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# Reliable Load-Balancing Routing Algorithm
# for Wireless Sensor Networks

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*Abstract*—**The most critical routing-related issue of wireless sensor network (WSNs) is the quality of the underlying links. While most routing protocols are formulated in a graph-theoretical manner, it is often by no means clear which sensor nodes are connected by a wireless link. Links fluctuate in reliability and can have relatively high packet error rates. Using flooding-based protocols over such links can result in rather convoluted routing tables where nodes are considered to be neighbors only because a flooding packet happened to go through despite actually poor link quality. To overcome these problems, the proposed routing scheme advocate a careful selection of actual parents for a routing tree toward the base station, using information that the link layer can provide. In addition, the determined routes evidently influence the lifetime of the network. Hence, the proposed routing scheme goes a step further in that it attempts to provide guarantee on the lifetime of the network. The initial experimental results, on Crossbow's Mica2 sensor nodes, show that the proposed routing scheme achieves an overall average of over 30% energy savings over the standard network layer provided by TinyOS, i.e., MintRoute and achieves greater than 60% connectivity to neighboring nodes and communication reliability. Particularly, it shows a higher success rate of packet delivery and moderate energy consumption.**

*Keywords-routing, reliability; lifetime maximization; experimental field deployment.*

## I. INTRODUCTION

Many testing approaches have been proposed for WSN multihop routing protocols deployments, but sensor field implementations, compared to computer simulations and fully controlled testbeds, tend to be lacking in the literature and not fully documented. Although WSNs are being studied on a global scale, the major current research is still focusing on simulations experiments. In particular for sensor networks, which have to deal with very stringent resource limitations and that are exposed to severe physical conditions, real experiments with real applications are essential. In addition, the effectiveness of simulation studies is severely limited in terms of the difficulty in modeling the complexities of the radio environment, power consumption on sensor devices, and the interactions between the physical, network and application layers.

The main disadvantages of the existing reliability-aware routing protocols based on link quality are that they are unaware of the energy status of nodes and do not explicitly pursue balanced energy usage in their routing schemes; thereby diverting load to sensor nodes with low energy capacity. As a result, this paper focuses on balanced energy dissipation scheme for lifetime maximization by taking the advantage from reliability-oriented routing schemes, i.e., MintRoute [17] and traditional energy-aware routing schemes, i.e., Energy-Aware Routing (EAR) protocol [20].

In other words, although the main objective of load balancing routing is the efficient utilization of network resources, the literature [1,4,19,22] lacks such protocols that take jointly link reliability and energy-wise metrics into account with load balancing. There is no doubt that a better distribution of load leads to the more efficient use of bandwidth, which means that there is less contention and consequently less energy is consumed, but it is not self-contained for achieving complete energy efficiency. WSNs are not necessarily energy-homogeneous, and there is thus insufficient information about the sensor nodes' load tasks to enable the energy-wise selection of the paths. The current load of a given sensor node can be used to estimate the future dissipation of energy but it does not contain a record of past activities and the residual energy level of the sensor node remains hidden.

The proposed routing scheme allows a child sensor node dynamically searches for a new reliable parent node with more residual energy. This dynamic adaptation strategy can alleviate the energy hole problem [10]. The experimental work done in this paper aims to improve the indoor performance evaluation of the proposed routing scheme by extending the experiments to outdoor, and simulations on larger networks in its future work.

The remainder of the paper is organized as follows. In section II, the related work is introduced. Section III presents the proposed routing scheme. Section IV describes briefly the implementation platform. Experiment methodology and testing setup are presented in Section V. The experimental results are illustrated in section VI. Finally, Section VII ends up the paper with the conclusion and future work.

## II. RELATED WORK

The majority of the existing reliability-oriented routing protocols for WSNs, e.g., MintRoute [17], MultihopLQI [18] and CTP [19], rely on either Channel State Information (CSI)

from broadcast control traffic or delivery cost estimates from unicast traffic using the ETX link metric [21]. The earlier common form of CSI, the Received Signal Strength Indicator (RSSI), used to be considered a predictor of link quality of some platforms such as Mica2 CC1000 radio [8]. The RSSI has early been recognized as a good predictor of link quality; specifically, it has been shown that the RSSI, if higher than the sensitivity threshold, about -87dBm, correlates very well with the packet reception rate [18,19,23].

