WALIA journal 30(1): 104-114, 2014
Available online at www.Waliaj.com
ISSN 1026-3861

Methods for energy reduction in wireless sensor networks

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Abstract: A wireless sensor network consists of a large number of sensor nodes which are deployed over an area to perform local computations based on information gathered from the surroundings. Each node in the network is equipped with a battery, but it is almost very difficult to change or recharge batteries; Therefore, the crucial question is: "how to prolong the network lifetime to such a long time?" hence, maximizing the lifetime of the network through minimizing the energy is an important challenge in WSN. Due to their ad-hoc deployment in hazardous environment, sensors cannot be easily replaced or recharged. Thus, energy saving acts as one of the hottest topics in wireless sensor networks such circumstance; we will make a short survey on the main techniques used for energy conservation in sensor networks. Specifically, we will focus primarily on duty cycling schemes which represent the most compatible technique for energy saving then we will also survey data-driven approaches can be used to improve the energy efficiency even more. Finally, we will make a review on some communication protocols proposed for sensor networks.

Key words: *Wireless sensor networks; Energy conservation; Energy efficiency protocols*

1. Introduction

Recent advances in micro-electro-mechanical systems (MEMS), low power and highly integrated digital electronics have led to the development of micro sensors (Akyildiz et al., 2002; Dong et al., 1997). A wireless sensor network consists of sensor nodes deployed over a geographical area for monitoring physical phenomena like temperature, humidity, vibrations, seismic events, and so on(IEEE, 2005) . Typically, a sensor node is a tiny device that includes three basic components: a sensing subsystem for data acquisition from the physical surrounding environment, a processing subsystem for local data processing and storage, and a wireless communication subsystem for data transmission. In addition, a power source supplies the energy needed by the device to perform the programmed tasks. This power source often consists of a battery with a limited energy budget. The development of wireless sensor network was originally motivated by military applications such as battlefield surveillance. However, WSNs are now used in many civilian application areas; including the environment and habitat monitoring due to various limitations arising from their inexpensive nature, limited size, weight and ad hoc method of deployment, each sensor has limited energy. In addition, it could be inconvenient to recharge the battery, because nodes may be deployed in a hostile or impractical environment. At the network layer, intention is to find ways for energy efficient route setup and reliable relaying of data from the sensor nodes to the sink, so that the lifetime of the network is maximized. The major difference between the wireless sensor network and the traditional wireless network sensors are very sensitive to energy consumption. Moreover, the performance of the sensor network applications highly depends on the lifetime of the network. We adopt as a common lifetime definition the time; when the first sensor dies. This lifetime definition, proposed in (Chang and Tassiulas, 2000), is widely utilized in the sensor network research field. An alternative lifetime definition that has been used is the time at which a certain percentage of total nodes run out of energy. This definition is actually quite similar in nature to the one we use here. In a well-designed network, the sensors in a certain area exhibit similar behaviors to achieve energy balance. In other words, when one sensor dies, it can be expected the neighbors of this node will run out of energy very soon since they will have to take over the responsibilities of that sensor and we expect the lifetime of several months to be several years. Thus, energy saving is crucial in designing life time wireless sensor networks .the rest of the paper is organized as follows. Section 2 discusses the general approaches to energy conservation in sensor nodes (duty-cycling, data-driven). And in this Section presents Major sources of energy waste in WSNs in Section 3 deals with schemes related to the duty-cycling approach we highlight the schemes that will be then described in detail in the following sections Energy efficiency MAC Protocols in WSN are described briefly and in Section 4 deals with schemes related to the data-driven approach Finally conclusions and open issues are discussed in Section 5.

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2. Major sources of energy waste in WSNs

Energy is a very scarce resource for such sensor systems and has to be managed wisely in order to extend the life of the sensor nodes for the duration of a particular mission. Energy consumption in a sensor node could be due to either "useful" or "wasteful" sources. Useful energy consumption can be due to transmitting or receiving data, processing query requests, and forwarding queries and data to neighboring nodes. Wasteful energy consumption can be due to one or more of the following facts. One of the major sources of energy waste is idle listening, that is, (listening to an idle channel in order to receive possible traffic) and secondly reason for energy waste is collision (When a node receives more than one packet at the same time, these packets are termed collided), even when they coincide only partially. All packets that cause the collision have to be discarded and retransmissions of these packets are required, which increase the energy consumption. The next reason for energy waste is overhearing,(a node receives packets that are destined to other nodes). The fourth one occurs as a result of control-packet overhead ;(a minimal number of control packets should be used to make a data transmission.) finally for energy waste is over-emitting, which is caused by the transmission of a message when the destination node is not ready. Given the above facts, a correctly designed protocol must be considered to prevent these energy wastes.

3. General approaches to energy saving

Based on the above issue and power breakdown, several approaches have to be exploited, even simultaneously, to reduce the power consumption in wireless sensor networks. At a very general level, we identify two main enabling techniques namely: duty cycling and data-driven approaches. Duty cycling is mainly focused on the networking subsystem. The most effective energy-conserving operation is putting the radio transceiver in the (low-power) sleep mode whenever communication is not required. Ideally, the radio should be switched off as soon as there is no more data to send/receive, should be resumed as soon as a new data packet becomes ready. In this way nodes alternate between active and sleep periods depending on network activity. Duty cycle is defined as the fraction of time nodes are active during their lifetime. Data driven approaches can be used to improve the energy efficiency even more that will be then described in detail in the following sections (M. Medidi and Y. Zhou,2007).

