A Distributed Channel Selection Scheme for Multi-Channel Wireless Sensor Networks

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ABSTRACT

We consider the channel assignment problem in multi-channel wireless sensor networks for maximizing the network lifetime. We assume a data collection traffic pattern where all nodes forward data periodically to a sink and propose a distributed channel selection scheme that tries to maximize the lifetime of the nodes by controlling the energy consumption from overhearing. Some initial experimental results are included to show the effectiveness of the proposed scheme.

Categories and Subject Descriptors

C.2.2 [**Network Protocols**]: Routing protocols

Keywords

Wireless sensor networks, multi-channel routing, distributed algorithms

1. INTRODUCTION

Single channel sensor networks using contention based MAC protocols suffer from the overhearing problem where nodes waste energy by receiving packets intended for other nodes. One way to reduce this is to coordinate sleep cycles of neighboring nodes, which can be a complex problem for large-scale networks without a network-wide time synchronization mechanism. In this work we consider usage of multiple channels with dynamic channel selection to control the overhearing in the network. We consider *data collecting* wireless sensor networks where all nodes sense some paramemers and periodically forward them to the sink. We assume a multi-channel transmission model where nodes can choose their own channels for reception, which they monitor by default, and any node wishing to transmit to another node needs to temporarily switch to the channel of the receiver for transmission. This leads to a multi-channel tree rooted at the sink, where individual links can be on different channels as determined by the receive channel of the corresponding receiver (Figure 1(a)).

2. DESIGN OF OUR SCHEME

We define *receiver channel* as the channel on which a node receives packets. On the other hand *transmit channel* is the channel on which a node transmits, which is the receiver channel of its intended destination. Since nodes listen to their receiver channel by default, overhearing is limited to neighboring transmissions on a node's receiver channel only. In our scheme, nodes select their receiver channels to enable distribution of traffic over multiple orthogonal channels. While transmit channels are chosen dynamically to *prolong the lifetime of the neighboring node with the worst battery health*, by remaining on the same receiver channel, frequent switching is reduced. Note that channel selection is tied to parent selection, which leads to route determination. Hence the proposed approach leads to a joint channel selection and routing in the WSN.

With these objectives, we propose a channel selection scheme that runs in two stages. In the first stage all the nodes are on the default channel and runs the *Collection Tree Protocol (CTP)* [1]. In this stage nodes choose their channels collaboratively but do not switch. In the second stage, they switch to their respective receiver channels. We assume that all nodes broadcast periodic beacon messages, which include their hop-count, their receiver channel, and a parameter indicating their battery health. The battery health parameter is calculated based on the state-of-charge of its battery and usage, which is explained later.

First stage: Nodes that are immediate neighbors of the sink are termed as first level nodes (hop-count = 1). Neighbors of the first level nodes that have hop-count = 2 are second level nodes and so on. Each first level node chooses a random backoff, and selects the least used channel in its neighborhood when the backoff timer expires. This channel becomes its receiver channel. All the first level nodes then send their hop-count, health and chosen receiver channel in the beacon messages.

Then all second level nodes go on random backoff, and choose the least used channel in their neighborhood, when their timer expire. If there are more than one channel that are least used, the tie is broken as follows: for any channel c, each second level node calculates $\mathcal{H}_c = \min\{H_i\} \ \forall \ i \in S_c$ where S_c is the set of neighbors that are in receiver channel c and H_i is the health of node i. Then a node chooses the receiver-channel j such that $\mathcal{H}_j = \max\{\mathcal{H}_c\} \ \forall \ c$. All second level nodes then send their chosen channel, hop-count and health parameter through beacon messages. This process is repeated in successive levels. After a certain time interval τ, all nodes switch to their receiver channels and the second stage begins. In the first stage all nodes store their parents as well as the parent's receiver channel. Parents are the nodes whose beacons are received by the test node and whose hop-counts are less than that of test node.

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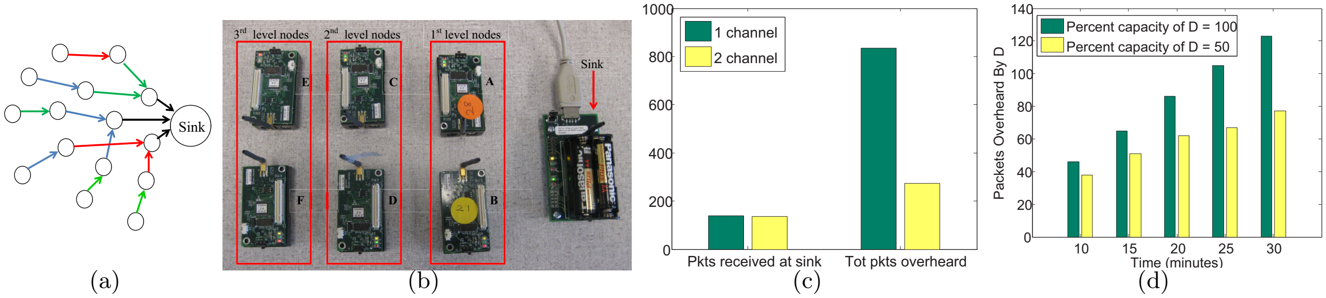

Figure 1: a) A multi-channel tree for WSN. (b) Experimental setup.(c) Comparison of packets received and total overhead with single channel and double channel. (d) Effectiveness of transmit channel selection.

