Wireless Sensor Networks
4. Medium Access

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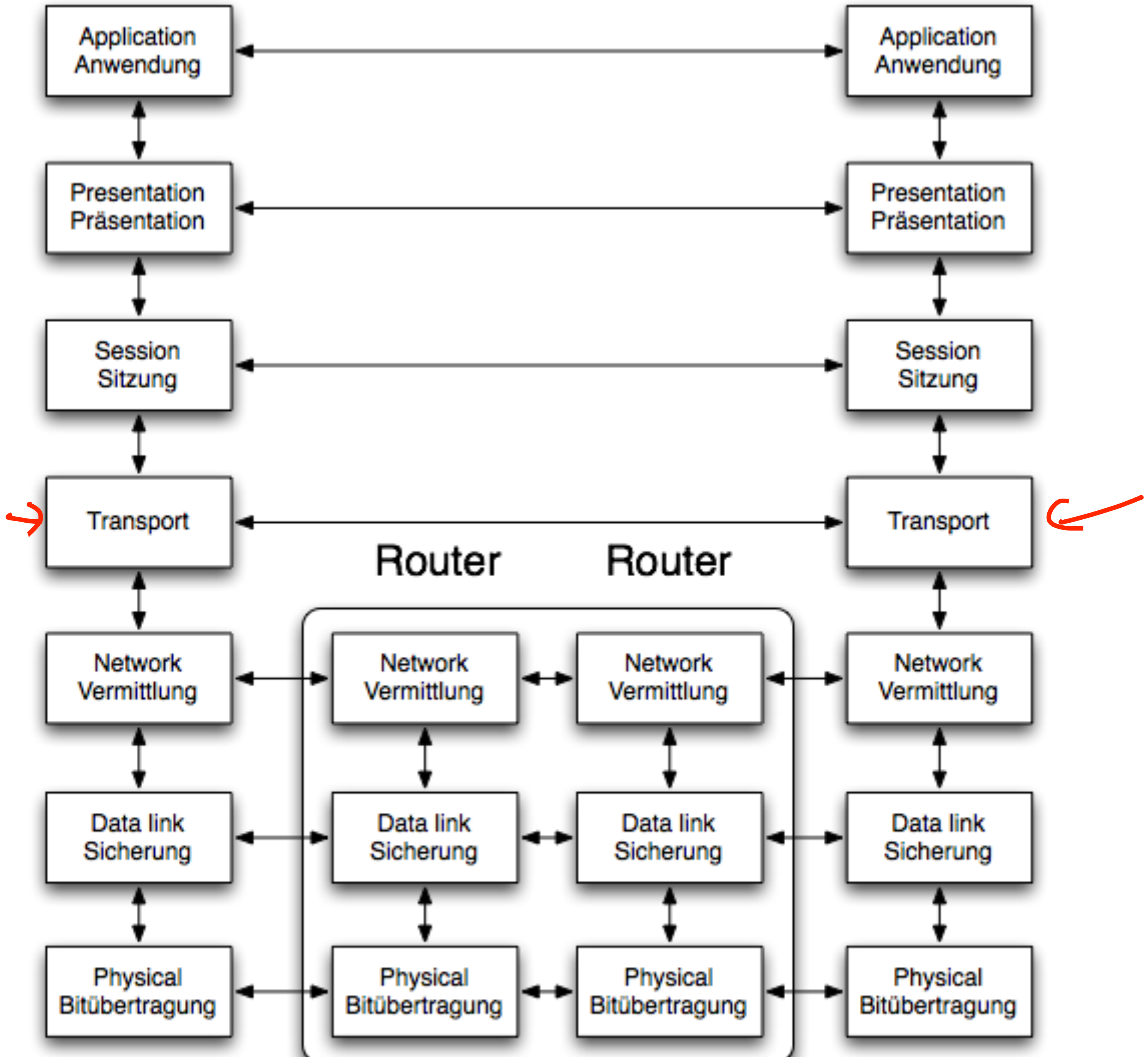
ISO/OSI Reference model

- 7. Application
  - Data transmission, e-mail, terminal, remote login
- 6. Presentation
  - System-dependent presentation of the data (EBCDIC / ASCII)
- 5. Session
  - start, end, restart
- 4. Transport
  - Segmentation, congestion
- 3. Network
  - Routing
- 2. Data Link
  - Checksums, flow control
- 1. Physical
  - Mechanics, electrics



MACAW

- Bharghavan, Demers, Shenker, Zhang
  - MACAW: A Media Access Protocol for Wireless LAN's, SIGCOMM 1994
  - Palo Alto Research Center, Xerox
- Aim
  - Redesign of MACA
  - Improved backoff
  - Fairer bandwidth sharing using *Streams*
  - Higher efficiency
    - by 4- and 5-Handshake

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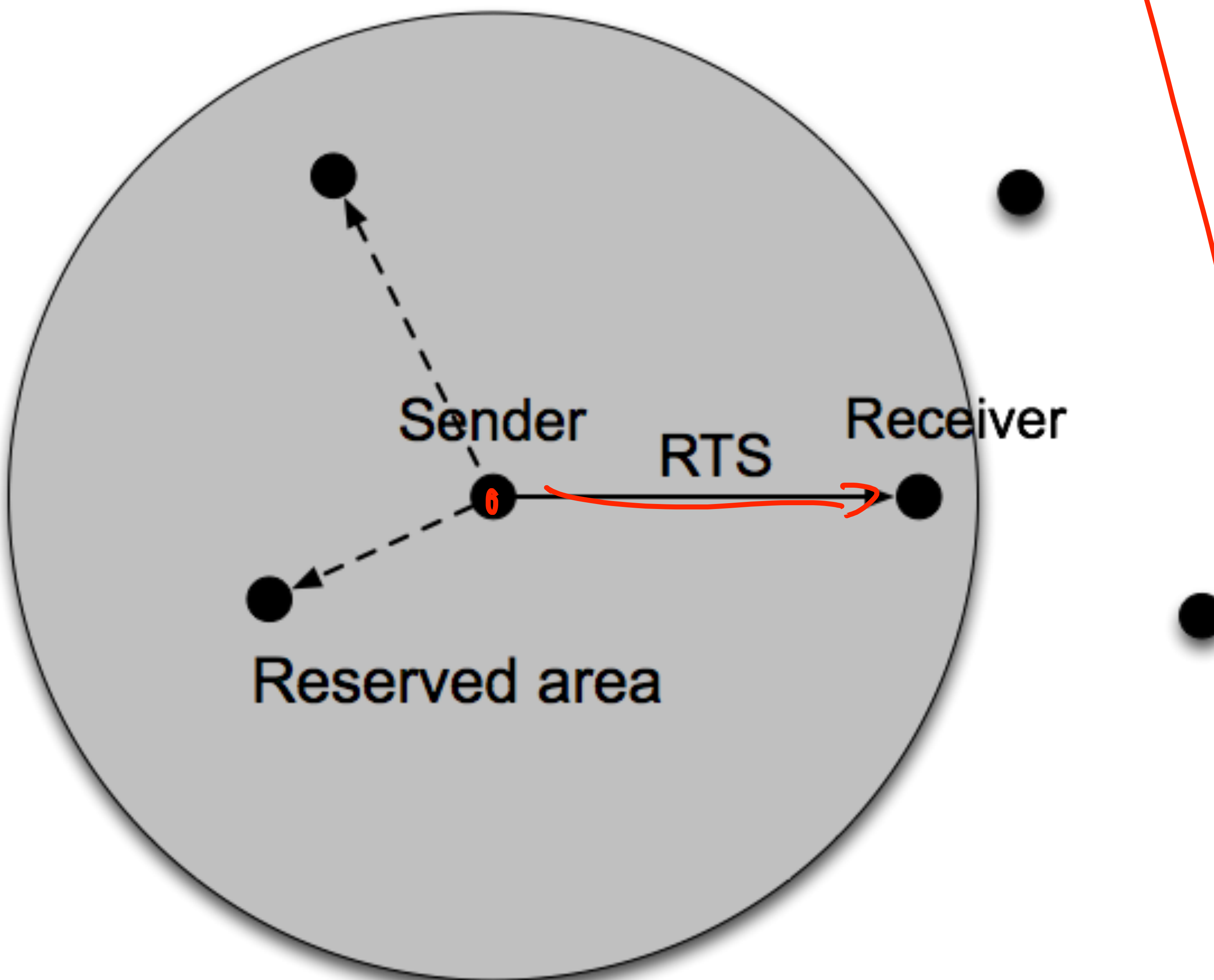
MACA 4-Handshake
RTS



