ENERGY EFFICIENCY IN WIRELESS SENSOR NETWORKS WITH MAC PROTOCOLS

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ABSTRACT - **Wireless Sensor Network consists of large number of heterogeneous sensor nodes for monitoring and recording the various conditions, such as temperature, sound, etc. from the environment. These sensor nodes have small batteries with limited power. Energy Conservation is the biggest challenges facing in WSNs. When the battery backup of a node is exhausted, the node goes into switch off mode and reduces the network life time. This paper provides the network life time by efficient usage of energy in Wireless Sensor Networks. This can be achieved by using SMAC and ZigBee protocols to reduce the power consumption in sensor nodes. These protocols reduce the energy consumption of nodes by using periodic sleep and listen methods. The parameters such as throughput and delay can be referred to analysis of performance.**

Keywords: Wireless Sensor Networks (WSN), Sensor-Media Access Control, Time division multiple access (TDMA), frequency division multiple access (FDMA) and code division multiple access (CDMA), carrier sense multiple access (CSMA) and energy- harvesting (EH)

I. INTRODUCTION

A sensor network is composed of a large number of sensor nodes that are densely deployed either inside the phenomenon or very close to it. The position of sensor nodes need not be engineered or predetermined. This allows random deployment in inaccessible terrains or disaster relief operations. On the other hand, this also means that sensor network protocols and algorithms must possess self-organizing capabilities. Another unique feature of sensor networks is the cooperative effort of sensor nodes. Sensor nodes are fitted with an onboard processor. Instead of sending the raw data to the nodes responsible for the fusion, they use their processing abilities to locally carry out simple computations and transmit only the required and partially processed data.

Some of the application areas are health, military, and home. In military, for example, the rapid deployment, self-organization, and fault tolerance characteristics of sensor networks make them a very promising sensing technique for military command, control, communications, computing, intelligence and targeting systems. In health, sensor nodes can also be deployed to monitor patients and assist disabled patients. Some other commercial applications include managing inventory, monitoring product quality, and monitoring disaster areas.

A. Sensor Networks

Sensor nodes are densely deployed.• Sensor nodes are prone to failures. The topology of a sensor network changes very frequently. Sensor nodes mainly use a broadcast communication paradigm, whereas most ad-hoc networks are based on point-to-point communications. Sensor nodes are limited in power, computational capacities and memory. Sensor nodes may not have global identification (ID) because of the large amount of overhead and large number of sensors. Many researchers are currently engaged in developing schemes that fulfill these requirements.

B. Overview of a Wireless Sensor Networks Communication Architecture

Wireless sensor networks consist of individual nodes that are able to interact with the environment by sensing or controlling physical parameters. These nodes have to collaborate to fulfill their tasks. The nodes are interlinked together and by using wireless links each node is able to communicate and collaborate with each other.

As shown in Figure 1, the wireless sensor network and the classical infrastructure comprises of the standard components like sensor nodes (used as source, sink/actuators), gateways, Internet, and satellite link, etc.

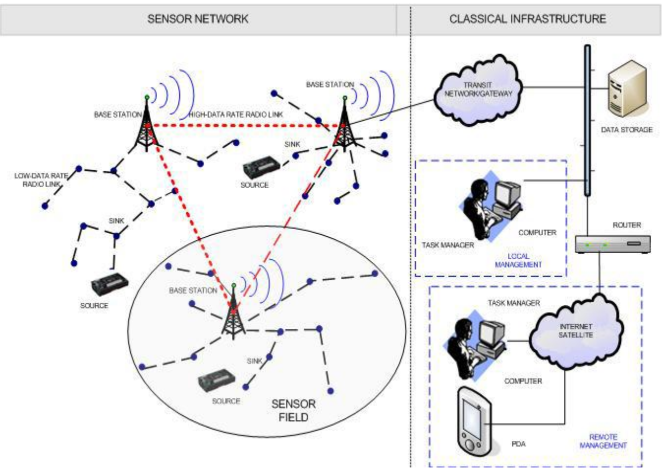

Figure 1 Illustration of sensor networks and backbone infrastructure

II. SENSOR NODES

Sensor nodes are the network components that will be sensing and delivering the data. Depending on the routing algorithms used, sensor nodes will initiate transmission according to measures and/or a query originated from the Task Manager. According to the system application requirements, nodes may do some computations. After computations, it can pass its data to its neighboring nodes or simply pass the data as it is to the Task Manager.

