Energy Conservation using Energy Efficient Protocols in Wireless Networks

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***Abstract*—**Wireless networking has witnessed an explosion of interest from consumers in recent years for its applications in mobile and personal communications. Wireless networks are an integral component of the modern communication infrastructure and energy efficiency is an important design consideration due to the limited battery life of mobile terminals. Mostly power conservation techniques are commonly used in the hardware design of such systems. As the network interface is a significant consumer of power, a lot of research has been devoted to low-power design of the entire network protocol stack of wireless networks in an effort to enhance energy efficiency. In this paper a comprehensive summary of recent work addressing energy efficient and low-power design within all layers of the wireless network and also the guidelines for energy conservation is provided. A review of Protocol Stack and various protocols is further done. We also introduce a new energy efficient protocol, TEEN (Threshold sensitive Energy Efficient sensor Network protocol) for reactive networks.

***Keywords*—**Energy Efficiency; Networks; Routing Protocols Wireless.

***Abbreviations*—**Infrared Data Association (IrDA); Low-Energy Adaptive Clustering Hierarchy (LEACH); Power-Efficient GAthering in Sensor Information Systems (PEGASIS); Threshold sensitive Energy Efficient sensor Network protocol (TEEN); Wireless Application Protocol (WAP); Wireless Sensor Networks (WSN).

I. INTRODUCTION

WIRELESS networks have had significant impact on the world. Telecommunication wireless networks have made significant impacts as far back as World War II. As the mobility of these networks increase and these networks move into remote locations, there is an increase in energy efficiency of wireless protocols for battery operated devices. Energy densities of batteries have only doubled in every 5 to 10 years, depending on the particular chemistry of the battery. In the prolonged refinement of any given chemistry yields diminishing returns and for this reason, energy conservation in wireless protocols will continue to be a critical issue in the foreseeable future. Wireless networks that are commercially available today have protocols that included designs to increase power efficiency. Wi-Fi and Bluetooth are widely available in commercial products today. In today's world many of the newer energy efficient protocols take concepts utilized in these protocols and improve them or tweak them for networks designed for a slightly different purpose.

A category of wireless networks where energy efficient protocols are a major interest is wireless sensor networks (WSN). WSNs are a relatively new emerging research area with many applications in environmental monitoring and in precision agriculture, military, home automation and security, context-aware personal assistants, and medical monitoring. WSNs consist of many randomly scattered and possibly moving sensor nodes where these nodes are generally powered by non-rechargeable limited power batteries so efficient use of power is key to these networks. A secure head selection and secure data transfer is achieved in Ramachandran & Shanmugam (2013) using TESLA based certificates. The performance metrics of secured LEACH Packet delivery ratio, network throughput, and average network delay and energy consumption are measured and compared with Unsecured LEACH using NS-2 simulator.

Also some amount of energy is spent to transmit data packets from source to destination. The amount of energy the network spends for transmitting one data packet can be minimized by applying data compression techniques, because if the data packet will be heavier it will consume more energy. There are many energy efficient protocols in each layer that have been proposed to prevent the energy consumption in sensor nodes too. As the sensor nodes are densely deployed in a phenomenon to be monitored, sometimes multiple nodes may sense the same event and transmit the redundant readings. In this context, the non redundant data should be transmitted. So in such scenario an efficient scheme with efficient protocols should be chosen which can address the above issue. The class of Hierarchical routing protocol is providing maximum energy efficient routing protocols [Heinzelman et al., 2000; Bhuvaneswari & Vaidehi, 2009; Singh et al., 2010; Wang et al., 2011]. A new protocol called Equalized Cluster Head Election Routing Protocol, which pursues energy conservation through balanced clustering, is proposed in Nikolidakis (2013).

This paper is very well organized in sections as follows. In Section II, gives us the background information on wireless network architecture and power consumption sources and various energy conservation mechanisms that are effectively and efficiently used in wireless networks, section III briefly describes various protocol stacks. Section IV discusses sensor network protocols and an elaborate discussion is done on a newly introduced protocol called TEEN protocol. Section V provides the performance evaluation of new protocol. Finally, Section VI presents the conclusion of the work done.