3.1. Duty-cycling

Normally, a sensor radio has 4 operating modes: transmission, reception, idle listening and sleep. Measurements showed that the most power consumption is due to transmission and, in most cases; the power consumption in the idle mode is approximately similar to receiving mode. On contrary, the energy consumption in sleep mode is much lower. Duty-cycling can be achieved through two different and complementary approaches. From one side, it is possible to exploit node redundancy which is typical in sensor networks and adaptively select only a minimum subset of nodes to remain active for maintaining connectivity. In some applications (e.g., event detection), the events are typically rare and hence sensor nodes spend a majority of their time in the idle period which reduces the lifetime and the utility of the sensor networks. Nodes that are not currently; needed for ensuring connectivity can go to sleep and save energy. Finding the optimal subset of nodes that guarantee connectivity is referred to as topology control. On the other hand, active nodes (i.e. nodes selected by the topology control protocol) do not need to maintain their radio continuously on. They can switch off the radio (i.e. put it in the low-power sleep mode) when there is no network activity, thus alternating between sleep and wakeup periods. Throughout we will refer to duty cycling operated on active nodes as power management. Therefore, topology control and power management are complementary techniques that implement duty cycling with different granularity. Power management protocols could be implemented either as independent sleep/wakeup protocols running on top of a MAC protocol. Several criterions can be also used to decide which nodes to activate/deactivate and when. In this regard, topology control protocols can be broadly classified in the following two categories: Location driven protocols define which node to turn on and when, based on the location of sensor nodes which is assumed to be known such as Geographical Adaptive Fidelity (GAF) (Xu, et al., 2001), Geographic Random Forwarding (GeRaF) (Zorzi and Rao, 2003; Casari et al., 2005). (Connectivity driven protocols dynamically activate/deactivate sensor nodes so that network connectivity or complete sensing coverage is fulfilled). On-demand protocols such as Span (Chen et al., 2002) is a connectivity-driven protocol that adaptively elects "coordinators" of all nodes in the network and Adaptive Self-Configuring sensor Networks Topologies(ASCENT) (Cerpa and Estrin, 2004); Location-driven topology control protocols distinctly require that sensor nodes in term of recognizing their position .This is generally achieved by providing sensors with a GPS unit. On-demand protocols take the most intuitive approach to power management. The basic idea is that a node should wakeup only when another node wants to communicate with it. The main problem associated with on-demand schemes is how to inform the sleeping node that some other nodes are willing to communicate with it. To this end, such schemes typically use multiple radios with different energy/performance tradeoffs (i.e. a low-rate and low power radio for signaling, and a high-rate but more power hungry radio for data communication).

An alternative solution consists in using a scheduled rendezvous approach. The basic idea behind scheduled rendezvous schemes is that each node should wake up at the same time as its neighbors. Typically, nodes wake up according to a wakeup schedule and remain active for a short time interval to communicate with their neighbors. Then, they go to sleep until the next rendezvous time. Finally, an asynchronous sleep/wakeup protocol may be used. With such protocols, a node can wake up when it wants and still be able to communicate with its neighbors. This goal is achieved by properties implied in the sleep/wakeup scheme thus no explicit information exchange is needed among nodes. On-demand schemes are based on the idea that a node should be awaken just when it has to receive a packet from a neighboring node. This minimizes the energy consumption thus, makes on-demand schemes particularly compatible 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) therefore briefly Several criterions can be used to decide which nodes to activate/deactivate, and when. From this regard, topology control protocols can be broadly classified in the following two categories: the first Location *driven*. The decision about which node to turn on, and when, is based on the location of sensor nodes which is assumed to be known (Xu et al, 2001). secondly *Connectivity driven*. Sensor nodes are dynamically activated/deactivated in such way to ensure network connectivity (Cerpa and Estrin, 2002), The implementation of such schemes typically requires two different channels: a data channel for normal data communication and a wakeup channel for awaking nodes; when needed. Sparse Topology and Energy Management (STEM) (Schurgers et al., 2002) uses two different radios for wakeup signal and data packet transmissions, respectively. The wakeup radio is not a low power radio (to avoid problems associated with different transmission ranges). Therefore, an asynchronous duty cycle scheme is used on the wakeup radio as well. Each node periodically turns on its wakeup radio for Tactive every T duration. When a source node has to communicate with a neighboring node (target), it sends a stream of periodic beacons on the wakeup channel. As soon as the target node receives a beacon it sends back a wakeup acknowledgement and turns on its data radio. In addition to the above beacon-based approach, referred to as STEM-B, in the authors propose a variant (referred to as STEM-T) that uses a wakeup tone instead of a beacon. The main difference is that in STEM-T all nodes in the neighborhood of the initiator are awakened. Both STEM-B and STEM-T may be used in combination with topology control protocols .To achieve a tradeoff between energy saving and wakeup latency, it proposes a Pipelined Tone Wakeup (PTW) scheme. Like STEM, PTW relies on two different channels for transmitting wakeup signals and packet data, and uses a wakeup tone to awake neighboring nodes. Hence, any node in the neighborhood of the source node will be awakened. Scheduled rendezvous schemes require that all neighboring nodes wake up simultaneously. 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 a node is awake it is guaranteed that all its neighbors are awake as well. This allows sending broadcast messages to all neighbors (Anastasi et al., 2009). On the flip side, scheduled rendezvous schemes require nodes to be synchronized in order to wake up at the same time. Power management with node sleeping has been extensively studied in WSNs. The existing power management schemes can be categorized into three classes. The first class includes various TDMA protocols, such as TRAMA (Rajendran et al, 2003) and DRAND. However, a node in TDMA networks has to wait for its time slot to transmit; disadvantage of this protocol is inefficient for applications with tight and varying delay requirements. The second class includes synchronous duty cycling protocols, such as S-MAC and T-MAC that we described in following. The major issue with these protocols is that the sleep schedules of nodes needed be frequently synchronized, which may lead to energy waste and additional communication delays. The third class of power management schemes consists of asynchronous channel polling protocols, such as B-MAC and X-MAC (Polastre et al., 2004);nodes in these protocols wake up periodically to poll the channel for activities that described in detail in the following sections. A medium access control (MAC) protocol directly controls the communication module, so the MAC protocol has important effect on the nodes' energy consumption. According to the five Major sources of energy waste, researchers have proposed different types of MAC protocols to improve the energy efficiency for prolonging network lifetime a good MAC protocol for wireless sensor networks should have the following attributes. The firstly energy efficiency. In order to prolong the network lifetime, The second and third attributes are scalability and adaptability. In order to handle the changes in network size, node density, and topology, the MAC protocol should effectively and rapidly adapt the changes such that the network connectivity and topology can be recovered. Other important attributes such as latency, throughput, and bandwidth utilization may be secondary in sensor networks (Demirkol et al., 2006).

