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Mobility-aware timeout medium access control protocol for wireless sensor networks

Mahdi Zareei*, A.K.M. Muzahidul Islam, Asim Zeb, Sabariah Baharun, Shozo Komaki

Electronic Systems Engineering Department, Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia (UTM), Jalan Semarak, 54100 Kuala Lumpur, Malaysia

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A B S T R A C T

Wireless sensor networks (WSNs), has been under development for a while by the academia and industry. Due to limited computational power, a typical sensor node may experience operational challenges. Moreover, mobility has become an important feature since emergency and healthcare related applications are evolving in WSNs. Consideration of mobile nodes in WSNs introduce new challenges for the designers. In this paper, an enhanced version of T-MAC protocol (a well-known medium access control protocol in WSNs) known as MT-MAC is proposed. Using the capturing fluctuation in RSSI and LQI values of the received SYNC packets, MT-MAC solves high packet drop ratio in T-MAC. By detecting the mobility, a mobile node softly handover to a new virtual cluster without losing connection with other nodes. The performance of the proposed solution is then compared with T-MAC, S-MAC as well as other well-known mobility-aware MAC (MS-MAC) protocol. The simulation results show that the proposed protocol significantly increases the throughput and packet delivery ratio of T-MAC in exchange for a small increase in power consumption. Compared to MS-MAC protocol, the proposed approach can reduce power consumption by 20–65%, and achieve slightly higher packet delivery ratio.

1. Introduction

Wireless sensor networks (WSNs) became a popular kind of networking technology in recent years, with a wide variety of applications from environmental monitoring to disaster recovery. Due to the limited power source in sensor node, power consumption and its control is one of the most important aspects for a sensor node. As highlighted by Bachir et al. [1] the main source of the power consumption is the energy waste caused by idle listing, collision, overhearing and protocol overhead. However, among all, idle listening is the most significant source of energy dissipation. It happens when a node keeps its radio on while listening to the channel for potential data frames. Since the radio is controlled by MAC, controlling of the power consumption through improvement in MAC protocol can significantly increase the lifetime of the power sources in a WSN.

By moving toward emergency and healthcare related applications such as structural health monitoring [2], elderly assist healthcare [3], etc. mobility has become a new feature of WSNs. These emerging mobile sensors basically are mobile Ad-Hoc nodes, however with much more constraints related to resource management, coverage, routing protocols, security, etc. These new conditions require improved techniques and adopted scheme. Having critical applications, increasing the data rates and mobility of nodes in emerging wireless sensor networks, highlight the network reliability and its throughput as equally important factors as power consumption. Most of the existing MAC protocols neglect the importance of one of these factors, though an effective MAC protocol needs a careful trade-off in energy-efficiency, throughput, and robustness under mobility.

T-MAC is one of the well-known energy-efficient MAC protocols proposed in 2003 by Van Dam and Langendoen [4]. Previous studies [5,6] have shown that T-MAC performs well in predefined stationary networks. Even though the performance of T-MAC has been evaluated in various situations, however the performance of T-MAC is yet to be evaluated in a dynamic environment, where mobile nodes are present along with stationary nodes. Thus, this study is performed to investigate the performance of T-MAC protocol by considering node mobility. Furthermore, we propose an energy-efficient solution for handling the mobility problem in T-MAC protocol which is known as MT-MAC. The rest of this paper is organized as follows: Section 2 has a comprehensive discussion

* Corresponding author. Tel.: +60 3 2203 1283; fax: +60 3 2203 1266.
E-mail addresses: zarei.1982@gmail.com (M. Zareei), akmmislam@ic.utm.my (A.K.M.M. Islam), asimzeb1@gmail.com (A. Zeb), drsabariah@ic.utm.my (S. Baharun), komaki@ic.utm.my (S. Komaki).

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about the three popular MAC protocols, namely S-MAC, T-MAC and MS-MAC protocol as related works. Section 3, proposes an enhanced mobility-aware MAC scheme, based on T-MAC protocol. The simulation-based performance evaluation results and their discussion have been provided in Section 4 and finally a brief discussion of the proposed idea and findings of this paper has been concluded in Section 5.

2. Medium access control

By their nature, wireless sensor networks have to communicate. Therefore, node communication devices have to be carefully managed to allow efficient and effective communication. For wireless communication, each node needs to have a radio device to transfer data between adjacent network nodes. An important part of the data link layer is the MAC protocol. This protocol defines when a node is allowed to transmit packets and when it should receive packets. One of the major tasks of the MAC protocol is to avoid collision from interfering nodes. Thus a MAC protocol has tight control over energy efficiency, delay, mobility, and other metrics of the network [7].

There are four popular approaches in designing MAC protocols.

The first approach is common active/sleep period MAC, which arises from Carrier Sense Multiple Access (CSMA) protocols (also known as Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA)). This group of protocols usually provides wireless access to random multiple nodes without relying on central coordination. Protocols such as S-MAC [8] and MS-MAC [9] belong to this group.

