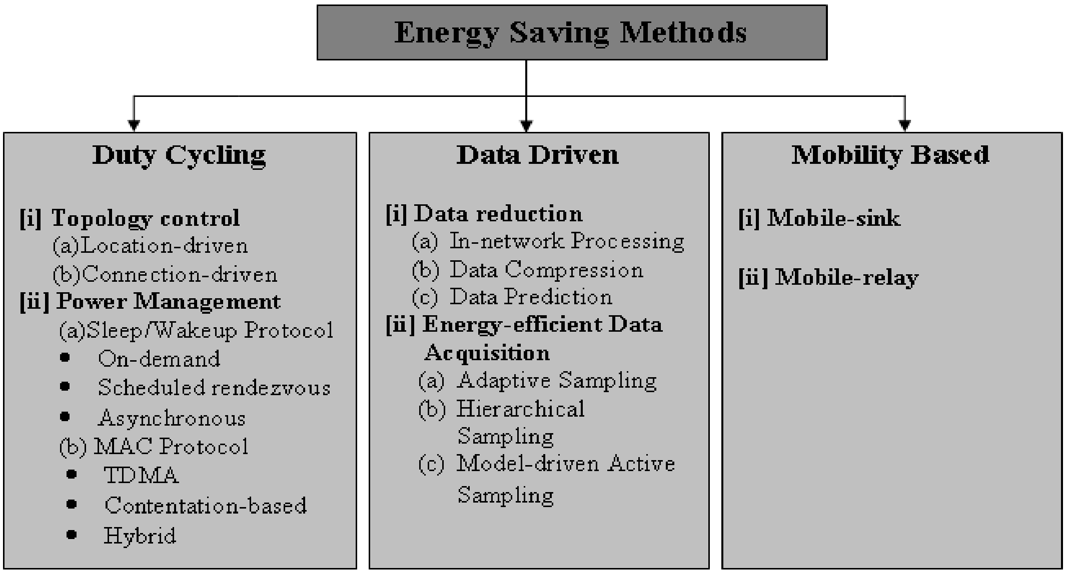

Fig 5: Different Energy Conservation Schemes in Wireless Sensor Networks

In this case all nodes in the network awaken at the same time according to a periodic pattern. In [17] the authors also propose a multi-parent scheme that can be combined with any of the above sleep/wakeup patterns. The shifted even and odd pattern is derived from the fully synchronized pattern by shifting the wakeup times of nodes in even levels of by $T_{wakeup}/2$. This minimizes the overall average packet latency, i.e., the average latency considering both the forward and backward directions, and also increases the life time. Finally, the Two-staggered pattern and Crossed Staggered pattern [17] are obtained as combinations of the backward wakeup pattern and forward Wakeup pattern.

Asynchronous schemes allow each node to wake up independently of the others by guaranteeing that neighbors always have overlapped active periods within specified number of cycles. Random Asynchronous Wakeup (RAW) [18] takes a different approach as it leverages the fact that sensor networks are typically characterized by a high node density. This allows the existence of several paths between a source and a destination and, thus, a packet can be forwarded to any such available paths. Actually, the RAW protocol consists of a routing protocol combined with a random wakeup scheme. In RAW the packet is sent to any of active neighbors in the forwarding candidate set, i.e. the set of active neighbors that meet pre-specified criterion. The basic idea of random wake up scheme is that each node wakes up randomly once in every time interval of fixed duration T, remains active for a predefined time T_a ($T_a \leq T$), and then sleep again. Once awake, a node looks for active neighbors by running a neighbor discovery process. Suppose that a node S has to transmit a packet to destination node D, and that in the forwarding set of S there are m neighbors as possible forwarders towards D. Then, Probability that at least one of these neighbors is awake along with S is given by

$$P = 1 - \left(1 - \frac{2.T_a}{T}\right)^m \qquad (6)$$

If the sensor network is crowded, the number (m) of neighbors in the Forward Candidate Set is large and, by (6), the probability P to find active neighbors to which forward the packet is large as well. The random wakeup scheme is extremely simple and relies only on local decision. This makes it well studied for networks with frequent topology changes.

