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Abstract

- This paper presents Control-Tone MAC (CT-MAC), a scheduled contention-based medium access protocol especially designed for Wireless Sensor Networks (WSNs).
- CT-MAC coordinates sensor nodes into sleep/wakeup schedules, allowing them to remain awake only for brief contention periods.
- Unlike most of the current solutions, CT-MAC employs short control tones, instead of control packets (e.g. RTS/CTS) in order to realize an energy-efficient contention resolution mechanism in multi-hop networks.
- The simulation results demonstrate that CT-MAC significantly reduces energy waste due to collisions, overhearing and idle listening in respect to SCP-MAC.
Overview

- Wireless Sensor Networks (WSN)
- MAC Protocols for WSN
- CT-MAC Protocol Description
- Performance Evaluation
- Conclusion
Wireless Sensor Networks

WSN

- WSN - collection of large number autonomous sensor nodes that self-organize into a multi-hop wireless network.
- Low-cost sensor nodes, composed of a single chip embedded with memory, processor, and short-range transceiver perform sensing, computation, and data delivery
- Low power - impractical to charge/replace exhausted batteries.
- Design goal - maximizing node/network lifetime (minimize communication)
Wireless Sensor Networks

Military applications
- Asset monitoring and management
- Surveillance and battle-space monitoring
- Urban warfare (sensors in buildings, movement of friend and foe, localizing snipers,...)
- Protection (for sensitive objects)
- Self-healing minefields

Civil engineering
- Monitoring of structures
- Urban planning (groundwater patterns, percent of CO2 cities are expelling,...)
- Disaster recovery (locating signs of life after earthquake)

Applications of Wireless Sensor Networks

Agriculture and environmental monitoring
- Precision agriculture (crop and livestock management)
- Planetary exploration (inhospitable environments)
- Geophysical monitoring (seismic activity)
- Monitoring of freshwater quality
- Zebranet project
- Habitat monitoring
- Disaster detection (forest fires and floods)
- Contaminant transport

General engineering
- Automotive telematics (cars networked)
- Fingertip accelerometer virtual keyboards
- Sensing and maintenance in industrial plants
- Aircraft drag reduction
- Smart office spaces
- Tracking of goods in retail stores
- Tracking of containers and boxes
- Social studies (human interaction and social behavior)
- Commercial and residential security

Health monitoring and surgery
- Medical sensing (physiological data transmitted to a computer or physician, wireless sensing bandages worn of infection, sensors in the blood stream which prevent coagulation and thrombosis)
- Micro-surgery (swarm of MEMS-based robots)

Others
- ...
MAC Protocols for WSN

- Medium Access Control (MAC) decides when competing nodes may access the shared medium.
- Trade off performance (latency, throughput, fairness) for cost (energy efficiency, reduced algorithmic complexity), while providing scalability and adaptability.
- Achieves energy efficiency by reducing energy wastes due to: idle listening, collision, overhearing, control packet overhead, overemitting, and traffic fluctuations.
- Two types of MAC protocols:
  - contention-based protocols (CSMA/CA, based on RTS/CTS handshake)
  - schedule-based protocols (TDMA)
Contention-based MACs for WSN

- Based on common active/sleep periods (active periods for communication and the sleep periods for saving energy)
- Nodes contend for the medium at the beginning of each active period using contention-based approaches (only nodes participating in data transfer remain awake after this)
- Used different contention-based media access mechanisms
- S-MAC uses carrier sense and RTS/CTS handshaking procedure
- RTS/CTS can alleviate the hidden terminal problem, but incurs high overhead because data packets are typically very small in WSN
Our Solution

- Control Tone MAC – CTMAC
- Control tone instead of RTS/CTS packets.
- Short signal tone (to wakeup intended receivers and for handshake mechanism).
- Signal tone is a flag signal that encodes no data
- Collision tolerant – control tones may collide with each other without affecting functionality
- Receiving nodes individually decide how to react to those tones, based on their own states at that time.
- Requires new contention scheme
CT-MAC frame

Time slot (for one CT transmission/reception) – 3 - 5 ms

N + 2M slots

N

M

M

CW1

CW2

Contention period

Data transfer period

CW – Contention Window

DATA

ACK

Frame
Contention slot

The duration of the slot is $T_s = T_d + T_g$
- $T_d$ - the duration of the control tone, typically 2 – 3 ms
- $T_g$ - the guard time - compensate time discrepancy among nodes, and depends on clock drift rate and the efficiency of synchronization mechanism employed in order of several milliseconds

