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POWER CONTROL TECHNIQUES IN WIRELESS SENSOR NETWORKS

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ABSTRACT

The major issue in wireless sensor network (WSN) is the power control since it is impossible to recharge or replace the batteries of the sensors. The sensors transmit at high power to make it s transmission successful. Transmitting at high power not only reduces the lifetime of the nodes and that of the network, it also introduces excessive interference. Therefore, every node should transmit at minimal power while satisfying the quality of service (QoS) requirements. This paper gives introduction of a different power control techniques.

KEYWORDS: Wireless Sensor Networks, Power Control

INTRODUCTION

WSNs present a vast application field, for example, in the scientific, logistic, military and health field. According to MIT'S Technology Review, this technology is one of the ten new technologies which will change the world and our manner of living and work [1]. The battery is an important component of a sensor. Generally, it is neither replaceable nor rechargeable. With its small size, it provides an energy quantity which is very limited. So, it limits the lifetime of the sensor and influences the total operation of the network. This is the reason why, today, protocols ensuring low energy consumption occupy an important research orientation in this field. A sensor ensures acquisition, data processing and communications. The communications are the most energy consuming. Thus, a good diagram of energy management must, in priority, take into account communications. The majority of communication protocols in the Ad-Hoc networks do not satisfy the characteristics of the WSNs. This is the reason why there is a need for improving them or developing new power control techniques.

POWER CONTROL

The energy incurred in transmission can also be reduced by using different transmission power levels and/or coding/modulation mechanisms. This is termed as power control. Ideally, power control explores a continuous control space and is more theoretically attractive. However, in reality wireless devices are only capable of changing power levels and/or coding/modulation in a discrete fashion. It has been widely recognized that energy conservation trades. One example is that users experience a significant delay to bring up a laptop from the hibernation mode. Similar observations can be made in applying power management and power control techniques in wireless systems. Many research endeavors explore the energy-performance design space to devise better energy-conservation protocols subject to several performance constraints [2]. In particular, an intelligent energy conservation mechanism should leverage information from the various layers of the protocol stack. For example, QoS requirements of applications such as the delay bound can be used to guide power management/control decisions. Knowledge of communication patterns also helps to conserve energy without degrading performance.

POWER CONTROL TECHNIQUES

Clustering Protocols

LEACH (low energy adaptive clustering hierarchy) protocol and a centralized version of this protocol, called LEACH-C. These protocols are based on clustering (Figure 1). Clustering consists in the segmentation of the network into groups (clusters). Sensors transmit their data towards group representatives called cluster heads (CHs), which send these data to the base station (BS). In some applications, CHs make a simple data processing (data aggregations for example) on the received data before retransmitting them to the BS. This approach permits the bandwidth re-utilization. It also offers a better resource allocation and helps to improve the energy control in the network [1,6,7,8]. With the LEACH protocol, aggregations and compressions of data, and routing minimize energy consumption by reducing the data flow and thus the total communications. The sensors are homogeneous and have the same energy constraints. Clustering allows sensors to establish small communication distances with their CHs. The CHs communicate their calculation results to the BS.

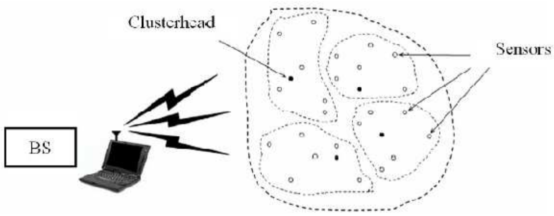

Figure 1: Clustering in WSNs

The system is based on a probabilistic demand models and fixes the optimal number of clusters according to some parameters such as the network topology, the communications and the computational cost. (Generally, CHs represent 5% of the sensors number in the network). With this method, sensors die randomly.

CHs receive the answers from simple sensors. They create TDMA (time division multiple access) tables according to the number of sensors in a cluster. Each sensor transmits its data to its cluster head using the time slots specified in the TDMA tables. Sensors turn off their antennas and wait for their speaking time. This method permits to minimize the energy dissipation. CHs leave their receivers on to receive all the sensors data. Then CHs compress received data and transmit them to the BS.

