Experimental Study of Load Balancing Routing for Improving Lifetime in Sensor Networks

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Abstract—**Organizing Wireless Sensor Networks (WSNs) using energy efficient routing tree enables the efficient utilization of the limited energy resources of the deployed sensor nodes. However, the problem of unbalanced energy consumption and the unbalanced workload exists, and it is tightly bound to the role and to the location of a particular node in the network. This paper presents a detailed performance study of a novel load-balancing routing algorithm using a real-world WSN platform. In this routing algorithm, the parent selection process depends on three factors; two potential factors: the residual power in the intermediate sensor node and the channel state; and the hop count as a third tier-break factor. In WSNs, the significant resource constraints of the sensor nodes combined with the irregularity of a many-to-one traffic pattern have encouraged the development of an energy efficient load-balancing wireless routing algorithm. Since the communications overheads are the major energy consumer during a sensor node's operation, the algorithm demonstrates minimal overheads in low power multi-hop communications.**

Keywords-wireless sensor networks; load balancing; multihop routing; performance measurements; experimental evaluation.

I. INTRODUCTION

Besides maximizing the lifetime of the sensor nodes, it is preferable to distribute the energy dissipated throughout WSN in order to minimize maintenance cost and maximize overall system performance. Any communication protocol incurs some overhead of setting up the communication. The usual topology of WSNs involves having many network nodes dispersed throughout a specific physical area. There is usually no planned topology or hierarchy in place and therefore, WSNs are considered to be ad hoc networks. An ad hoc WSN may operate in a standalone fashion, or it may be connected to other networks, such as the larger Internet through a base station [1]. Base stations are usually more complex than other simple sensor nodes and usually have an unlimited power supply. Regarding the limited power supply of wireless sensor nodes, spatial reuse of wireless bandwidth, and the nature of radio communication cost which is a function of the distance transmitted squared [2], it is ideal to send information in several smaller hops rather than one transmission over a long communication distance [3]. Sensor node is mainly constructed from four basic units with limited performance capabilities: embedded processor, memory, low power radio transceiver, and sensing unit. Among theses aforementioned units it has been documented that the transceiver unit is the major power consumer. One fact is that the energy cost to transmit one bit is typically around 500 to 1000 times greater than a single 32-bit computation [4].

The rest of the paper is organized as follows. In section II, the proposed routing algorithm and the construction of the routing tree are explained. Section III describes briefly the implementation platform. Experiment methodology and testing scenario are presented in Section IV. The obtained experimental results are illustrated in section V .Finally, Section VI concludes the paper.

II. LOAD BALANCING ROUTING

A. Algorithm Discription

In the parent selection process during the routing tree construction, the residual power in relay nodes and the link or channel quality between communicating nodes are the primary factors that shape the network topology; link or channel quality may be measured directly by most radios, whereas residual power may be measured and fed into the microcontroller of the sensor node. These quantities may be used to form a cost function for the selection of the most energy efficient route. Moreover, the presence of a time constraint requires the network to favor routes over a short path with minimum number of hops in order to minimize end-to-end delay.

B. Routng Tree Construction

In a wireless network of ten sensor nodes (nine "3x3" wireless sensor nodes and the base station), the construction of the routing tree is performed in three stages: Route setup; Data transmission; and Route maintenance stage.

1) *Route setup.* In route setup phase, primarily, the destination (the base station or node number ten) acts as a tree root and disseminates a route setup message into the network to build the routing tree and to measure the link quality between the communicating sensor nodes. By this message, the receiving nodes determine all routes with their costs (link quality and hop count) towards the base station (base station's tree level or depth=0). The sensor nodes (one-hop from the base station) that receive the setup message from the base station forward a route setup packet to the nearest neighbor (one-hop further) to keep them informed with the quality of their link to the base and their residual power accompanied with the other useful information (e.g., depth=1, node id). The adjacent sensor nodes (two-hops from the base station) that receive the-forwarded packets generate and transmit similar packets to

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advertise that they are two hops away from the base station. The next hop sensor nodes will repeat the previous steps and all information travels until reaches the leaf sensor nodes and all nodes know their depth and the tree is fully defined. The route setup is targeted from the base station to the end-leaf nodes, and its effectiveness is reliant upon link symmetry. In environments where asymmetric links are abundant, link quality estimation from reverse link quality information often does not work and handshakes between nodes are necessary.

