M-cube: A Duty Cycle Based Multi-Channel MAC Protocol with Multiple Channel Reservation for WSNs

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Outline

- Introduction
- Protocols Design
- Theoretical Analysis
- Performance Evaluation
- Conclusions
Introduction

• **MAC Protocols:**
  • **Single-Channel MAC**
    • S-MAC, B-MAC, T-MAC…
      • Packet Collision.
      • Longer latency and lower throughput.
  • **Multi-Channel MAC**
    • MMSN, CAM-MAC, PMC…
      • Parallel transmission.
      • Improvement in **throughput** and **latency**.
Introduction

• **Multi-Channel MAC :**
  – **Channel selection**
    • Decides **how to select idle channels for nodes**
    • *Static* and *Dynamic*
  – **Media access**
    • Decides **when and how nodes access the channels**
    • *Time Division Multiple Access (TDMA)* and *Carrier Sense Multiple Access (CSMA)*
Dynamic Channel Selection ↔ CSMA

1. **Dynamic** selection requires **less channels** than static schemes;
2. **CSMA** involves no overhead of **time synchronization** in **TDMA**;

These **combined schemes** cannot provide **satisfactory performances** due to **Triple Hidden Terminals problems**.

(1) **multi-hop hidden terminal** which is the traditional hidden terminal in **multi-hop** networks;
(2) **multi-channel hidden terminal** which is a new kind of hidden terminals in **multi-channel** networks;
(3) **sleep hidden terminal** which is the latest kind of hidden terminals defined by this paper in **duty cycle based** networks.
THT

Network Topographies

CC : 
DC₁ : 
DC₂ : 
Sleeping: 
Overhearing: 

2011-1-14
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Contributions

1. This paper makes the first attempt to apply the idea of multiple channel reservation to solve THT in WSNs.
2. This paper proposes an asynchronous multi-channel MAC protocols, called M-cube, for WSNs.
3. Extensive simulations are conducted to evaluate the performance of M-cube compared with other four protocols.
4. M-cube is implemented in a real testbed and lessons learned in the implementation are shared.
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M-cube
M-cube

• **(1) Handshake Phase:** Based on its CUI, S computes EIDCL recording that DC\(_1\) and DC\(_3\) are idle, and then S sends a RTS with EIDCL to R. When R receives this RTS, R computes its own EIDCL, and then S computes FEIDCL, and finally sends a CTS with FEIDCL back to S.

• **(2) Channel Announcement Phase:** Assume DC\(_1\) is the first DC in FEIDCL, and then both S and R switch to DC\(_1\) and listen for time T and 2T where T is set according to the maximum data packet size. Because DC\(_1\) is occupied by EF, both S and R could receive a packet from E or F, which means that DC\(_1\) is busy. Therefore, both S and R continue to switch to DC\(_3\) without sending since they both aware of that EF are their common neighbors. After monitoring DC\(_3\), S and R exchange to make sure that DC\(_3\) is idle for both of them due to the multi-hop hidden terminal problem. Then, S and R switch to the CC, and sequentially send the same about this channel selection, which helps their idle neighbors to update their CUIs.

• **(3) Data Communication Phase:** S and R switch back to DC\(_3\) and communicate with each other by exchanging. When these exchanging are over, S and R switch back to the CC again and update their CUIs via overhearing the sent by their communicating neighbors on the CC.
Algorithm 1: Media Access of M-cube

If (upper layer message coming) { put message into packet buffer queue;}
If (sleeping timer fired) { turn off radio; set up active timer by duty cycle;}
If (active timer fired) { turn on radio; set up sleeping timer by duty cycle;}
If (sending timer fired){
    check whether R is on the DC by CUI; use CCA to sense the CC;
    If (R is on DC || CC is busy){
        back off for a while and tries to send later;
    } Else {obtain AIDCL by CUI; send it to R;}
If (receiving a packet){
    If (packet is RTS) { // as a receiver
        obtain EIDCL by CUI; obtain FEIDCL; send it in CTS to S
        While (switch to next DC in FAIDCL) {
            monitor this DC for 2T (explain later in subsection III.D);
            If (this DC is busy) {
                If (node occupying this DC is not a neighbor of S) {
                    send CSC on this DC to inform to switch again;
                }
            } Else If (receiving the DII packet from S) {
                send DII on this DC to S; switch to the CC;
                inform neighbors which DC it occupied with ANC;
                switch to that DC; wait to receive DATA from S; send ACK;
            } Else If (receiving CSC) {continue;}
        }
    } Else If (packet is CTS) { // as a sender
        While (switch to next DC in FEIDCL) {
            monitor this DC for T;
            If (this DC is busy) {
                If (node occupying this DC is not a neighbor) {
                    send on this DC to inform to switch again;
                }
            } Else { send DII on this DC to R;
            If (receiving DII) {
                switch to CC; inform neighbors occupied DC with ANC;
                switch to that DC; send DATA to R;
            } Else if (receiving CSC) {continue;}
        }
    } Else if (packet is ANC) { update CUI; } // as a neighbor
    If (packet is ACK) { send next DATA; } // as a sender
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Key Idea of Theoretical Analysis

• (1) The lower bound of the average numbers of times (denoted as $x$) that a node-pair switches among the DCs is computed.

• (2) Represented by the function of the duty cycle $q$, the value of $x$ can basically decide the latency and the energy consumption on channel switching among DCs.

• (3) The optimal duty cycle $q'$ is obtained, which is defined as the duty cycle that minimizes the lower bound of $x$. 
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Simulation Setup

• **(1)** 289 nodes, whose radio communication ranges are set to 40m, are uniformly deployed in a square area of size 200m*200m with a node density of **38**.

• **(2)** The traffic model that all packets are delivered from many sources to many destinations is used in the simulation.

• **(3)** The payload size is set to **32 Bytes** and the channel bandwidth is set to **250 Kbps**.
Throughput Evaluation

![Graph showing throughput evaluation results for different protocols and parameters.](image)
Energy Evaluation

The Energy Consumption (E-7mWht)

TNC

The Energy Consumption (E-7mWht)

NCBR
Testbed Experiment
Throughput Evaluation
Conclusion

- To address **Triple hidden terminal**, a duty cycle based MAC protocol, called M-cube, with multiple channel reservation is presented in this paper.
- Being fully distributed with no requirements of **time synchronization** or **multi-radio scheme**, M&M is suitable to be implemented in large-scale WSNs.
- The simulation results show that with multiple channel reservation, M-cube can solve **Triple hidden terminal** with a lower cost. Therefore, M-cube achieves a **significant improvement** of the energy efficiency.
- The testbed experiment results show that multiple channel reservation actually enables M-cube to achieve better throughput.
Thank you!