II. BACKGROUND

This section describes the wireless network architecture. Also, a discussion of the Power consumption sources and conservation mechanisms is done.

2.1. Wireless Network Architecture

There are two different wireless network architectures are considered in this paper: infrastructure and ad hoc networks. Below, a description of each system architecture is presented. Infrastructure Wireless networks often extend wired networks, and are referred to as infrastructure networks. Large hierarchy of wide area and local area wired networks is used as the backbone network. Wired backbone connects to special switching nodes called base stations. The Base stations are often conventional PCs and workstations equipped with custom wireless adapter cards. They are responsible for coordinating access to one or more transmission channel(s) for mobiles located within the coverage cell. The Transmission channels may be individual frequencies in FDMA (Frequency Division Multiple Access), time slots in TDMA (Time Division Multiple Access), or orthogonal codes or hopping patterns in the case of CDMA (Code Division Multiple Access). Within infrastructure networks, wireless access to and from the wired host occurs in the last hop between base stations and mobile hosts that share the bandwidth of the wireless channel. Ad hoc networks are nothing but multi hop wireless networks in which a set of mobiles cooperatively maintain network connectivity. The on-demand network architecture is completely un-tethered from physical wires. The Ad hoc networks are characterized by dynamic, unpredictable, random, multi-hop topologies with typically no infrastructure support. The mobiles must periodically exchange topology information which is used for routing updates.

Ad hoc networks are helpful in situations in which temporary network connectivity is needed, and are mostly used for military environments, disaster relief, and so on.

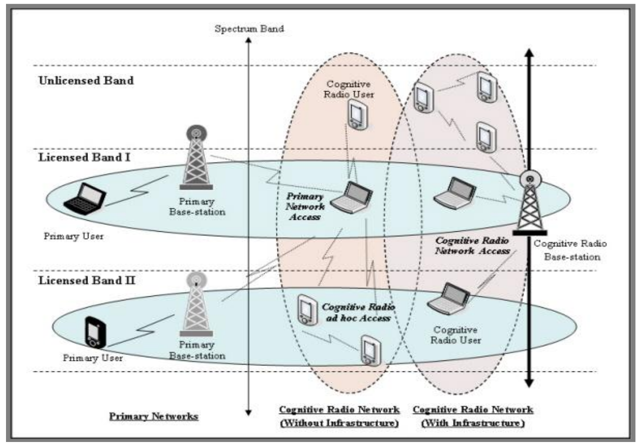

Figure 1: Wireless Network Architecture

2.2. Power Consumption Sources and Conservation Mechanisms

This section presents the chief sources of power consumption with respect to the protocol stack. After that it presents an overview of the main mechanisms and principles that may be used to develop energy efficient network protocols.

2.2.1. Sources of Power Consumption

The sources of power consumption can be classified into two types: communication related and computation related. The communication process involves usage of the transceiver at the source, intermediate (in the case of ad hoc networks) nodes and destination nodes. The transmitter is used for sending the control, route request and response, as well as data packets originating at or routed through the transmitting node. Receiver is used to receive data and control packets – some of which are destined for the receiving node and some of which are forwarded. The understanding of the power characteristics of the mobile radio used in wireless devices is important for the efficient design of communication protocols. A typical mobile radio may exist in three modes: transmit, receive, and standby mode. The maximum power is consumed in the transmit mode, and the least in the standby mode.