802.15.4

WPAN

PAN

LAN

WAN

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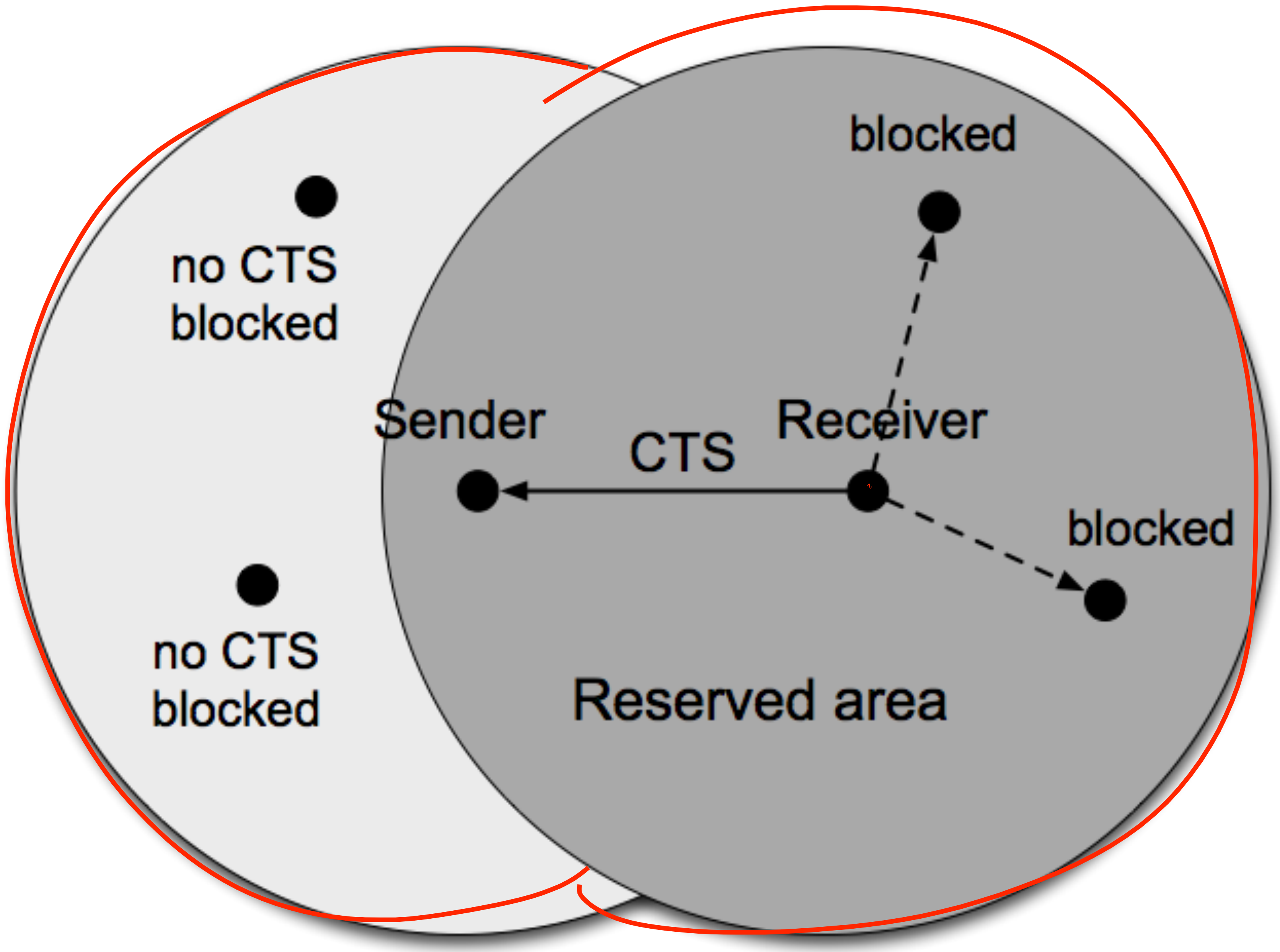
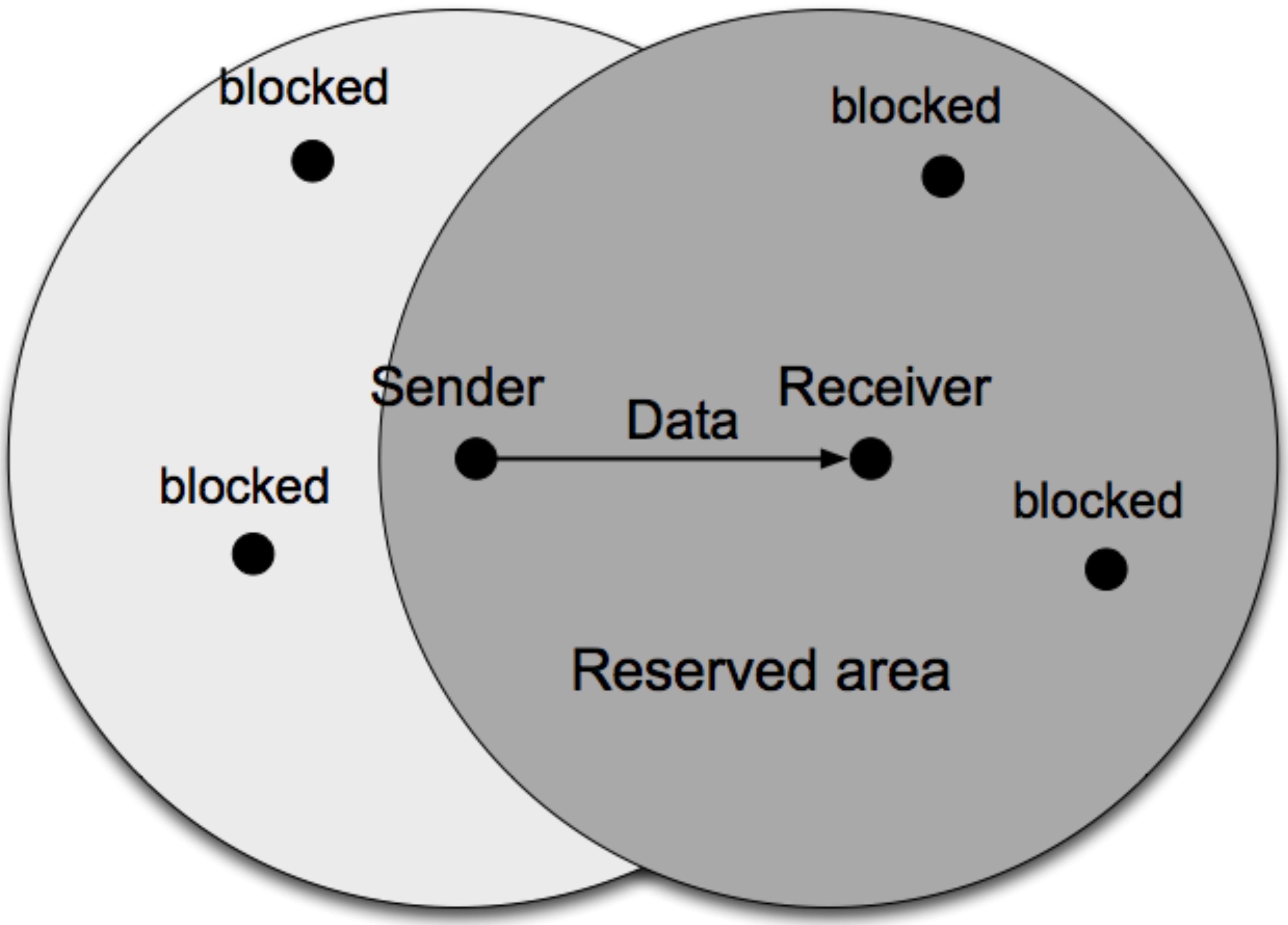
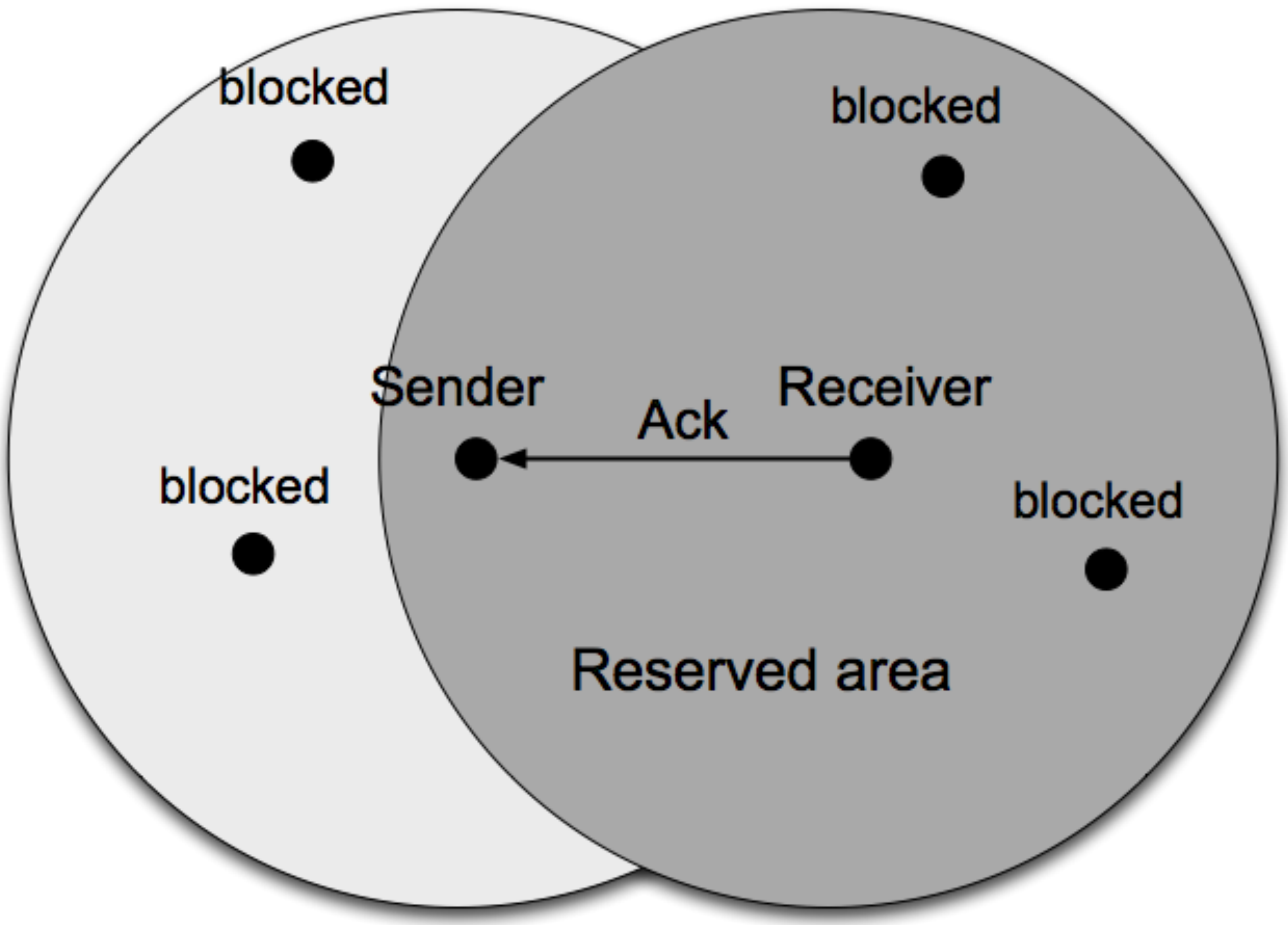
MACAW 4-Handshake
CTS