3.2. Energy efficient mac protocols for WSNS

A wide range of energy efficient MAC protocols are described briefly, which are categorized into contention-based, TDMA-based, hybrid, and cross layer MAC protocols according to channel access policy. Then, their pros and cons are briefly summarized. Contention-based MAC protocols, which are mainly based on the Carrier Sense Multiple Access (CSMA) or Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA), require no coordination among the nodes accessing the channel. The core idea is when a node needs to send data it will compete for the wireless channel. Colliding nodes will back off for a random duration of time before attempting to access the channel again. The typical contention-based MAC protocols are S-MAC (Sensor-MAC), T-MAC (Timeout-MAC) (Demirkol et al., 2006), and U-MAC (Utilization-MAC). TDMA-Based MAC Protocols In contrast to contention-based MAC protocols, the scheduling based TDMA technique offers an inherent collision-free scheme by assigning unique time slot for every node to send or receive data. The first advantage of TDMA is that interference between adjacent wireless links can be avoided. Thus, the energy waste coming from packet collisions is diminished. Secondly, TDMA can solve the hidden terminal problem without extra message overhead because neighboring nodes transmit at different time slots. Main TDMA-based MAC protocols include µ-MAC (Energy-efficient MAC), DEE-MAC (Dynamic Energy Efficient MAC), SPARE MAC (Slot Periodic Assignment for Reception MAC) . Hybrid Contention-Based and TDMA-Based MAC Protocols In recent years, some hybrid MAC protocols are proposed, which combine the advantages of contention-based MAC protocols and TDMA-based MAC protocols. All these protocols divide the access channel into two parts. Control packets are transmitted in the random access channel, while data packets are transmitted in the scheduled access channel. Compared with the contention-based MAC protocols and the TDMA-based MAC protocols, the hybrid protocols can obtain higher energy saving and offer better scalability and flexibility. In detail, the hybrid MAC protocols comprise Z-MAC (Zebra MAC) , A-MAC (Advertisement-based MAC) and IEEE 802.15.4 .and at the end of this section we are described briefly the major sources of energy waste in a MAC protocol for wireless sensor networks: collision: When a transmitted packet is corrupted it has to be discarded, and the follow-on retransmissions increase energy consumption ,control packet overhead: Sending and receiving control packets consumes energy too, and less useful data packets can be transmitted ,idle listening: listening to receive possible traffic that is not sent can consume extra energy and overhearing: meaning that a node picks up packets that are destined to other nodes can unnecessarily consume energy.

3.2.1. S-MAC

There are two states in a time frame: active state and sleep state. S-MAC (Ye et al. 2004), adopts an effective mechanism solve the energy wasting problems, that is periodical listening and sleeping. When a node is idle, it is more likely to be asleep instead of continuously listening to the channel. S-MA reduces the listen time by letting the node go into periodic sleep mode.

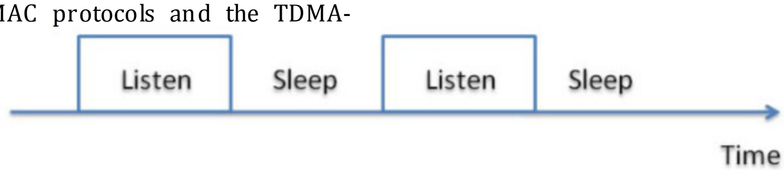

Fig. 1: Periodic listen and sleep

In order to make S-MAC robust to synchronization errors, two techniques can be used. First, all timestamps that are exchanged are relative rather than absolute. Secondly, the listen period is significantly longer than the clock error or drift in Compared with TDMA schemes with very short time slots, S-MAC requires much looser synchronization among neighboring nodes. This protocol is summarized as follow: main goal of S-MAC is reduce power consumption that is include three major components : situation wake up and sleep is the periodic i.e. periodic sleep and listen, this protocol avoidance of collision and overhearing that means in this protocol is interfering nodes go to sleep after they hear an RTS or CTS packet and duration field in each transmitted packet indicates how long the remaining transmission will be and communication between senders is the message passing that is shown in fig. 2.

