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Algorithms for Radio Networks

MAC for WSN

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Media ACcess
MAC

- **Prevention of collisions on the medium**
  - Fair and efficient bandwidth allocation
- **MAC for WSN**
  - Regulates sleep cycles for participants
  - Reduces waiting time for active reception
- **Standard protocols are not applicable for WSN**
  - Energy efficiency and sleep times must be added

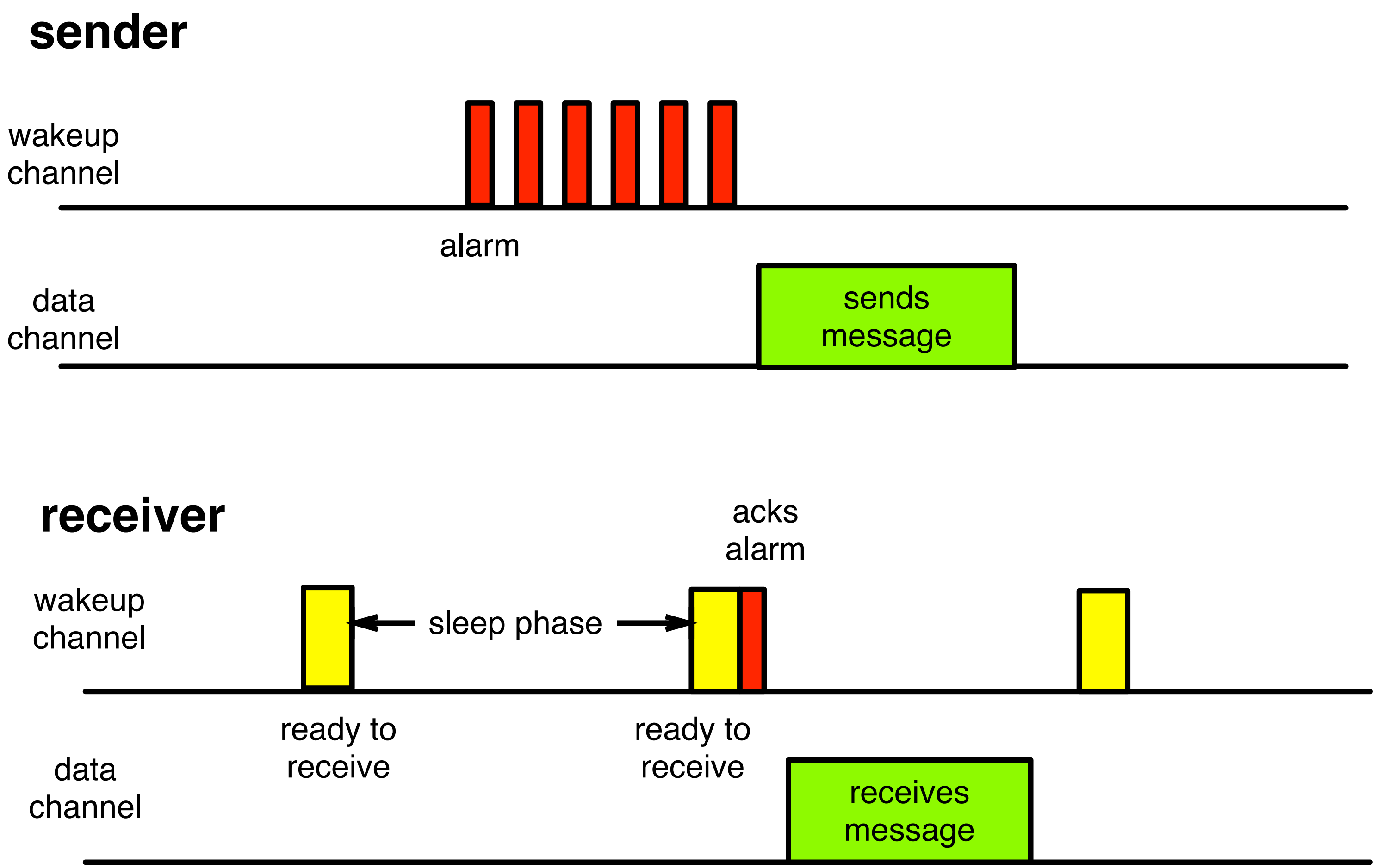
MACA and WSN

- **MACA:**
  - Channel must be monitored for RTS and CTS
  - Nodes waking up can disrupt existing communications
- **Solution in IEEE 802.11:**
  - Announcement Traffic Indication Message (ATIM)
    - prevents receiver from starting a sleep cycle
    - informs about upcoming packages
    - is sent within the beacon interval
  - When no message is pending, then the client can switch off its receiver (for a short time)

STEM

- **Schurgers, Tsiatsis, Srivastava**
  - STEM: Toplogy Management for Energy Efficient Sensor Networks, 2001 IEEEAC
- **Sparse Topology and Energy Management (STEM)**
- **Special hardware with two channels**
  - Wakeup channel
  - data channel
- **no synchronization**
- **No RTS / CTS**
- **Suitable for decentralized multi-hop routing**

STEM


sender
wakeup
channel
alarm
data
channel
sends
message
receiver
acks
alarm
wakeup
channel
sleep phase
ready to
receive
ready to
receive
data
channel
receives
message

STEM

Sparse Topology and Energy Management Protocol

- **Wakeup channel**
  - sender announces message
  - announcement will be repeated until the receiver acknowledges
  - receiver sleeps in cycles
- **Data channel**
  - is used for undisturbed transmission
- **No RTS / CTS**
- **No carrier sensing**