Each CH chooses randomly a code in a list of CDMA (code division multiple access) propagation codes; it transmits this list to its sensors in the cluster. The sensors will use this list for their transmissions. This method permits to minimize the communication interferences between closed CHs.

The LEACH Protocol Ensures that

- Clusters are self-configured independently of the BS (distributed algorithm.)
- Data are aggregated to reduce the amount of transmitted information to the BS.
- Energy consumption is shared between sensors and thus the network lifetime is increased.
- Using TDMA/CDMA techniques, a hierarchy built on a multilevel clustering can be built and used to increase the amount of saved energy

Robust Cooperative Routing Protocol (RRP)

Due to the broadcast nature of wireless medium, neigh-boring nodes of a transmitting node can overhear the packet, which is called *Wireless Broadcast Advantage (WBA)* [3]. This is illustrated in Figure 2. Inherently, it is also cooperative caching in the neighbourhood. As nearby nodes with a copy serve as caches, the next-hop node could retrieve the packet from any of them. Suppose node 1 attempts to deliver a packet to node 5 over path 1−3−5. When 1 transmits to node 3, nodes 2 and 6 may also correctly receive the packet. Cooperation among those nodes may result in high energy-efficiency and robustness when we carefully utilize diversity.

In our work, we assume the wireless sensor network is densely deployed, so each node has plenty of neighbours. In our proposed robust cooperative routing protocol (RRP), multiple nodes with a same packet attempt to deliver it to another node cooperatively. Assume all nodes have the same transmission range and a path has already been established between a source and a destination, which is referred to as the intended path. The nodes on the intended path are called intended nodes. A guard node is at least a neighbouring node of two intended nodes, i.e., a guard node can reach at least two intended nodes. Likewise, a link between a guard node and an intended node is called a guard link. As guard nodes are able to take advantage of WBA, they can work cooperatively to deliver packets along the intended path. The intended path, along with the guard nodes, collectively constitute the *robust path* (the wider path), which is used to enhance the robustness. Thus, using multiple guard links, the robustness of an intended link is enhanced at each hop. Revisit the example in Figure 3, if link 1−3 fails due to deep fading or the departure of node 3, then node 3 cannot receive the packet correctly. Without waiting for potential multiple retransmissions over the unreliable or disappeared link 1 – 3 before re-routing or dropping the packet, a substitute link 2−4 or 6 − 5 could transfer the packet proactively. As long as at least one link is capable of delivering the packet successfully, the packet can be received and further forwarded towards the destination. Actually, robust routing works like forwarding in a zone. Nodes in the zone collaboratively forward the packet to the next zone progressively towards the destination. Different from the traditional narrow path consisting of one node at each hop, the robust path contains multiple nodes at each hop, as shown in Figure 3.