As you see, the listen/sleep scheme requires synchronization among neighboring nodes and updating schedules is accomplished by sending a SYNC packet. The result of this investigate is energy waste caused by idle listening is reduced by sleep schedules and sleep and listen periods are predefined and constant which decreases the efficiency of the algorithm under variable traffic load. Advantages of Sensor MAC protocol: energy waste caused by idle listening is reduced by sleep schedules and secondly Beside implementation simplicity, global time synchronization overhead may be prevented with sleep schedule announcements and Disadvantages of Sensor MAC protocol: S-MAC fixed duty cycle i.e. Active time is fixed. It is not optimal, if message rate is less energy is still wasted in idle-listening, sleep and listen periods are predefined and constant which decreases the efficiency of the algorithm under variable traffic load, long listening interval is expensive - Everyone stays awake unless somebody transmits, time sync overhead even when network is idle and RTS/CTS and ACK overhead when sending data

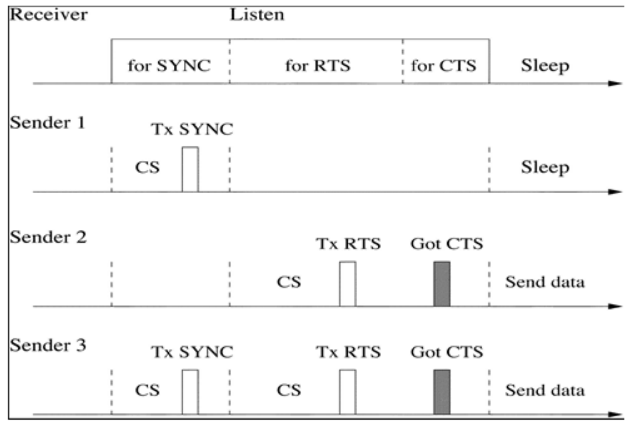

Fig. 2: Investigate CTS and RTS packet

3.2.2. T-MAC

T-MAC (Dam and Langendoen, 2003) is an extension of the previous protocol which adaptively adjusts the sleep and wake periods based on estimated traffic flow to increase the power savings and reduce delay. TMAC also reduces the inactive time of the sensors compared to S-MAC. Hence, it is more energy efficient than S-MAC.

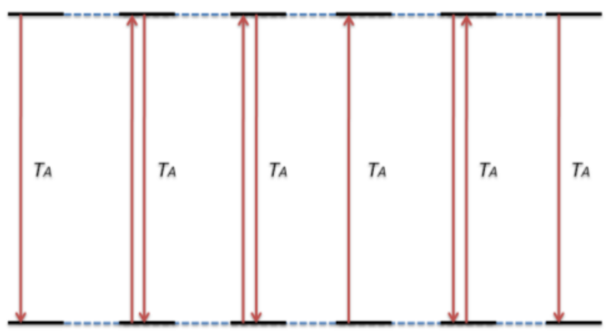

Fig. 3: The basic T-MAC protocol scheme with adaptive active times

This protocol proposed to enhance the poor results of S-MAC protocol under variable traffic load that listen period ends when no activation event has occurred for a time threshold TA .Reduce idle listening by transmitting all messages in bursts of variable length, and sleeping between bursts and the end of advantage this type of MAC is times out on hearing nothing.

Can be said that T-MAC gives better result under variable load and Suffers from early sleeping problem node goes to sleep when a neighbor still has messages for it.

3.2.3. U-MAC

U-MAC (Yang et al., 2005) presents a solution for improving the performance on energy consumption for various wireless sensor network applications. In U-MAC, a transmission may end at a scheduled listen time like "*a*", or a scheduled sleep time like "*b*", which is shown in Figure 5. If a transmission ends at the scheduled sleep time *b*, the node will keep listening until the next scheduled sleep time *d*, so that between *b* and the next scheduled listen time *c*, the energy is wasted. U-MAC is based on the S-MAC protocol and provides three main improvements on S-MAC: various duty cycles, utilization based tuning of duty-cycle, and selective sleeping after transmission.

The various duty cycles are assigned for different nodes, which then exchange their schedules and synchronize with neighbors in a fixed period. In addition, time of the next sleep of a node is piggy-backed in ACK packets. It avoids unnecessary retransmission of RTS caused by missing update schedules from neighbors.

3.2.4. µ-MAC

µ-MAC (Campelli et al., 2007) is proposed to obtain high sleep ratios while preserving the message latency and reliability at a acceptable level. µ-MAC assumes a single time slotted channel, depicted in Figure 6. Protocol operation alternates between a contention and a contention-free period.

The contention period is used to build a network topology and to initialize transmission sub-channels. µ-MAC differentiates between two classes of sub-channels: general traffic and sensor reports. In μ-MAC protocol, the contention period incurs large overhead and has to take place frequently.

3.2.5. DEE-MAC

DEE-MAC (Cho et al., 2005) is an approach to reduce energy consumption, which lets the idle listening nodes go into sleep using synchronization performed at the cluster head. Note here that the time division multiple accesses (TDMA)-based MAC scheme is viewed as a natural choice for sensor networks because radios can be turned off during idle times in order to conserve energy.