Discussion STEM

- **Sleep cycles ensure efficiency in the data reception**
  - longer cycles improve energy efficiency
  - but increase the latency
- **Too long sleep cycles**
  - increase the energy consumption at the transmitter
  - lead to traffic congestion in the network
- **Lack of collision avoidance**
  - can result in increased traffic because of long waiting times
  - increase energy consumption

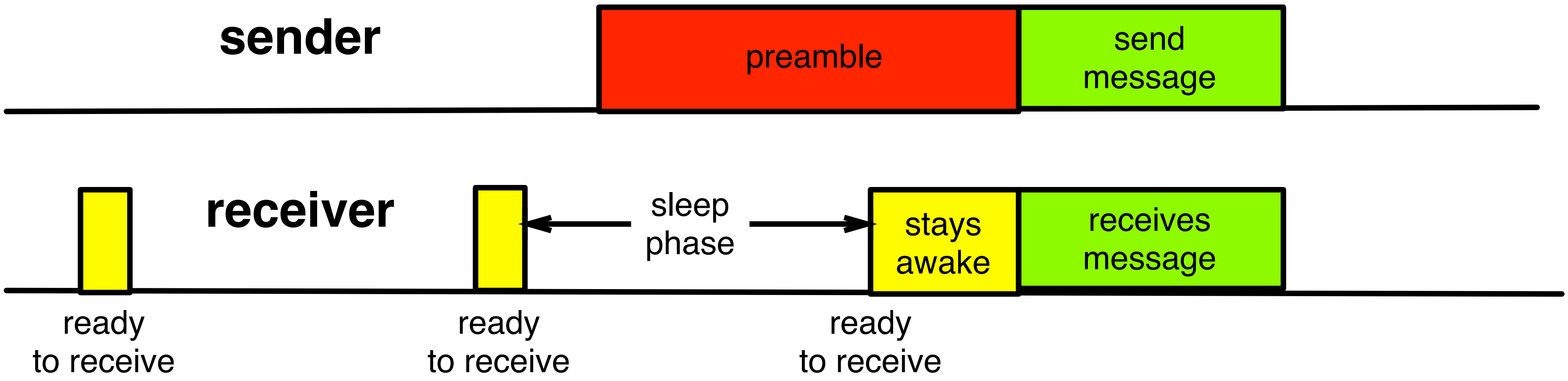
STEM

- **STEM**
  - can be combined with GAF (Geographic Adaptive Fidelity)
  - GAF reduces the sensor density, by allowing only the activation of one sensor in a small square
- **T-STEM**
  - STEM adds a busy-signal channel to wake up and to prevent communication from interruption

Preamble Sampling

- **Only one channel available and no synchronization**
- **Receiver**
  - wakes up after sleep period
  - listens for messages from channel
- **Sender**
  - sends a long preamble
  - and then the data packet

Preamble Sampling



Efficiency of Preamble Sampling

- **Few messages**
  - Better: long sleep phases
  - Receiver consume most of the total energy
- **Many messages**
  - Short sleep phases
  - Sender consume most of the total energy
  - We observe for preamble time T and some positive constants c, c ', c'':

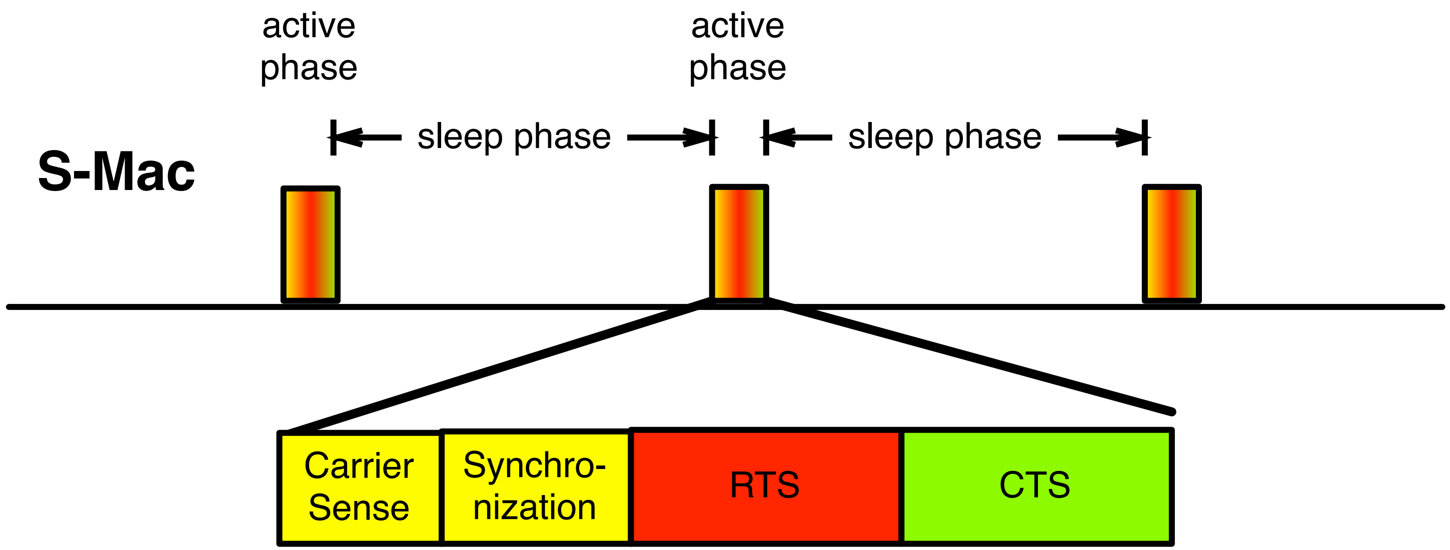
$$\text{Energy} = cT + \frac{c'}{T} + c''$$

Sensor-Mac (S-MAC)