During contention, a node can be put into one of the following five states: P_SEND, P_REC, IDLE, SEND, and REC.
- contention period enters either in state P_SEND or P_REC
- contention period leaves in one of three final states, IDLE, SEND or, REC (node in IDLE state will be put into sleep mode, in state SEND is a potential sender, and in state REC is entering the listening mode in order to receive a data packet)
Contention procedure for CW1

- Each node is assigned a listening slot.
- A potential sender announces its intention to send a data packet by transmitting the control tone in the listening slot of the intended receiver.
- A potential receiver modifies its state to REC if it hears a tone in its slot. If it hears tone in some of the neighbors slots after that, it changes its state back to IDLE.
- A potential sender listens all its neighbors slots until the listening slot of the potential receiver and changes its state back to IDLE if it hears something. If not, it transmits the tone (changes its state to SEND) and skips all slot until the end of the CW1.
Contestation procedure for CW1

CW1 slot start

State

P_SEND
SlotID = DestSlotID

Yes
Transmit control tone
State = SEND

No
Poll the channel

Control tone detected

Yes
SlotID = MySlotID

Yes
State = REC

No
State = IDLE

Control tone detected

No

P_REC
SlotID = MySlotID

Yes
Poll the channel

Control tone detected

Yes
State = REC

State = IDLE

No

REC

No

Send IDLE

Poll the channel

Control tone detected

Yes

No
Contention procedure for CW2

- A sending node randomly picks a slot in CW2a and transmits a tone.
- A receiving node listens from the beginning of the CW2a, until it hears a tone, remembers number of that slot and skips remaining of the slots.
- During CW2b nodes switch roles: a receiving node transmits a control tone in slot during which it was heard the tone.
- A sending node listens from the beginning of the CW2b until it hears the tone. If the tone is heard in the same slot number it sends tone in CW2a, it keeps SEND status. Otherwise, it became IDLE.
Distribution of nodes, example

a) initial

b) after CW1

c) after CW2

- SEND
- RECEIVE
- IDLE
Performance evaluation

- We implement CT-MAC and SCP-MAC protocols in a custom WSN simulator build in C++
- SCP-MAC is an existing contention-based MAC protocol with common active period. It uses short wake up tones instead of RTS/CTS, as CT-MAC, but it does not implement an appropriate mechanism to alleviate the hidden terminal problem.
Simulation Setup

- Fixed parameters:
  - 200 nodes
  - Area - 100x100 m²
  - average size of one-hop neighborhood - 6
  - Data rate - 20 Kbps
  - Data packet length - 32 B
  - CW1 - 32 slots, CW2 - 16 slots

- Varying parameter:
  - Traffic load (λ)
## Timing parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time needed to pool channel once</td>
<td>3 ms</td>
</tr>
<tr>
<td>Time to transmit a control tone</td>
<td>5 ms</td>
</tr>
<tr>
<td>Time to transmit/receive a data packet</td>
<td>40 ms</td>
</tr>
<tr>
<td>Time to transmit/receive an ACK packet</td>
<td>18 ms</td>
</tr>
<tr>
<td>Time to receive MAC header</td>
<td>16 ms</td>
</tr>
<tr>
<td>Idle channel timeout period</td>
<td>8 ms</td>
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</tbody>
</table>
Performance Metrics

- **Energy consumption per transferred packet.** We vary the percentage ($\lambda$) of nodes that generate data packet during each frame and count successfully transferred data packets and record all nodes’ activities.

- **Throughput over varying traffic load.** We define the throughput as the ratio between the number of successfully transferred packets and the number of packets that are generated per frame.
Performance Evaluation

- energy consumption per transferred packet -

![Graph showing energy consumption per packet vs traffic load](image)
Performance Evaluation - throughput over varying traffic load -

The graph illustrates the throughput over varying traffic load for two different MAC protocols: SCP-MAC and CT-MAC. As the traffic load increases, the throughput decreases for both protocols, with SCP-MAC showing slightly better performance than CT-MAC at higher traffic loads.
Conclusion

- CT-MAC - energy-efficient, contention-based MAC protocol.
- Use of short control tones instead of control packets in order to implement a contention scheme in a WSN.
- Although CT-MAC does not alleviate the hidden terminal problem entirely, it significantly reduces probability of collisions and lowers energy waste due to overhearing and idle listening in respect to SCP-MAC.
- Future work: the problems of node synchronization and contention slot assignment.
Questions?