2.2.2. General Conservation Guidelines and Mechanisms

Collisions should be eliminated as much as possible within the MAC layer since they result in retransmissions. Retransmissions lead to unnecessary power consumption and to possibly unbounded delays. Retransmissions cannot be completely avoided in a wireless network due to the high error-rates. In the same way, it may not be possible to fully eliminate collisions in a wireless mobile network and this is partly due to user mobility and a constantly varying set of mobiles in a cell. In a typical broadcast environment, receiver remains on at all times which results in significant power consumption. Mobile radio receives all packets but forwards only the packets destined for the receiving mobile and this is the default mechanism used in the IEEE 802.11wireless protocol in which the receiver is expected to keep track of channel status through constant monitoring. One solution is to broadcast a schedule that contains data transmission starting times for each mobile as in Sivalingam et al., (2000). This enables the mobiles to switch to standby mode until the receive start time. Another solution is to turn off the transceiver whenever the node determines that it will not be receiving data for a period of time. The PAMAS protocol [Heinzelman et al., 2000] uses such a method. Furthermore, significant time and power is spent by the mobile radio in switching from transmit to receive modes, and vice versa. A protocol that allocates permission on a slot-by-slot basis suffers substantial overhead. Therefore, this turnaround is a crucial factor in the performance of a protocol. The mobile should be allocated contiguous slots for transmission or reception if possible to reduce turnaround, resulting in lower power consumption. This is similar to buffering writes to the hard disk in order to minimize seek latency and head movement. Also, it is beneficial for mobiles to request multiple transmission slots with a single reservation packet when requesting bandwidth in order to reduce the reservation overhead. This leads to improved bandwidth usage and energy efficiency. The scheduling algorithms studied in [Heinzelman et al., 2000] consider contiguous allocation and aggregate packet requests.

III. Protocol Stack

Application programs using the network do not interact directly with the network hardware. Instead, an application interacts with the protocol. The notion of protocol layering provides a conceptual basis for understanding how a complex set of protocols work together with the hardware to provide a powerful communication system but recently, communication protocol stacks such as the Infrared Data Association (IrDA) protocol stack for point-to-point wireless infrared communication and the Wireless Application Protocol (WAP) protocol stack have been developed specifically for wireless networks. Here we will have a brief discussion about these protocol stacks.

3.1. Infrared Data Association protocol stack (IrDA)

The Infrared Data Association (IrDA) was formed in 1993 to address some of these issues. The IrDA's stated mission is "to create an interoperable but low cost IR data interconnection standard that supports a walk-up, point to point user model for a wide range of appliances and devices." IrDA has created the Serial Infrared Data Link Standard, which supports data transfer rates up to 4.0 Mbps. Many industry segments can benefit from wireless communications. It is quite possible that in the future, you will be able to walk up to your local ATM machine obtain some cash (or reload your debit card) and balance your electronic checkbook using IrDA and you can use that new found money to pay off the auto mechanic who just performed some drive up point and shoot diagnostics on your car. On your way home, as the toll booths automatically debit your account when you car drives through them, one can stop by the local store and print out some of those pictures you've taken with your digital camera and all this could be done without plugging in a single cable.

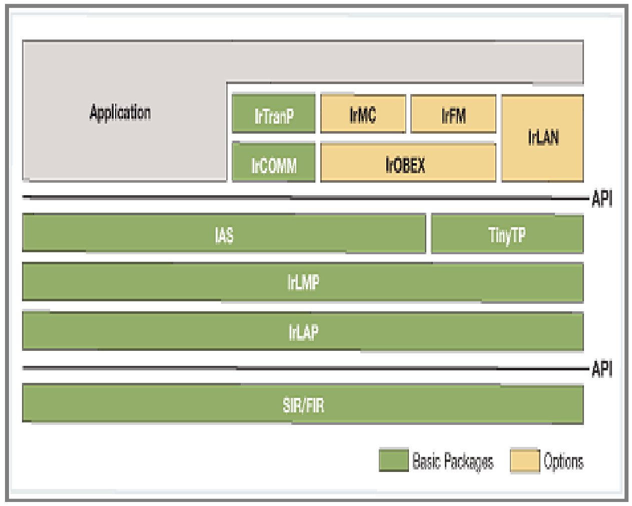

Figure 2: IrDA Protocol Stack Architecture

3.2. Wireless Application Protocol (WAP)

Wireless Application Protocol (WAP) is a technical standard for accessing information over a mobile wireless network. The WAP browser is a web browser for mobile devices such as mobile phones that uses the protocol. Prior to the introduction of WAP, the mobile service providers had limited opportunities to offer interactive data services such as Email, new headlines etc. WAP Protocol stack is layered in a way similar to OSI protocol stack, where each of the layers is accessible by the layers above and as well as other services and applications. In WAP there are four major layers:

