• MAC Essentials for Wireless Sensor Networks
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Medium access control

• Part of the link layer (OSI model)
• Controls access to physical medium
• Assigns a unique address to the host (MAC address)
Why is MAC important in WSNs?
Some WSN characteristics

- **Limited energy resources**
- Low data load, but highly directed
- Control often decentralized
- Huge amount of nodes with low computing capabilities
- Volatile radio links
Energy constraints in WSN

- Energy consumption dominated by nodes radio consumption
- MAC controls active and sleep mode
- MAC essential in energy consumption of a WSN design
Energy consumption

- Idle listening
- Collisions
- Overhearing
- Large overheads
Traditional MAC families

- Reservation-based protocols
- Contention-based protocols
Reservation-based protocols

- Nodes access network in a scheduled order
- Global time synchronization
- High fixed throughput
- Poor mobility
- TDMA
Contention-based protocols

• Nodes access the network in a random and competitive order (e.g. channel sensing and contention)

• Robust to node mobility

• Degraded throughput with heavy loads

• CSMA, ALOHA
Energy consumption vs throughput

[Graph showing energy consumption vs interarrival times for different protocols such as CSMA/CA, T-MAC 10%, T-MAC 5%, T-MAC 1%, WiseMAC, and Ideal protocol.]
Thematic taxonomy

- Traditional surveys classify MAC protocols according to reservation or contention based medium access techniques.

- Need guidelines to determine MAC protocols suited for a given set of circumstances.

- Focus on thematic classification of protocols suited for specific needs of different WSN.
Proposed families

- **Scheduled protocols:**
  Fixed high load traffic

- **Protocols with Common active periods:**
  Periodic medium load traffic

- **Preamble sampling protocols:**
  Random low load traffic
Scheduled protocols

- Optimized for high-load WSNs e.g multimedia applications
- Maintains network wide schedule among nodes
- No collisions, no overhearing and minimized idle listening reduce energy consumption
- Weak node mobility
- Requires global synchronization
Basic functionality

- Nodes assigned slots inside timeframes
- Slots assigned using a distributed schedule
- Network-wide synchronisation and scheduling needed
- TDMA
Time synchronized Mesh Protocol

- A node can participate in multiple frames at once having multiple refresh rates for different tasks
- TDMA combined with FDMA and frequency hopping
- Increased robustness against narrowband interference
Time Synchronised Mesh protocol

Fig. 5. Possible schedule for given connectivity graph.
Some related problems

- Maintaining tight synchronization in multi-hop networks
- Repetitive broadcast may waste energy
- Poor flexibility: Changes in traffic load or network structure require new schedules to be calculated
- Maintaining memory of neighbourhood topology consumes energy inside nodes
Protocols with Common Active Periods

- Suited for periodic medium-load traffic (typical to e.g industrial applications)
- Common active periods among nodes to reduce energy consumption
- Local self-scheduling among nodes increase network flexibility
- Weak against node mobility
- Some degree of synchronization needed
Basic functionality

- Nodes define common active/sleep periods
- Nodes contend for channels during active periods
- Synchronization among nodes to define active periods
Sensor MAC (SMAC)

- Active period split into two sub periods (Sync and data)
- Sync packets exchanged to build local schedule
- Nodes with common schedule form virtual clusters
- Sub periods divided into mini-slots where nodes contend for channel
- Random backoff time to reduce collisions
Fig. 6. SMAC alternates turning on and off the radio. SMAC splits the active period into two sub-periods: one for exchanging sync packets and the other for exchanging data packets. Data packet exchange may require RTS, CTS and ACK [57].
Some related problems

• Determining optimal size of active periods (Short periods reduce idle listening but increase collisions)

• Long sleep periods increase network latency

• Irregular traffic increase collisions during active periods

• Mobile nodes waste energy rescheduling
Preamble sampling protocols

• Good for WSN’s with low traffic and remote node locations (e.g. metering applications, environmental monitoring)

• Long sleep cycles reduce energy consumption except during transmission

• Robust against node mobility

• Requires few synchronization among nodes
• Sleeping node switch on radio for short durations to sample channel (check intervals)

• Transmitter uses long preamble to ensure detection by receiving node during check intervals
Some related problems

- Transmitter preamble needs to cover entire receiver check time interval to ensure detection

- Long preamble drains transmitter energy and increase chance of collisions when network traffic increases

- High cost of transmission can drain more energy than saved from reduced listening
Finding optimal check intervals depend on traffic load
Reducing preamble length without reducing check interval: Wireless sensor MAC (WiseMAC)

- Node learns about neighbours checktimes to reduce preamble

- Recieving nodes share check-times using piggybacking on ACK returned to transmitter

- Neighbours check times stored in nodes internal table

- If reciever check times change, transmitter can switch back to full preamble length to ensure detection
Wireless sensor MAC (WiseMAC)
Hybrid protocols

• Combine categories to achieve high performance in variable traffic patterns

• Zebra MAC: CSMA inside large TDMA slots
Conclusions

• MAC important in WSNs

• Complete system-wide quantification of WSN constraints not available

• No MAC exist that is highly scalable

• Power harvesting in future applications may favour some scheduling of nodes active modes
Debate

• Will real world systems with varying traffic, multi hops etc, result in too many hybrids making the families useless?

