Energy Efficiency Design Challenge in Sensor Networks

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Abstract: In this paper we describe the concept of sensor networks and its applications. A review of factors influencing the energy consumption and energy conserving methods is provided. Energy consumption can only be reduced significantly by switching the radio to a sleep state when it is idle. We observe that under light traffic conditions (as is usually the case in sensor networks), more sleeping time leads to more energy saving but at the moderate or heavy traffic condition there is a complex relationship between energy saving and sleeping time.

1 Introduction

Recent advances in micro-electro-mechanical systems (MEMS) technology, wireless communications and digital electronics have enabled the development of low-cost, low-power, multifunctional sensor nodes [1]. Sensor nodes are autonomous devices equipped with heavily integrated sensing, processing, and communication capabilities [2][3]. When these nodes are networked together in an ad-hoc fashion, they form a sensor network. The nodes gather data via their sensors, process it locally and forward the information to a data sink such as base station. Due to the node's limited transmission range, this forwarding mostly involves using multi-hop paths through other nodes [3]. A node in the network has essentially two different tasks: (1) sensing its environment and processing the information, and (2) forwarding traffic as an intermediate relay in the multi-hop path.

Applications of such sensor networks include environmental control in office buildings; robot control and guidance in automatic manufacturing environments; warehouse inventory; integrated patient monitoring, diagnostics, and drug administration in hospitals; interactive toys; the smart home providing security, identification, and personalization; wildlife observation; battlefield or disaster area monitoring and interactive museums.

2 Energy efficiency design challenge

Sensor nodes are likely to be battery powered, and it is often very difficult to change or recharge batteries for these nodes. In fact, someday we expect some nodes to be cheap enough that they are discarded rather than recharged. Prolonging network lifetime for these nodes is a critical issue. Reducing power consumption is clearly an important goal because battery life is not expected to increase significantly in the coming years. In terms of energy consumption, the wireless exchange of data between nodes strongly dominates other node functions such as sensing and processing [6][7].

There are some major sources of energy waste for such communication. The first one is collision. Usually data in sensor network is transferred by radio therefore two nodes may transfer data to each other at the same time or several nodes transfer data to the same node at the same time. When a transmitted packet is corrupted it has to be discarded, and the follow-on retransmissions increase energy consumption. Collision increases latency as well. The second source is overhearing, which occurs when a node picks up packets that are destined to other nodes. In an ad hoc fashion, a transmission from one node to another is potentially overheard by all the neighbours of the transmitting node thus all of these nodes consume power even though the packet transmission was not directed to them. The third source is control packet overhead. Sending and receiving control packets such as routing update and synchronization consumes energy and effectively reduces the network bandwidth for data packets. The last major source of inefficiency is idle listening, i.e., listening to receive possible traffic that is not sent. This is especially true in many sensor network applications since if nothing is sensed, nodes are in idle mode for most of the time. However nodes must listen to the channel to receive possible traffic. Many measurements [7][8] have shown that in such networks idle listening consumes 50–100% of the energy required for receiving.

3 Energy-conserving methods

Recently many researchers have done research work about energy conserving in sensor network.

The EC-MAC [10] (Energy Conserving-Medium Access Control) protocol reduces energy consumption by the use of a centralized scheduler. Therefore, collisions over the wireless channel are avoided and this reduces the number of retransmissions. The EC-MAC protocol is defined for an infrastructure network with a single base station serving nodes in its coverage area. This definition can be extended to an ad hoc fashion by allowing the nodes to elect a coordinator to perform the functions of the base station.

PAMAS [13] made an improvement in energy saving by trying to avoid the overhearing among neighbouring nodes. Power conservation is achieved by requiring nodes that are not able to receive and send packets to turn off the wireless interface. The idea is that all the neighbours of the transmitter need not overhear a data transmission between two nodes. The use of a separate control channel allows for nodes to determine when and for how long to power off. A node should power itself off when: (i) it has no packets to transmit and a neighbour begins transmitting a packet not destined for it, and (ii) it does have packets to transmit but at least one pair of nodes is communicating.

An Adaptive fidelity algorithm [12] is one where the quality (fidelity) of the answer can be traded against battery lifetime, network bandwidth, or number of active sensors. This algorithm turns off the radio to reduce energy consumption with the involvement of application-level information, and the additional use of node deployment density to adaptively adjust routing fidelity to extend network lifetime.

4 Sleeping effect for energy saving

In wireless sensor networks, energy consumption can only be reduced significantly by switching the node's radio to a sleep state when they are idle and letting them awaken precisely when they need to transmit or receive data. Unfortunately, current radio technology does not easily allow a radio to be awakened upon request. Hence, a node's radio must wake up periodically, see if anyone wants to talk to it, and, if not, go back to sleep. However by theoretical analysis we observe that under light traffic conditions (as is usually the case in sensor networks), more sleeping time leads to more energy saving but at the moderate or heavy traffic condition there is a complex relationship between energy saving and sleeping time.