- **Ye, Heidemann, Estrin**
  - An Energy-Efficient MAC Protocol for Wireless Sensor Networks, INFOCOM 2002
- **Synchronized sleep and wake cycles**
- **MACA (RTS / CTS)**
  - for collision avoidance
  - and detection of possible sleep cycles

S-MAC Protocol

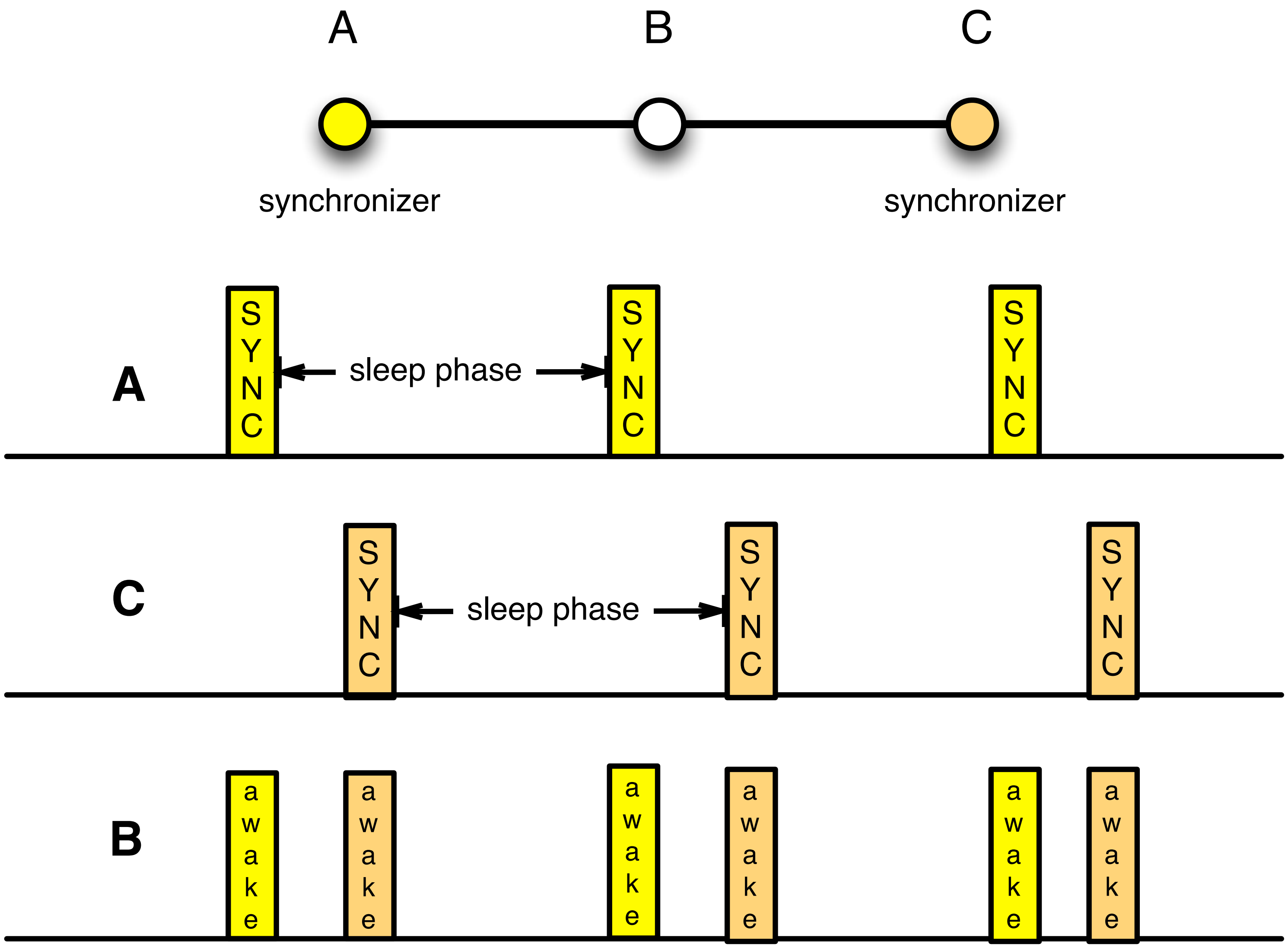
- **Active phase**
  - Carrier Sensing
  - Send Sync packet synchronizer short sleep duration with ID and
  - Interval for Request to Send (RTS)
  - Interval for Clear-to-Send (CTS)



Schedule

- **Each node maintains Schedule Table**
  - with the sleep cycles of known neighbors
- **At the beginning listen to the channel for potential neighbors**
  - the sender adapts to the sleep cycles of the neighbors
  - if several sleep cycles are notices, then the node wakes up several times
- **If after some time no neighbors have been detected (no sync)**
  - then the node turns into a synchronizer
  - and sends its own Sync packets