• Making specific families linked to real world systems may encourage thinking inside a box and hinder seeing new solutions

• Difficult to see practical difference between reservation based and scheduling protocol family
T-Lohi: A New Class of MAC Protocols for Underwater Acoustic Sensor Networks

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Paper motivation

• No MAC protocol widely available to support dense UWSNs

• Unique characteristics of underwater communication may be exploited in MAC design

• Energy-efficient design important in UWSNs
Paper main contributions

• Evaluation of space time uncertainty and latency and how these may be exploited in MAC design

• T-Lohi, a new class of MACs for UWSNs
Underwater Acoustic sensor networks

- Traditional networks very long range (several kilometers)

- Many new limitations not seen in radio

- Short range acoustic networks may be easier to implement
Challenges with underwater acoustic communication

- High propagation latency
- Low bandwidth
- Surface scattering
- Complex multipath fading
- Temperature, salinity and pressure influence
Challenges with underwater acoustic communication

- Short range communication (less than 500m) may simplify propagation characteristics and allow simpler and cheaper design
- Transmission often 100 times more expensive than reception
- These characteristics create new-phenomena in MAC protocol design
Energy reliable applications

- Static sensing applications
- Gliders and low-energy mobility platforms
- Water-life tagging
Energy efficiency design challenges

- High transmit costs
- Long idle listening time
- Replace battery may be difficult
Space time uncertainty

• High latency cause unfairness in contention due to node locations

• Clear channel assessment needs to consider worst case latency of neighbours

• Nodes in close proximity may monopolize a channel

• High latency may be exploited in counting and detecting contenders
Deafness conditions

• Nodes cannot transmit and recieve simultaneously (half-duplex)

• Two contending nodes far away may not hear each other's contending tone and think they won round

• Nodes may start contending while receiving other contenders and not hear

• Short receiver detection time important to reduce deafness probability
Deafness conditions impact

- Tone-data collisions
- Data-data collisions
- Increasing number of conteders reduce risk of deafness
T-Lohi MAC protocol
Tone-LOHI MAC protocol goals

- Efficient channel utilization
- Stable throughput with both low and high loads
- Low energy consumption
- Flexible for a range of applications and traffic patterns
Tone-LOHI MAC protocol

- Nodes reserve channel prior to data transmission using contention rounds

- Contention rounds may be common or random among nodes
T-LOHI energy reduction

- Channel reservation prevents packet collisions
- Special wake-up tone reciever allowing low-power wakeup listening
T-LOHI channel reservation

• Nodes contend to reserve channel

• Nodes send short tone and wait to listen if channel clear

• If not clear, count number of contenders and decide backoff time
T-Lohi Frame structure

Fig. 4. The Tone-Lohi protocol frame
T-LOHI Data transfer

• Transmitter responsible for waking up recievers

• Reciever of wake-up tone scan data channel for preamble

• If preamble, scan data header to check if correct recipient
T-LOHI tone implementation

- Custom, low power tone receiver
- Share channel with data
- Consume 1/100th the energy of listening for data
- Can be replaced by short data packets
False tone detection

• Channel noise may sound like tone

• Noise tone may be interpreted as false contender and prolong contention rounds

• Longer contention rounds reduce throughput

• Low energy cost of contention give false tone detection small impact on energy consumption
T-LOHI Flavours

- Synchronized T-Lohi (ST-Lohi)
- Conservative Unsynchronized T-Lohi (cUT-Lohi)
- Aggressive UT-Lohi (aUT-Lohi)
Synchronized T-Lohi (ST-Lohi)

- Contention rounds synchronised among nodes
- Observe channel for worst case propagation time
- Count contenders and estimate distances
- No bidirectional deafness
- Nodes close to receiver higher chance of backoff (SAI)
Conservative Unsynchronized T-Lohi (cUT-Lohi)

- Random contending from nodes
- Observe channel for twice the worst case propagation time to avoid collision
- Simpler to implement
- Cannot count number of contending nodes
Aggressive UT-Lohi (aUT-Lohi)

- Random contending from nodes
- Half the contention rounds of cUT-Lohi
- Shorter rounds give higher throughput
Protocol weakness

• Tone-data collisions may occur in aUT-Lohi due to random low contention periods

• Data-data collisions may occur from bidirectional deafness

• Adding more contenders reduce risk of bidirectional deafness
Performance evaluation

- Performance of protocols tested in a network simulator
- Packet loss due to channel noise and multi path not accounted for
- Results show throughput increase of 34-50% of comparable underwater MAC protocols
Channel utilization with increasing load

- Protocols show high efficiency at low load

- Stable throughput at about 50% of channel capacity at heavy loads

- ST-Lohi and aUT-Lohi offer higher throughput due to smaller contention rounds

- ST-Lohi throughput not affected by increasing network density
(a) Eight Node Network

(b) Two node network
Energy efficiency

• Energy eff. Measured as cost beyond optimal energy per packet during transmission (Overhead)

• ST-Lohi show very low and constant overhead (4%) due to collision prevention mechanisms

• aUT-Lohi show highest overhead at heavy loads due to increased collisions

• cUT-Lohi has longer sleeping periods during transmission so energy cost per packet becomes similar to aUT-Lohi
Energy efficiency

Fig. 9. Relative energy overhead for T-Lohi for an 8 node network
Packet loss

- Increase in network density reduce collisions in aUT-Lohi
- More contenders reduce risk of deafness conditions and data-data collisions
- cUT-Lohi provide most robust and reliable data transfer for sparse and low traffic networks
Packet loss

Fig. 10. Packets lost in a fixed duration as offered load is varied
Impact of counting contenders on fairness

Fig. 11. Jain’s fairness index for T-Lohi that can count contender vs. a MAC that can only detect contenders and uses BEB.
Conclusions

• T-Lohi offer good performance in fully connected network. Need studies of multi-hop networks

• All flavours within 3-9% of optimal energy efficiency

• All flavours within 30% of optimal channel utilization
Discussion