The sensor node can act as a source or sink/actuator in the sensor field. The definition of a source is to sense and deliver the desired information (see Figure I). Hence, a source reports the state of the environment. On the other hand, a sink/actuator is a node that is interested in some information a sensor in the network might be able to deliver.

A. Gateways

Gateways allow the scientists/system managers to interface Motes to personal computers (PCs), personal digital assistants (PDAs), Internet and existing networks and protocols. In a nutshell, gateways act as a proxy for the sensor network on the Internet. According to [1], Gateways can be classified as active, passive, and hybrid. Active gateway allows the sensor nodes to actively send its data to the gateway server. Passive gateway operates by sending a request to sensor nodes. Hybrid gateway combines capabilities of the active and passive gateways.

B. Task Managers

The Task Manager will connect to the gateways via some media like Internet or satellite link [2]. Task Managers comprise of data service and client data browsing and processing. These Task Managers can be visualized as the information retrieval and processing platform. All information (raw, filtered, processed) data coming from sensor nodes is stored in the task managers for analysis. Users can use any display interface (i.e. PDA, computers) to retrieve/analyze these information locally or remotely.

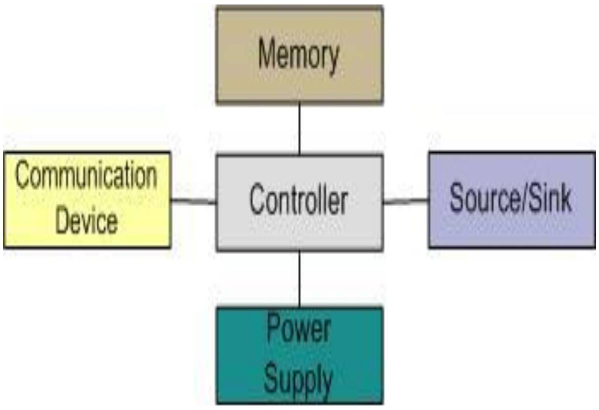

Figure 2 Overview of sensor node hardware components

The sensor field constitutes sensor nodes. Typically, a sensor node can perform tasks like computation of data, storage of data, communication of data and sensing/actuation of data. A basic sensor node typically comprises of five main components and they are namely controller, memory, sensors and actuators, communication device and power supply (see Figure 2). A controller is to process all the relevant data, capable of executing arbitrary code. Memory is used to store programs and intermediate data. Sensors and actuators are the actual interface to the physical world. These devices observe or control physical parameters of the environment. The communication device sends and receives information over a wireless channel. And finally, the power supply is necessary to provide energy.

For actual communication, both a transmitter and a receiver are required in a sensor node. The essential task is to convert a bit stream coming from a microcontroller (or a sequence of bytes or frames) and convert them to and from radio waves. As half duplex operation is recommended in wireless sensor network [3], a transceiver is generally used. In the transceiver, circuitry includes modulation, demodulation, amplifiers, filters, mixers.

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C. Protocols

MAC protocols control how sensor nodes access a shared radio channel to communicate with neighbors. Traditionally, this problem is known as the channel allocation or multiple access problems. Though MAC protocols have been extensively studied in traditional areas of wireless voice and data communications (e.g. Time division multiple access (TDMA), frequency division multiple access (FDMA) and code division multiple access (CDMA) [4], ALOHA [5] and carrier sense multiple access (CSMA) [6], sensor networks requirements of a MAC protocols differ from these traditional wireless voice or data networks in several ways. First of all, most nodes in sensor networks are likely to be battery powered and it is often very difficult to change batteries for all the nodes. Second, nodes are often deployed in an ad-hoc fashion rather with careful pre-planning. Hence after deployment, the sensor nodes must quickly organized them into a communication network. Third, many applications employ large numbers of nodes. Finally, most traffic in the network is triggered by sensing events, and it can be extremely bursty.