- Session layer (WSP)
- Transaction layer (WTP)
- Security Layer (WTLS)
- Transport layer or datagram layer (WDP)

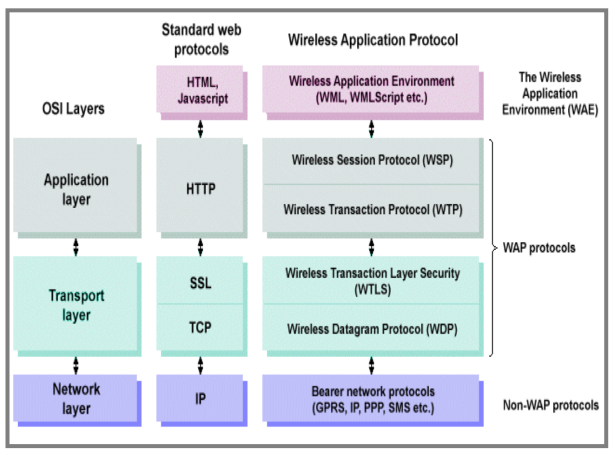

Figure 3: WAP Architecture

IV. Sensor Network Protocols

These are of two types Proactive Protocols and Reactive Protocols which we will discuss here.

4.1. Proactive Network Protocol

Here in this section, we discuss the functionality and the characteristics expected in a protocol for proactive networks.

Functioning

At each cluster change time, once the head clusters are selected, the cluster-head broadcasts the following parameters:

Report Time (TR): This is the time period between successive reports sent by a node.

Attributes (A): These are physical parameters in which user is interested in obtaining data about. At every report time, the cluster members sense the parameters specified in the attributes and send the data to the cluster-head. Head clusters aggregate this data and send it to the base station or the higher level cluster-head, as the case may be. This ensures that the user has a complete picture of the entire area covered by the network.

Important Features

The highlighting features of this scheme are mentioned below:

1. Since the nodes switch off their sensors and transmitters at all times except the report times, the energy of the network is conserved.
2. At every cluster change time, TR and *A* are transmitted afresh and so, can be changed. Thus, the user can decide what parameters to sense and how often to sense them by changing *A* and TR respectively. This scheme, however, has an important drawback. Because of the periodicity with which the data is sensed, the possibility is that time critical data may reach the user only after the report time. This scheme may not be very suitable for time-critical data sensing applications.

LEACH

LEACH (Low-Energy Adaptive Clustering Hierarchy) is a family of protocols developed in Nikolidakis (2013). LEACH is a good approximation of a proactive network protocol, with some minor differences. Once the clusters are formed, the clusters broadcast a TDMA schedule giving the order in which the cluster members can transmit their data. Time (Total) required to complete this schedule is called the frame time TF. Every node in the cluster has its own slot in the frame, and in each slot it transmits data to the cluster head. When the last node in the schedule has transmitted its data, the schedule repeats. As discussed earlier the *report time* is equivalent to the *frame time* in LEACH. The *frame time* is not broadcast by the head cluster, though it is derived from the TDMA schedule. However, it is not under user control. The attributes are predetermined and are not changed midway. ILEACH (Improved LEACH) along with couple of modifications is discussed in Kumar & Kaur (2011), the selection of CH (Cluster Head) is based on residual energy instead of probability used in LEACH. Secondly coordinates are used in the arrangement of clusters such that cluster head is accessible close to every sensor node.

Example Applications

This network can be used to monitor machinery for fault detection and diagnosis. It can also be used to collect data about temperature change patterns over a particular area.

4.2. Reactive Network Protocol: TEEN

In this section, we present a new network protocol called TEEN (Threshold sensitive Energy Efficient sensor Network protocol). This protocol is targeted at reactive networks and is the first protocol developed for reactive networks.