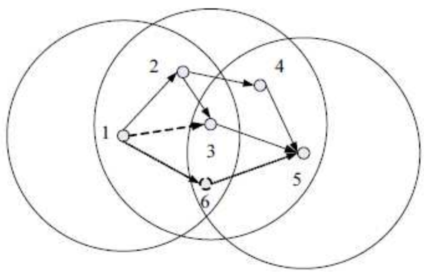

Figure 2: Relay Path with Equivalent or Remedy Nodes

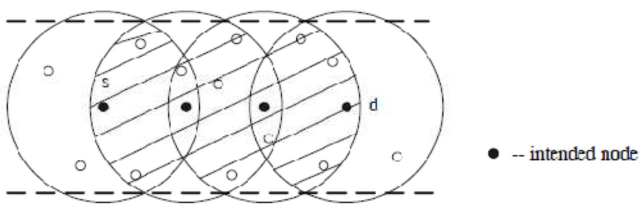

Figure 3: A Robust Path between s and d

To sum up, when an intended node fails to receive a packet from its intended upstream node, guard nodes successfully receiving the packet will help forward the packet proactively to the downstream node(s) without waiting for the routing instruction (re-routing via alternate path). The packet is delivered to the intended downstream node (the two-hop-away node on the path) if reachable, or to the node that lost the packet otherwise. Figure 2 best illustrates the idea. Through node 6, the number of transmissions needed from node 1 to node 5 reduces to 2 if node 6 transfers the packet successfully. Otherwise, the total number of transmissions needed from node 1 to 5 would be at least 4, if node 1 only retransmits to node 3 once and selects another path, say $1-6-5$, thereafter. The probability that all guard links and the intended link fails simultaneously is much smaller than the probability of a failed intended link. Therefore, guard links can improve the reliability and reduce the end-to-end delay at the cost of spending more energy in overhearing at guard nodes. On the other hand, energy savings via avoiding retransmissions over a hostile or lost link may potentially offset the energy consumption of overhearing. It is possible that cooperation among guard nodes lowers the energy consumption while achieving robustness. Finally, our approach is different from traditional relaying and alternative routing. Traditional relaying schemes forward the overheard packet to the intended receiver of the packet transmission while our RRP forwards packets to reachable downstream nodes closer to the destination. Traditional alternative routing has to wait for the time-out at the network layer (i.e., after multiple retransmission attempts at the MAC layer and declaring the link failure) and then find the alternative path to replace the failed path while our RRP could forward the packet at the MAC layer, hence reduces the transfer delay at the intermediate nodes on the path. Rather than purely relying on the network layer to implement cooperation, MAC and network layer cooperation can achieve better channel utilization, reduce delay and improve energy efficiency. Our RRP is different from multicast or any cast, because cooperation nodes have the knowledge about succeeding nodes. So the trace of a packet is restricted in the determined robust path, instead of propagating information network-wide.

Virtual Multi Input Multi Output (MIMO) Scheme

Multipath fading strongly impacts the communication and increases the possibility of signal cancellation which leads to higher packet loss and therefore resulting in more power consumption in wireless environments. MIMO technology has the potential to enhance channel capacity and reduce transmission energy consumption particularly in fading channels [4]. This is done by exploiting array gain, multiplexing gain and diversity gain. However, direct application of multi-antennas to sensor nodes is not viable due to the restricted physical dimension of a sensor node which typically can only prop up a single antenna. If individual nodes cooperate for transmission and/or reception, a cooperative MIMO system can be build such that energy-efficient MIMO schemes can be employed in WSN. Cooperation among sensor nodes termed as virtual MIMO (VMIMO) has the ability to reduce the total power consumed for data transmission in the sensor network.

- **Virtual MIMO System Model:** In virtual MIMO systems, transmit and receive diversity are achieved in a distributed manner by the sending and receiving groups. The VMIMO system model is shown in Figure 4. It consists of cooperative sender having multiple sending nodes and receiver having multiple receiving nodes, each with a single antenna. In the sending group, the signals from multiple sending nodes are encoded by space time technique and transmitted to the receiving group. At the receiver, space time decoding is used to separate the received signals and extract the original information.

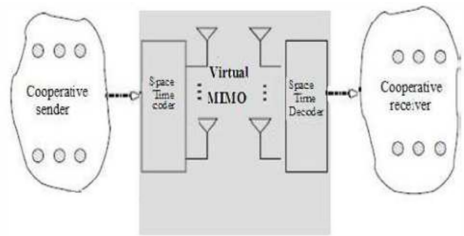

Figure 4: Virtual MIMO System Model

Medium Access Control (MAC) Protocols

There are three main techniques that can be employed in the MAC layer to decrease energy consumption. In the first technique, nodes coordinate transmissions and receptions among themselves. Since each node knows when to receive and send data, collisions are diminished, and it is possible to completely turn the radio off when it becomes idle. The second technique consists of turning off nodes which are not essential to the network operation, thus reducing the amount of packets transmitted. This task is commonly performed by topology control protocols, which periodically rotate the dormant nodes, while still maintaining a connected network and ensuring sensor and actuator coverage over the sensed area [5]. In the two techniques mentioned above, the amount of unnecessary traffic is reduced to the minimum, and the radio is active only when strictly necessary. Hence, the third strategy to reduce energy is to minimized the amount of energy required to send packets. Whenever a node has to transmit data, it does so at the lowest transmission power necessary to reach the destination, thus less energy is consumed. The reduction of the transmission power diminishes the likelihood of collisions on the network, increases the number of simultaneous transmissions and improves the capacity of the network. TPC (transmission power control) techniques have been widely utilized in CDMA cellular networks, and also researched and evaluated in mobile ad hoc networks (MANET). However, the use of TPC techniques still has been one of the issues less studied to reduce energy in MAC for WSNs.