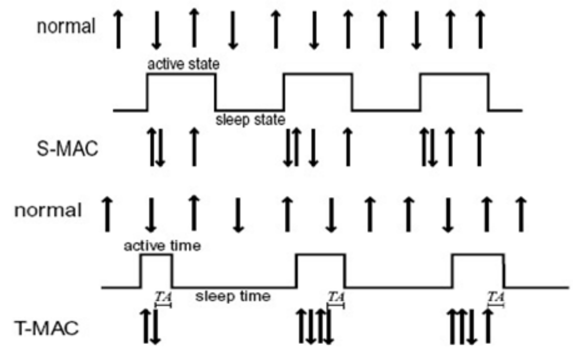

Fig. 4: Comparison of S-MAC and T-MAC

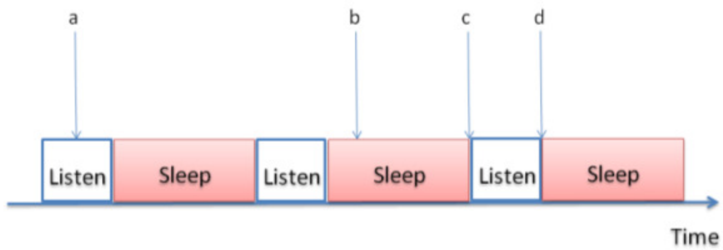

Fig. 5: A transmission may ends at scheduled sleep time or listen time

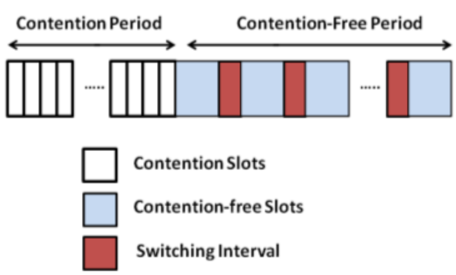

Fig. 6: Time slot organization

In addition, clustering is a promising distributed technique used in large-scale WSNs. Clustering solutions can be combined with TDMA based schemes to reduce the cost of idle listening. The operation of DEE-MAC is divided into rounds, as in LEACH system (Fasolo et al., 2007). A round is the time duration between nodes disseminates its interest to the event and receives the response from the event. Each round consists of a cluster formation phase and transmission phase in other words DEE-MAC operations comprise of rounds. Each of the rounds includes a cluster formation phase and a transmission phase. In the cluster formation phase, a node decides whether to become the cluster head based on its remaining power. The node with the highest power level is elected as the cluster head. Each new round introduces formation of another cluster with different group of nodes based on the current node power level and the network structure changes. After the successful cluster head election, the system enters the transmission phase. This phase comprises of a number of sessions and each of the session consists a contention period and a data transmission period. For the time of the contention period, each of the nodes keeps their radio on, and indicates interest to send a packet to the cluster head. After this period, the cluster head knows which of the node has data to transmit. The cluster head builds a TDMA schedule that is broadcasted to all nodes. Each of the nodes is assigned with one data slot in each session. Based on the broadcasted schedule each of the nodes, having a data to receive or send, is awaken. Clustering and TDMA based schemes present a rational solution to reduce the cost of idle listening in large-scale wireless sensor networks. However, the DEE-MAC is rather intended to event-driven applications. Additional energy efficiency improvement may be obtained by analyzing the error possibility in a packet in the contention period, and by employing inter-cluster communication through nodes instead of only through the cluster heads.

3.2.6. SPARE-MAC

SPARE MAC is a TDMA based MAC protocol for data diffusion in WSNs. The core idea of SPARE MAC is to save energy through limiting the impact of idle listening and traffic overhearing. To realize the goal, SPARE MAC utilizes a distributed scheduling solution, which assigns specific radio resources (i.e., time slots) to each sensor node for reception, termed as Reception Schedules (RS), and spreads the information of the assigned RS to neighboring nodes. A transmitting node can consequently become active in correspondence with the RS of its receiver (Bachir et al., 2010).

3.2.7. Z-MAC

One of the most interesting hybrid protocols is Z-MAC (Rhee et al., 2008). In order to define the main transmission control scheme, Z-MAC starts a preliminary setup phase. By means of the 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. As a result, it is guaranteed that no transmission from a node to any of its one-hop neighbor interferes with any transmission from its two-hop neighbors. The local frame exchange is aimed at deciding the time frame. Z-MAC does not use a global frame equal for all nodes in the network. It would be very difficult and expensive to adapt when a topology change occurs. Instead, Z-MAC allows each node to maintain its own local time frame that depends on the number of neighbors and avoids any conflict with its contending neighbors. 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, regulated by the transmission control procedure. Nodes can be in one of the following modes: Low Contention Level (LCL) and High Contention Level (HCL). A node is in the LCL unless it has received an Explicit Contention Notification (ECN) within the last TECN period. ECNs are sent by nodes when they experience high contention. In HCL only the owners of the current slot and their one-hop neighbors are allowed to compete for accessing the channel. In LCL any node (both owners and non-owners) can compete to transmit in any slot. However, the owners have priority over non-owners. This way Z-MAC can achieve high channel utilization even under low contention because a node can transmit as soon as the channel is available simply Z-MAC utilizes both TDMA and CSMA techniques. In ZMAC, CSMA is considered as the baseline MAC scheme and TDMA is used to improve the contention resolution. Z-MAC uses the concept of owner slot. A node has a guaranteed access to its owner slot (TDMA style) and a contention-based access to other slots (CSMA style). In this way, collisions and energy consumptions are reduced. There are two basic components in Z-MAC. One is called neighbor discovery and slot assignment, and the other is called local framing and synchronization.

3.2.8. A-MAC

In order to provide collision-free, non-overhearing and little idle-listening transmission services, A-MAC is proposed recently, which is designed for long-term surveillance and monitoring applications. In such applications, nodes are typically vigilant and inactive for a long time until something is detected. In A-MAC, some additional latency will be introduced at an acceptable level, while the life time of a network is dramatically prolonged. The major feature of AMAC is that nodes are notified in advance when they will become the receivers of packets. A node is active only when it is the sender or the receiver, during other time it just goes to sleep. With this method, energy waste is avoided on overhearing and idle listening.

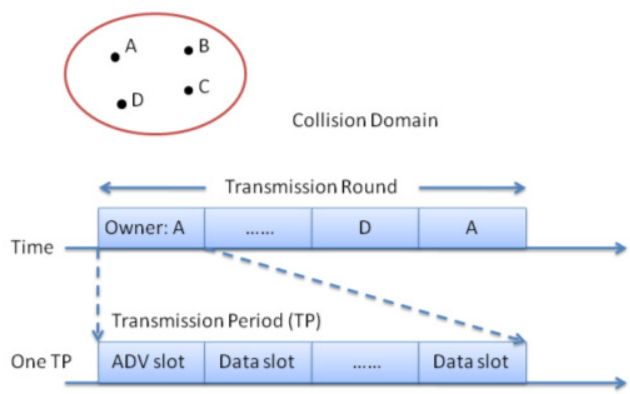

Fig. 7: Structure of A-MAC

3.2.9. WiseMAC

In this protocol (El-Hoiydi and Decotignie, 2005), all nodes defined to have two communication channels: data channel uses TDMA and control channel uses CSMA, preamble sampling used to decrease idle listening time. Nodes sample the medium periodically to see if any data is going to arrive that is shown in figure 8.