Several MAC protocols for wireless sensor networks have been proposed, and many surveys and introductory papers on MAC protocols are available in the literature [19]-[22]. We will survey below the most common MAC protocols by classifying them according to the classification illustrated in Figure3: TDMA-based, contention-based, and hybrid protocol. Time Division Multiple Access (TDMA) schemes naturally enable a duty cycle on sensor nodes as a channel access is done on a slot-by-slot basis. As nodes need to turn on their radio only during their own slots, the energy consumption is ideally reduced to the minimum required for transmitting/receiving information. In TDMA-based MAC protocols [23]-[27] time is divided in (periodic) frames and each frame consist of a certain number of time slots. Every node is assigned to one or more slots per frame, according to certain scheduling algorithm, and uses such slots for transmitting/ receiving packets to/from other nodes. In many cases nodes are grouped to form clusters with clusters-head which is in- charge to assign slots to nodes in cluster as in Bluetooth [24], LEACH [25], and Energy-aware TDMA-based MAC protocol [23]. Contention based protocols are the most popular class of MAC protocol for wireless sensor networks. They achieve duty cycling by tightly integrating channel access functionalities with a sleep/wakeup scheme similar to those describe above. The only difference is that in this case the sleep/wakeup algorithm is not a protocol independent of MAC protocol, but is tightly coupled with it. One of the most well-liked contention-based MAC protocols is B-MAC (Berkeley-MAC) [28], a low complexity and low power MAC protocol which is shipped with the TinyOS operating system [29]. D-MAC [30] is an adaptive duty cycle protocol optimized for data gathering in sensor networks where a tree organization has been established at the network layer. In D-MAC the node's schedules are staggered according to their position in the data gathering tree, i.e., the nodes' active periods along the multi-hop path are adjacent in order to minimize the latency. Hybrid protocols adapt the protocol behavior to the level of contention in the network. They behave as a contention- based protocol when the level of contention is low, and switch to a TDMA scheme when the level of contention is high. The basic idea behind hybrid MAC protocols switching the protocol behavior between TDMA and CSMA, depending on the stage of contention.

In the specific context of wireless sensor networks, one of the interesting hybrid protocols is Z-MAC [31]. In order to define the main transmission control scheme, Z-MAC starts a preliminary setup phase. By means of neighbor discovery process each node builds a list of two-hop neighbors. Then a distributed slot assignment algorithm is applied to ensure that any two nodes in the two-hop neighborhood are not assigned to the same slot. Z-MAC allows each node to maintain its own local time frame that depends on the number of neighbors and avoids any difference with its contending neighbor. The local slot assignment and time frame of each node are then forwarded to its two-hop neighbors. Thus any node has slot and frame information about any two-hop neighbors and all synchronize to a common reference slot. At this point the setup phase is over and nodes are ready for channel access, keeping pace by the transmission control procedure.

3.2 Data-driven Approaches

Data driven approaches is basically based on data reduction and energy-efficient data Acquisition. Data-driven approaches are planned to reduce the amount of sampled data by keeping the sensing accuracy within the acceptable level for application. Sampled data are generally having strong spatial and/or temporal correlation, so there is no need to communicate the redundant information to the sink. Energy-efficient data acquisition schemes are mainly aimed at reducing the energy spent by the sensing subsystem.

3.2.1 Data Reduction

In data reduction techniques, data prediction methods construct a model describing the sensed phenomenon, so that queries can be answered using the model instead of the actually sensed data. There are two instances of a model in the network, one residing at the sink and the other at source nodes. The model at the sink can be used to answer queries without requiring any communication, thus reducing the energy consumption. Sensor nodes just sample the data as usual and compare the actual data against the prediction. If the sensed value falls within an application-dependent tolerance, then the model is considered valid. Otherwise, the source node may transmit the sampled data and/or start model update procedure involving the sink as well. The features of a specific data prediction technique depend on the way the model is built. Stochastic approaches utilize a characterization of the phenomenon in terms of a random process, so that a probabilistic model can be used to forecast sensed value. The Ken solution [32] well describes this approach. There are a number of models, and each one is replicated at the source and at the sink. In this case base model is probabilistic, i.e. after a training phase a probability density function (PDF) referred to a set of attributes is obtained. When the model is not considered valid any more, the source node updates it and transmits a number of samples to the sink, so that the corresponding occurrence can be updated as well. An extension of [32] is given in [33], where a Dynamic Probabilistic Model (DPM) is exploited to implement a probabilistic database view, i.e. a consistent snapshot of data coming from a model with a user-friendly interface.

The second class of data prediction techniques is time series forecasting, where a set of chronological values obtained by periodical samplings are used to predict a future value in the same series. The main difference with respect to other statistical or probabilistic approaches is that time series analysis explicitly considers the internal structure of data. A typical method to characterize time series is given by Moving Average (MA), Auto-Regressive (AR) or a Auto-Regressive Moving Average (ARMA) models. PAQ [34] is based on a low-order AR model, with the aim of reducing the amount of computation to be performed by sensors. The first instance of the model is computed by sensor nodes using a set of sampled values. During this learning phase, nodes store the samples in a queue. When the queue is full they can get the model and send it to the sink.