As for link estimation by means of delivery cost estimates, the ETX link metric is proposed in [21]; the idea is to estimate the total number of transmissions needed to get a packet across a link, and use the route with the minimum ETX. ETX has been shown to be very robust, especially on top of an Automatic Repeat Request (ARQ) scheme [19] which strengthens low quality links. However, using ARQ scheme in the link layer, the child sensor node will retransmit the unacknowledged packet and degrade the network throughput. The traditional way of estimating the ETX relies on link symmetry assumption. While this may be reasonable in mobile ad hoc networks (MANETs) due to mobility, it is not accurate in typical WSN deployments where packets losses on the direct and reverse channel are not correlated albeit sensor nodes are static [19].

The observations in [2,3,4,17] states that it is vital to use link layer acknowledgments to evaluate the ETX metric. Reliability-oriented routing protocols, e.g., MintRoute [17], experience the asymmetric link problem inappropriately as child sensor nodes might not get their packets acknowledged from their current parents albeit maximum number of successive transmission failure is reached. The proposed load balancing scheme solves the asymmetric link problem by using active bidirectional monitoring of link status and switching to a new valid parent when exceeding a threshold of maximum successive transmission failures, and puts the old invalid parent into blacklist to avoid switch oscillation.

Since the data rate in WSNs is typically low, route messages do not need to be exchanged frequently and the rate of route message exchanges is very low as in MintRoute. In terms of energy dissipation cost, this helps MintRoute to reduce its energy consumption in low data rates. However, MintRoute is more expensive at high data rates. Also MintRoute takes a long time to convey the topological changes to the whole network (i.e., due to node failure or damage); during this period, many packets are routed through optimal paths, which consume additional energy and thus offsets the benefit of energy balancing in reliability-based routing schemes. Hence, the proposed distributed routing algorithm considers the acceleration of route message exchange rate for propagating the topological changes. Although MintRoute protocol balances the traffic load with occasional switches of nodes' parents which is a direct consequence of the MT metric, MintRoute protocol does not explicitly apply a metric that considers workload balancing. Hence, the proposed algorithm is proposed to address load balancing in energy efficient manner by maintaining a reliable set of valid parent nodes in the routing table to allow sensor nodes to quickly find a new parent upon parent loss due to the existing of node failure or routing hole.

III.    RELIABLE ROUTING SCHEME

In the proposed routing scheme, each node periodically broadcasts beacon packets to update route information. The sensor node with invalid parent must wait new beacons to re-discover a new route to the base station. During this waiting period, the sensor node may discard some packets due to its buffer overflow. When a loop is detected, a route beacon is not received from a parent sensor node within predetermined waiting period, or maximum successive transmission failures is detected, the intended sensor node will invalidate its link to its current parent and wait until a new route is discovered. The time delay is proportional to the length of the beacon period. To keep the sensor network responsive to link dynamics, a sensor node will immediately cancel its current parent that contains poor link quality or lower energy level and generates a beacon packet indicating higher route cost to notify other sensor nodes immediately and waits until a new alternative route is discovered. While the reactive approach is effective for responsive network, the multipath backup proactive routing table reduces the recovery delay time. Hence, the routing scheme is proposed to address load balancing in energy efficient manner by maintaining a reliable set of parent nodes in the routing table to allow sensor nodes to quickly find a new valid parent upon parent loss due to the existing of node failure or routing hole.

In a dense sensor network, a sensor node may have more neighbor nodes than the routing table size. Similar to MintRoute, the proposed routing scheme adopts a neighborhood management strategy based on memory efficient WMEWMA filter [17] as a link blacklisting solution to prevent the neighborhood routing table from growing beyond a given threshold size, thereby allowing a given sensor node to only keep track of a good subset of its neighbors with the lowest cost routes. The proposed routing scheme addresses the asymmetric link problem by monitoring link status. If its link loss ratio during a time window exceeds the threshold, the child sensor node switches to an alternative valid parent using the reactive approach, and puts the old parent into blacklist to avoid inappropriate parent selections.

