REP—Making Self-healing Wireless Networks Efficient

D. C. Rojas Quiros, D. Piguet, J.-D. Decotignie

Wireless Sensor Networks are a keystone of the Internet-of-Things. In order to recover from environmental disturbances and provide high reliability in multi-hop data collection applications, networks require adaptive routing (self-healing). However, the implementation of adaptive routing imposes a cost in terms of energy and traffic overhead and can result in packet losses while the network recovers. CSEM's answer to this challenge is REP, a method to significantly improve the speed and reduce the overhead required to implement self-healing. REP can also improve the performance of mobile networks, indoor localization and Radio Tomographic Imaging, among other fields of application.

Wireless sensor networks (WSNs) promise an Internet of Things with thousands of reliably connected low cost devices that can operate autonomously for years. However, real life deployments have shown that WSNs are subject to multiple perturbations (such as road traffic, weather, hardware malfunctions, etc.) that, if not handled correctly, can adversely impact their reliability and battery-life.

The state-of-the-art solution today is a protocol stack that combines a low-power listening medium access control (LPL-MAC) with a routing protocol. The LPL-MAC duty cycles the radio to prolong the battery-life, while the routing protocol autonomously repairs (self-heals) the topology. For example, Contiki OS (a dominant operating system for WSNs) has two default stacks that follow the previous scheme: RPL (a routing protocol proposed by the IETF) + ContikiMAC and Contiki-Collect (another routing protocol) + ContikiMAC.

Each self-healing procedure requires sending packet probes in order to estimate the quality of the neighboring links (Link Estimation, LE) and to evaluate alternative routes. This process presents a significant energy and traffic overhead. Moreover, a lengthy recovery impacts the reliability of the network, since the nodes might not have valid routes to convey the data until the healing is completed. These factors limit the application and effectiveness of network self-healing techniques by forcing protocol designers to reserve it only for disruptions deemed as critical.

At CSEM, we created REP, a novel mechanism that leverages LPL-MACs in order to significantly improve the utility of self-healing networks. REP does so by reducing the energy consumption and the traffic overhead associated with self-healing, making self-healing a more attractive solution for reducing packet losses in networks.

Operating principle

REP performs LE by exploiting a common resource in LPL-MACs: the packet repetitions used to wake up neighboring nodes during a transmission [1]. LPL-MACs achieve high-energy efficiency in the presence of low-traffic volume by keeping the radios in sleep mode, but require a transmitting node to send the same packet several times (i.e. the repetitions) in order to wake up the neighbors.

LE is a ubiquitous primitive in WSNs and typically requires broadcasting multiple beacons. Each beacon sent by the routing layer necessitates the transmission of multiple repetitions of the same packet in the LPL-MAC (Figure 1 - Top). With REP, it is possible to send a single broadcast packet, but to overhear several repetitions, enabling us to extract the required LE information (Figure 1 - Bottom).

Results

An evaluation of REP was performed in a real WSN deployment. The evaluation system consisted of 10 TelosB nodes with ContikiMAC and ContikiOS (v. 2.7) arranged in a star topology, where a single node (N2, center of the star) broadcasted beacons and 9 other nodes independently estimated the quality of the link (N1 in Figure 1) [2]. The results show that the use of REP consistently reduces the overhead to perform a LE by two orders of magnitude (from 80 beacons to 1 beacon), while keeping an equivalent accuracy.

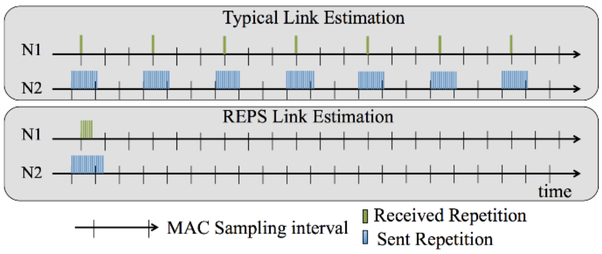

Figure 1: Typical LE schemes listen to 1 repetition per beacon, thus requiring multiple beacons in order to obtain several samples (top). REP overhears multiple repetitions enabling it to perform LE with a single beacon (bottom).

Application domains

Due to its ability to extend the battery-life, enable a more efficient use of the available bandwidth (less overhead) and reduce packet losses in the presence of channel perturbations, REP is convenient for large-scale deployments in general environments with hundreds of nodes, which may be difficult or expensive to access. Potential applications include environmental, industrial and infrastructure monitoring, as well as, home automation and body area networks.

The fast LE enabled by REP can also be exploited to improve the reliability of mobile networks by quickly adapting the topology to the displacement of the nodes. Moreover, REP increases the rate of information acquisition, which can improve the accuracy of radio tomographic imaging and indoor localization, among other applications.

[1] D. C. Rojas Quiros, D. Piguet, J.-D. Decotignie, "Poster: Single packet link estimation", EWSN Int. Conference on Embedded Wireless Systems and Networks (2016).

[2] D. C. Rojas Quiros, J.-D. Decotignie, "Poster abstract: Enabling a new resource for WSN radio tomographic imaging: LQI in transitional links", ACM SenSys Conference on Embedded Networked Sensor Systems (2016).