This protocol has several features that we describe briefly: the first that preamble length adjustment is dynamic causes the better performance, the second, conflict, when one node starts to send the preamble to a node that is already receiving another node's transmission where the preamble sender is not within range, another problem in this protocol is hidden terminal problem.

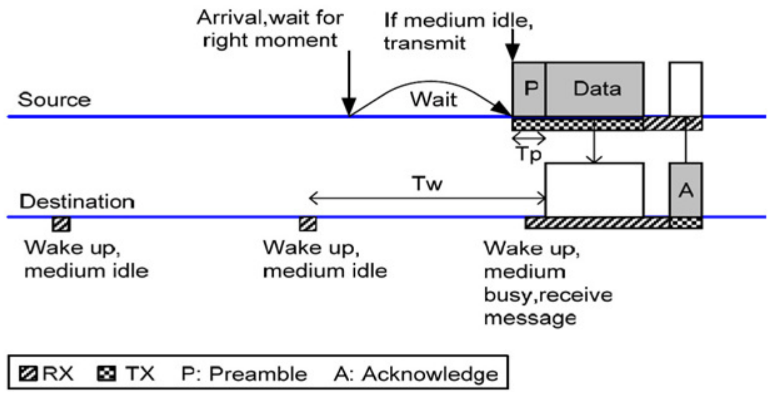

Fig. 8: Structure of Wise MAC

4. Data-driven approaches

Data-driven approaches can be used to improve the energy efficiency even more. In fact, data sensing impacts on sensor nodes' energy consumption in two ways: Unneeded samples. Sampled data generally have strong spatial and/or temporal correlations, so there is no need to communicate the redundant information to the sink .secondly Power consumption of the sensing subsystem. Reducing communication is not enough when the sensor itself is power hungry. In first case unneeded samples result in useless energy consumption, even if the cost of sampling is negligible, because they result in unneeded communications? The second issue arises whenever the consumption of the sensing subsystem is not negligible. Data-driven approaches can be divided to data reduction schemes address the case of unneeded samples, while energy-efficient data acquisition schemes are mainly aimed at reducing the energy spent by the sensing subsystem. Data reduction can be divided to in-network processing and data prediction that will be then described in detail in these sections. In-network processing consists in performing data aggregation (e.g., computing average of some values) at intermediate nodes between the sources and the sink. In this way, the amount of data is reduced while traversing the network towards the sink. Data prediction consists in building an abstraction of a sensed phenomenon, for example a model describing data evolution. The model can predict the values sensed by sensor nodes within certain error bounds and reside both at the sensors and at the sink. If the needed accuracy is satisfied, queries issued by users can be evaluated at the sink through the model without the need to get the exact data from nodes.