The third category of data prediction techniques is Algorithmic Approach relies on a heuristic or a state-transition model describing the sensed phenomenon. In [35] the authors take a different approach to data prediction, which can refer to as behavioral, by means of Energy Efficient Data Collection (EEDC) mechanisms. Each node associates an upper and a lower bound, whose difference represents the accuracy of readings, to the actual value of sensed data. These bound are sent to the sink, which stores them for each sensor in the network. While acquiring the information, the sensors check the samples against the bounds. If they fall outside the expected precision, the nodes send an update to the sink. This kind of interaction is called source-initiated update. On the other side, the sink receives queries from users with an associated requested accuracy. When the requested accuracy is lower than the actual accuracy provided by the value limits, the sink can act in response using the cached range. Otherwise the sink may request the real value and its new approximation to be used for following queries directly to sensor. This kind of interaction is called consumer-initiated request and revise. Finally, algorithmic techniques have to be considered case by case, because they tend to be more application particular.

3.2.2 Energy Efficient Data Acquisition

Energy consumption of energy subsystem not only may be applicable, but it can also be greater than the energy consumption of radio or even greater than the energy consumption of the rest of sensor node [36]. This can be due to many different factors [37].

- **Power Hungry Transducers:** some sensors basically require high power resources to perform their sampling, for example, sensing array such as CCDs or CMOS image sensors or even multimedia sensors [38] generally require a lot of power.
- **Power Hungry A/D Converters:** Sensors like acoustic [39] and seismic transducers [40] generally require high rate and high resolution A/D converters. The power consumption of the converters can account for the most considerable power consumption of the sensing subsystem, as in [41].
- **Active Sensors:** Another class of sensors can get data about the sensed incident by using active transducers for example sonar, radar or laser rangers. In this case sensors have to send out a probing signal in order to obtain information about the observed quantity, as in [42].

- **Long Acquisition Time:** The acquirement time may be in the order of hundreds of milliseconds or even seconds; hence the energy consumed by the sensing subsystem may be high, even if the sensor power consumption is reasonable.

In this case reducing communications may be not enough, but energy conservation methods have to actually decrease the number of acquirement (i.e. data samples). By reducing the data sampled by source nodes, they decrease the number of communications as well. Adaptive sampling can decrease the number of samples by exploiting spatio-temporal correlations between information. The temporal analysis of sensed data is used in [42], where the authors propose an adaptive sampling scheme suitable to snow monitoring for avalanche forecast. A periodically sampled parameter – i.e. the snow equivalent capacity – can be used to derive the actual signal. From the nyquist theorem it is identified that the sampling frequency needed for the correct reconstruction of the original signal should be $Fs \geq 2\ F_{max.}$ Where F_{max} is the maximum frequency in the power spectrum of the considered signal. The algorithm relies on a modified CUSUM test [43-45] to set the sampling rate. As computations are intense, a centralized approach is taken, i.e. the algorithm is executed at the sink for each sensor node. The estimated sampling rates obtained by the sink are then to sensor nodes. Advanced/ complex sensors can give a more detailed characterization of the sensed data at the expense of high energy consumption.

Precision can be traded off for energy efficiency by using the low-power sensor to get coarse-gained information about the sensing field. Then, when an event is detected or a region has to be observed with greater detail, the accurate power hungry sensors can be activated. For example, consider a target tracking application. Target can be discovered using low power sensor such as magnetometers or passive acoustic energy detectors. Such sensors can detect targets, but they can lead to fake positives. In addition, also when the detection is successful, they can not be accurate enough to identify the type of type of target. In this case high resolution acoustic beam forming [46] or image capturing [47] sensor can help. Instead of keeping these power hungry sensors always on, the less accurate ones are used to detect possible targets. When a target is detected, the more accurate sensor is activated as long as the target has been completely characterized or tracked [48, 49]. Model-based active sampling takes an approach analogous to data prediction. A model of the sensed phenomenon is built upon sampled data, so that future values can be forecasted with certain accuracy. Model-based active sampling exploits the obtained model to reduce the number of data samples, and also the amount of data to be transmitted to the sink. The Barbie-Q (BBQ) query system [49] is a good example of this approach. The core components of the query system are a probabilistic model and a planner, both residing at the sink. The model is probabilistic i.e., starting from a given number of samples; a probability density function (PDF) over a set of attributes is derived. The resulting PDF is flexible adequate to get both spatial and temporal correlations.