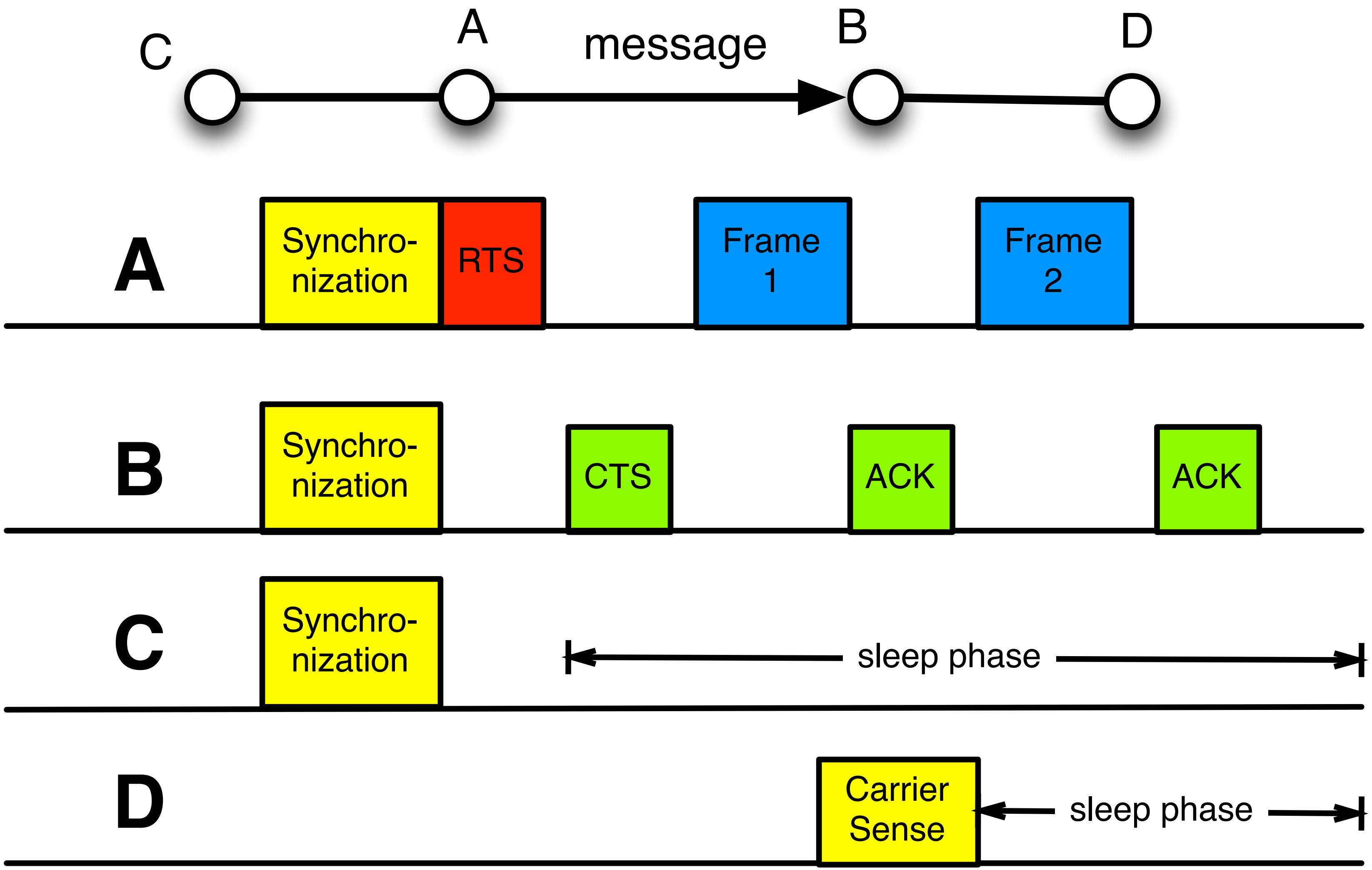
Synchronized Islands



Message Transmission

- **If a node receives RTS for a foreign a node**
  - then he goes to sleep for the announced time
- **Packet is divided into small frames**
  - be individually acknowledged with (ACK)
  - all frames are announced with only one RTS / CTS interaction
  - If ACK fails, the packet is immediately resent
- **Small packets and ACK should avoid the hidden terminal problem**
- **All frames contain the planned packet duration in the header**