III. ENERGY RELATED ISSUES

MAC sub-layer protocols for WSNs must address the following energy-related issues

A. Collisions

The collisions occur when two nodes transmit at the same time. The packets can get corrupted and it may be require to be transmitted. So a lot of time and energy gets wasted during this transmission and reception. Collisions should be avoided because of the extra energy wasted in frame retransmission.

B. Control Packet Overhead

The other major problem is the Control Packet Overhead. These Control Packets do not contain any application data but are essential for the communication .The transmission and reception of the packets is overhead on the sensor network. Control messages and long headers in frames need to be avoided as much as possible, as they imply extra expensive communication costs.

C. Overhearing

The other problem is overhearing in which a sensor node may receive packets that are not intended for it .This node could have turned off its radio to save its energy. Overhearing is the energy consumed by being constantly listening and decoding frames that are not meant for them. This is a consequence of using a shared media in which nodes do not know a priori whether the transmissions are for them or not.

D. Idle listening

Idle listening refers to the energy expended by the nodes by having their circuits ON and ready to receive while there is no activity in the network. This is particularly important in WSNs, as nodes use the channel sporadically. Strategies to turn ON and OFF are very important in WSNs .The idle listening problem in wireless networks can be minimized by putting the radio into sleep mode.

E. Complexity

Complexity refers to the energy expended as a result of having to run computationally expensive algorithms and protocols. One of the most important design goals in WSNs is therefore simplicity. The other important characteristics of the Wireless Sensor Network are fairness, latency, throughput and bandwidth.

IV. ENERGY HARVESTING DEVICE

The design of Medium Access Control (MAC) protocols for wireless sensor networks (WSNs) has been conventionally tackled by assuming battery-powered devices and by adopting the network lifetime as the main performance criterion. While WSNs operated by energy-harvesting (EH) devices are not limited by network lifetime, they pose new design challenges due to the uncertain amount of energy that can be harvested from the environment. Increasing the life time of the battery itself by energy harvesting techniques .Common energy harvesting devices are solar cells, wind turbines and piezo-electric cells, which extract energy from the environment. Among these, solar energy harvesting through photo-voltaic effect seems to have emerged as a technology of choice for many sensor, now there is potentially an infinite amount of energy available to the node

The analysis and design of WSNs with EH devices by focusing on conventional MAC protocols, namely TDMA, framed-ALOHA (FA) and dynamic-FA (DFA), and by accounting for the performance trade-offs and design issues arising due to EH. A novel metric, referred to as delivery probability, is introduced to measure the capability of a MAC protocol to deliver the measurement of any sensor in the network to the intended destination (or fusion center, FC). The interplay between delivery efficiency and time efficiency (i.e., the data collection rate at the FC), is investigated analytically using Markov models. Numerical results validate the analysis and emphasize the critical importance of accounting for both delivery probability and time efficiency in the design of EH-WSNs.

Recent advances in low-power electronics and energy- harvesting (EH) technologies enable the design of self- sustained devices that collect part, or all, of the needed energy from the surrounding environment. Several systems can take advantage of EH, ranging from portable devices to wireless sensor networks (WSNs) [7]. However, EH devices open new design issues that are different from conventional battery-powered (BP) systems [8], where the main concern is the net- work lifetime [9]. In fact, EH potentially allows for perpetual operation of the network, but it might not guarantee short- term activities due to temporary energy shortages [8]. This calls for the development of energy management techniques tailored to the EH dynamics. While such techniques have been mostly studied at a single-device level [10], in wireless scenarios where multiple EH devices interact with each other, the design of EH-aware solutions needs to account for a system-level approach [11][12]. We focus on system-level considerations for networks operating with EH devices.