4.1. Data Prediction approaches and in-network processing

Data prediction techniques build 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 so that there are as many pairs of models as sources. Many sensor network query systems, such as TinyDB and Cougar , are developed by database research society. Beside the mentioned systems, many research studies have investigated techniques for query processing in sensor networks. Energy efficient routing protocols, in-network query processing techniques, approximate data query processing, strategy adaptive techniques, and plan optimization over time are some of these techniques. Most of these studies are concentrated on optimizing and executing a single long term query. Demers et al studied the effect of different routing trees in data aggregation In this work, multiple query optimization is done in the nodes of the network. This method should detect when to share partial data between different queries and how the redundant information should be eliminated across the path. A proper encoding method is also used to send the minimum volume of data to the base station. One approach is formal model for multiple query optimizations in the sensor networks for the first time. The concentration of this work is on region based aggregation queries. Arrived queries are not sent to the nodes immediately; instead, the query optimizer in the base station batches the ones with the same aggregation operator into a single group and optimizes each group independently. The main idea of this approach is using linear reduction and a combinational method for reducing the number of regions that are necessary to execute the queries. Muller at el., considered the multiple query optimization as a rewriting and merging queries problem . The idea of this approach is to share the sensor network among multiple queries. This model contains a processing unit in the base station which merges all the queries together to construct a network query. The user query must be a subset of the network query. In other words, the network query must cover all of the user queries. Also, the sampling frequency of the network query has to be the greatest common devisor of all the sampling frequencies of the user queries. The network query is injected into the network and the nodes return the network result to the base station. Then, the corresponding result of each user is extracted to be delivered. The main advantage of this method is that each node of the network just belongs to a single routing tree and there is no possibility of having multiple parents or paths for propagating results. Another approach is dividing the queries into two classes: backbone and non-backbone (Yang et al., 2007). The backbone queries are propagated in the normal manner and should share their partial results with the queries of non-backbone set. The main goal of this algorithm is to determine the backbone tree and the number of its members in a way that the number of total transmitted messages in the network is minimized. In order to solve this, the problem is mapped to a Max-Cut problem. Having a set of queries, a graph is formed that each of the vertices represents a query and the weight of each edge shows the number of reduced messages in effect of sharing partial results of the two corresponding queries. According to the obtained graph, a heuristic algorithm is used for backbone selection in order to choose the best cut of backbone queries. TAMPA is a taboo search based algorithm for multiple query optimization which looks for the optimal order of merging queries .Data prediction Techniques belonging to the first class derive at the first stochastic characterization of the phenomenon, particularly in terms of probabilities and statistical properties. Two main approaches of this kind are the following. On the one hand, it is possible to map data into a random process described in terms of a probability density function (PDF). Data prediction is then obtained by combining the computed PDFs with the observed samples. The Ken solution well exemplifies this approach. The general scheme is the same already introduced at the beginning of the current section, likely there are a number of models, and each one is replicated at the source and at the sink. In this case, the 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 instance can be updated as well .Secondly Time series forecasting A typical method to represent time series is given by Moving Average (MA), Auto-Regressive (AR) or a Auto- Regressive Moving Average (ARMA) models. These models are quite simple, but they can be used in many practical cases with good accuracy. More sophisticated models have been also developed (as ARIMA and GARCH), but their complexity does not make them compatible to wireless sensor networks. At the end of Algorithmic approaches and several other kinds of models have been proposed for data prediction in wireless sensor networks. The common factor they share is the algorithmic approach used to get predictions, starting from a heuristic or behavioral characterization of the sensed phenomena. In the following we discuss the most important approaches of this kind. The approach taken by the stochastic techniques is general and sound and also provides means to perform high level operations such as aggregation. The main drawback of this class of techniques is their rather high computational cost, which may be too heavy for current off-the shelf sensor devices. Eventually, stochastic approaches seem to be more convenient when a number of powerful sensors (e.g. Stargaze nodes in a heterogeneous wireless sensor network) are available. Possible improvements in this direction might focus on deriving simplified distributed models for obtaining the desired trade-off between computation and fidelity. On the contrary, time series forecasting techniques can provide satisfactory accuracy even when simple models (i.e. low order AR/MA) are used. To this end, their implementation in sensor devices is simple and lightweight. In addition, most advanced techniques like do not require the exchange of all sensed data until a model is available. Moreover, they provide the ability to detect outliers and model inconsistencies. However, using a specific type of model needs it to be actually suitable to represent the phenomenon of interest. This would require an a-priori validation phase, which may be not always feasible. An interesting direction involves the adoption of a multi-model approach .As this kind of technique has not been fully explored, there is room to further research and improvements. Finally, algorithmic techniques have to be considered case by case, because they tend to be more application specific. To this end, a research direction would focus on assessing if a specific solution is efficient for a certain class of applications in real scenarios, so that it can be taken as a reference for further study and possible improvements.

5. Conclusions

Energy is one of the most critical resources for WSNs. Most of works in the literatures about WSN routing have emphasized energy conservations as an important optimization goal. However, merely saving energy is not enough to effectively prolong the network lifetime. The uneven energy depletion often results in network partition and low coverage ratio which deteriorate the performance. Energy saving in wireless sensor networks has attracted a lot of attention in the recent years and introduced unique challenges compared to traditional wired networks. Extensive research has been conducted to address these limitations by developing schemes that can improve resource efficiency. In this paper, we have summarized some research results which have been presented in the literature on energy saving methods in sensor networks. Although many of these energy saving techniques look promising, there are still many challenges that need to be solved in the sensor networks. Therefore, further research is necessary for handling these kinds of situations.

References

F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci,(2002) "Wireless Sensor Networks: a Survey", Computer Networks , Vol 38, N. 4.

IEEE Pervasive Computing,(2005), "Energy Harvesting and Conservation", vol 4.

J. Chang and L. Tassiulas,(2000) "Energy conserving routing in wireless ad hoc networks," in Proceedings of the Nineteenth International Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM).

Y. Xu, J. Heidemann, D. Estrin,(2001) "Geography-informed energy conservation for ad hoc", in: Proc. ACM MobiCom.

M. Zorzi, R.R. Rao,(2003) "Geographic Random Forwarding (GeRaF) for Ad Hoc and Sensor Networks: Energy and Latency Performance", IEEE Transactions Mobile Computing 2 (4).

B. Chen, K. Jamieson, H. Balakrishnan, R. Morris,(2002) "Span: an energyefficient coordination algorithm for topology maintenance in ad hoc wireless networks", ACM Wireless Networks 8 (5).

C. Schurgers, V. Tsiatsis, M.B. Srivastava,(2002) "STEM: topology management for energy efficient sensor networks, in: IEEE Aerospace Conference"02, Big Sky, MT.

G. Anastasi, M. Coti, M.Frrancesco,APassarella,(2009) "Energy conservation in wireless sensor networks: A survey", Elsever, Ad Hoc Network .

I.Demirkol, C.Ersoy, and F.Alagöz, Bogazici University,(2006), "MAC Protocols for Wireless Sensor Networks: A Survey", IEEE Communications Magazine • April.

A.Bachir, Mischa Dohler, T.Watteyne, and K. Leung,(2010)," MAC Essentials for Wireless Sensor Networks", IEEE COMMUNICATIONS SURVEYS & TUTORIALS, VOL. 12, NO. 2, SECOND QUARTER.

M.C. Vuran, O.B. Akan, I.F. Akyildiz, (2004) "Spatio-temporal correlation: theory and applications for wireless sensor networks", Computer Networks Journal 45 (3).

D. Chu, A. Deshpande, J.M. Hellerstein, W. Hong," Approximate data collection in sensor networks using probabilistic models", 22nd International Conference on Data Engineering (ICDE06),2007.

D. Tulone, S. Madden,(2008)" PAQ: time series forecasting for approximate query answering in sensor networks", in: Proc. 3rd European Conference on Wireless Sensor Networks (EWSN06).