In Figure 1, the normalized energy consumption $e = \frac{E}{E_{\max}}$ of two communicating nodes is plotted versus the amount of traffic A, where $E_{\max}$ is the maximum energy consumption; K is the length of the waiting queue of sending node; $T = \frac{T_l}{T_s + T_l}$, where T_s is the sleeping time and T_l is the listening time of receiving node, is determined by the sleeping schedule; and the energy consumption ratio of radio card is defined by the radio $\text{listen} : \text{receive} : \text{send} = 1:1:b$.

When traffic is light, increasing the sleeping time T_s, (i.e. smaller T), results in less energy consumption and more energy saving (compare curve T=0.1,K=5,b=1.5 and T=0.5,K=5,b=1.5 at point p1), as we would expect.

When traffic is moderate, increasing the sleeping time T_s, (i.e. smaller T), may increase the energy consumption and save less energy (compare curve T=0.1,K=5,b=1.5 and T=0.5,K=5,b=1.5 at point p2). Similarly behaviour occurs between the curves T=0.5,K=20,b=3 and T=1.0,K=20,b=3 at point p3 (T=1.0 represents the case when there is no sleeping and the receiving node keeps listening even when there is no occurring traffic). In both cases this is because connection trying is the major factor affecting the energy consumption. More sleeping time of receiving node means more connection trying is needed and the energy consumption for connection trying may exceed that of sleeping saving.

Perversely, when traffic is very heavy, increasing the sleeping time T_s, (i.e. smaller T), can result in less energy consumption (compare curve T=0.1,K=5,b=1.5 and T=0.5,K=5,b=1.5 at point p4) because packet loss is the major factor affecting the energy consumption and sleeping time in heavily loaded network results in significant packet loss (and less energy consumption than if the whole of the offered traffic was carried).

Therefore, when the traffic is light in sensor networks we can increase the proportion of the sleeping time of nodes' radio under the acceptable packet delivery quality such as packet loss ratio to save the energy. When there is moderate or heavy amount of traffic in sensor networks we should delicately design the sleeping schedule to get the acceptable QoS and meanwhile save the energy according to the complex relationship between sleeping time and energy consumption.

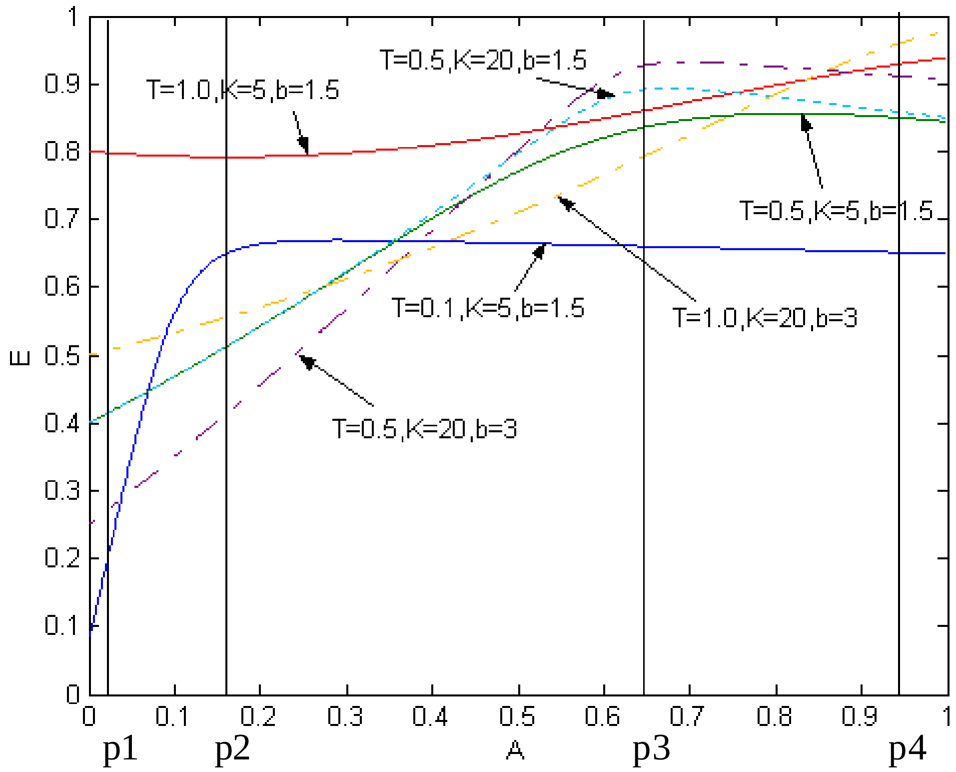

Figure 1: Power saving as a function of traffic for the energy-conserving method of turning off the radio

5 Conclusions

The flexibility, fault tolerance, high sensing fidelity, low-cost and rapid deployment characteristics of sensor networks create many new and exciting application areas of remote sensing. However energy conserving design is the key challenge for the realization of sensor networks because of battery power supply. Many research works have focused on this important issue. Energy consumption can only be reduced significantly by switching the radio to a sleep state when it is idle. We observe that under light traffic conditions (as is usually the case in sensor networks), more sleeping time leads to more energy saving but at the moderate or heavy traffic condition there is a complex relationship between energy saving and sleeping time.

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