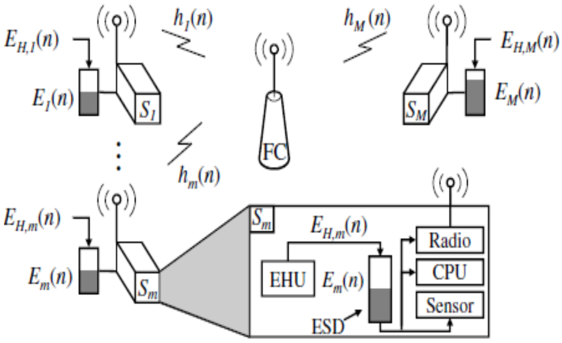

Figure 3 Energy Harvesting Unit

By addressing the analysis and design of medium access control (MAC) protocols for single-hop WSNs, where a fusion center (FC) collects data from sensors in its surrounding (see Figure. 3). Specifically, we investigate how performance and design of MAC protocols routinely used in WSNs, such as TDMA [13], framed-ALOHA (FA) and dynamic-FA (DFA) [14], are influenced by the discontinuous energy availability in EH devices.

V. PROPOSED SYSTEM

The issues involved in a node with an energy harvesting source can be quite different. The source of energy and the energy harvesting device may be such that the energy cannot be generated at all times (e.g., a solar cell). However, one may want to use the sensor nodes at such times also. Furthermore, the rate of generation of energy can be limited. The node should perform satisfactorily for a long time, i.e., at least energy starvation should not be the reason for the node to die. Energy Harvesting Device occupies more space when it comes to real time implementation. To overcome this problem we have taken SMAC and ZigBee protocols to efficiently use the energy. We are going to analysis the performance of SMAC and ZigBee protocols by using parameters such as throughput and delay.

A. SMAC protocol

Sensor-MAC (S-MAC), a new MAC protocol designed explicitly for wireless sensor networks. While reducing energy consumption is the primary goal in their design, their protocol also has good scalability and collision avoidance capability. It achieves good scalability and collision avoidance by utilizing a combined scheduling and contention scheme. To achieve the primary goal of energy efficiency, we need to identify what are the main sources that cause inefficient use of energy as well as what trade-offs we can make to reduce energy consumption.

S-MAC tries to reduce the waste of energy from all the above sources. In traditional wireless voice or data networks, each user desires equal opportunity and time to access the medium, *i.e.*, sending or receiving packets for their own applications. Per-hop MAC level fairness is thus an important issue. However, in sensor networks, all nodes cooperate for a single common task. Normally there is only one application. At certain time, a node may have dramatically more data to send than some other nodes. In this case fairness is not important as long as application-level performance is not degraded. In this protocol, re-introduce the concept of message passing to efficiently transmit a very long message. The basic idea is to divide the long message into small fragments and transmit them in a burst. The result is that a node has more data to send gets more time to access the medium. This is unfair from a per-hop, MAC level perspective, for those nodes that only have some short packets to send, since their short packets have to wait a long time for very long packets.

Latency can be important or unimportant depending on what application is running and the node state. During a period that there is no sensing event, there is normally very little data flowing in the network. Most of the time nodes are in idle state. Sub-second latency is not important, and we can trade it off for energy savings. S-MAC therefore lets nodes periodically sleep if otherwise they are in the idle listening mode. In the sleep mode, a node will turn off its radio. The design reduces the energy consumption due to idle listening. However, the latency is increased, since a sender must wait for the receiver to wake up before it can send out data.

An important feature of wireless sensor networks is the in-network data processing. It can greatly reduce energy consumption compared to transmitting all the *raw* data to the end node [15], [16], [17]. In network processing requires store-and-forward processing of messages. A message is a meaningful unit of data that a node can process (average or filter, *etc.*). It may be long and consists of many small fragments. In this case, MAC protocols that promote fragment-level fairness actually increase message-level latency for the application. In contrast, message passing reduces message-level latency by trading off the fragment-level fairness.

The scheme of periodic listen and sleep reduces energy consumption by avoiding idle listening. The use of synchronization to form virtual clusters of nodes on the same sleep schedule. These schedules coordinate nodes to minimize additional latency. The use of in-channel signaling to put each node to sleep when its neighbor is transmitting to another node. This method avoids the overhearing problem. Applying message passing to reduce application perceived latency and control overhead.