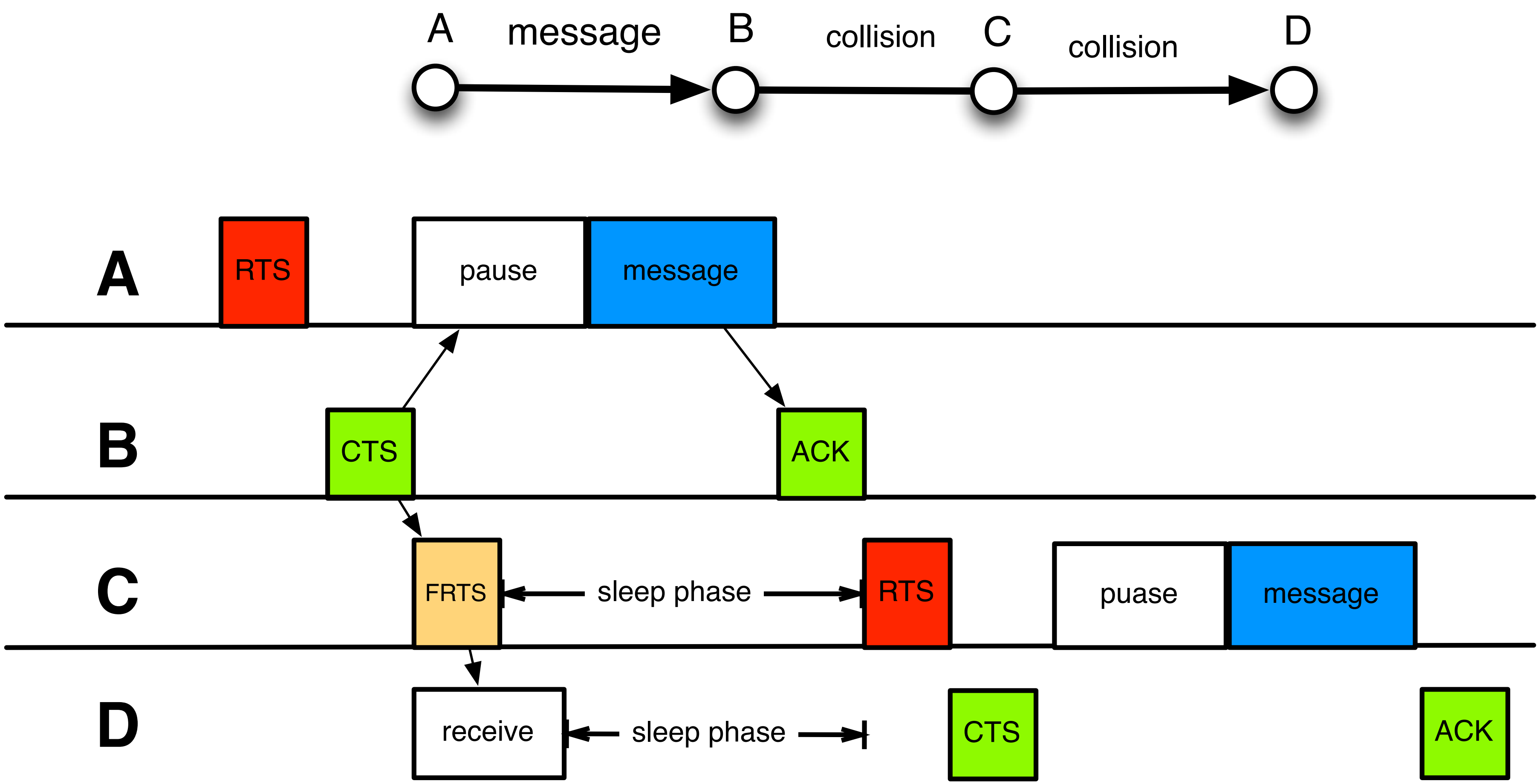
Message Transmission
S-MAC



Timeout-MAC (T-MAC)

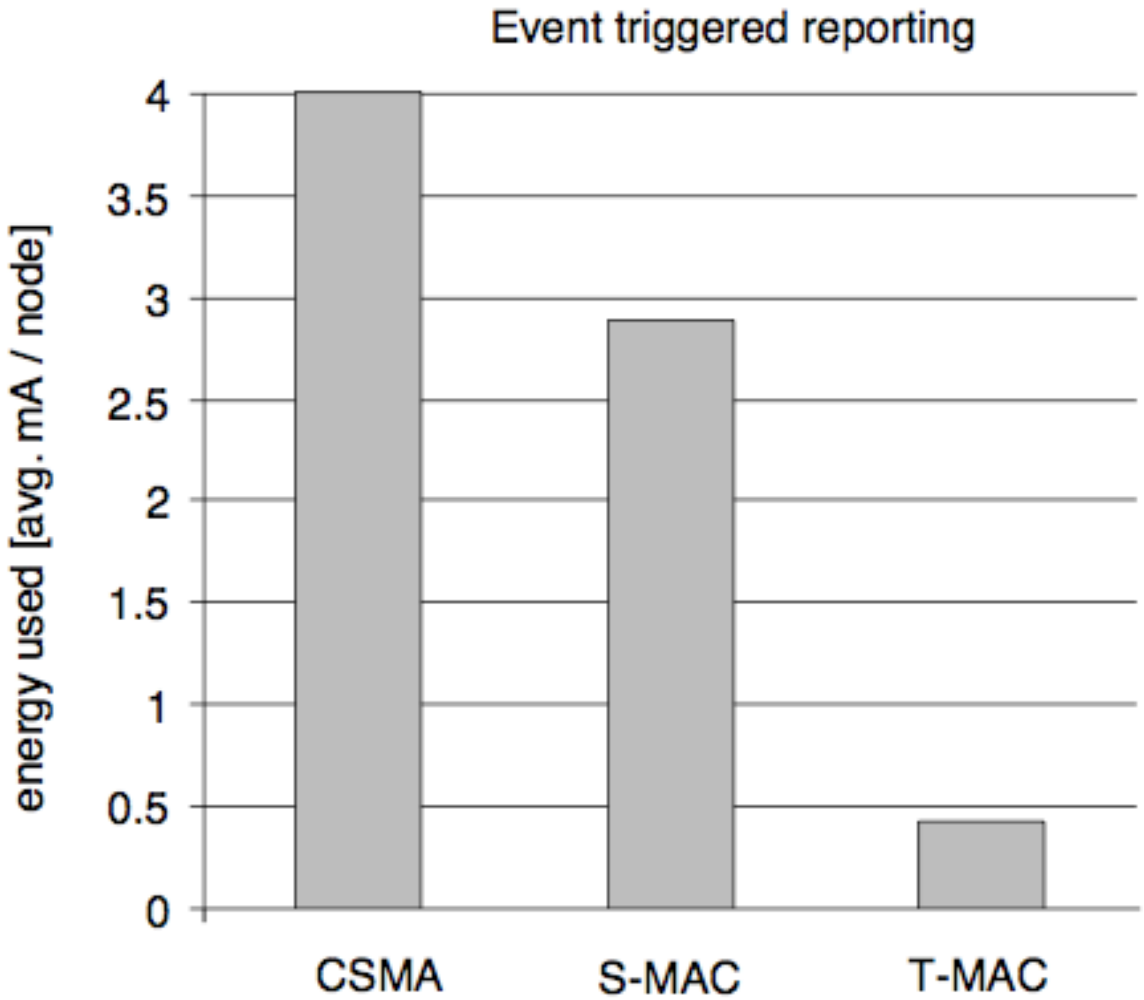
- **T. van Dam, K. Langendoen**
  - An Adaptive Energy-Efficient MAC Protocol for Wireless Sensor Networks, SenSys 2003
- **Main goal**
  - extension of the MACA-protocol to save energy
- **Method**
  - Traffic dependent sleep cycles
  - New: FRTS-Signal (Future Request to Send)
    - informs about future message
    - Allows adapted sleep phases of the receiver