E. Fasolo, M. Rossi, J. Widmer, M. Zorzi,(2007)" In-network aggregation techniques for wireless sensor networks: a survey", IEEE Wireless Communications 14 (2).

F.Bouabdallah,N.Bouabdallah, R.Boutaba.(2009)" On Balancing Energy Consumption in Wireless Sensor Networks", IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 58, NO. 6.

Ilyas M. and Mahgoub I.(2005), "Handbook of Sensor Networks: Compact Wireless and Wired Sensing Systems", in: Proceedings of the CRC Press, London, Washington, D.C.

M. Dong, K. Yung, and W. Kaiser(1997). Low Power Signal Processing Architectures for Network Microsensors. In *Proceedings 1997 International Symposium on Low Power Electronics and Design*, pages 173–177, Aug.

M. Medidi and Y. Zhou,(2007) "Extending lifetime with differential duty cycles in wireless sensor networks," in *In Proc. Globecom07*.

P. Casari, A. Marcucci, M. Nati, C. Petrioli, M. Zorzi,(2005) "A detailed simulation study of geographic random forwarding (GeRaF) in wireless sensor networks", Proc. of Military Communications Conference 2005 (MILCOM 2005), Vol. 1, Pp. 59-68, 17-20 Oct.

A. Cerpa, D.Estrin,(2004) ,ASCENT: "Adaptive Self-Configuring sensor Networks Topologies", IEEE TRANSACTIONS ON MOBILE COMPUTING, VOL. 3, NO. 3, JULY-SEPTEMBER.

X. Yang, N. Vaidya,(2004) "A Wakeup Scheme for Sensor Networks : Achieving Balance between Energy Saving and End-to-end Delay", Proc. of the IEEE Real-Time and Embedded Technology and Applications Symposium (RTAS 2004), pp. 19-26.

T. Armstrong, "Wake-up Based Power Management in Multi-hop Wireless Networks", available at http://www.eecg.toronto.edu/trevor/Wakeup/index.html.

Y. Xu, J. Heidemann, D. Estrin,(2001) "Geography-informed Energy Conservation for Ad Hoc", Proc. ACM MobiCom 2001, pp. 70 – 84. Rome,

A. Cerpa, D. Estrin,(2002) "Ascent: Adaptive Self-Configuring Sensor Network Topologies, Proc. IEEE INFOCOM.

B. Chen, K. Jamieson, H. Balakrishnan, R. Morris.(2002) "Span: An Energy-Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Wireless Networks", ACM Wireless Networks, Vol. 8, N. 5, Septembe.

V. Rajendran, K. Obracza, J. J. Garcia-Luna Aceves,(2003) "Energy-efficient, Collision-free Medium Access

Control for Wireless Sensor Networks", Proc. ACM SenSys 2003, Los Angeles (USA), November.

J. Polastre, J. Hill and D. Culler,(2004) "Versatile Low Power Media Access for Sensor Networks", Proc. of the Second ACM Conference on Embedded Networked Sensor Systems (SenSys), November 3-5.

W. Ye, J. Heidemann and D. Estrin,(2004), "Medium Access Control With Coordinated Adaptive Sleeping for Wireless Sensor Networks", IEEE/ACM Transactions on Networking, Volume: 12, Issue: 3, Pages: 493-506, June.

T. V. Dam and K. Langendoen,(2003) "An Adaptive Energy-Efficient MAC Protocol for Wireless Sensor Networks", The First ACM Conference on Embedded Networked Sensor Systems (Sensys'03), Los Angeles, CA, USA, November.

S.H.Yang, H.W.Tseng, E.H.K.Wu and G. H.Chen,(2005)" Utilization Based Duty Cycle Tuning MA Protocol for Wireless Sensor Networks", IEEE Communications Society subject matter experts for publication in the IEEE GLOBECOM.

L.Campelli, A. Capone, M.Cesana,(2007)" A Receiver Oriented MAC Protocol for Wireless Sensor Networks", Mobile Adhoc and Sensor Systems, Pisa. IEEE Internatonal Conference on 8-11 Oct.

Rhee I, Warrier A, Aia M, et al.(2008) Z-MAC: a Hybrid MAC for Wireless Sensor Networks[M]. Networking IEEE/ACM Transactions, 16(3):511 – 524.

Sungrae Cho, K. Kanuri, Jin-Woong Cho, Jang-Yeon Lee, and S.-D. June,(2005), "Dynamic Energy Efficient TDMA-based MAC Protocol for Wireless Sensor Networks", Autonomic and Autonomous Systems and International Conference on Networking and Services, 2005. ICAS-ICNS 2005. Joint International Conference on 23-28 OctPage(s):48 – 48.

A. El-Hoiydi and J. Decotignie. (2005), Low power downlink mac protocols for infrastructure wireless sensor networks. ACM Mobile Networks and Applications, 10(5):675–690.

R Muller and G. Alonso,(2006) "Efficient Sharing of Sensor Networks," in Mobile Adhoc and Sensor Systems (MASS), IEEE International Conference, Vancouver, Canada, pp. 109-118,.

R Muller and G. Alonso,(2006), "Shared queries in sensor networks for multiuser support," Department of Computer Science, ETH Zurich February.

M. Tang, J. Cao, and N. K. Chilamkurti,(2007), "TAMPA: Tabu Search-Based Multiple Queries Optimization for Wireless Sensor Networks," in IEEE Wireless Communications (WiCOM) Shanghai, RO.

H.-y' Yang, W.-C. Peng, and C.-H. Lo,(2007) "Optimizing Multiple InNetwork Aggregate Queries in Wireless Sensor Networks" in Advances in Databases: Concepts, Systems and Applications, 12th International Conference on Database Systems for Advanced Application (DASF AA '07) Bangkok, Thailand.