MACAW 4-Handshake
Data



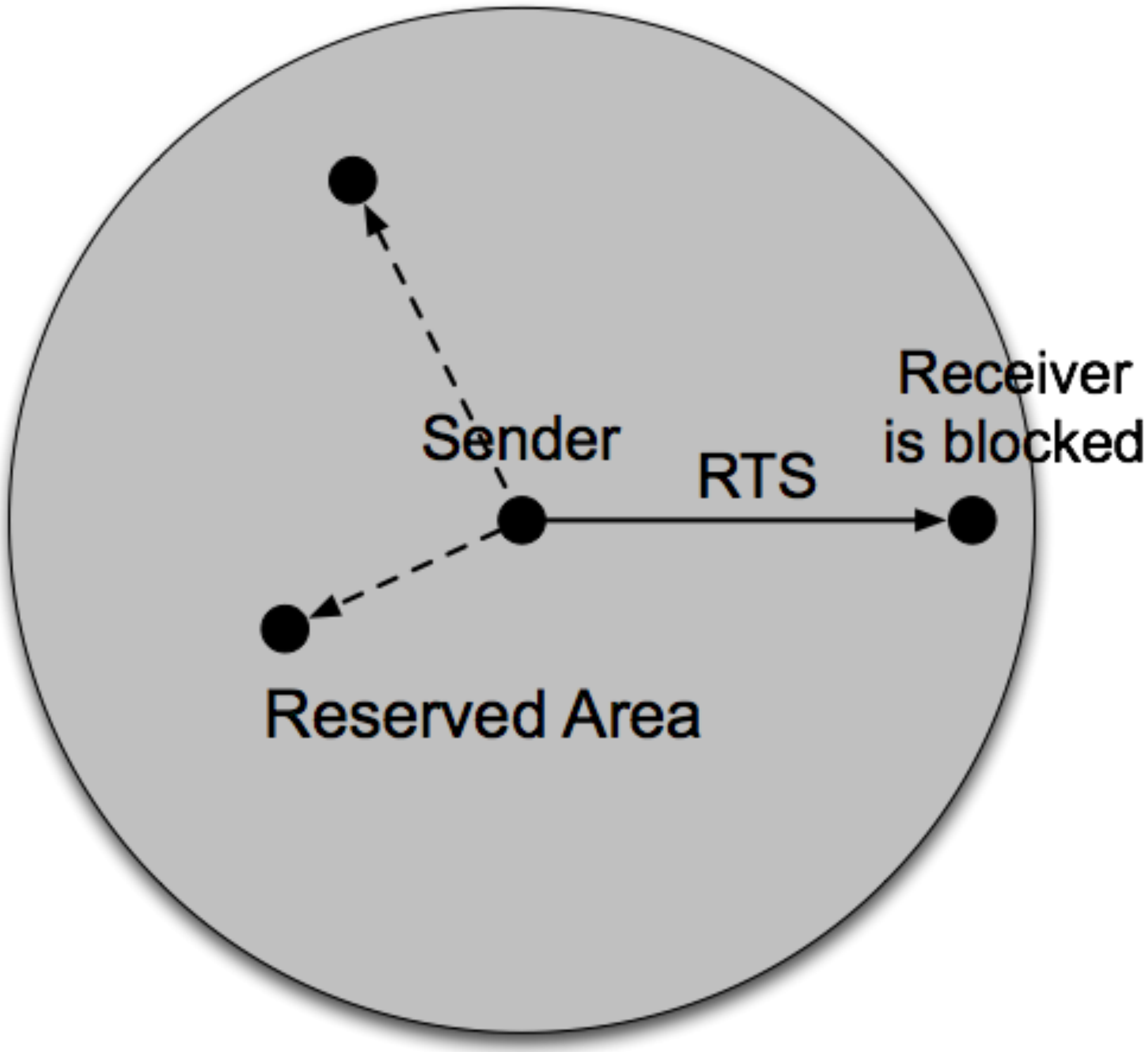
MACAW 4-Handshake
Ack



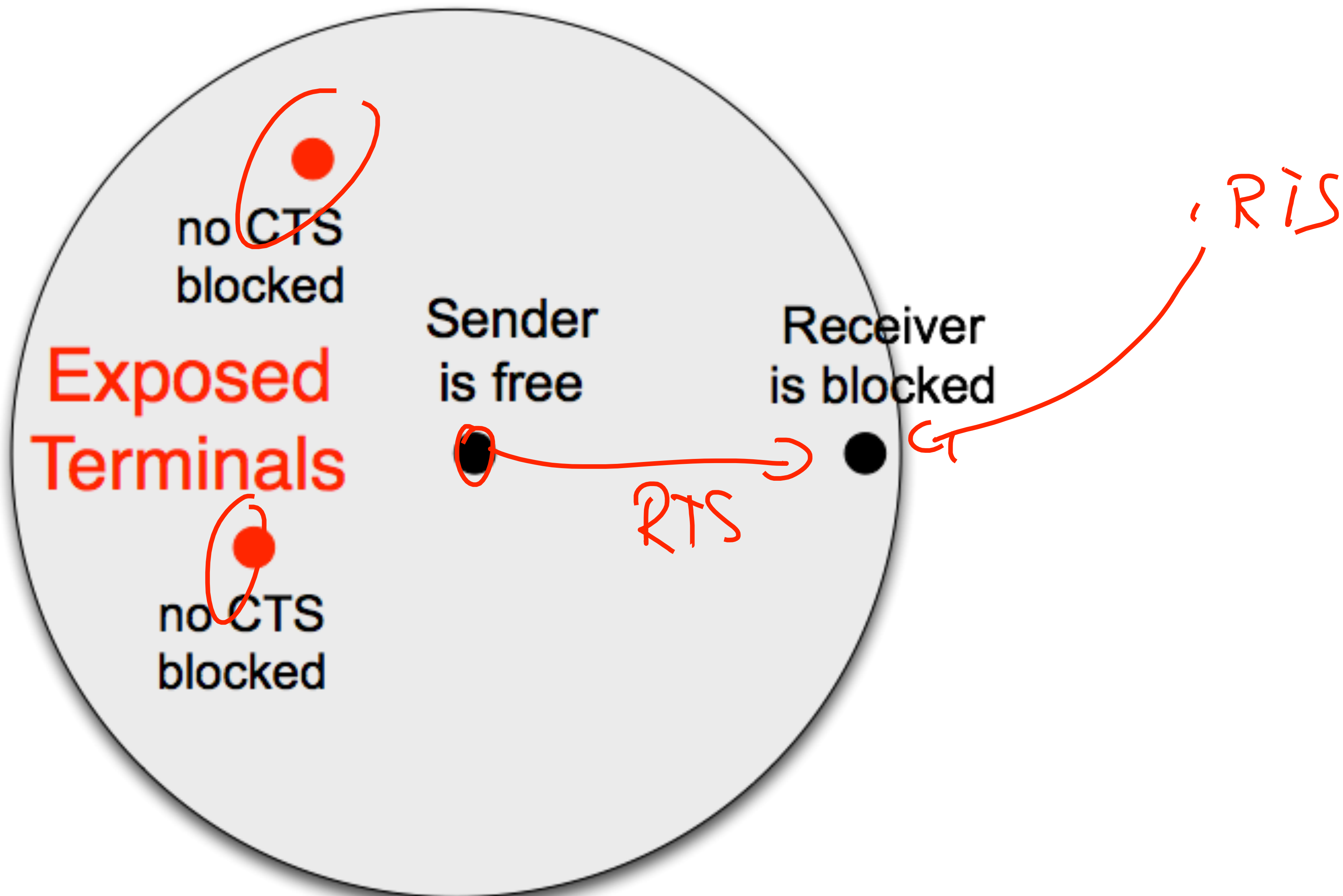
MACAW
4 Handshake

- Worst-Case blockade
  - Sender sends RTS
  - Receiver is blocked
  - Sender is free
  - But the environment of the sender is blocked

MACAW 4-Handshake
RTS



MACAW 4-Handshake
CTS is missing



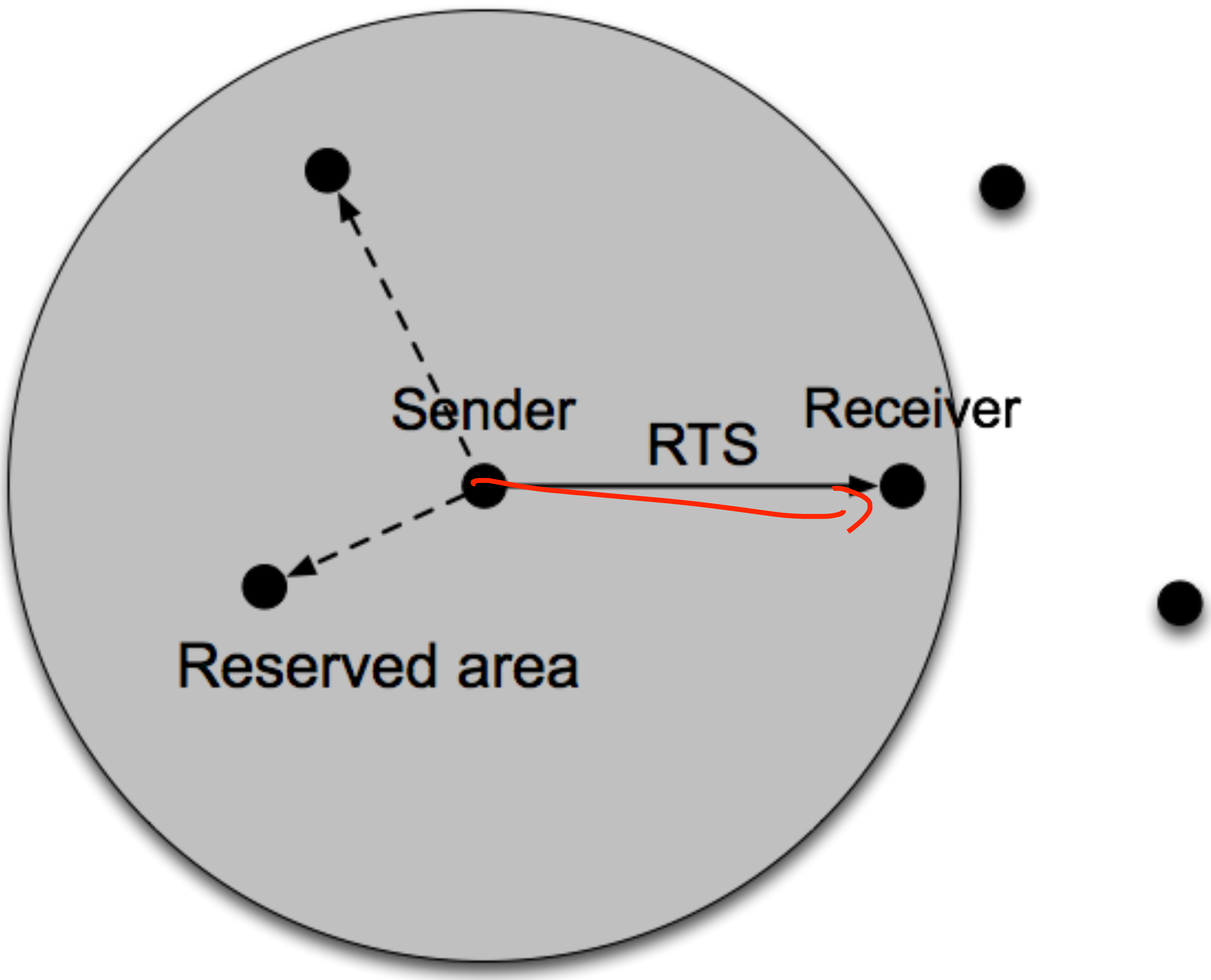
MACAW
5 Handshake

- 4-Handshake increases Exposed Terminal Problem
  - Overheard RTS blocks nodes
  - even if there is no data transfer
- Solution
  - Exposed Terminals are informed whether data transmission occurs
  - Short message DS (data send)
- 5 Handshake reduces waiting time for exposed terminals