The routing tree formation is performed in three phases: *Route searching*, *Data transmission*, and *Route maintenance phase*. The most critical phase is the route maintenance which is performed using adaptive periodic beacons to handle link dynamics and disconnection failures and all valid routes are reactively kept on-demand available before any data packet transmissions. Hence, the routing tree is sustained and the neighbor routing tables are kept updated to avoid relays with lower energy, and to avoid unreliable links. To achieve reliable data packets delivery and parent selection process, each sensor node maintains a neighbor routing table indicating one hop sensor nodes it can reach. This table contains the links quality to such sensor nodes, their residual energy, depth, id, and other local routing information. The rationale behind maintaining neighbor table is to proactively keep track of possible efficient 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 (reactively and proactively) of the channels with minimum link quality and the sensor

nodes with the lowest residual energy, overloaded relays "bottlenecks" can be promptly identified and avoided during network operations.

## IV. IMPLEMENTATION PLATFORM

Considerable advances have been made in recent years in hardware [5] and software [6] for building wireless sensor networks. 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 and communications are much more expensive than computation on wireless sensor devices, explicit energy saving techniques are necessary to extend battery lifetime as much as possible [4]. Furthermore, to ensure effective data gathering by sensor networks in indoor or outdoor environments, there are problems such as the ability of network sensor nodes to function correctly in such environments; and maximising the length of time the network is able to deliver data before nodes' batteries are exhausted.

## V. 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 preliminary stage of this sensor field work, the real wireless sensor network was evaluated considering different performance metrics. Particularly, the results show how the RSSI measurements in the considered scenarios. Then, the network behavior was characterized in terms of average dissipated energy, and packet delivery performance

### B. Testing Setup

The motes are programmed using nesC (network embedded systems C) language in the operating system TinyOS [6]. TinyOS was used as the development environment in this is work, which is an event-driven operating system intended for sensor networks with limited resources. The TinyOS development environment directly supports a variety of device programmers and permits programming each device with a unique address attribute without having to compile the source code each time.

The testing environment was conducted indoor and was done on a network of 20 Mica2 sensor nodes with one perimeter base station used 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 successful packet delivery rate was used which is calculated as the total number of packets received successfully divided by the total packets transmission epochs.

In indoor environment, where the radio behavior is irregular, 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 [17], 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.

The base station node sends out a message requesting a response from the source sensor nodes. The response nodes measure the message's RSSI. Each sensor node then sends a reply message after a delay that is a function of its node ID, ensuring no collisions among response messages. The data in the message contains all RSSI and link quality information, as well as information about the sensor node's transmit power, internal voltage, humidity, temperature, and light readings. These readings are taken from the sensors on board the motes.

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 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.

## VI. Experimental Results

In this section, observations and results obtained from the experimental testing were presented and analysed using Matlab® scripts. Although the network has been positioned in environment with 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 Dynamics

Figure-1 show RSSI as a function of distance and direction at the highest transmit power. The RSSI values are shown as measured at the base station node to the sensor nodes (forward channel). Although the experiment was performed with stationary sensor nodes, the RSSI values have a tendency to fluctuate as shown in figure-2 where the values presented are average values from the packets that were received and do not imply a steady link with various packet sizes.

The CC100 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].

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.
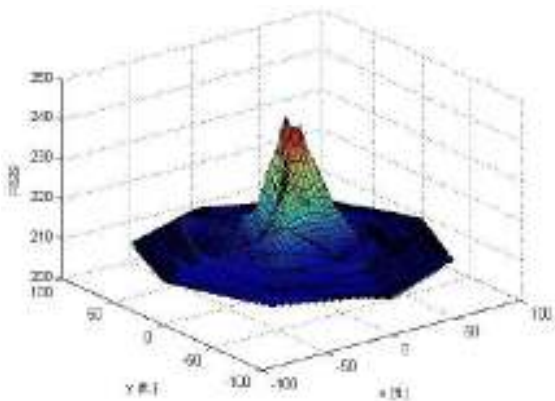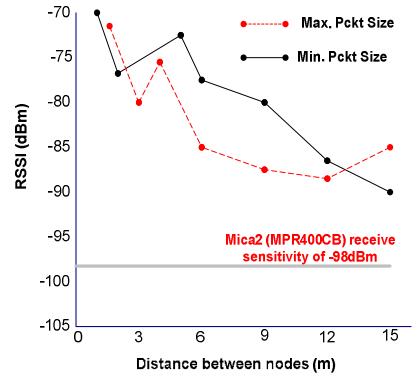


Figure 2.    RSSI Indoor Measurements

### B. End-to-End Delivery Rate

At the physical layer of WSNs; 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 due to surrounding environmental conditions, and mote and antenna orientation.