2) *Data transmission.* In this stage, the source node starts to transmit data packets towards the base station through the predetermined the least-cost path which has been built in the route setup stage and chosen according to the parent selection parameters.

3) *Route maintenance.* Source nodes continue transmitting beacon packets every five seconds in order to sustain the routing tree and update the neighbor tables and keep useful information. To achieve reliable data packets delivery and parent selection process, each sensor node maintains a neighbor table indicating the nodes it can reach (one-hop neighbor). This table contains the links quality to such nodes, their residual power, their depth, and node id. The base station does not need to maintain an internal table. The rationale behind maintaining neighbor table is to keep track of possible routes to the base station and be able to order them on the basis of a joint metric favoring high-quality links, relays with good energy resources above predetermined threshold, and low number of hops. By keeping track of the minimum links quality and the lowest residual energy levels in the route, overloaded relays "bottlenecks" can be identified and avoided during network operations.

III. IMPLEMENTATION PLATFORM

The implementation was based on real world testbed of wireless sensors nodes, specifically the UC Berkeley's Mica2 motes which are popular due to their tiny architecture, open source development and commercially available from Crossbow® Technology [5] with TinyOS operating system [6]. Mica2 (MPR400CB) mote is a low-power sensor device whose low cost can be attributed to its lack of limited resources. Mica2 was built with an 8-bit, 7.3828MHz Atmel® ATmega 128L processor, 128 kilobytes (KB) of in-system program memory, 4KB of in-system data memory, and 512KB of external flash (serial) memory for measurements storage [7].

Mica2 mote uses a low powered radio "Chipcon SmartRF CC1000 transceiver" which is a single-chip very low power radio frequency transceiver. CC1000 has 23 different digitally programmable output radio power levels ranges from -20dBm to +5dBm and linear RSSI (received signal strength indicator) to measure the strength of the received signal. [8].

Since these limited resources seem unfit for computationally expensive or power-intensive operations, explicit energy saving techniques are necessary to extend battery lifetime as much as possible. Besides that, communication is much more expensive than computation on wireless sensor devices [4].

IV. EXPERIMENTAL EVALUATION

A. Experiment Methodology

In this sensor network experiment, source nodes transmit data packets at the nominal rate to any nodes that can hear it. Receiving nodes forward the data to the base station depending on the local information that have been maintained in the node's neighbor table, so the most energy efficient path is selected. The work in this paper considers the following assumptions: the testbed network is a homogeneous sensor network; all nodes are identical with the same resources and initially with the same residual power; the network topology is static unless occurring of obstacles or node failures; the base station is fixed and the communications pattern is many-to-one; single radio channel; Omni-directional whip antenna, and event-driven sensing mode.

In the early stage of this work, two performance metrics were chosen to analyze the performance of the proposed protocol on a network of nine Mica2 motes: *average dissipated energy* and *packet reception rate*.

- *Packet Reception Rate* is the ratio of the number of packets received to the number originally sent [9]. This metric also indicates the successful transmissions rate and its complement is packet loss rate.
- *Average Dissipated Energy* measures the ratio of total dissipated energy per node in the network to the number of distinct events received by the base station. This metric computes the average work done by a node in delivering data of interest to the base station. This metric also indicates the overall lifetime of sensor nodes.

B. Testing Senario

The testing environment was conducted indoor and was done on a network of nine (3x3) sensor nodes where the tenth node was used as a perimeter base station to collect messages sent within the network. To limit the transmission range, the motes were placed directly on the ground and to determine the distance which provides a reliable delivery rate but minimizes the possibility of a mote transmitting further than to adjacent motes; motes closer to the base station were placed at varied distances and the delivery rate recorded. Then, the distance that provided a packet delivery rate of about 90% was used which is calculated as the total number of packets received successfully divided by the total packets transmission epochs. In indoor environment, where space is more limited, the radio power was initially reduced to the minimum output power setting -20dBm (10µW), and variable in-between spaces to provide a one-hop reliable delivery rate and to minimize opportunistic reception. However, as shown in [10], it is still likely that some reliable long distance links will form. Chipcon CC1000 can select a minimum output power level using a variable power radio such that messages are transmitted successfully to their destination, possibly using less power than the default setting.