3.3 Mobility-based Approaches

If some of nodes are mobile, the traffic flow can be changed if mobile devices are accountable for data collection directly from stationary nodes. Ordinary nodes wait for the passage of the mobile device and route messages towards it, so that communication takes place in immediacy. As a consequence, ordinary nodes can save energy because path length and forwarding overheads are reduced as well. Mobility is also helpful for reducing energy consumption. Packets coming from sensor node negotiate the network towards the sink by following a multi-hop path. When the sink is static, a few paths can be more loaded than others depending on the network topology and packet generation rates at sources. Mobility-based energy conservation schemes can be classified depending on the nature of the mobile element, i.e. a mobile sink (MS) or a mobile relay (MR).

3.3.1 Mobile-sink-based Approaches

Many approaches projected in the literature about sensor networks with mobile sinks (MS) rely on a linear programming (LP) formulation which is used in order to optimize parameters such the network life span. In [50] the authors suggest a model consisting of a MS which can move to a limited number of locations (sink sites) to visit a given sensor and communicate with it. During visits to nodes, the sink stays at the locations for a period of time. Nodes not in the coverage area of the sink can send messages along multi-hop path ending at the MS and obtained using shortest path routing. Simulation outcome show that the multiple sink approach of [51] can achieve a network lifetime which is five/ten times longer than with the stationary sink approach. The model of [50] has been extended in [52], where no specific postulation is made on the way sensors are arranged in the sensing area. In addition [52] also considers the residual energy at sensors and the routing guidelines, so that it obtains network life time two times longer than one achieved with [50].

3.3.2 Mobile-relay-based Approaches

The Mobile Relay (MR) representation for data collection in multi-hop ad hoc networks has already been explored in the context of opportunistic networks [53]. One of the most famous approaches is given by the message ferrying scheme [54-59]. Message ferries are special mobile nodes which are introduced into a sparse mobile ad hoc network to offer the service of message relying. Message ferries move around in the network area and collect data from source nodes. They carry stored information and forward them towards the destination node. Thus, message ferries can be seen as a moving communication infrastructure which accommodates data transfer in sparse wireless networks.

4. ENERGY OPTIMIZATION METHODS

The methods [60] in which energy savings can be affected or can be classified under two heads:

1. Device Level: Hardware component selection and their configuration to achieve low energy consumption in a wireless sensor node.
2. Network Level: Choice of communication methods and protocols to minimize energy consumption.

In a sensor node [61-63] there are four essential parts: processing unit, sensing unit, transceiver unit and power unit. Processing unit is a part of microcontroller unit which can read sensor data, perform some minimal computations and make a packet ready to transfer in the wireless communication channel. Figure 6 reflects power consumption of WSN in various states.

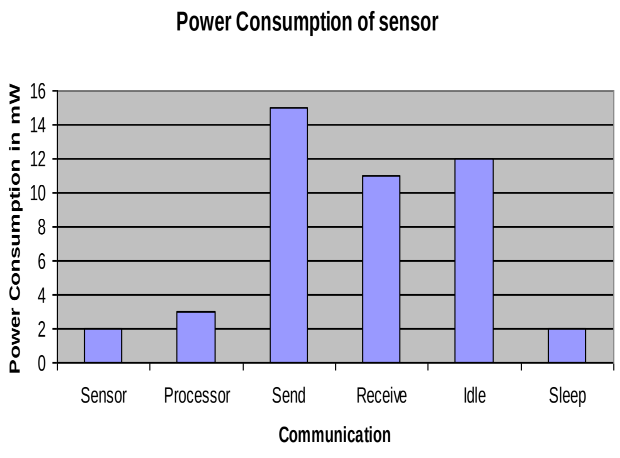

Fig 6: Power Consumption of WSN in Various States

4.1 Node Architecture

The architecture of node [64] can be designed based on the following conditions:

- Criteria for component selection based on end goal of energy saving
- A practical combination of components that satisfy the end criteria.

4.1.1 Processing Unit

Basically the processor is built on the microcontroller [65], which reads sensor data and makes the data ready for transfer. In other words, processor is a core unit for the calculation in a wireless sensor node. This part of the node helps to control the task scheduling, to calculate energy to define communication protocols, to make suitable coordination, and for data manipulation and data transfer. The power consumption of processor mainly depends on how long it supports sleep mode has a straight connection with the operation of node. The power consumption of nodes depends on operating voltage, duty-cycle internal logic and above all on efficient manufacturing technology. MPS430 is quite suitable for wireless sensor network due to its ultra-low power, high performance and its design for minimum power for portable system. It has five energy saving mode and range of current consumption mode of only 0.1 to 400 µA and 0.8 µA in the waiting mode.

