Leveraging Multiple Heterogeneous Radios for Energy-efficient Routing

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When wireless sensors were originally designed, energy constraints led the engineers to include in the architecture radio devices characterized by very low energy consumption for the idle state (*e.g.*, Zigbee radios). This choice was justified through the claim that these sensor nodes would spend only a small percentage of time transmitting. While devices using 802.11 radios may have a better energy per bit efficiency than these lower-power radios due to their higher bit rates, the larger idle costs make them less efficient in such, idle-dominated networks.

But that argument was based on devices using a single radio. The emergence of powerful sensor platforms capable of using multiple radios (e.g., Intel Stargate [1], LEAP - Low Power Energy Aware Processing [2],), calls for reevaluation of the tradeoffs involved in using high-power radios in energy-constrained sensor networks. Stathopoulous, *et al.* [3] focused on topology control mechanism in dual-radio networks event is a requirement. where data gets transmitted through the high-power radio after setting up the end-to-end path in an energy efficient way using the low-power radios. However, the possibility of energy savings during the actual data transmission was not explored as the data was considered delay sensitive. One the other hand our previous work [4] focused on environment where data is not delay sensitive. We showed how in a device equipped with both a low power and a high power radio, it is possible to define a break-even point (*i.e.*, the minimum data size that needs to be accumulated so that a high-power/high-rate radio can save energy in comparison to communicating via a low-power/low-rate radio) and presented a dual-radio communication protocol that manages the transitions of the high-power radio based on analytic models of the break-even point.

To strike the balance between the two conflicting objectives of minimizing delay and maximizing energy savings, we are working on a protocol where the goal is to save energy while keeping delay within some acceptable bound. Formally, let us assume that that for any data sent from node a to node b, the maximum acceptable delay is d and the length of the path is n hops using only the high-power radio for transmission. Our goal is to ensure that for any pair of consecutive nodes on this high-power radio path, the delay never exceeds d/n and then it will be sufficient to ensure that the overall delay does not exceed d. A trivial way to achieve this objective is to send data as soon as it arrives through the high-power radio. However, the energy cost of such an approach will be very high. On the other hand, waiting for the break-even amount of data to accumulate might cause delays in excess of the required bound. To ensure that the bound is met with a comparatively low energy cost, our protocol accumulates data until a point, called the *critical point*, is reached, where the anticipated delay of waiting for the break-even amount of data to accumulate and then send goes beyond d/n. To calculate the anticipated delay, each node monitors the amount of traffic that it is forwarding per unit of time, computing a *data generation rate* for itself. If the critical point is reached, data gets transmitted immediately using the low-power radio. Otherwise, the node waits for the break-even amount of data to accumulate before transmitting through the high-power radio.

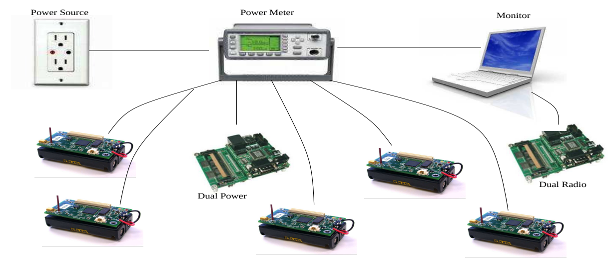

Figure 1: Demo architecture

We will demonstrate the effectiveness of our protocol on a network made of a number of sensor nodes equipped with a single, low-power Zigbee radio chip, and other devices with both 802.15.4 and 802.11 communication capabilities. One of the dual-radio devices will act as a Base Station, collecting all the data sent on both channels.

All the devices will be powered by the same power source, which will also be connected to a power meter, as in Figure 1.

A laptop will be equipped with a testbed managing software that allow users to select whether the network should use only the low-power/low-rate radios, or if our protocol should be active. Additionally they will be able to tune the data generation rate for each node, as well as several other parameters related to the protocol.

The power consumption of all the nodes is measured by the meter, connected to the laptop, where the effect of the users' choice of the various parameters will be shown in real-time. This monitoring system can be used on a variety of network protocols and is useful to perform tests regarding their energy efficiency on a real network deployment.

1. REFERENCES

[1] "Intel stargate," http://platformx.sourceforge.net/index.html.

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[3] T. Stathopoulos, M. Lukac, D. McIntire, J. Heidemann, D. Estrin, and W. J. Kaiser, "End-to-end routing for dual-radio sensor networks," in *INFOCOM*, 2007.

[4] C. Sengul, M. Bakht, A. Harris, T. Abdelzaher, and R. Kravets, "Improving energy conservation using bulk transmission over high-power radios in sensor networks," in *ICDCS*, June 2008.