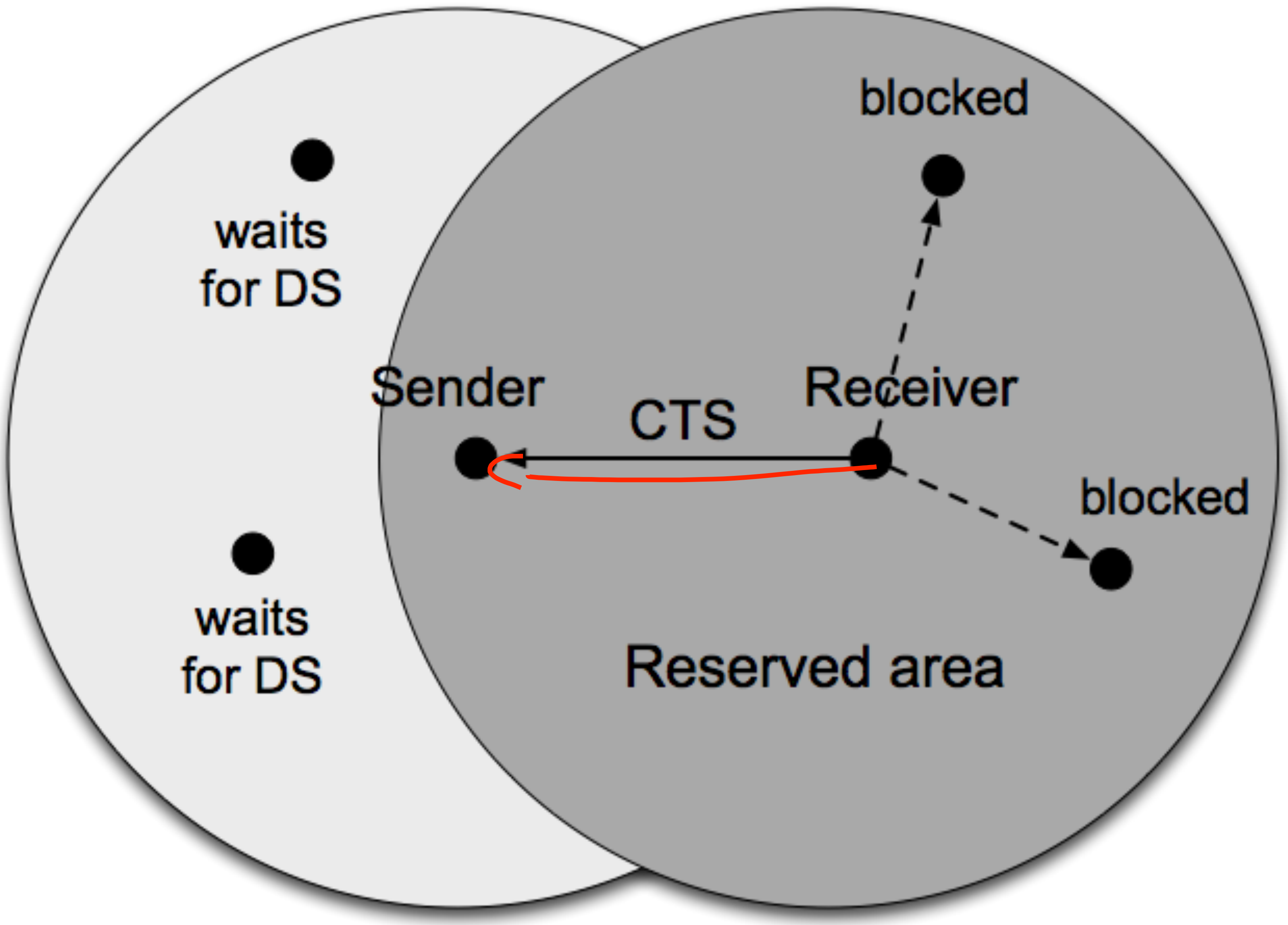
MACAW
5 Handshake

- Participants
  - Sender sends RTS
  - Receivers answers with CTS
  - Sender sends DS (Data Send)
  - Sender sends DATA PACKET
  - Receiver acknowledges (ACK)
- RTS and CTS announce the transmission duration
- Blocked nodes
  - have received RTS and DS
  - have received CTS
- Small effort decreases the number of exposed terminals