There are four new techniques to TPC for MAC protocols in WSN. These techniques are evaluated by four MAC protocols, called Iterative, Attenuation, AEWMA and Hybrid, developed for the Mica2 commercial platform wireless sensor nodes. The Iterative and Hybrid protocols calculate the minimum transmission power by successive interactions between the sensor nodes. In these protocols, the quality of the communication is determined by iterating on the radio transmission power. The transmission power is increased or decreased by small steps at a time, until the minimum transmission power is found. The two others protocols, Attenuation and AEWMA (Attenuation with Exponentially Weighted Moving-Average), keep the reliability of the link by calculating the minimum transmission power based on the reception power, taking in to account the fade-out of the signal in the transmission media. In order to calculate the minimum transmission power based on the medium attenuation, simplified equations are used considering the resource limitations of the nodes. Due to their simplicity, those protocols can also be applied to more resourceful networks.

Power Control Algorithm

Two Power Control Algorithms[6]: One Multiplicative-Increase Additive-Decrease Power Control (MIAD PC) and one power control based on the estimation of the packet error rate (PER PC).

- **Power Control:** A simple adjustment rule for the transmit power can be based on the following mechanism: when an erroneous packet is detected, the power P_i is increased by $d\Delta$, where d is an integer and Δ the step size, whereas each correctly received packet imposes a decrease of the transmit power by Δ

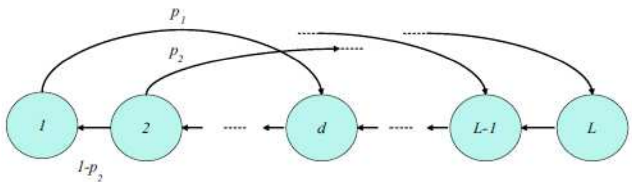

Figure 5: Markov Chain Model of the MIAD Power Control Algorithm

The parameters d and Δ obviously influence performance of the packet error rate process, and the power consumption. The dynamics of power transmission can be modelled through a discrete Markov chain, see Figure 5. Transmitted power is quantized into L values and each value is associated to a state of the chain. Detection and power control force jumps from one state to another. According to this scheme, there is a Δ-length jump forward (to the right in the figure) if a packet error occurs, and a single jump backward if a packet is correctly received. If *p* is the desired packet loss probability, then it should hold that Δ= *p*/(1- *p*).The transition probabilities from one state to another depend on the packet error probability, whereas the steady-state probabilities π_k, k = 1,….,L, can be easily computed through the equilibrium equations together with $\sum_{k=1}^{P} \pi_k = 1$. Here F_k denotes the packet error probability associated to level k of the transmit power. An analytical model of the transition probabilities enables the analysis of the packet loss process. This is for example useful in situations when an ARQ protocol is used for the retransmission of erroneously received packets. Indeed, the Markov model allows for an accurate characterization of the delay of packet delivery [14].

$$\begin{aligned}
&\pi_k = (1 - F_{k+1})\pi_{k+1}, \qquad 1 \le k < d \\
&\pi_k = F_{k-d}\pi_{k-d} + (1 - F_{k+1})\pi_{k+1}, \qquad d \le k \le L-1 \\
&\pi_P = \pi_{P-d} F_{P-d} \,,
\end{aligned}$$

The implementation of the MIAD PC requires knowledge of the packet error probability, once a power level is fixed. Such a probability can be estimated either using an analytical model of the SINR (signal to interference plus noise ratio), or simply observing the sequence of the packets erroneously received. The first solution is the most accurate, but requires an estimation of the channel statistics. This estimation may be difficult on computationally constrained sensor nodes, since some accurate signal processing is required to estimate the average and standard deviation of the transmitted and interfering signals. The second solution is simpler, as it requires just the computation of the number of erroneous packets. The disadvantage of this solution is that it takes some time to collect an accurate estimation of the loss process. Hence, the packet error probability could be over- or under-estimated, leading to an too high power consumption or to a too high packet error rate, respectively.