With variable separating spaces between each two adjacent nodes, only adjacent nodes are within the transmission range of each other to allow multihop communications. Also transmission distance has to be exceeded to make multi-hop more energy efficient than direct transmission [11]. The source nodes were transmitting packets periodically, while the network operates for four hours; the number of messages received by the base station was recorded. The nine Mica2 motes were labeled with numbers and placed in predetermined locations. The base station mote was placed on the MIB520 Mote Interface Board which powered by an AC power supply and attached to a laptop to collect the data of interest.

During node's operation, the residual energy can be measured and fed into its microcontroller, then to be used in the cost function for the selection of the most energy efficient route. Mica2 components, such as ATMega128L ADC, have an accurate voltage reference that can be used to measure battery voltage [12]. Since the eight-channel, ATMega128L ADC uses the battery voltage as a full scale reference, the ADC full scale voltage value changes as the battery voltage changes. Thus, the battery voltage can be computed and measured regularly from the ADC's channel 7 and then multiplied by the drained current and time consumed to obtain the energy value.

V. EXPERIMENTAL RESULTS

In this section, observations and results obtained from the experimental testing were presented and analyzed using Matlab® scripts. Although the network has been positioned in indoor environment with very limited ambient noise, multi-hop WSNs have several challenges which represent in: end-to-end reliable delivery of data requires each packet to traverse one or more intermediate hops on the route from the source node to the base station; the wireless network limits the number of data packets that can be in flight concurrently from source to destination due to unreliable wireless transmission at each hop and contention problems from hidden nodes and/or exposed nodes; and the physical-layer properties that may constrain the throughput achievable over a multihop path. This empirical research in the context of WSNs has given a good understanding of the complex and irregular behavior of low-power wireless links.

A. Link Stability

For the integrity of packet delivery, a CRC criterion is used to decide whether a packet was received correctly or not. Therefore, for the sensor nodes being tested, errors on the actual data will not occur. The only source of error is when a packet for some reason is lost. However, there are three different ways for a packet to be corrupted and thereby to be considered lost at the destination. Firstly, a packet may be lost due to errors in the wireless transmission which results in a bad CRC or not even received at all. The second possibility is that two sensor nodes send their packets at times so that the transmissions overlap in time due to the hidden node problem [13], resulting in two lost packets. Finally, a packet may be lost before it is ever sent. This is possible if a node senses a channel as busy a maximum number of times. In this situation, the node will simply discard the packet and move on to the next packet. As a result, predicting the source of the packet loss is complicated in terms of the hardware at hand and not considered crucial for the following results and discussion. The received signal strength indicator (RSSI) was measured indoor and the results were recorded. Although the indoor experiment was performed with stationary sensor nodes, the RSSI values have a tendency to fluctuate as shown in figure 1 where the values presented are average values from the packets that were received and do not imply a steady link with various packet sizes.

It was observed that within few meters closer to the base station the RSSI of small size packets were generally stronger than with the larger size packets with a small packet loss. For longer distances the larger size packets gave stronger RSSI. Mica2 (MPR400CB) radio has a receive sensitivity of -98dBm [7]. This extreme sensitivity can be interfered by another oscillator from adjacent Mica2 node. A distance of at least 65cm should be maintained between adjacent mica2 nodes to avoid local oscillator interference.

The radio on the Mica2 provides a measurement of the RSSI. This output is measured on ADC channel 0 and is available to the software. Some versions of TinyOS provide this measurement automatically, and others must be enabled by the user during the programming of the mote [13].

