Ad Hoc Networks 48 (2016) 66–79

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

Low-power neighbor discovery for mobility-aware wireless sensor networks

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ARTICLE INFO

Article history:
Received 15 January 2016
Revised 18 May 2016
Accepted 24 May 2016
Available online 27 May 2016

Keywords:
Wireless sensor networks
Medium access control
Mobility
Neighbor discovery
Bursty traffic
Energy efficiency

ABSTRACT

While more and more deployments of Wireless Sensor Networks (WSNs) are successful, very few are actually mobility-aware. Due to their intermittent connectivity, mobile nodes induce certain instabilities, and thus, require to transmit multiple data packets in a short period of time. The nature of mobile nodes can lead to a link quality deterioration or even more to link disconnection. This instability requires frequent link establishments between a mobile and a neighboring static node before initiating data packet transmissions. To do so, the need for an efficient Medium Access Control (MAC) protocol is extremely important and challenging. In this paper, we present MobiDisc, an advanced mobile-supporting scheme for low-power MAC protocols, which allows for efficient neighbor(hood) discovery and low-delay communication. Moreover, we propose a FAN (First Ack Next-hop) mode that accelerates transmissions. Both MobiDisc and MobiDisc-FAN come with a Fast Recovery Mechanism (FRM) that enables seamless handovers in the network. Our thorough performance evaluation, conducted on top of Contiki OS, shows that MobiDisc outperforms a number of state-of-the-art solutions (including MoX-MAC and ME-ContikiMAC), by terms of reducing both delay and energy consumption, while the reliability is kept over 98%.

1. Introduction

Most of current Wireless Sensor Networks (WSNs) applications are oriented to stationary infrastructure, where nodes are deployed statically [1]. Recently, applications such as patient or animal monitoring emerged, with mobility and bulk transmission schemes very often appearing to be essential [2,3]. In such applications, sensor nodes are attached to persons, animals or objects, while under burst transmissions, nodes may transmit n packets in a row once they gain access to the wireless medium [4]. Even though the number of mobile applications keeps growing, most existing Medium Access Control (MAC) protocols focus mainly on static networks, where the topology is considered fixed while the next-hop of each node may change, depending on the physical layer conditions and the status of devices (e.g.,remaining battery, faults) [5,6].

In this paper, we focus on mobile-to-static communications that are subject to frequent link fluctuations and disconnections due to the movement of nodes. We investigate mobile-to-static link management in order to first set up wireless transmissions (i.e., link establishment) and then to allow for next-hop switching upon data offloading (i.e., handover).

We place our work in the context of low power mobile nodes whose prime objective is to dequeue their transmission buffers (in a bursty mode) as soon as any sink-connected neighbor shows up in their vicinity. We here consider that mobile nodes do not participate in the routing structure. Indeed, constructing and maintaining a coherent routing backbone with such dynamics may either endanger network connectivity or induce crippling communication costs. Consequently, as detailed throughout this paper, link establishment and handovers are performed jointly with the MAC layer mechanisms.

In addition, the MAC layer handles all operations related to the main source of energy consumption in WSNs, and in particular packet transmissions [7]. Many MAC protocols have been devised for coordinating access to the wireless medium shared by several nodes [8]. Some of them target mobility-aware WSNs, where mobile nodes aim at establishing communication links with selected

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http://dx.doi.org/10.1016/j.adhoc.2016.05.011
1570-8705/

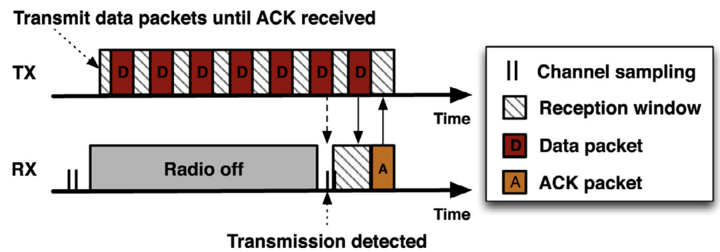

Fig. 1. A representative scheme from preamble-sampling family of MAC protocols. Under unicast transmission mode, nodes sample the medium periodically to detect a transmission. If a carrier is detected, the receiver keeps its radio *ON* to receive the associated data packet.

next-hop static nodes without increasing neither delay nor energy consumption due to potentially longer routing paths.