Functioning

In this scheme, at every cluster time change, in addition to the attributes, the head cluster broadcasts to its members.

*Hard Threshold (*HT*)*: This is a threshold value for the sensed attribute.The absolute value of the attribute beyond which the sensing node must switch on its transmitter and report to its cluster head.

Soft Threshold (ST): This is a small change in the value of the sensed attribute which triggers the node to switch on its transmitter and transmit. The nodes sense their environment continuously. First time a parameter from the attribute set reaches its hard threshold value; node switches on its transmitter and sends the sensed data. Sensed value is stored in an internal variable in the node, called the sensed value (SV). The nodes will next transmit data in the current cluster period, when both the following conditions are true:

1. The current value of the sensed attribute is greater than the hard threshold.
2. The current value of the sensed attribute differs from SV by an amount equal to or greater than the soft threshold.

Whenever a node transmits data, SV is set equal to the current value of the sensed attribute. Thus, the hard threshold tries to reduce the number of transmissions by allowing the nodes to transmit only when the sensed attribute is in the range of interest. Soft threshold further reduces the number of transmissions by eliminating the transmissions which might have otherwise occurred when there is little or no change in the sensed attribute once the hard threshold.

Important Features

The special features of this scheme are as follows:

1. Time critical data reaches the user almost instantaneously. This scheme is eminently suited for time critical data sensing applications.
2. Message transmission consumes much more energy than data sensing. Even though the nodes sense continuously, energy consumption in this scheme can potentially be much less than in the proactive network, because of the fact that data transmission is done less frequently.
3. The soft threshold can be varied, which depends on the criticality of the sensed attribute and the target application.
4. A smaller value of the soft threshold gives a more accurate picture of the network, which is done at the expense of increased energy consumption as a result of which the user can control the trade-off between energy efficiency and accuracy.
5. At every cluster change, attributes are broadcast afresh. So the user can change them as required.

The main drawback of this scheme is that, if the thresholds are not reached, then the nodes will never communicate, then the user will not get any data from the network at all and will not come to know even if all the nodes die. This scheme is not well suited for applications where the user needs to get data on a regular basis. Other problem with this scheme is that a practical implementation would have to ensure that there are no collisions in the cluster. TDMA scheduling of the nodes can be used to avoid this problem. However this will introduce a delay in the reporting of the time-critical data. The CDMA technology is another possible solution to this problem.

Example Applications

This protocol is well suited for time critical applications such as intrusion detection, explosion detection etc.

V. Performance Evaluation

Evaluation of the performance of our protocol is done by comparing it with other protocols such as LEACH and PEGASIS, LEACH is one of the fundamental and powerful routing protocols which are designed for hierarchical networks; but LEACH weak points led to the design of other protocols such as PEGASIS. However PEGASIS increases network life time and decreases overhead on CHs, but it needs to keep the information of neighbored nodes and it leads to network overhead. TEEN is a protocol which uses hierarchical and cluster structure ideas to optimize network parameters.

Table 1: Comparative Analysis of protocols such as LEACH, PEGASIS and TEEN

	LEACH	PEGASIS	TEEN
Working Mode	Hieratical	Hieratical	Hieratical
Use Specified path	Yes	Yes	Yes
Mobile Base Station	No	No	No
Network Lifetime	High	Very High	High
Negotiation	No	No	No
Use Meta-Data	No	No	No
Aggregation	Yes	No	Yes
Improve Routing	No	No	No
QoS	No	No	No
Power Consumption	High	High	High

VI. Conclusion

In this paper, we present a formal classification of sensor networks. We also introduce a new network protocol, TEEN for reactive networks. TEEN is well suited for time critical applications and is also quite efficient in terms of energy consumption and response time. This protocol also allows the user to control the energy consumption and accuracy to suit the application. In future work, TEEN can be tested on various simulators and further improved by taking into consideration metrics related to time constraints and quality of service.

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