4.1.2 Radio and Transceiver

The radio transmission and reception has proven to be the major energy consumer in sensor network. In [66] most of the sensor network, energy conservation involves two methods to minimize communication overhead. Configuring MAC and network layer is the first method for which the multi-hop communication nodes switches off their radios when they are not in use (adaptive duty cycle). Data reduction and data aggregation is the second method where exploitation of the correlation in the data is achieved to decrease the size of the data and also the communication expenditure. Radio needs to be active for long period in multi-hop communication more often when nodes send data to one or more base station. In multi-hop routing [67] when node is not requisite, power conservation policy will switch off broadcasting. However these nodes will switched off will be unavailable for multi-hop communication. And the network region where these nodes are present can become inaccessible by queries because of routing partition. Maintaining the communication stamina and enabling the multi-hop routing will powering down radios of the nodes for conserving energy involves others techniques. 'Wakeup on demand': 'wake up' the high-power radio when the need arises. In selecting radio one of the areas that need to be considered strongly is turn-off, turn-on time, which will have an effect on the overall system performance. A short time for the radio to go into sleep mode and to wakeup from sleep mode is preferable while making the selection of the radio. Transceiver can be described as the combination of receiver and transmitter. Communication between node within the network and transfer of data between base stations to node, require a combination of transmitter and receiver.

In the Table 1, we compared different transceivers and IC's like AT86RF210 MC13193 Chipcons's CC2420 and Maxtream's XBee [68] that support IEEE 802.15.4. Most of the devices are fabricated using surface mounting technology. However CC2420 RF-transceiver comes out as the better option due to low power compared to others, because very promptly it enters in to the sleep mode when no communication occur. In practice CC2420 is used for wireless sensor network to home and building automation, industrial monitoring and control systems.

Table 1 Comparison of Different Transceivers

Characteristics	**CC2420**	**XBee**	**AT86RF210**
Operation Voltage	1.8-3.6V	2.8-3.4 V	1.8-3.6V
Tx Power	-24dbm	0dbm	6-12dbm
Current Tx Mode	17.4mA	45mA	35mA
Current Rx Mode	18.8mA	50mA	14.5mA
Rx Sensitivity	-95db	-92db	-95db
Throughput	250Kbps	250 Kbps	20Kbps
Modulation Type	DSSS	DSSS	DSSS BPSK
Carrier Frequency	2.4GHZ	2.4GHZ	850-930MHz

4.1.3 Sensor

In reality sensor unit [69] is the medium to communicate between the physical world and the conceptual world of processing unit. The sensor unit is the one of the vital part of wireless sensor mode, it sense and detect the physical state of environment and sends the data to processor. Processor manipulates data and decides where it has to promote or else transmit the data to base station. Sensor converts energy from one form to another form. In reality sensor acts as the transducer where energy is convert into analog signal or digital signal. Sensor can be distinguished based on what kind of energy they detect or transfer to the system. A wireless sensor node [70] can be built with different type of sensor, and different types of sensors use different amount of energy. Some of them require a significant large amount of energy than others. For example, gas sensor requires a comparatively higher amount of energy than temperature sensors, pressure or image sensor because it requires active heating elements. Table 2 shows power requirement of different sensors. Image sensors also require a higher amount of energy because thousand of conversions (analog to digital) are require for producing images.

Table 2: Power Consumption of different types of sensor

Sensor Type	Power Consumption
Gas sensor	500mW-800mW
Image sensor	150mW
Pressure sensor	10mW-15mW
Acceleration sensor	3mW
Temperature sensor	0.5mW-5mW

4.1.4 Battery

Generally sensor nodes are designed to run on ordinary AA batteries. It is very important to approximate the power consumption needs of the sensor node. Appropriate selection in the design phase of the transceiver and microcontroller will make sure that the hardware platform on which the sensor node is built is power conscious, and this will be useful in managing the power of the system. We can differentiate batteries in two categories, chargeable and rechargeable. If the sampling period or duty cycle is 1% using TDMA or Low power listing then,

Average drain current = 0.1 * (active current) + 0.99 * (sleep current) (7)

Lifetime = capacity / average Drain current (8)