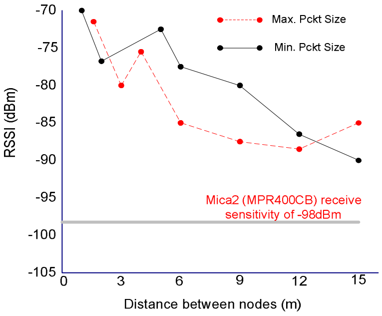

Figure 1. RSSI vs. Spacing Distance

B. Packet reception rate

Packet delivery performance in WSNs has some extent of uncertainty, at the physical layer; indoor environment has unconstructive effect on packet delivery performance, especially when a higher transmission power was used, conceivably due to the effect of Multipath Rayleigh Fading Channel (MRFC) [14]. Manchester coding has much more overhead and also has a negative effect on packet delivery performance in multi-hop settings. In addition, high signal strength is a necessary but not a sufficient condition for good packet reception ratio. Packet error cannot be distinguished if it was due to physical layer packet error or due to MAC layer collisions. At the MAC layer, about 50-75% of the energy spent in repairing lost transmissions and over 10% of links has over 50% asymmetry in packet delivery ratio due to surrounding environmental conditions, and mote and antenna orientation.

Figure 2 demonstrate how the packets transfer rate changes through 3-hops from the source node to the base station. The transmission rate at the source node has been programmed prior to the experiment. As the number of hops increases the transfer rate or reception rate decreases for constant transmission rate of 7Kbps as shown in table 1.

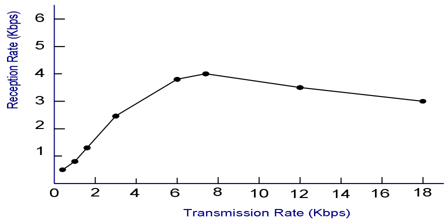

Figure 2. Transfer Rate in Multihop Communications

TABLE I. RECEPTION RATE VS. NUMBER OF HOPS

Number of Hops	Reception Rate (Kbps)
1 (Direct transmission)	6.34
2 (One intermediate node)	5.87
3 (Two intermediate nodes)	3.98

C. *Average dissipated energy*

The amount of power used for radio communication in wireless sensor nodes typically dominates that used in computation [15]. On the Mica2 (MPR400) mote, the Chipcon CC1000 radio chip draws a current of approximately 10.4mA while transmitting at default power (0dBm), about 26.7mA at maximum transmission power, up to 11mA when receiving, and 8mA in idle mode [14]. It is optimal to reduce the time the radio spends in active mode. Although the ability to use the sleep or idle modes mode depends on network and application behavior, one can assume that the device does not constantly communicate. While decreasing radio duty cycle is invaluable as an energy saving technique, reducing the cost of each transmission is equally important. There exists a lower bound on the amount of communication that a given sensor network deployment requires running a certain application. Further improvement is achieved only by minimizing the current used to power an active radio.

In the testbed network of nine nods (3x3 grid), it can be observed from figure 3 that the average power dissipated by the sensor nodes during their operation increases as the inter-nodes spacing increases.

VI. CONCLUSION

In this paper, a novel energy-efficient load-balancing routing algorithm has been presented and tested in its first design stage using a real-world WSN. This algorithm incorporate the residual energy of the relay nodes with the link state in the parent selection decision to distribute the load among the sensor nodes in order to prolong the entire network lifetime. A series of experiments were carried with different node spacing. Due to space limitations, a set of results is represented here. The results show that energy balancing scheme could benefit network lifetime extension.

Furthermore, it has been observed that the performance evaluation of the proposed algorithm achieved in the real-world environment is heavily affected by the number of hops that a packet needs to travel to reach the base station and also directly affected by the surrounding environment.

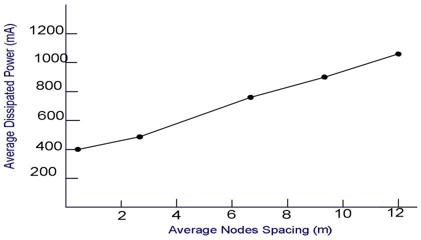

Figure 3. Average Dissipation Power Per Node vs. Nodes Spacing

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