B. Periodic Listen and Sleep

SMAC protocol reduces the listen time by letting node go into periodic sleep mode. For example, if in each second a node sleeps for half second and listens for the other half; its duty cycle is reduced to50%. So we can achieve close to 50% energy savings.

Basic Scheme

The basic scheme is shown in Figure 4. Each node goes to sleep for some time, and then wakes up and listens to see if any other node wants to talk to it. During sleep, the node turns off its radio, and sets a timer to awake itself later. The duration of time for listening and sleeping can be selected according to different application scenarios. For simplicity these values are the same for all the nodes. Our scheme requires periodic synchronization among neighboring nodes to remedy their clock drift. We use two techniques to make it robust to synchronization errors. First, all timestamps that are exchanged are relative rather than absolute. Second, the listen period is significantly longer than clock error or drift.

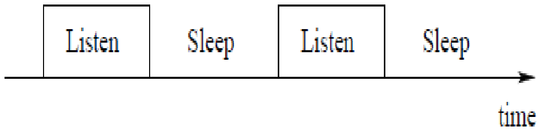

Figure 4 Periodic listen and sleep

For example, the listen duration of 0.5s is more than 105 times longer than typical clock drift rates. Compared with TDMA schemes with very short time slots, our scheme requires much looser synchronization among neighboring nodes. All nodes are free to choose their own listen/sleep schedules. However, to reduce control overhead, we prefer neighboring nodes to synchronize together. That is, they listen at the same time and go to sleep at the same time. It should be noticed that not all neighboring nodes can synchronize together in a multi-hop network.

Figure 5 Neighboring nodes A and B have different schedules. They synchronize with node C and D respectively

Two neighboring nodes A and B may have different schedules if they each in turn must synchronize with different nodes, C and D, respectively, as shown in Figure 5.Nodes exchange their schedules by broadcasting it to all its immediate neighbors. This ensures that all neighboring nodes can talk to each other even if they have different schedules. For example, in Figure 5 if node A wants to talk to node B, it just wait until B is listening. If multiple neighbors want to talk to a node, they need to contend for the medium when the node is listening. The contention mechanism is the same as that in IEEE802.11, *i.e.*, using RTS (Request to send) and CTS (Clear to send) packets. The node who first sends out the RTS packet wins the medium, and the receiver will reply with a CTS packet. After they start data transmission, they do not follow their sleep schedules until they finish transmission.

C. ZIGBEE

ZigBee is a new wireless technology guided by the IEEE 802.15.4 Personal Area Networks standard. It is primarily designed for the wide ranging automation applications and to replace the existing non-standard technologies. IEEE 802.15.4 is a new standard uniquely designed for low rate wireless personal area networks. It targets low data rate, low power consumption and low cost wireless networking, and its goal is to provide a physical-layer and MAC-layer standard for such networks.

The main feature of ZigBee is its limited power requirement. ZigBee is better for devices where the battery is rarely replaced, as it is designed to optimize slave power requirements, and battery life can be up to 2 years with normal batteries. ZigBee is also outstanding when facing timing critical, low power applications. The join time for a new slave is typically 30ms, and the time needed by a slave changing from sleeping to active, or accessing the channel is typically 15ms.

C.1 Components of the IEEE 802.15.4

IEEE 802.15.4 networks use three types of devices:

1. **The network Coordinator** maintains overall network knowledge. It is the most sophisticated one of the three types, and requires the most memory and computing power.

2. **The Full Function Device (FFD)** supports all IEEE 802.15.4 functions and features specified by the standard. It can function as a network coordinator. Additional memory and computing power make it ideal for network router functions or it could be used in network-edge devices (where the network touches the real world).

3. **The Reduced Function Device (RFD)** carries limited (as specified by the standard) functionality to lower cost and complexity. It is generally found in network-edge devices. The RFD can be used where extremely low power consumption is a necessity.

C.2 Network Topologies

IEEE 802.15.4 can manage two types of networks, i.e., star topology or the peer-to-peer topology. Both the topologies are illustrated in Figure 6. In ZigBee, these two topologies can be combined to build so-called mesh networks.