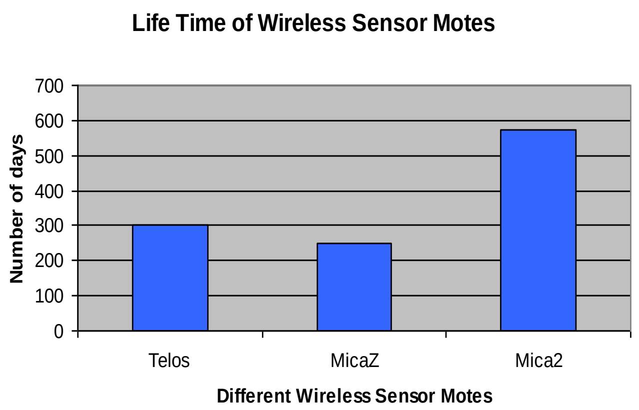

Fig 7: Life Time of MICAZ and TELOS Wireless Sensor Motes When Duty Cycle is 1

The life time of MicaZ and Telos wireless sensor motes [69-70] are shown in the Figure 7, where vertical axis represents number of days and horizontal axis represents different motes. In some cases battery life can be increase by reducing duty cycle, like if WSM read the data every 3 minutes it means that same battery will give more life time.

4.2 Communication Architecture

Communication architecture [71] for energy-constrained wireless sensor networks introduces various challenges. Wireless channels are generally a difficult communications medium, with relatively low capacity per unit bandwidth, random amplitude and phase fluctuations due to multipath fading, intersymbol interference due to delay spread, and interference from other nodes due to the broadcast nature of the radio channel. The goal of communication architecture for energy-constrained wireless sensor networks is to achieve rates close to the fundamental capacity limits of the channel while overcoming channel impairments using relatively little energy. In this section, we explore design strategies to provide good link layer performance under an energy limitation.

4.2.1 Channel Coding

Channel coding can considerably reduce the power required to achieve a given BER and is therefore a common attribute in energy-constrained wireless sensor network design. For example, in deep space communications engineers have aggressively pursued the use of very complex codes to minimize power. Most wireless systems also use some form of error con-Conventional error control codes use block or convolutional code designs: the error correction capability of these codes is obtained at the expense of an increased signal bandwidth or a lower data rate [72]. A typical parallel concatenated encoder is shown in Figure 8. It consists of two parallel convolutional encoders separated by an interleaver, with the input to the channel being the data bits m along with the parity bits $\mathbf{X}_1$ and $\mathbf{X}_2$ output from each of the encoders in response to input m.

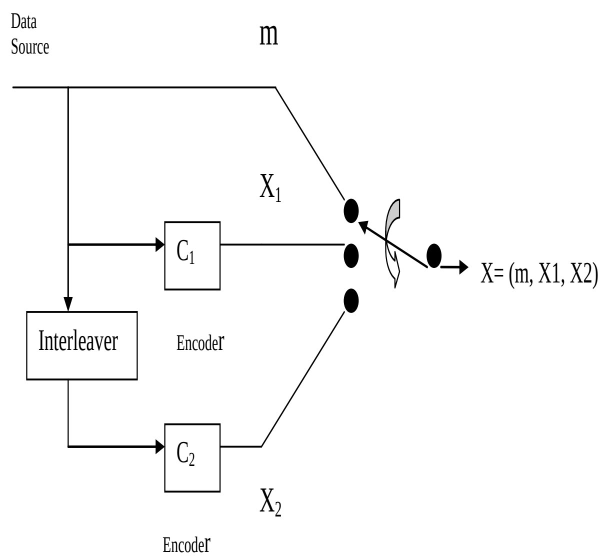

Fig 8: A Parallel Concatenated Encoder

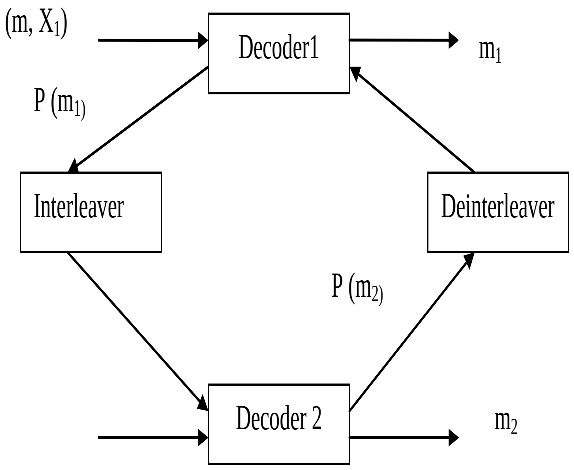

Fig 9: A Turbo Decoder

The key to parallel concatenated encoding lies in the recursive nature of the encoders and the impact of the interleaver on the information stream. Interleavers also play a significant role in the elimination of error floors [73-76]. Iterative or turbo decoding exploits the component- code substructure of the turbo encoder by associating a component decoder with each of the component encoders. More specifically, each decoder performs soft input/soft output decoding, as shown in figure 9. In this figure decoder 1 generates a soft decision in the form of a probability measure $p(m_1)$ on the transmitted data bits based on the received codeword (m, X_1). This reliability information is passed to decoder 2, which generates its own probability measure $p(m_2)$ from its received codeword (m, X_2) and the probability measure $p(m_1)$. This reliability information is input to decoder 1, which revises its measure based on this information and the original received codeword. Decoder 1 sends the new reliability information to decoder 2, which revises its measure using this new information. Turbo decoding proceeds in an iterative manner, with the two component decoders alternately updating their probability measures. Ideally the decoders eventually agree on probability