In this paper, we focus on Low-Power Listening (LPL) MAC protocols, mainly due to the topology dynamics induced by mobile nodes. We discuss to what extent current LPL methods fail to meet those requirements, thus, emphasizing neighbor discovery as a key primitive in mobility-aware WSNs. Consequently, we assume that static neighbors can provide valuable information (e.g.,battery power, number of hops to the sink) that would help surrounding mobile nodes select the best next-hop. We therefore introduce MobiDisc, a mobility-aware scheme that allows an enhanced neighbor(hood) discovery. While the default mode of MobiDisc leads to the discovery of the whole neighborhood, we also propose a FAN (First Ack Next-hop) mode that enables quick and efficient transmissions. Both approaches allow mobile nodes to perform efficient communications, in terms of energy, 1-hop and end-to-end delay. In order to fulfill the mobility-aware application requirements, we further introduce a Fast Recovering Mechanism (FRM) that can be activated in order to enable seamless handovers in the network.

The contributions presented in this paper are as follows:

- After a thorough study of the state-of-the-art MAC layer protocols for mobility-aware WSNs, we first present MobiDisc, an advanced scheme that allows mobile nodes to selectively choose the next hop node while reducing the end-to-end delay.
- We then introduce the FAN mode of MobiDisc that mitigates the tradeoff situation between 1-hop and end-to-end delay. We also implement and integrate a fast recovering mechanism (FRM) in MobiDisc for delay efficient handovers.
- We perform a thorough performance evaluation on top of COOJA (a simulator for Contiki OS). In addition, we compare MobiDisc (by considering default and FAN modes) against state-of-the-art solutions such as ME-ContikiMAC [2] and MoX-MAC [9].

The remainder of our paper is organized as follows. In Section 2 we review the most pertinent related works from the literature. We then detail our problem formulation in Section 3. In Section 4, we present a detailed description of MobiDisc, the FAN mode and the FRM mechanism. We implement our solutions on top of the Contiki OS (Section 5) and then demonstrate the performance of our solutions in Section 6, in terms of latency, energy consumption and reliability. Finally, Section 7 provides the concluding remarks and future perspectives for our work.

2. Background and related work

In the research community, different approaches for MAC layer protocols have been proposed, mainly categorized as scheduled, common active periods, preamble-sampling, hybrid [8] and mobility-aware [10].

Considering the topology dynamics induced by mobile nodes, our work studies the preamble-sampling family of MAC protocols [11]. Under these protocols, nodes sample the wireless medium at regular intervals to detect a transmission for incoming packets. In between, they turn their radio *OFF*, thus reducing energy consumption (i.e., duty cycling). Once transmitting a data packet, a node repeatedly sends the same packet (until a link layer acknowledgment is received), which aims at triggering a transmission detection at the receiver node, which should then forward the packet towards the sink station (see Fig. 1).

In mobility-aware WSNs, many existing solutions require mobile nodes to constantly evaluate link quality, based on the Received Signal Strength Indicator (RSSI) of acknowledgments received from its temporary next-hop (e.g.,MA-MAC [12], MX-MAC [3], MARI-MAC [13]). Hence, if the mobile node evaluates a too low quality of the link between its current next-hop and itself (i.e., persisting deterioration in the link quality), it initiates a neighborhood discovery process which may lead to a handover situation. These schemes are suitable for environments with few mobile nodes and their efficiency strongly depends on the network density. Moreover, to handle mobility by triggering handover procedures, distance thresholds are defined. Therefore, these protocols strongly correlate the RSSI level with the distance. In real-word scenarios using the received signal level as a mobility indication does not provide fair accuracy to evaluate proximity, as reported in [14].

In [15], authors consider that data packets originated from a mobile node are of higher priority compared to those of static ones. Their solution, named X-Machiavel, therefore allows any mobile node to steal the wireless medium from a static node that has gained it earlier. Potential steals are detected by overhearing mobile nodes, which prevents those nodes from low power operations, due to intensive sampling of the medium. In addition, static nodes can postpone their own data transmissions, which may induce some further issues in terms of message buffering, retransmissions and end-to-end delay in the static infrastructure.

In [9], authors present the MoX-MAC protocol. Under MoX-MAC, similarly to X-Machiavel, when a mobile node expects to transmit a data packet, it overhears the wireless medium to detect transmission between two static nodes. It waits until the end of the scheduled transmission, and afterwards, it transmits its own data packet to the transmitter static node (see Fig. 2). If no transmission is detected, then a mobile node acts as in a typical preamble-sampling procedure (i.e., X-MAC [16]: preamble sending, data sending upon ACK). The efficiency of this approach strongly depends on the communication frequency between the static nodes.

Under MOBINET [17], a mobile node, by overhearing the medium, builds a neighborhood table with destination addresses of the static nodes within its transmission range. Later, when it expects to transmit, it unicasts a data packet to one of the destination addresses listed in its neighborhood table. For the next-hop selection, MOBINET comes with two methods, the random and selective respectively.

In [18], authors introduce M-ContikiMAC which extends the statically oriented ContikiMAC [19] protocol to allow for mobile to static node communication. Mobile nodes transmit in anycast