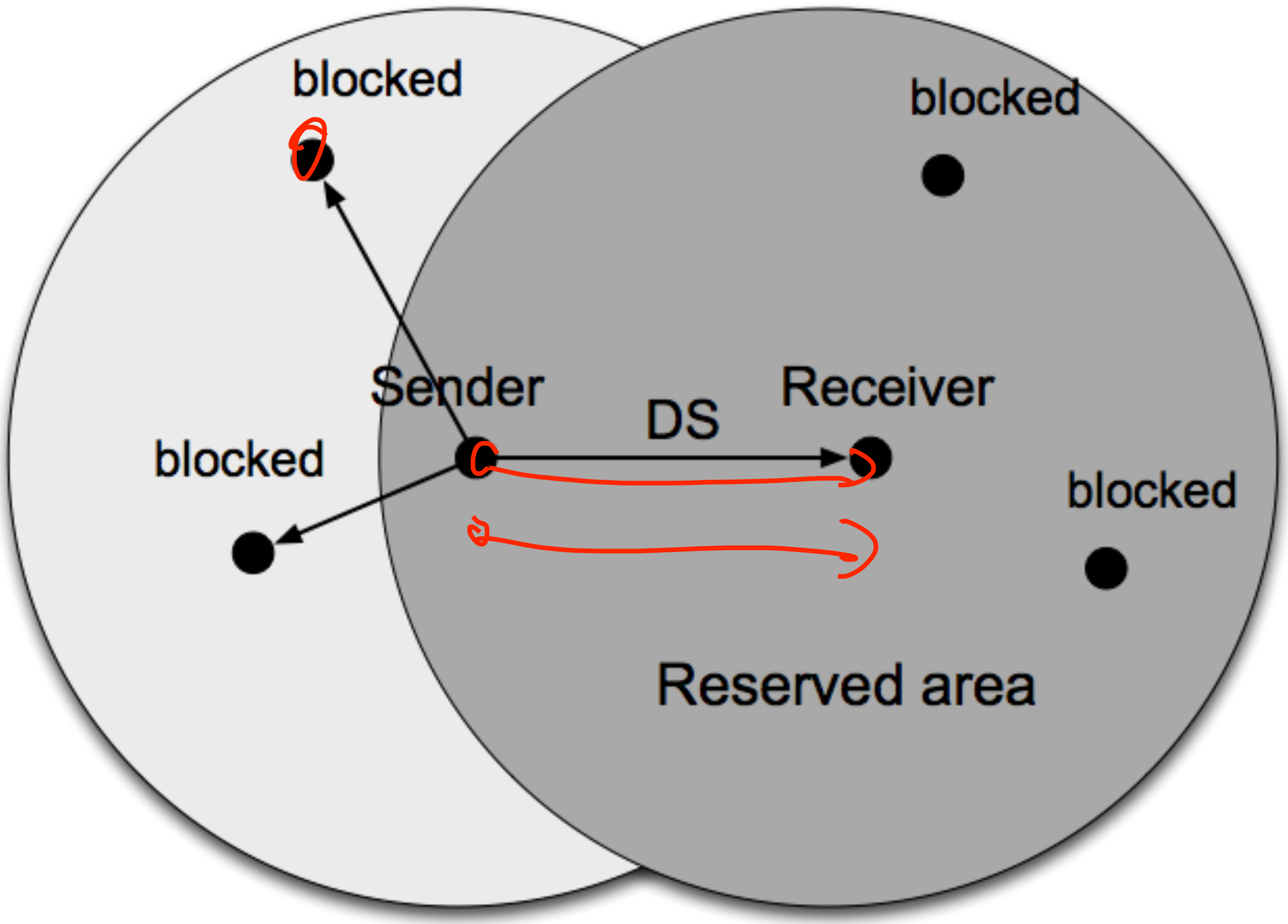
MACAW 5-Handshake
RTS



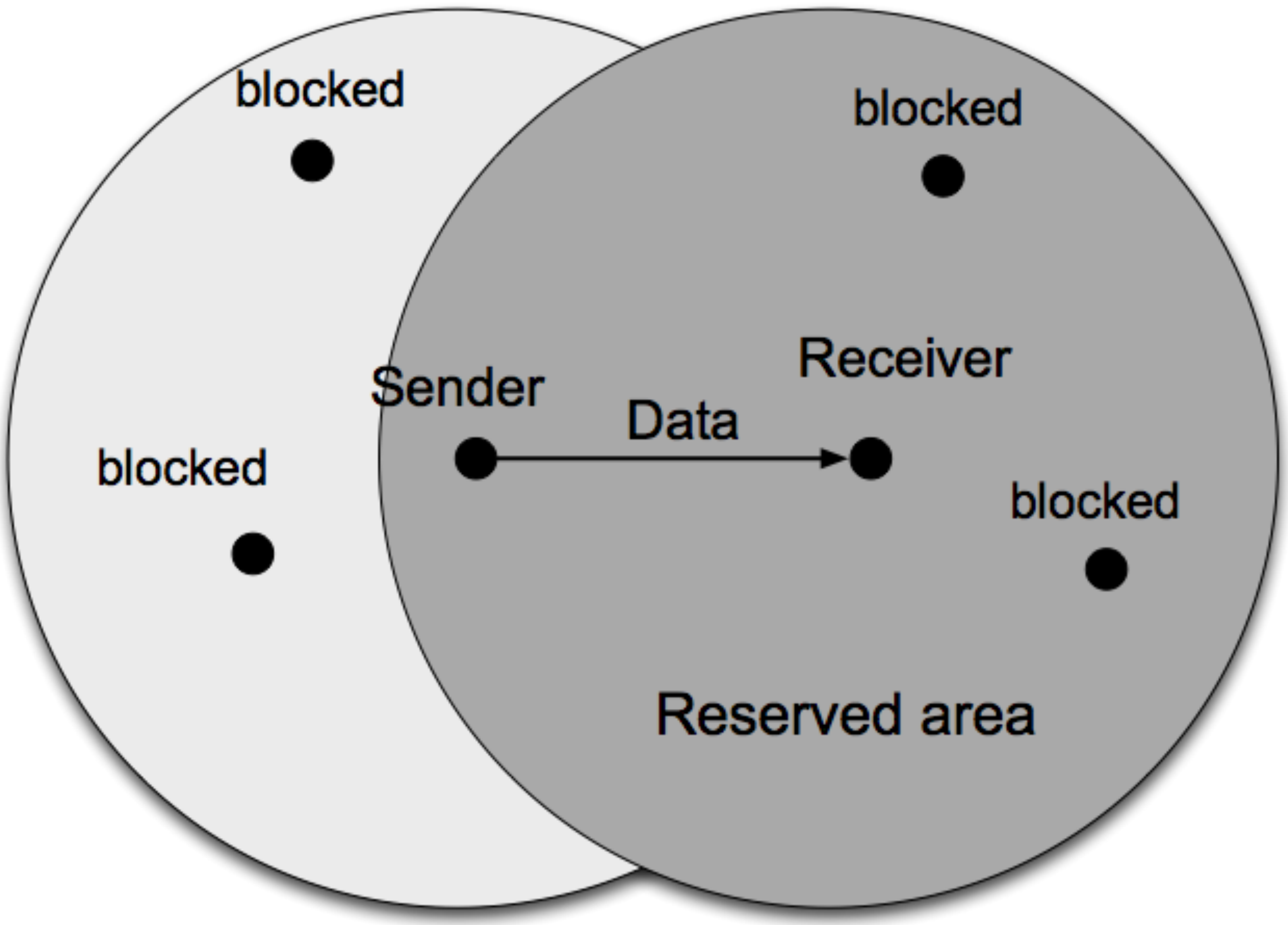
MACAW 5-Handshake
CTS



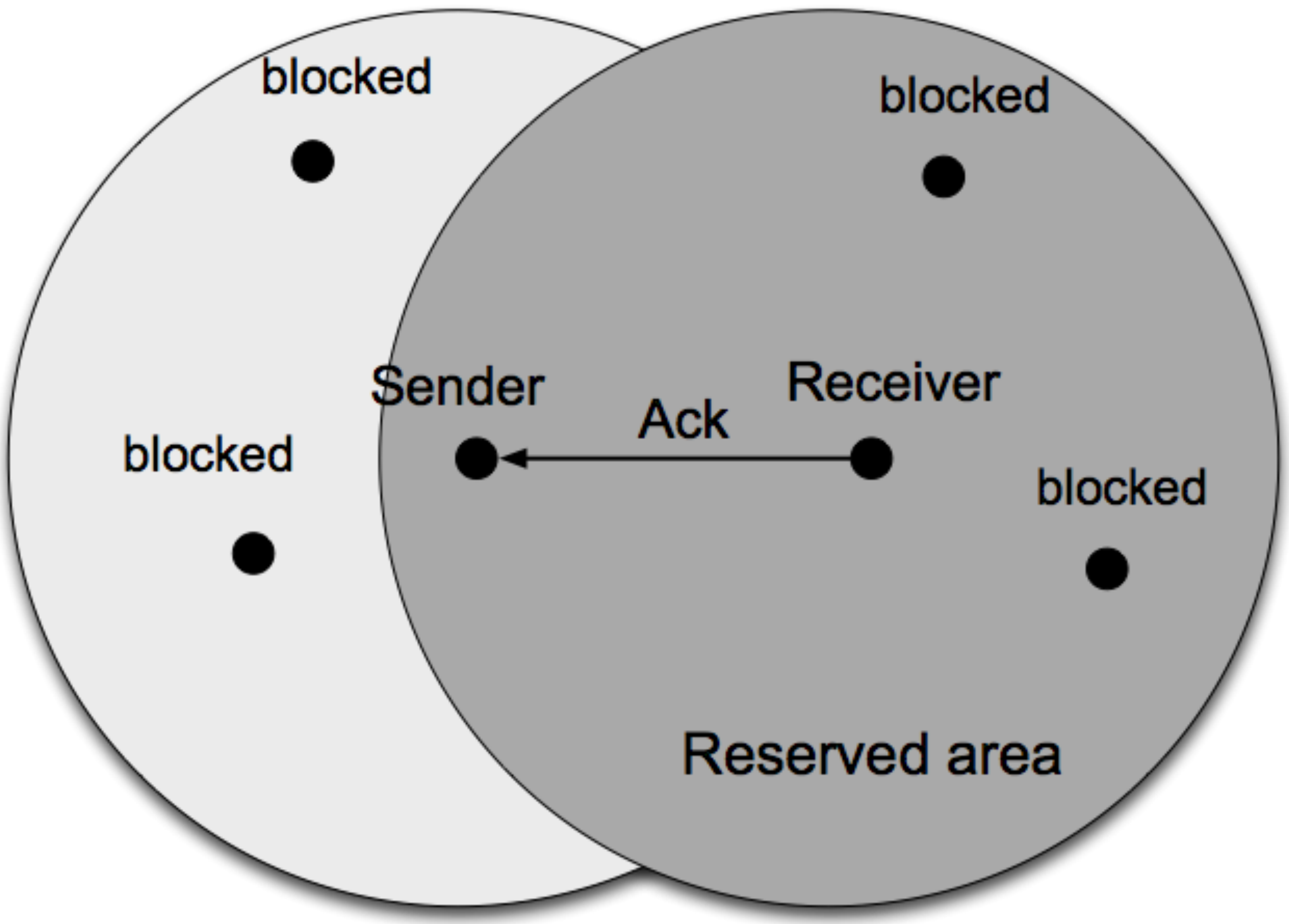
MACAW 5-Handshake
DS



MACAW 5-Handshake
Data

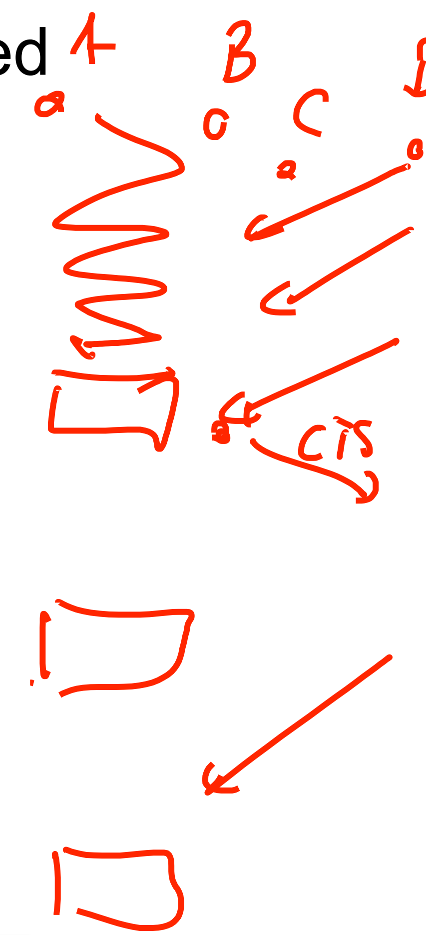


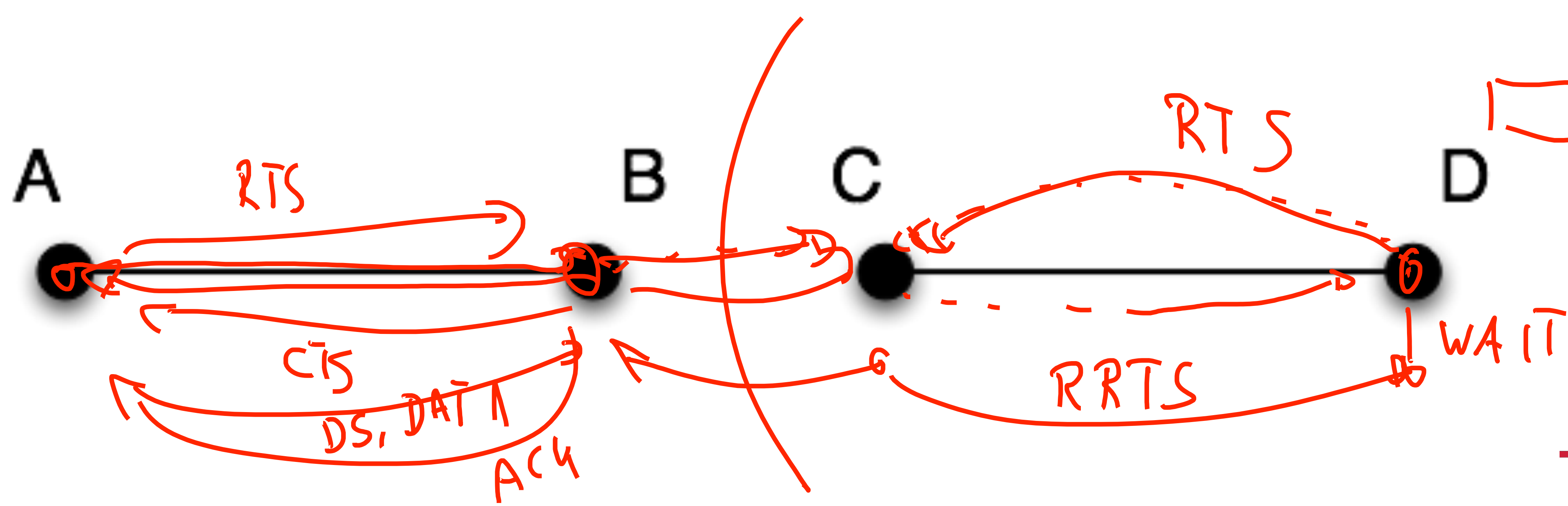
MACAW 5-Handshake ACK



Unfair Distribution

- 4 and 5-Handshake create unfair distribution
  - A has a lot of data for B
  - D has a lot of data for C
  - C receives B and D, but does not receive A
  - B can receive A and C, but does not hears D
- A is the first to get the channel
- D sends RTS and is blocked
  - Backoff of D is doubling
- At the next transmission
  - A has smaller backoff
  - A has higher chance for next channel access

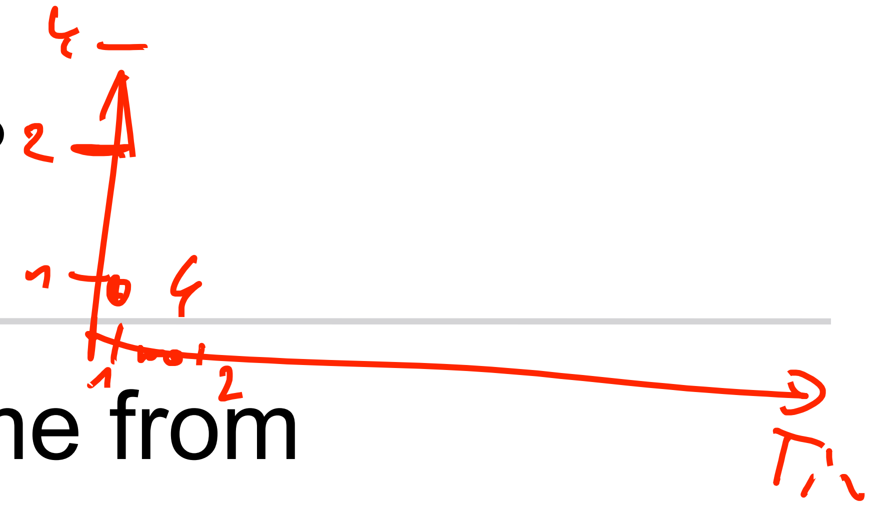




RRTS

- Solution
  - C sends RRTS (Request for Request to Send)
    - if ACK has been received
  - D sends RTS, etc.
- Why RRTS instead of CTS?
  - If neighbors receive CTS, then they are blocked for a long time
  - Possibly, D is not available at the moment

Backoff Algorithms

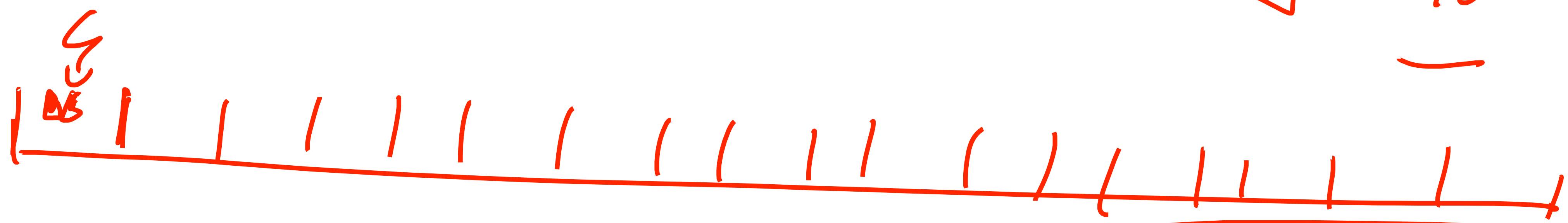


- After collision wait random time from {1,.. Backoff}
- Binary Exponential Backoff (BEB) algorithm
  - Increase after collision
    - backoff = min{2 backoff, maximal backoff}
  - Else:
    - backoff = Minimal Backoff
- Multiplicative increase, linear decrease (MILD)
  - Increase:
    - backoff = min{1.5 backoff, maximal backoff}
  - Else:
    - backoff = max{backoff - 1, minimal-backoff}

$n = 10$ participants

p : Prob. Send

$p = \frac{1}{n} = \frac{1}{10}$



0 Messages : $(1-p)^n$

1 Message : $n \cdot p(1-p)^{n-1}$

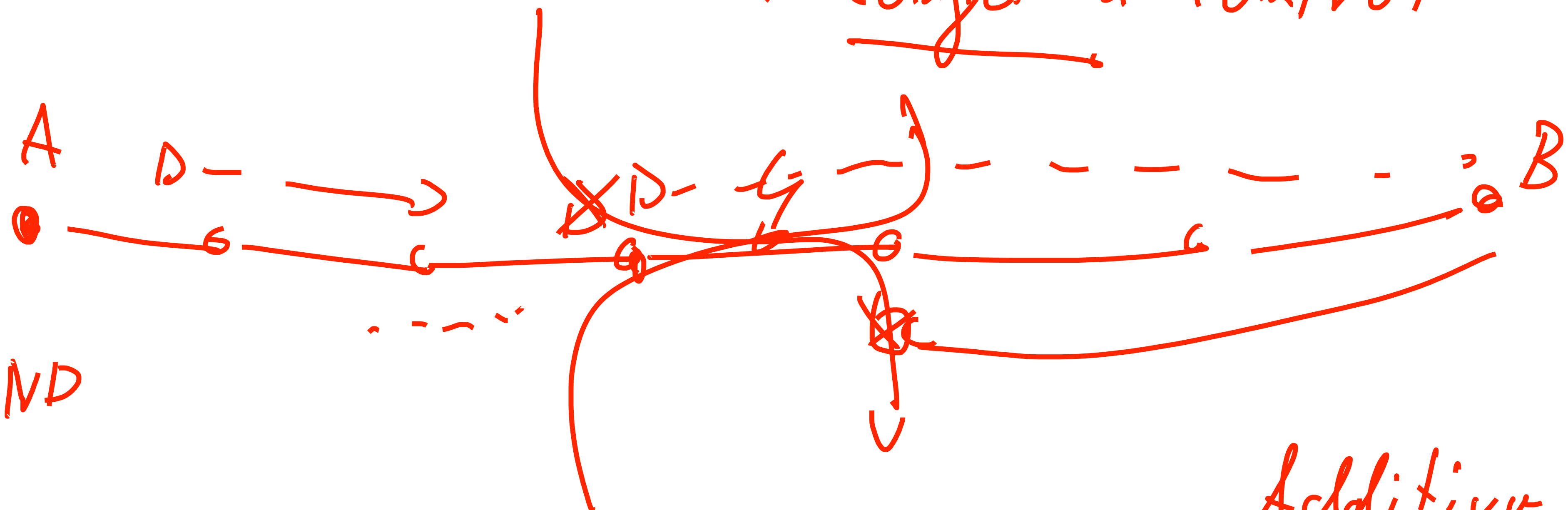
≥ 1 Mess : $1-(1-p)^n - n \cdot p(1-p)^{n-1}$