The second approach is slotted TDMA based MAC protocols which offers an inherent collision-free scheme by assigning unique time frames ('slots') to each node for sending or receiving data. Protocols such as LMAC [10] and MCMAC [11] belong to this group.

The third approach is preamble sampling MAC protocols. In contrast with schedule-based MAC protocols, sensor nodes in the preamble sampling technique are usually unaware of the active/sleep schedule of their neighbors, as each of them are independent. Machiavel [12] represents this group.

The last group is hybrid MAC protocols which combine the concepts of the common active/sleep period MAC with slotted TDMA-based MAC protocols in order to get the best of each. MH-MAC [13] is one of the well-known hybrid protocols.

The present paper focuses on common active/sleep period MAC protocols since the common active/sleep period scheme does not use channel division (i.e. time frames). Therefore, they can be more flexible when the topology of a network changes [14].

2.1. Sensor MAC (S-MAC)

Sensor MAC (S-MAC [8]) is an energy-efficient MAC protocol that is specifically designed for stationary sensor networks. S-MAC is a contention-based protocol, which is basically obtained from IEEE 802.11 technology. The lifetime of the power source in S-MAC equipped sensor nodes can be extended by having periodic and cyclic listen and sleep modes. This technique significantly reduces the total idle-listening time that consequently reduces the power consumption.

In order to reduce controlling overhead, S-MAC has opted the clustering concept. This protocol logically divides nodes into different virtual clusters (VCs). Nodes inside each VC share same listen–sleep schedule. The nodes that are adjacent to other VC, which are known as border nodes, have to follow the schedules of neighboring VCs. In doing so, the border nodes can provide a seamless communication between neighboring VCs. In S-MAC, each border node suffers from extra energy consumption, due to excessive listening time.

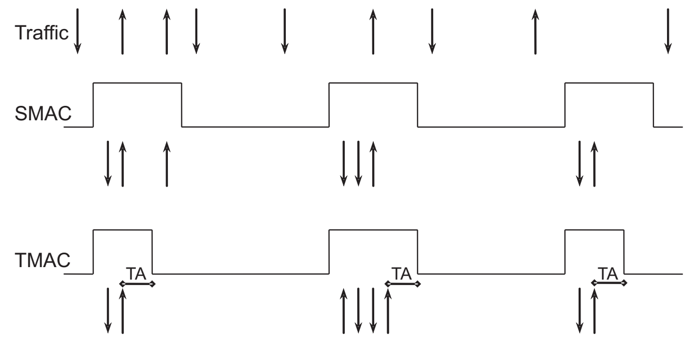

Fig. 1. T-MAC flexible duty cycle compare to S-MAC [4].

2.2. Timeout MAC (T-MAC)

An enhanced version of S-MAC has been suggested by Van Dam and Langendoen in [4] known as timeout MAC (T-MAC). As illustrated in Fig. 1, this new enhancement employs dynamic active time under variable load that reduces the idle period by transmitting messages in burst. It also adjusts the sleeping mode for each node since there is no activation event for a predefined time.

T-MAC utilizes a dynamic and adaptive schedule (duty cycle) according to changes in traffic load. Similar to S-MAC, T-MAC divides network into different virtual clusters (VCs) to reduce the control overhead and it does not consider the mobility of nodes in its mechanism.

2.3. Mobility-aware sensor MAC (MS-MAC)

MS-MAC [9], an enhanced form of S-MAC, attempts to solve mobility issues, where stationary nodes are given more time to sleep compared to mobile nodes. In a static network, both MS-MAC and S-MAC have the same performance, where in case of mobility, nodes go directly into synchronization and neighbor discovery.

Every node in the network stores the signal strength of the SYNC messages of its neighbors. To detect the mobility of the proximity, a node uses the variation in the received signal of the SYNC messages from each neighbors. Whenever the signal level of the SYNC message goes down to a certain threshold, neighboring sensor nodes consider the movement in the neighborhood. From the variation of the SYNC message, a node sometimes detects its own mobility. However, when a node detects a neighbor movement, it determines the speed of the movement from the change of the receiving signal. When multiple mobile nodes exist in the neighborhood, the SYNC packet contains the maximum speed.

3. Mobility-aware timeout MAC (MT-MAC)

In this section, we explain the MT-MAC algorithm. The proposed scheme is based on T-MAC protocol and uses the 'make before break' idea to handover mobile node from one VC to another. In T-MAC protocol, a mobile node which leaves its VC and enters into a new VC has to wait for a long time (approximately 5 min) to obtain new VC's schedule, resulting in high packet drop ration and low throughput. The algorithm is divided into two phases: Scheduling phase and mobility handling phase.

The proposed scheme initiates the scheduling process similar to T-MAC, however, improves it further as follows: nodes wake up randomly and start to listen to the medium for a random time to receive a SYNC packet from other nodes in order to get schedule and synchronize themselves with neighbors. If a node wakes up

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