Second stage: In the second stage the nodes remain in their receiver channel. In this stage nodes perform parent selection, and consequently, their transmit channel, dynamically. The first level nodes, while transmitting DATA packets switch to the channel of the sink (default channel). All nodes other than first level nodes, while transmitting the DATA packets, choose a channel c with a probability of $\frac{\mathcal{H}_c}{\mathcal{H}}$ where $\mathcal{H} = \sum \mathcal{H}_i$ $\forall$ channel i in the node's neighbor. This ensures that the receiver channel of the node with the worst health is chosen with the smallest probability. Thus overhearing is minimized for the neighboring node with worst battery health. Then it chooses the parent among all its parents on c with a probability proportional to their health. Beacons are generally transmitted alternatively in different channels, so that neighbors that are on different channel get the new health periodically.

In a real network, nodes may join the the network at any time. Thus when a node joins the network, it first stays in the default channel for τ time (first stage). If it does not receive any message from any neighbor within τ, it chooses a channel randomly and stays in that channel as its receiver channel and goes in the second stage.

Battery health calculation: Based on the experimentally validated model [2], we represent the estimated average current consumption in a node by

$$\begin{aligned}\mathcal{I} &= \frac{I_{Rt}T_{Rt}}{T_{rui}} + \frac{I_{Dt}T_{Dt}}{T_D} + O\left(I_{Rr}T_{Rr} + I_{Dr}T_{Dr}\right) \\ &+ F.I_{Dt}T_{Dt} + \frac{I_s T_s}{T_D} + 8I_P T_P \qquad (1)\end{aligned}$$

where I_x and T_x represent the current drawn and the duration, respectively, of the event x; and T_{RUI} and T_D represent the route update (beacon update) and data intervals, respectively. Transmission/reception of route uptate packets is denoted by R_t/R_r, data transmit/receive is denoted by D_t/D_r and processing and sensing are denoted as P and S, respectively. O and F are the overhearing and forwarding rate respectively. With this, the *health* of a mote can be calculated as $H \propto \frac{B}{\mathcal{I}}$ where B is the capacity of the battery.

We consider *MICAz* nodes, which operate in a voltage range of 2.7V to 3.3V. The actual battery voltage is related to the ADC reading as follows: $V_{bat} = \frac{1.223\times1024}{VoltageADC}$. Thus we assume that when battrey voltage is greater than or equal to 3V (VoltageADC = 417 from MicaZ voltage sensor), the capacity is 100% and when it goes lower than 2.6V (VoltageADC = 482) the capacity is 0%. Between these two levels it is assumed that the capacity varies linearly with the voltage, approximately. Thus we come up with an approximation expression for the capacity $B = \frac{482-VoltageADC}{0.65}$. Even if the battery decays are not linear, we assume this linearity for simplicity. The health of a node is calculated using equation(1) in a periodic interval.

3. EXPERIMENTAL RESULTS

We implement our proposed scheme in TinyOS using MicaZ motes, and use an experimental setup as shown in Figure 1(b). The beacon interval, DATA interval and τ are chosen to be 30, 36 and 180 seconds, respectively.

We perform several experiments. First, we compare the performance of our channel selection scheme using two channels with the single channel case. The results are shown in Figure 1(c), where we run the experiment for 15 minutes. From Figure 1(c) we observe that the total packets received by the sink is almost similar for both cases (implying that packet delivery performance is not affected by channel switching), whereas the overhearing effect is drastically reduced in case of two channels.

To show the effectiveness of choosing transmit channels dynamically, we made the battery capacity of all nodes to be 100 in one case; in the second case, we change the capacity of node D to be 50. The number of packets overheard in node D (Figure 1(d)) is much lower for the second case as the proposed channel selection scheme reduces the transmissions in D's receiver channel.

4. CONCLUSIONS

This paper proposes a channel selection scheme for wireless sensor networks. Through experimental study, we show the effectiveness of our proposed scheme. But the experimental setup is fairly small; thus our future work aims to implement our routing scheme with large number of nodes.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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