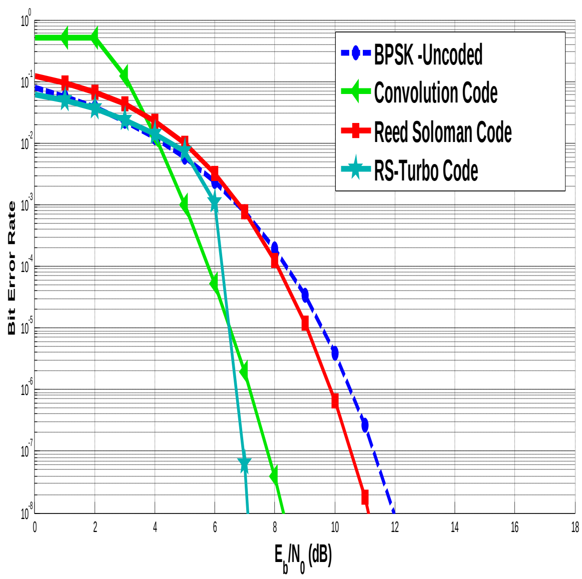

Figure 10: Turbo Code Performance

measures that reduce to hard decisions $m = m_1 = m_2$. However, the stopping condition for turbo decoding is not well defined, in part because there are many cases in which the turbo decoding algorithm does not congregate; that is, the decoders cannot agree on the value of m. Several methods have been proposed for detecting convergence (if it occurs), including bit estimate variance and neural net-based techniques. Figure 10 illustrates the performance of turbo coding. It can be seen that at a BER of 10^{-8} a recursive convolution systematic (RS) turbo code provides a 5 dB coding gain over uncoded systems and lies within 1.5 dB of the Shannon capacity limit.

4.4.2 Multiple Antennas

Multiple antennas at the transmitter and/or receiver play a powerful role in improving the performance and reducing the required transmits power for wireless link layer designs. Multiple antenna systems typically use either diversity, beamsteering, or multiple input multiple output (MIMO) techniques. Diversity combining, a common method to mitigate flat fading, combines coherently multiple independently fading copies of the signal. By significantly reducing the impact of flat fading, diversity combining can lead to considerable power savings [77]. The MIMO system with two transmit antennas and two receive antennas, proposed in [85], as shown in Figure.11, uses two different symbols s_1 and s_2 that are transmitted simultaneously during the first symbol period from antennas 1 and 2 , respectively , followed by signals $-s_2^*$ and s_1^* from antennas 1 and 2, respectively , during next symbol period. It has been shown [85] that for Rayleigh fading channels MIMO system based on Alamouti scheme can achieve lower average probability of error than SISO systems under the same transmit energy budget due to the diversity gain and possible array gain (when $M_r > 1$) . In other words, under the same BER and throughput requirement, MIMO systems require less transmission energy than SISO systems.