Figure-3 demonstrate how proposed routing scheme outperforms the reliability-based MintRoute routing algorithm the packets transfer rate changes through few hops from the source node to the base station. The transmission rate at the source node has been programmed prior to the experiment. Figure-4 shows that the transfer rate or reception rate decreases as the number of hops increases for constant transmission rate.
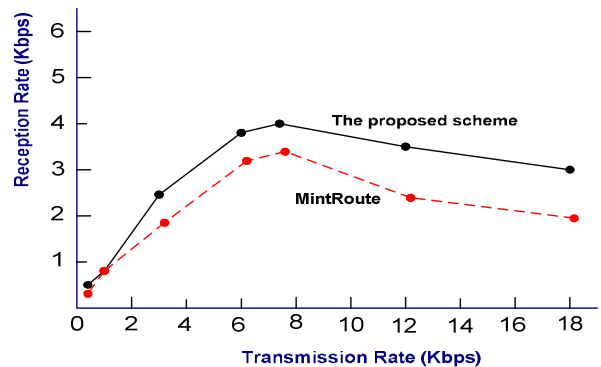


Figure 1.    RSSI vs. Distance and Orientation
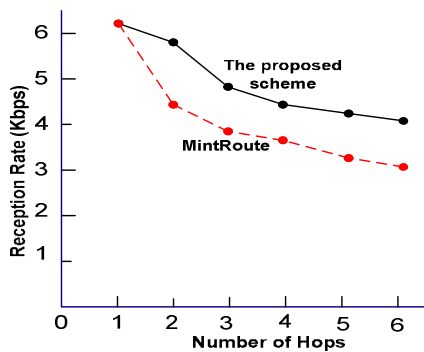


Figure 3.   End-to-End Delivery Rate

Figure 4.   Reception Rate vs. Hop Count

## C.  Average Dissipated Energy

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 [14,15]. 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. It can be observed from figure-5 that the average power dissipated by the sensor nodes during their operation increases as the inter-nodes spacing increases.
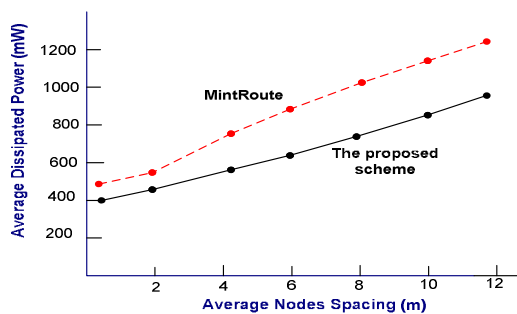


Figure 5.   Average Dissipated Power

## VII.   Conclusion and Future Work

It has been observed that the performance evaluation of the proposed routing scheme 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. The leveling out of RSSI beyond a certain distance suggests that it should not be used to indicate distance between sensor nodes beyond this threshold distance. In general, a close inspection of a sensor's radio pattern may be required before deploying a WSN.

Since testing of the range and radio pattern of wireless sensors is often not fully documented in the literature, this paper performed an experimental study on Mica2 motes developed by Crossbow. Radio packet yield in CC100 radio, the RSSI, is measured as a function of distance, orientation, and transmission power, while taking the environmental conditions, e.g., fading effects, into consideration. The preliminary experimental results show that RSSI do not degrade solely as a polynomial function of distance, and that transmitting and receiving node heights have a major impact on link performance. The main contribution of this paper is the design and test of a simple, reliable, and energy efficient routing scheme for sensor networks that successfully meets the goal of network longevity, and that demonstrates satisfactory robustness and network lifetime.

Maximising the network lifetime is the subject of the ongoing work on IEEE802.15.4 compliant sensor nodes, i.e., TelosB that built with the CC2420 radio and provides a much more reliable RSSI/LQI/bit error patterns. Also comparisons using scalable simulations are being addressed with existing stat-of-the-art collection tree-based routing protocols.

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