$f(p) = n \cdot p(1-p)^{n-1}$

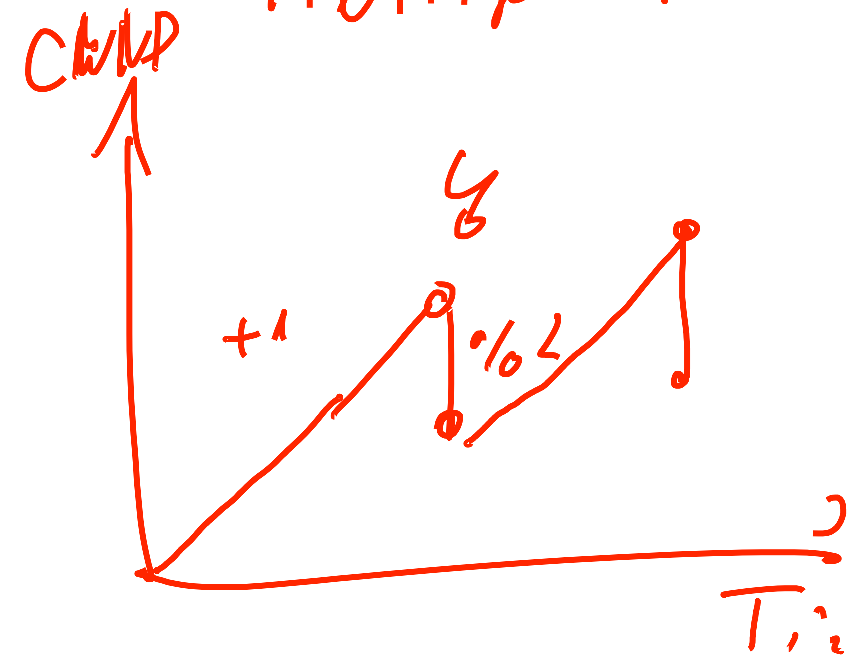
$\max_p f(p)$

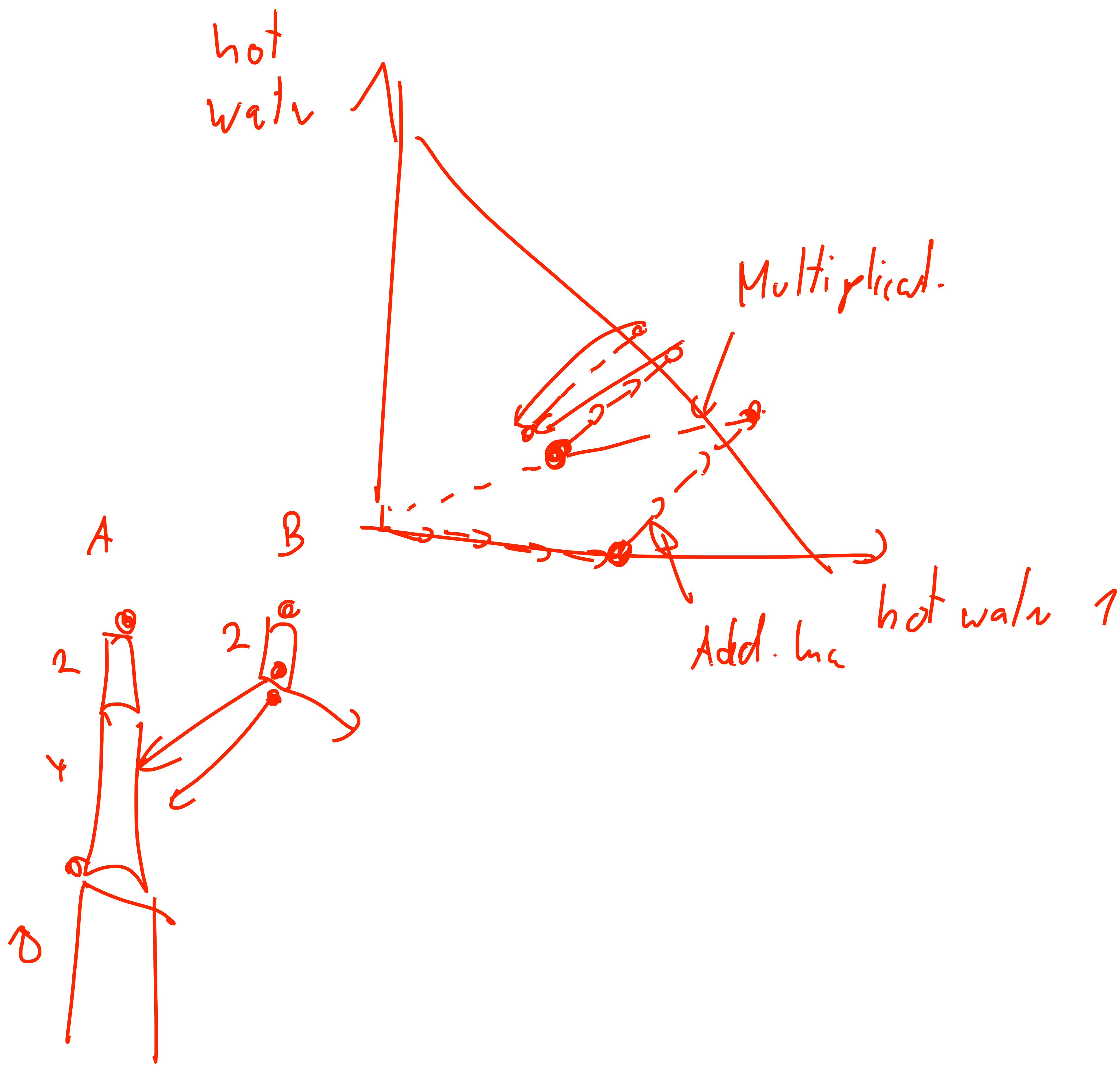
AIMD → TCP

↳ Congestion Control



Additive Incr.
Multipl. Decr.




hot water
Multiplicat.
A
B
Add. Inc
hot water 1
2
2
4
0

Information Dissemination for Backoff-Algorithm

- Backoff parameter are overheard
  - participants adapt the parameters to the overheard backoff values
  - using MILD
- Motivation
  - if a participant has the same backoff value, then the fairness has been reached

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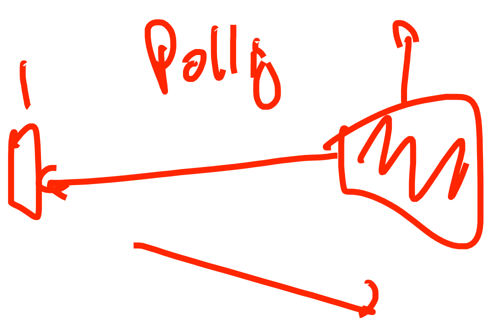
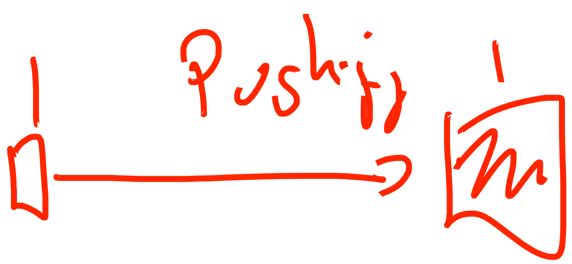
Media ACcess
MAC

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





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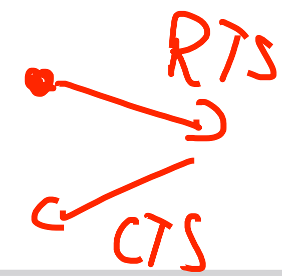
MACA and WSN

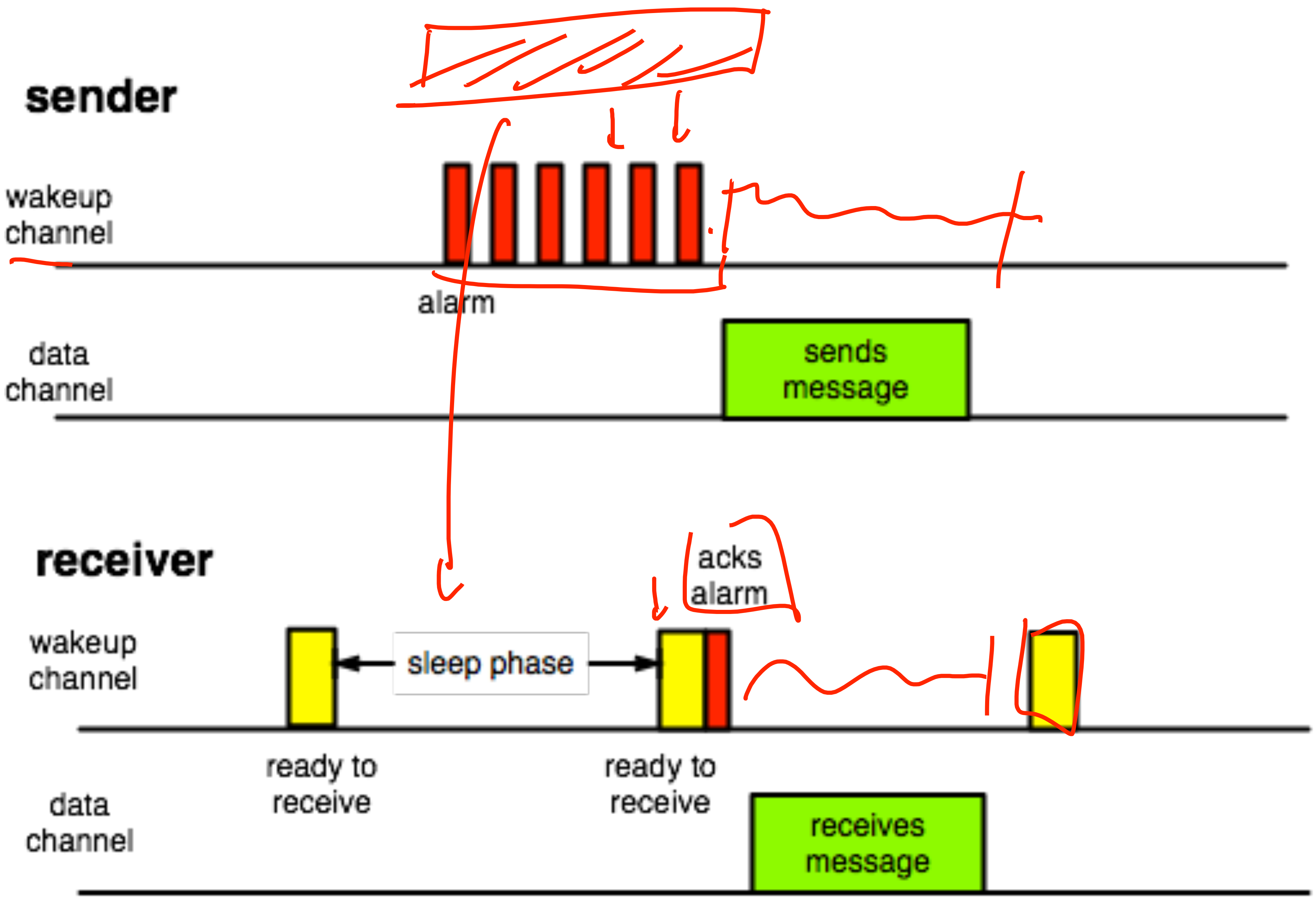


- MACA:
  - Channel must be monitored for RTS and CTS
  - Nodes waking up can disrupt existing communications
- Solution in IEEE 802.11:
  - Announcement Traffic Indication Message (ATIM)
    - prevents receiver from starting a sleep cycle
    - informs about upcoming packages
    - is sent within the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