- **PER Power Control:** When a model of the wireless channel is available, the packet error probability can be analytically computed for each communication link. By setting a constraint on the probability, the transmit power can be derived. Let us denote the packet error probability of the node *i* by $F(P_i)$, indicating the dependence on the transmit power P_i. Under the assumption of bit-to-bit error independence, where *l* is the number of bits of a packet, and *Fb(Pi)* is the average bit error probability. Such a probability has to be computed according to the modulation scheme and the wireless propagation statistics. The Telos motes use the OQPSK (offset quadrature phase shift keying) modulation. In a AWGN wireless channel, it is easy to see that the bit error probability is given as follows:

$$F(P_i) = 1 - [1 - F_b(P_i)]^l \tag{1}$$

$$F_b(P_i) = \frac{1}{2}\mathrm{Q}(\sqrt{\overline{\gamma}(P_i)})\,, \tag{2}$$

Where $Q(x) = 1/\sqrt{2\pi}\int_x^\infty e^{-t^2/2}dt$ is the complementary standard Gaussian distribution. In a slow fading environment, which exhibits non-selective behaviour in frequency and time, the bit error rate can be expressed as

$$F_b(P_i) = \frac{1}{2}\left(1 - \sqrt{\frac{\overline{\gamma}(P_i)}{1+\overline{\gamma}(P_i)}}\right), \tag{3}$$

Where $\overline{\gamma}(P_i)$ is the average SINR.

SINR has a log normal distribution. Hence, its average is given by

$$\bar{\gamma}(P_i) = e^{\mu_\gamma + \sigma_\gamma^2/2}, \tag{4}$$

Where

$$\mu_\gamma = 2\ln M_i^{(1)}(P_i) - \frac{1}{2}\ln M_i^{(2)}(P_i) \tag{5}$$

$$\begin{aligned} \mu_\gamma &= 2\ln M_i^{(1)}(P_i) - \frac{1}{2}\ln M_i^{(2)}(P_i) \\ \sigma_\gamma^2 &= \ln M_i^{(2)}(P_i) - 2\ln M_i^{(1)}(P_i)\,. \end{aligned} \tag{6}$$

The terms $M_i^{(1)}$ *(Pi)* and $M_i^{(2)}$ *(Pi)* are statistical expectations of the first two moments of the SINR.

By setting a constraint on the packet error probability, say *p*, the corresponding average SINR γ_p can be derived by (1) and (2) for the AWGN environment, and from (1) and (3) for the Rayleigh case. At the receiver, the transmit power can be computed in the controller such that the average SINR is met. The algorithm is as follows: The average SINR for transmitter *i* is computed using (4)-(6), where the statistical expectations (5) and (6) are estimated using sample averages. Denote the period time of the power control by *T* and denote the number of samples of the RSSI collected during one period by *M*. We then have this value (or its quantization) is communicated to the transmitter.

$$\widetilde{M}_i^{(1)}(nT) = \frac{1}{M}\sum_{j=1}^{M}\widetilde{\gamma}_i(nT+j) \tag{7}$$

$$\widetilde{M}_i^{(2)}(nT) = \frac{1}{M}\sum_{j=1}^{M}\widetilde{\gamma}_i^2(nT+j) \tag{8}$$

$$P_i(nT+T) = \bar{\gamma}_p\frac{P_i(nT)}{\gamma(nT)}\,. \tag{9}$$

CONCLUSIONS

In this paper, we have presented power control techniques for wireless sensor networks. Wireless Sensor Networks (WSNs) are a specialized type of ad-hoc networks, where hundreds or thousands of low cost nodes are networked to monitor a given region. Energy consumption is one of the fundamental constraints that must be minimized in WSNs and communication is usually the most energy-intensive operation in such networks. Hence, the design of energy-aware protocols & algorithms is a challenging task. This paper has examined some important topics related to energy control techniques.

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