ARM: an Asynchronous Receiver-initiated Multi-channel MAC Protocol with Duty Cycling for WSNs

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Outline

- Introduction
- Motivation
- Related Work
- Detailed Design of ARM
- Performance 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
    • Classified as Static and Dynamic
  – Media access
    • Decides when and how nodes access the channels
    • Fall in tow categories: Time Division Multiple Access (TDMA) and Carrier Sense Multiple Access (CSMA)
Introduction

Dynamic 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 three problems.

(1) Control Channel Saturation (CCS), leading to severe collisions of control packets and prevent all the channels being fully utilized.

(2) Triple Hidden Terminals (THT), resulting in the fact that two node-pairs employ one channel to transmit data.

(3) Ineffective supporting for broadcast, leading to Low Reliability of Broadcast (LRB).
Contributions

• Makes effective solutions for CCS and THT in WSNs context by adopting a receiver-initiated transmission scheme and a probability-based random channel selection.

• Proposes a duty cycling based multi-channel MAC protocol ARM for WSNs, which exploits a receiver adjusted asynchronous broadcast scheme to solve LRB.

• Analyzes two factors related to channel selection and duty cycling, i.e., the probability of random channel selections and duty cycle by Queueing theory and Markov chain.

• Conducts extensive simulation to evaluate ARM’s performance. More importantly, ARM is also implemented in a real testbed.
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MOTIVATION 1: Need for solving CCS

Under certain circumstances the control channel (CC) is considered as a bottleneck of network performance, which is verified in Fig.1 as the loads and number of channels increase in the simulation with 144 nodes.
Motivation 2: Need for solving THT

Triple Hidden Terminals (THT) includes:
(1) traditional multi-hop hidden terminal;
(2) multi-channel hidden terminal [5];
(3) sleep hidden terminal.
**Motivation 3: Need for Solving LRB**

In the asynchronous multi-channel scenario, it is hard to guarantee that all the neighbors receive broadcast packets, because of two reasons.

1. Only a small subset of neighbors is on the same channel with the sender, when it decides to send a broadcast packet.

2. In duty cycle based WSNs, the idle nodes enter sleeping state periodically, so the sleeping neighbors of a broadcast sender cannot receive the broadcast packet.
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## Related Work

### MAC PROTOCOL FEATURE TABLE

<table>
<thead>
<tr>
<th>Protocol Name</th>
<th>For WSNs</th>
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<th>Multiple Channel</th>
<th>Non-SYNC</th>
<th>Broadcast</th>
<th>Duty cycling</th>
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Unicast scheme of ARM
Broadcast scheme of ARM
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Performance Analysis

Two parameters bring **significant influence** on ARM’s performance, which are:

- **Probability** $p$, with which a receiver randomly selects a DC and communicates with the sender.
  - We had utilized **queueing theory** to derive $p$, which can be found in Section V.A.

- **Duty cycle** $r$, with which idle nodes enter to the sleeping state periodically.
  - We had utilized **node state diagram** to derive $r$, which can be found in Section V.B.
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Simulation Setup

• The 289 nodes, whose radio communication ranges are set to 40m, are uniformly deployed in a square area of size with a node density of 38.
• The traffic model that all packets are delivered from many sources to many destinations is used in the simulation.
• The payload size is set to 32 Bytes and the channel bandwidth is set to 250 Kbps.
• Protocols for comparison:
  – RI-MAC which is a single channel receiver-initiated MAC protocol for WSNs
  – MMSN that is a typical synchronous multi-channel MAC protocol for WSNs
  – PMC that is a latest asynchronous multi-channel MAC protocol for WSNs
  – CAM-MAC that is a synchronous multi-channel MAC for ad hoc networks
• Two varieties of ARM are also involved:
  – The first variety utilizes the duty cycle of 25% (ARM-25%)
  – The second variety exploits the duty cycle of 50% (ARM-50%)
Throughput Evaluation

![Graphs showing throughput evaluation for different MAC protocols]

- RI-MAC
- MMSN
- PMC
- CAM-MAC
- ARM-25%
- ARM-50%
- ARM-OPDC

Aggregate MAC Throughput (Kbps)

TNC

NCBR

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GSU & HeiLongJiang University
Energy Evaluation

The energy consumption for different protocols is shown in the graphs. The x-axis represents TNC and NCBR, while the y-axis represents the energy consumption in E-7mW/Hz. The protocols compared include RI-MAC, MMSN, PMC, ARM-25%, ARM-50%, CAM-MAC, and ARM-OPDC. The graphs demonstrate how these protocols perform under varying TNC and NCBR conditions.
Reliability Evaluation

![Graph showing the broadcast reliability vs. broadcast packet arrival rate and number of broadcast nodes for different MAC protocols.

RI-MAC, MMSN, CAM-MAC, and ARM-OPDC protocols are compared. The reliability decreases as the packet arrival rate and number of broadcast nodes increase. The graphs illustrate the trade-offs between reliability and network load for these protocols.

The Broads...
Testbed Experiment Setup
Throughput Evaluation

Throughput Evaluation

Throughput (Kbps)

CAM-MAC
ARM-25%
ARM-50%
ARM-OPDC

Throughput (Kbps)

CAM-MAC
ARM-25%
ARM-50%
ARM-OPDC

Aggregate MAC Throughput (Kbps)

Aggregate MAC Throughput (Kbps)
Broadcast Evaluation
Conclusions

• In this paper, a multi-channel MAC protocol called ARM is proposed.

• The simulation results of large scale networks indicate that compared with the other four protocols, ARM achieves 162% more throughput at most and 35% higher broadcast reliability at most.

• Moreover, the experimental results of small scale testbed networks show that ARM achieves 67% more throughput ratios at most.

• These results clearly indicate that ARM successfully solves control channel saturation, triple hidden terminal and lower reliability of broadcast problems.
Thank you!