STEM

- Schurgers, Tsiatsis, Srivastava
  - STEM: Topology 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

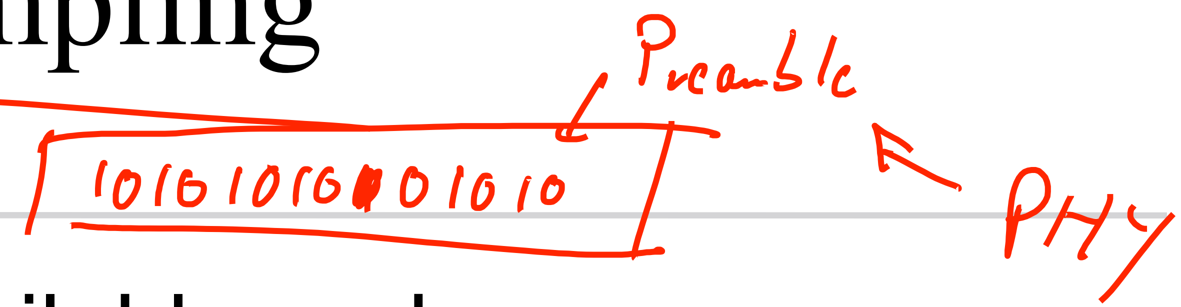
Discussion STEM

- 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

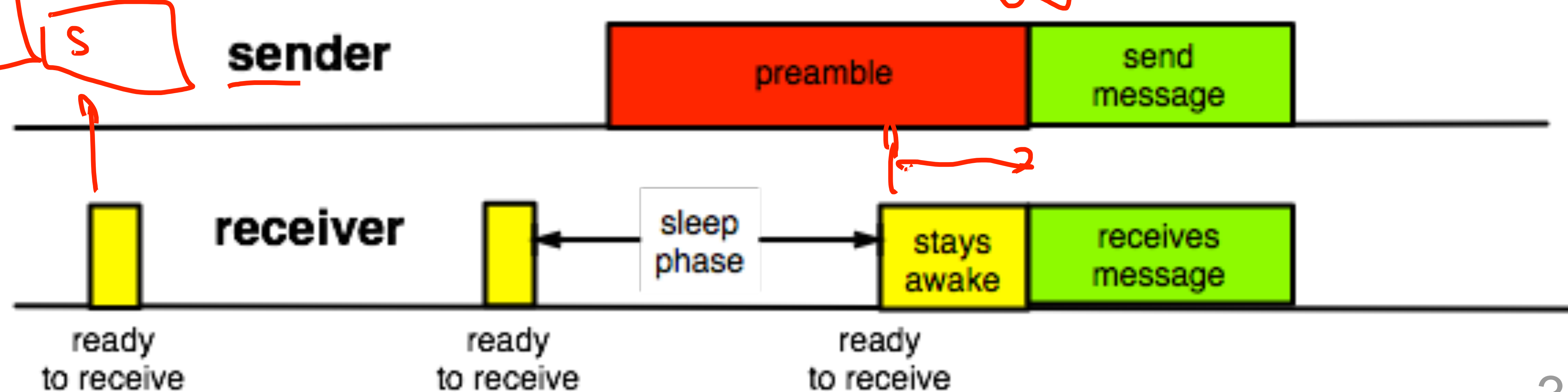
Preamble Sampling



- 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

- Only one channel available, no synchronization
- Receiver
  - is awake after sleep period
  - listens channel for messages from
- Transmitter
  - sends long preamble
  - and then the package



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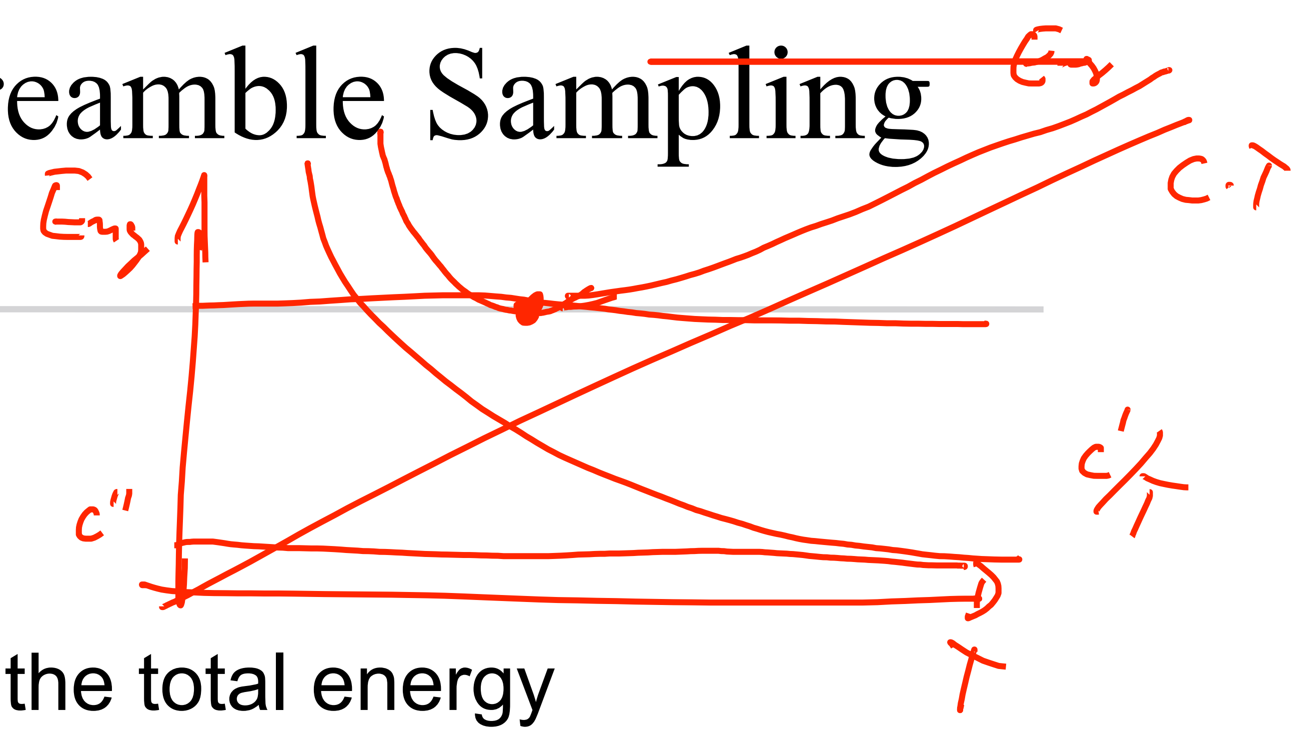
Efficiency of Preamble Sampling



- 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'':

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

$$\frac{d\,E(T)}{dT} = c - \frac{c'}{T^2} = 0$$

$$\sqrt{\frac{c}{c'}} = T$$

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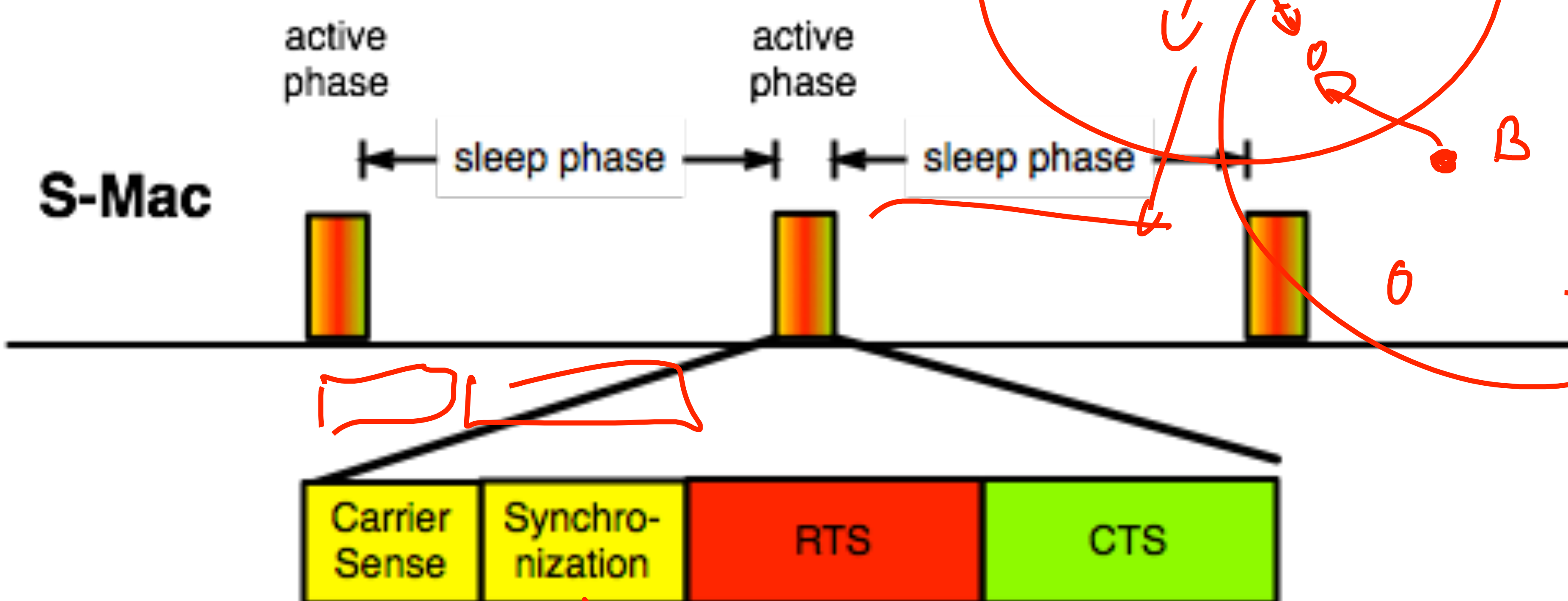
Sensor-Mac (S-MAC)