T-MAC


A
message
B
collision
C
collision
D
A
RTS
pause
message
B
CTS
ACK
C
FRTS
sleep phase
RTS
puase
message
D
receive
sleep phase
CTS
ACK

Comparison of S-MAC and T-MAC

- **FRTS solves problems that are increased by adapted sleep cycles**
  - e.g. Early Sleeping i.e., Falling asleep because sender is blocked by foreign CTS
- **Simulation indicates significant energy reduction**
  - also improve the throughput

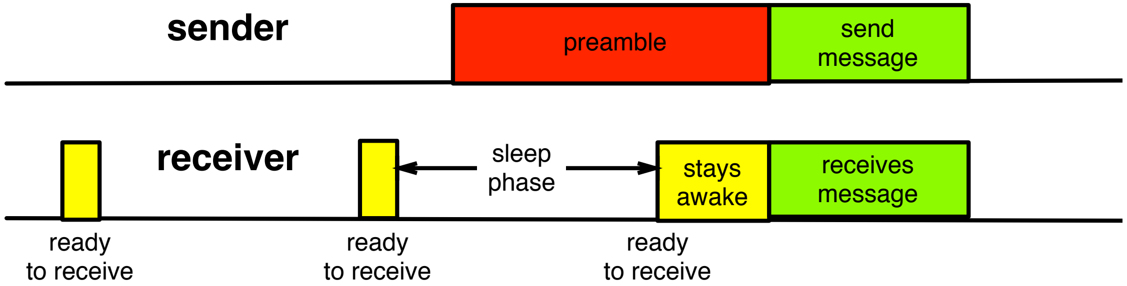


T. van Dam, K. Langendoen, An Adaptive Energy-Efficient MAC Protocol for Wireless Sensor Networks, SenSys 2003

B-MAC

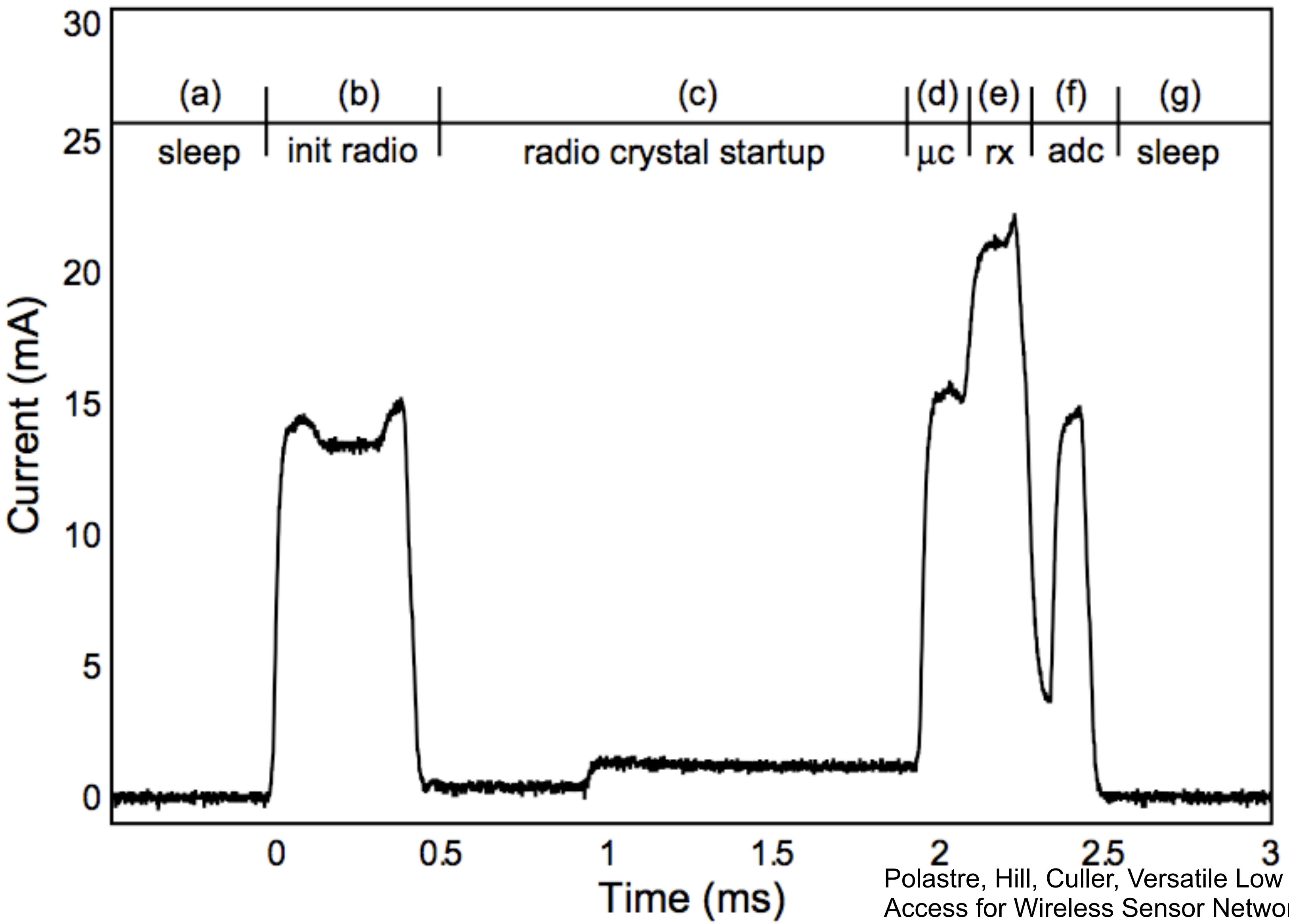
- **Polastre, Hill, Culler**
  - Versatile Low Power Media Access for Wireless Sensor Networks, SenSys'04, November 3–5, 2004, Baltimore, Maryland, USA.
- **B-MAC (Berkeley-MAC)**
  - no synchronization
  - Clear Channel Assessment
  - Evaluation of RSSI compared to noise
  - Hardware-oriented implementation
  - Very simple, low memory and power consumption

