A Multifrequency MAC Specially Designed for Wireless Sensor Network Applications

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Multifrequency media access control has been well understood in general wireless ad hoc networks, while in wireless sensor networks, researchers still focus on single frequency solutions. In wireless sensor networks, each device is typically equipped with a single radio transceiver and applications adopt much smaller packet sizes compared to those in general wireless ad hoc networks. Hence, the multifrequency MAC protocols proposed for general wireless ad hoc networks are not suitable for wireless sensor network applications, which we further demonstrate through our simulation experiments. In this article, we propose MMSN, which takes advantage of multifrequency availability while, at the same time, takes into consideration the restrictions of wireless sensor networks. Through extensive experiments, MMSN exhibits the prominent ability to utilize parallel transmissions among neighboring nodes. When multiple physical frequencies are available, it also achieves increased energy efficiency, demonstrating the ability to work against radio interference and the tolerance to a wide range of measured time synchronization errors.

CCS Concepts: • **Computer systems organization → Embedded systems**; *Redundancy*; Robotics; • **Networks** → Network reliability;

Additional Key Words and Phrases: Wireless sensor networks, media access control, multi-channel, radio interference, time synchronization

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1 INTRODUCTION

As a new technology, Wireless Sensor Networks (WSNs) has a wide range of applications [Akyildiz et al. 2002; Bahl et al. 2004; Culler et al. 2004], including environment monitoring, smart buildings, medical care, industrial and military applications. Among them, a recent trend is to develop commercial sensor networks that require pervasive sensing of both environment and human beings, for example, assisted living [Akyildiz et al. 2007; CROSSBOW 2008; Harvard CodeBlue 2008] and smart homes [Adya et al. 2004; CROSSBOW 2008; Harvard CodeBlue 2008].

> "For these applications, sensor devices are incorporated into human cloths [Adya et al. 2004; Bahl et al. 2004; Natarajan et al. 2007; Zhou et al. 2008] for monitoring health related information like EKG readings, fall detection, and voice recognition".

While collecting all these multimedia information [Akyildiz et al. 2007] requires a high network throughput, off-the-shelf sensor devices only provide very limited bandwidth in a single channel: 19.2 Kbps in MICA2 [Bahl et al. 2004] and 250 Kbps in MICAz.

In this article, we propose MMSN, abbreviation for Multifrequency Media access control for wireless Sensor Networks. The main contributions of this work can be summarized as follows.

- To the best of our knowledge, the MMSN protocol is the first multifrequency MAC protocol especially designed for WSNs, in which each device is equipped with a single radio transceiver and the MAC layer packet size is very small.
- Instead of using pairwise RTS/CTS frequency negotiation [Adya et al. 2004; Culler et al. 2004; Tzamaloukas and Garcia-Luna-Aceves 2000; Zhou et al. 2008], we propose lightweight frequency assignments, which are good choices for many deployed comparatively static WSNs.
- We develop new toggle transmission and snooping techniques to enable a single radio transceiver in a sensor device to achieve scalable performance, avoiding the nonscalable "one control channel + multiple data channels" design [Natarajan et al. 2007].

2 MMSN PROTOCOL

2.1 Frequency Assignment

We propose a suboptimal distribution to be used by each node, which is easy to compute and does not depend on the number of competing nodes. A natural candidate is an increasing geometric

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sequence, in which

$$P(t) = \frac{b^{\frac{t+1}{T+1}} - b^{\frac{t}{T+1}}}{b-1}, \tag{1}$$

where $t = 0, \ldots, T$, and b is a number greater than 1.

In our algorithm, we use the suboptimal approach for simplicity and generality. We need to make the distribution of the selected back-off time slice at each node conform to what is shown in Equation (1). It is implemented as follows: First, a random variable α with a uniform distribution within the interval $(0, 1)$ is generated on each node, then time slice i is selected according to the following equation:

$$i = \lfloor (T+1)\log_b[\alpha(b-1)+1] \rfloor.$$

It can be easily proven that the distribution of i conforms to Equation (1).

So protocols [Adya et al. 2004; Akyildiz et al. 2002; Bahl et al. 2004; Culler et al. 2004; Tzamaloukas and Garcia-Luna-Aceves 2000; Zhou et al. 2008] that use RTS/CTS controls[1] for frequency negotiation and reservation are not suitable for WSN applications, even though they exhibit good performance in general wireless ad-hoc networks.

2.1.1 *Exclusive Frequency Assignment.*

In exclusive frequency assignment, nodes first exchange their IDs among two communication hops so that each node knows its two-hop neighbors' IDs. In the second broadcast, each node beacons all neighbors' IDs it has collected during the first broadcast period.

Eavesdropping. Even though the even selection scheme leads to even sharing of available frequencies among any two-hop neighborhood, it involves a number of two-hop broadcasts. To reduce the communication cost, we propose a lightweight eavesdropping scheme.

2.2 Basic Notations

As Algorithm **??** states, for each frequency number, each node calculates a random number (Rnd_α) for itself and a random number (Rnd_β) for each of its two-hop neighbors with the same pseudorandom number generator.

REFERENCES

A. Adya, P. Bahl, J. Padhye, A.Wolman, and L. Zhou. 2004. A multi-radio unification protocol for IEEE 802.11 wireless networks. In *Proceedings of the IEEE 1st International Conference on Broadnets Networks (BroadNets'04)*. IEEE, Los Alamitos, CA, 210–217.

I. F. Akyildiz, T. Melodia, and K. R. Chowdhury. 2007. A Survey on Wireless Multimedia Sensor Networks. *Computer Netw.* 51, 4 (2007), 921–960.

I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci. 2002. Wireless Sensor Networks: A Survey. *Comm. ACM* 38, 4 (2002), 393–422.

P. Bahl, R. Chancre, and J. Dungeon. 2004. SSCH: Slotted Seeded Channel Hopping for Capacity Improvement in IEEE 802.11 Ad-Hoc Wireless Networks. In *Proceeding of the 10th International Conference on Mobile Computing and Networking (MobiCom'04)*. ACM, New York, NY, 112–117.

CROSSBOW 2008. XBOW Sensor Motes Specifications. (2008). http://www.xbow.com.

D. Culler, D. Estrin, and M. Srivastava. 2004. Overview of Sensor Networks. *IEEE Comput.* 37, 8 (Special Issue on Sensor Networks) (2004), 41–49.

Harvard CodeBlue 2008. CodeBlue: Sensor Networks for Medical Care. (2008). http://www.eecs.harvard.edu/mdw/ proj/codeblue/.

[1]RTS/CTS controls are required to be implemented by 802.11-compliant devices. They can be used as an optional mechanism to avoid Hidden Terminal Problems in the 802.11 standard and protocols based on those similar to [Akyildiz et al. 2002] and [Adya et al. 2004].

A. Natarajan, M. Motani, B. de Silva, K. Yap, and K. C. Chua. 2007. Investigating Network Architectures for Body Sensor Networks. In *Network Architectures*, G. Whitcomb and P. Neece (Eds.). Keleuven Press, Dayton, OH, 322–328. arXiv:cs/960935712

A. Tzamaloukas and J. J. Garcia-Luna-Aceves. 2000. *Channel-Hopping Multiple Access.* Technical Report I-CA2301. Department of Computer Science, University of California, Berkeley, CA.

G. Zhou, J. Lu, C.-Y. Wan, M. D. Yarvis, and J. A. Stankovic. 2008. *Body Sensor Networks.* MIT Press, Cambridge, MA.

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