Star network formation

The first FFD that is activated may establish its own network and become a Personal Area Network (PAN) coordinator. Then both FFD and RFD devices can connect to the PAN coordinator. All networks within the radio sphere of influence must have a unique PAN identity. All nodes in a PAN must talk to the PAN Coordinator.

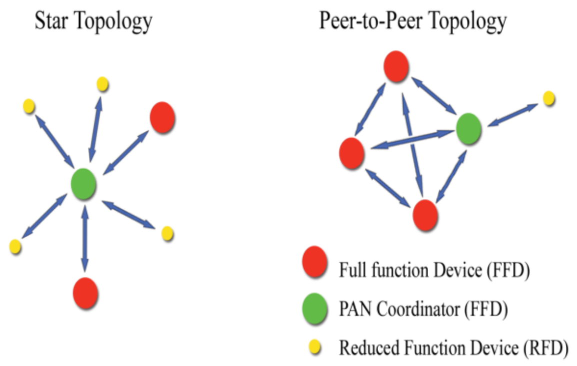

Figure 6 Network topologies of ZigBee

Peer-to-Peer Network formation

In the peer-to-peer topology there is also a PAN coordinator, but it differs from the star topology in that any device can communicate with any other device as long as they are in the range of one another. The peer-to-peer topology allows more complex network formations to be implemented, such as the mesh topology.

C.3. Operating Modes and Low Power Consumption

To enable different kinds of two-way data traffic ZigBee operates in two main modes: non-beacon mode and beacon mode.

Beacon Mode

The beacon mode is for battery-powered coordinators and so saves maximum energy, whereas the on-beacon mode serves mains-powered coordinators. In beacon-enabled networks, the coordinator periodically wakes up and sends beacons to the routers in its network. The beacons wake up other nodes to check whether there is any incoming message. If there is none, both the nodes and the coordinators go back to sleep. Beacon-oriented networks use guaranteed time slots – in other words, devices are active only when a beacon is being transmitted. The result is shorter duty cycles and longer battery lives.

Non-Beacon Mode

In non-beacon mode, some devices are always active and others sleep. The coordinator and routers' receivers do not sleep because any node can wake up and talk to it. Although the non-beacon mode requires a robust power supply (mains) and uses more energy, its overall power consumption is low because most of the network devices can remain inactive over long periods

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ZigBee's low power consumption is rooted not in RF power, but in a sleep mode specifically designed to accommodate battery powered devices. Any ZigBee-compliant radio can switch automatically to sleep mode when it's not transmitting, and remain asleep until it needs to communicate again. For radios connected to battery-powered devices, this results in extremely low duty cycles and very low average power consumption.

VI. PERFORMANCE ANALYSIS

By using NS2 simulator we have analysed the performance of SMAC and IEEE 802.15.4 Protocols. We had taken these two protocols because these are the low power energy consumption protocols. To analyse the performance of these protocols we had considered three parameters throughput, delay and energy consumption. Throughput is the maximum number of packets transferred per unit time and Delay in network specifies how long it takes for a bit of data to travel across the network from one node or endpoint to another.

Mac Protocols And Parameters						
	SMAC			**ZIGBEE**		
Nod-es	**Throughput**	**Delay**	**Energy consumed**	**Throughput**	**Delay**	**Energy consumed**
20	25628	2.050	31.43	14327	0.8839	30.675
30	24655	0.959	46.44	12099	0.6479	45.698
40	17311	1.054	61.44	8099	0.6601	59.897

Table 1 Performance Analysis

Table 1 shows the performance of SMAC and ZigBee protocol for 20 nodes, 30 nodes and 40 nodes. From this we analyzed ZigBee consumes low power energy and decreases throughput and delay. But SMAC transmits more number of packet i.e. throughput gets increases but delay also get increases.

VII. CONCLUSION

Energy Conservation is the biggest challenges facing in WSNs. This paper provides the network life time by efficient usage of energy in Wireless Sensor Networks (WSNs). Energy efficiency can be achieved by using SMAC and ZigBee protocols to reduce the power consumption in sensor nodes. Periodic listen and sleep methods are used in these protocols to reduce the energy consumption. We compared the performance of SMAC and ZigBee protocols by using parameters such as throughput and delay.

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