B-MAC



- **Low Power Listening**
  - Preamble Sampling
  - Special wake-up protocol
  - adapted to hardware with low power consumption
  - Node goes into sleep mode after test
- **optional**
  - RTS / CTS
  - Acknowledgments
- **De-facto standard for WSN MAC Protocols**

Low Power Listening



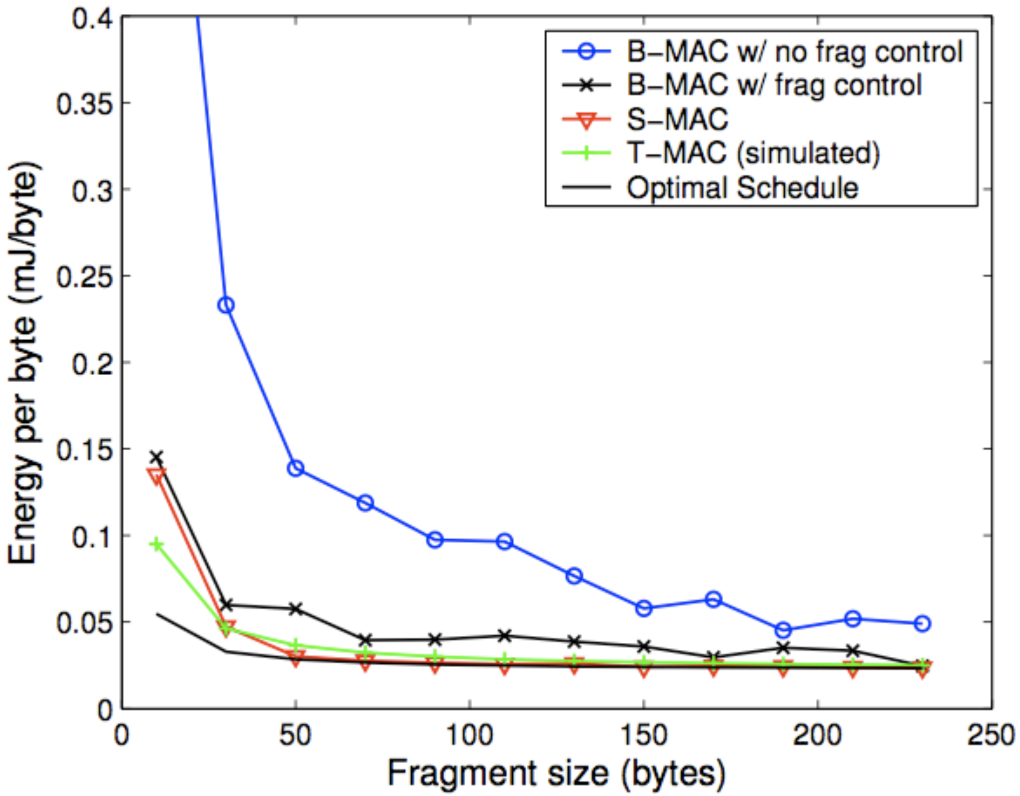
Polastre, Hill, Culler, Versatile Low Power Media Access for Wireless Sensor Networks, SenSys'04

Memory Consumption B-MAC and S-MAC

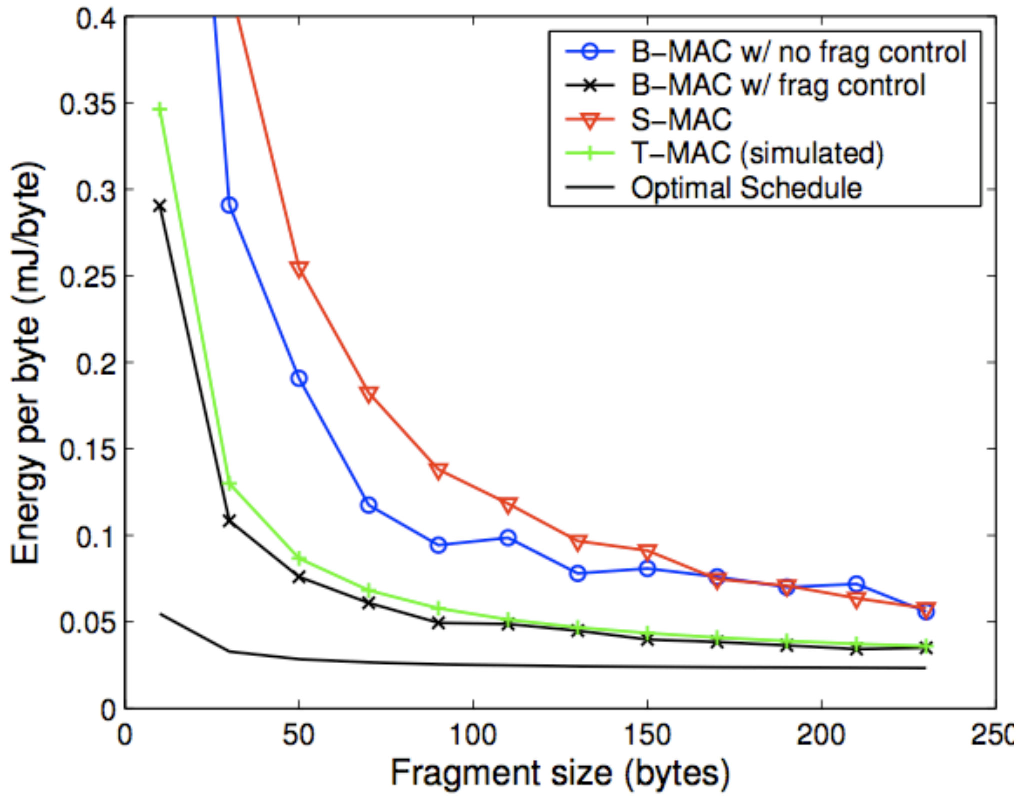
Protocol	ROM	RAM
B-MAC	3046	166
B-MAC w/ ACK	3340	168
B-MAC w/ LPL	4092	170
B-MAC w/ LPL & ACK	4386	172
B-MAC w/ LPL & ACK + RTS-CTS	4616	277
S-MAC	6274	516