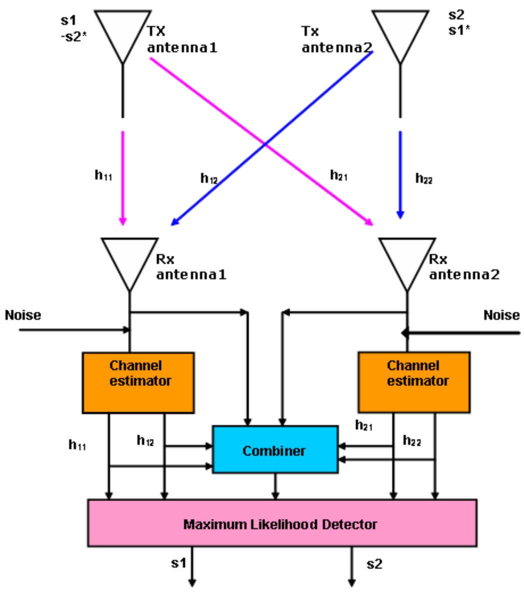

Figure 11 MIMO System

This is indicated in Figure 12, where we show the performance [78, 85] of maximal-ratio combining (MRC) diversity in rayleigh fading with one (no diversity), two, and four branches. We see that compared to no diversity, at a BER of 10^{-3} two-branch transmit diversity (2 x 1 MRC) provides 6.5 dB diversity gain and four-branch diversity (4 x 1 OSTBC) provides 10 dB diversity gain. MIMO systems, where both transmitter and receiver use multiple antennas, can significantly increase the data rates possible on a given channel and reducing the required transmits power for wireless link layer designs. Beam steering also reduces interference power along with fading and intersymbol interference due to multipath, since the interference and multipath signals are highly attenuated when they arrive from directions other than that of the line-of-sight signal. MIMO systems, where both transmitter and receiver employ multiple antennas, can significantly increase the data rates possible on a given channel.

Wireless sensor network (WSN) comprises of hundreds to thousands of small nodes in use in a wide range of data gathering applications such as military, environmental monitoring and other fields [79].Due to limited energy and difficulty in recharging a large number of sensor nodes, energy efficiency and maximizing network lifetime have been the most important design goals for the network. However, channel fading and radio interference pose a big challenge in design of energy efficient communication protocols for WSN. To reduce the fading effects in wireless channel, multi-input multi-output (MIMO) scheme is utilized for sensor network [80]. MIMO systems can dramatically increase the channel capacity and reduce the transmission energy in wireless fading channels. Sensor nodes using MIMO techniques would require lower transmission power to achieve the same bit error rate (BER) as point to point communications [81-82]. Applying multiple antenna techniques directly to sensor network is impractical because of the limited size of a sensor node usually supports a single antenna. Cooperative transmission and reception from antennas in a group of sensor nodes can be used to construct a system fundamentally equivalent to a MIMO system for WSN [83]. Normally, MIMO system needs to estimate all channels between sources

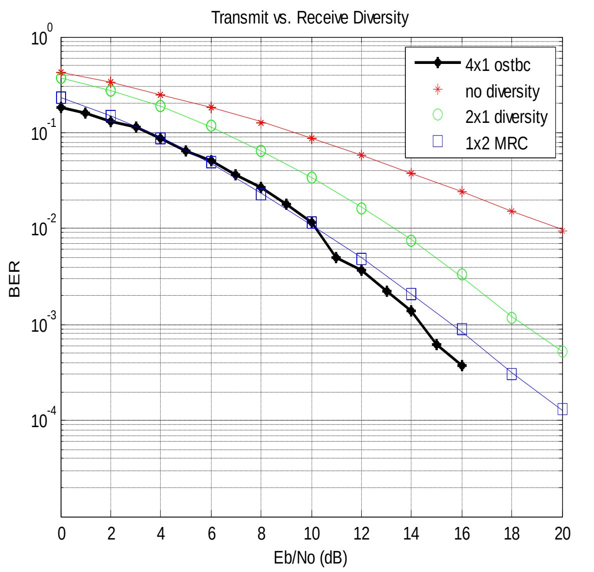

Fig 12: Performance of Diversity Systems

and destination. If cooperative transmissions from multiple sensor nodes are allowed, the amount of channel estimation at the receiver can be reduced and hence can save the energy of sensor nodes. The MIMO transmission system achieves lower overall energy consumption than point to point communications [82]. The proposed MIMO MAC protocol utilizes space time block code (STBC) scheme [84] and provides significant diversity gain to enhance the system performance. This protocol outperforms fixed group size cooperative MIMO MAC and point to point communication schemes in terms of energy and delay.

5. CONCLUSIONS

In this paper we have reviewed the main approaches to energy saving methods in Wireless Sensor Network. These energy saving methods are basically used to increase the life time of sensor nodes in wireless sensor networks. We have also stressed the importance of design issues of Wireless Sensors Networks such as power consumption, hardware constraints, environment, and transmission media.

We have surveyed issues on three different categories: (1) Duty-cycling Approaches (2) Data-driven Approaches (3) Mobility-based Approaches. We have summarized and compared different proposed designs for device level and network level for energy management in wireless sensor networks. Moreover, we have highlighted possible improvements and research in the area of energy optimization methods in wireless sensor networks. There are still many issues to be resolved around energy management in order to increase the life time sensor nodes such as data aggregation, and information management. By solving these issues, we can further, reduce the energy consumption of sensor node in wireless sensor networks. A methodical study of the relation between energy efficiency and system lifetime is an avenue of future research. Analytical results on the bounds of life span of sensor networks are another area worth exploring. The sensor data are usually highly interrelated and energy efficiency can be achieved by joint source coding and information compression. Although some research has been pursued in this direction, there is significant scope of future work.

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