- 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

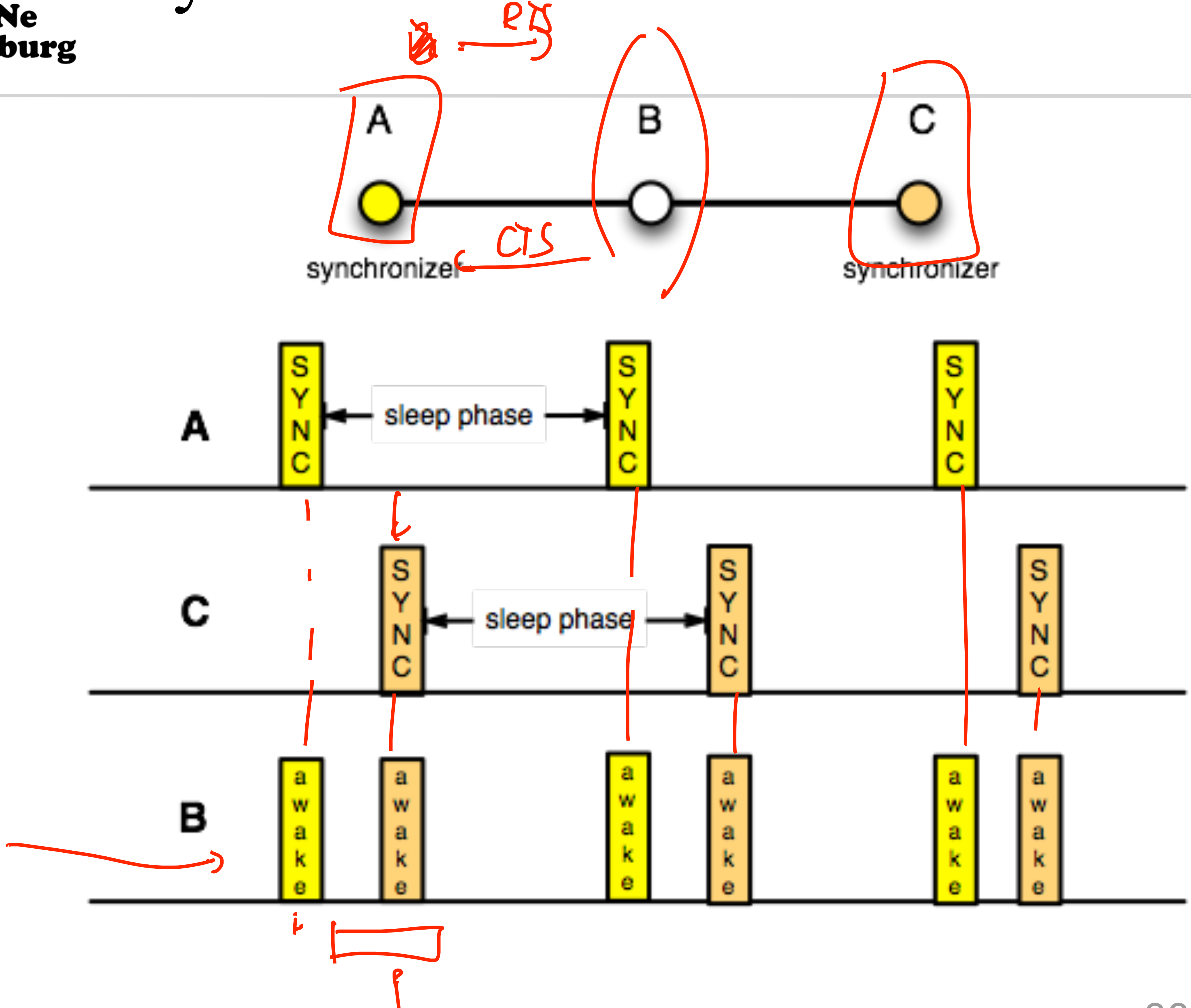
- Active phase
  - Carrier Sensing
  - Send Sync packet synchronizer short sleep duration with ID and
  - Interval for Request to Send (RTS)
  - Interval for Clear-to-Send (CTS)



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

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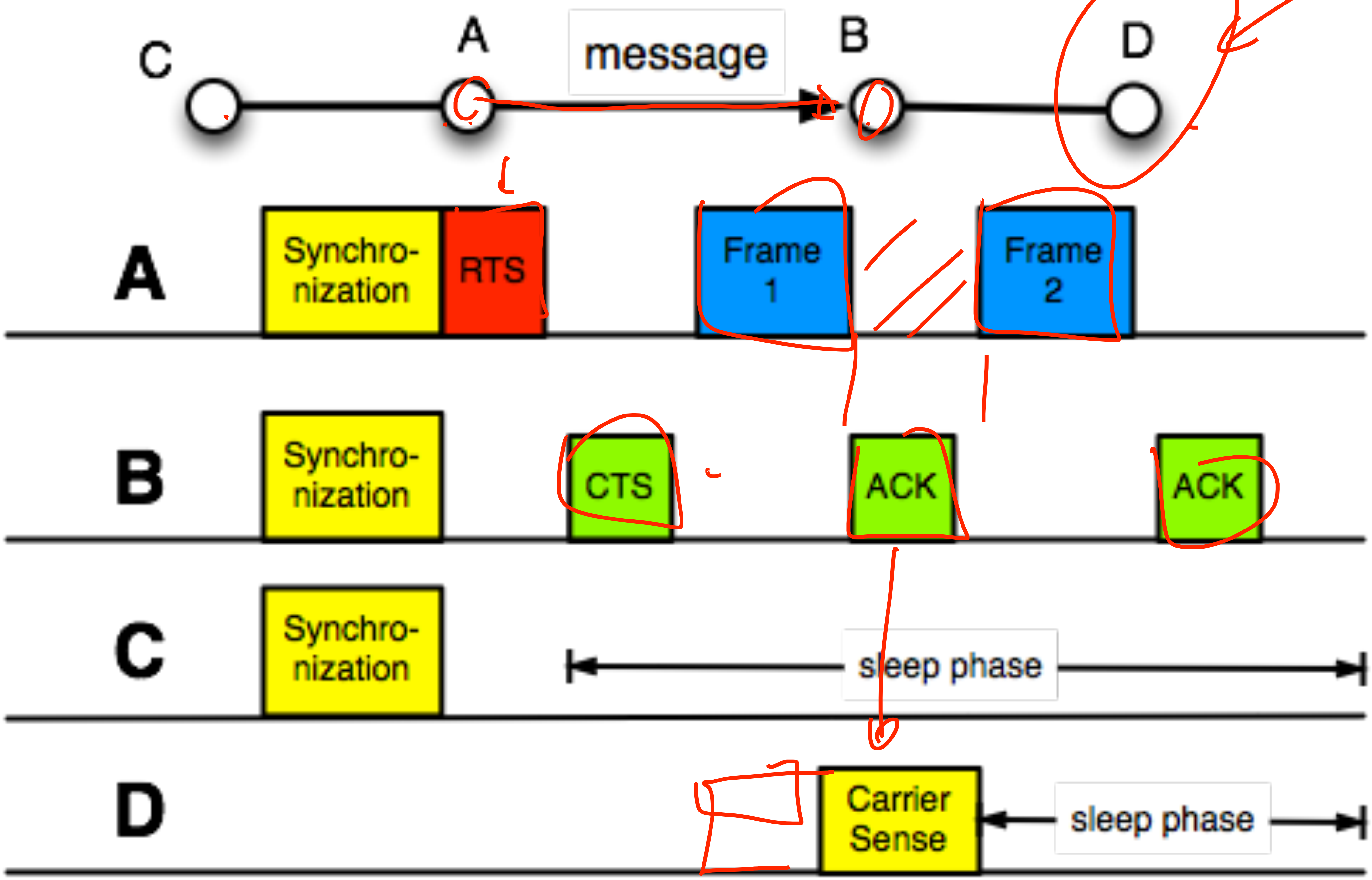
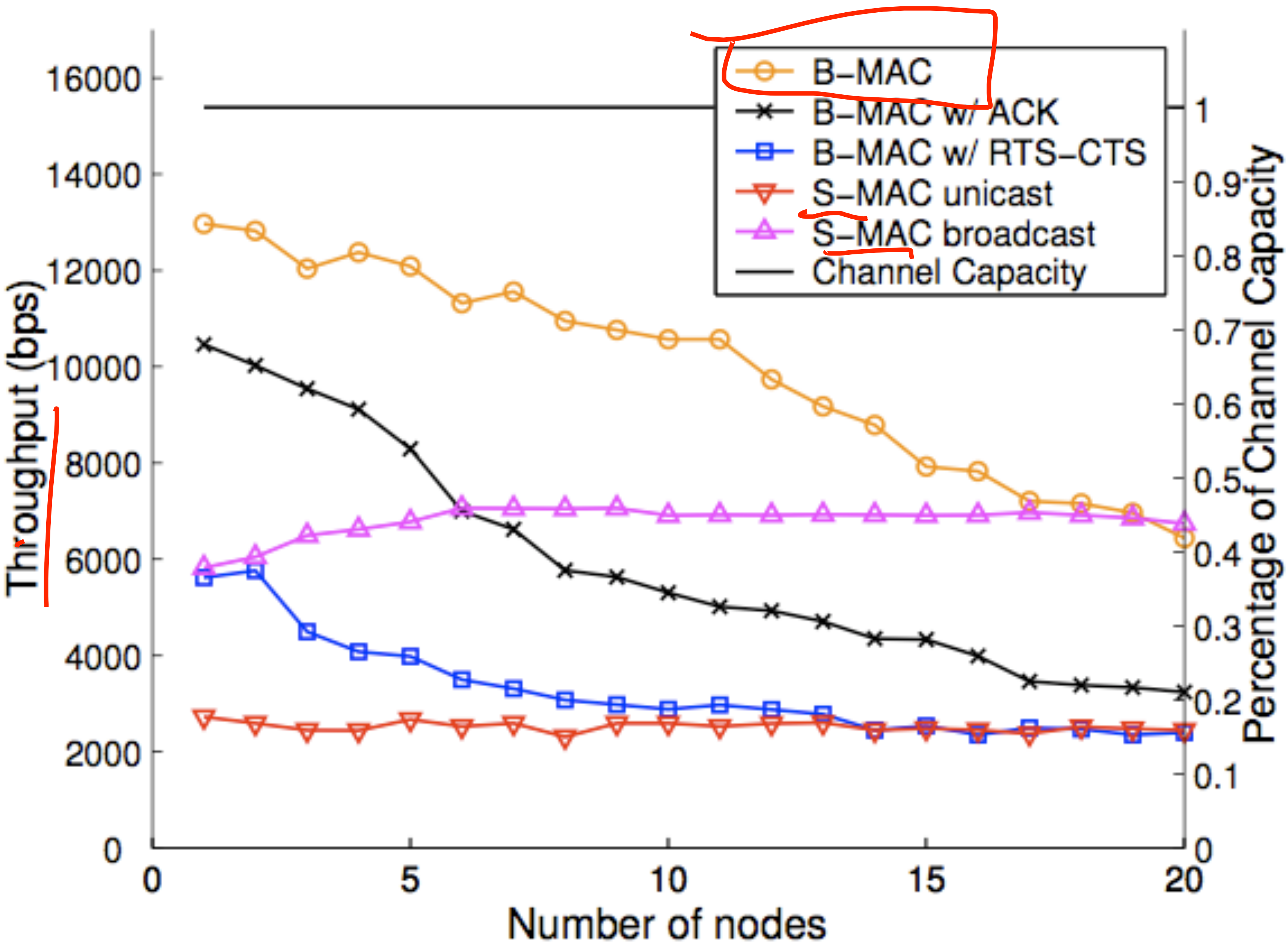
Message Transmission
S-MAC



Throughput



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