Polastre, Hill, Culler, Versatile Low Power Media Access for Wireless Sensor Networks, SenSys'04

Comparison of Energy Consumption



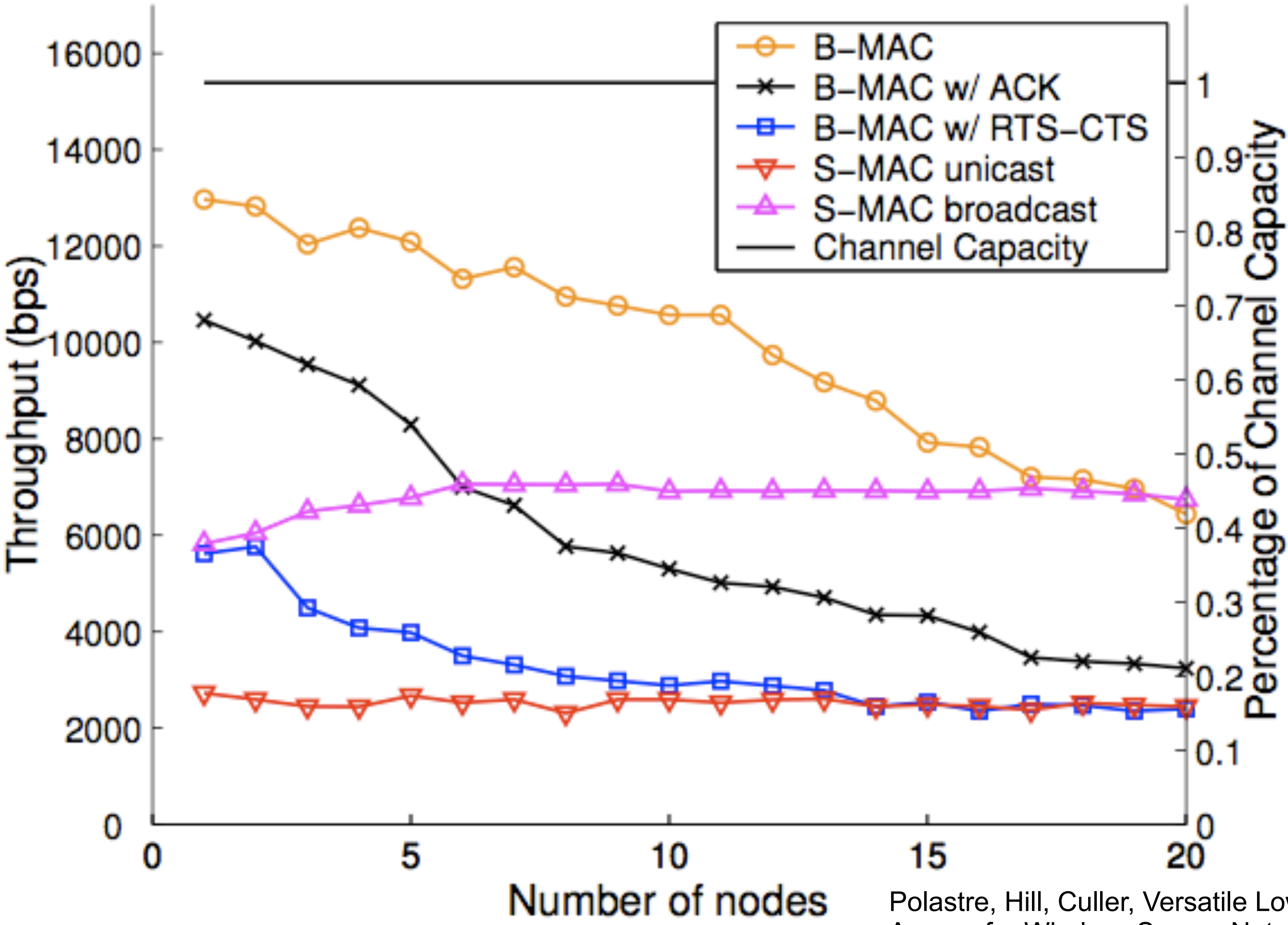
(a) 10 second message generation rate



(b) 100 second message generation rate

Polastre, Hill, Culler, Versatile Low Power Media Access for Wireless Sensor Networks, SenSys'04

Throughput



Polastre, Hill, Culler, Versatile Low Power Media Access for Wireless Sensor Networks, SenSys'04

Outlook MAC in WSN

- **Many other protocols in WSN**
  - LEACH, TRAMA, PAMAS, SMACS, ...
- **Very large diversity of protocols**
  - very simple and very complex protocols
  - very specialized for certain hardware or not at all
  - TDMA, CDMA, clustering, multi-hop, single-hop, ...
- **Further reading**
  - Karl, Willig: Protocols and Architectures for Wireless Sensor Networks, Wiley, 2005

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