Wireless Sensor Networks
4. Medium Access

Christian Schindelhauer
Technische Fakultät
Rechnernetze und Telematik
Albert-Ludwigs-Universität Freiburg
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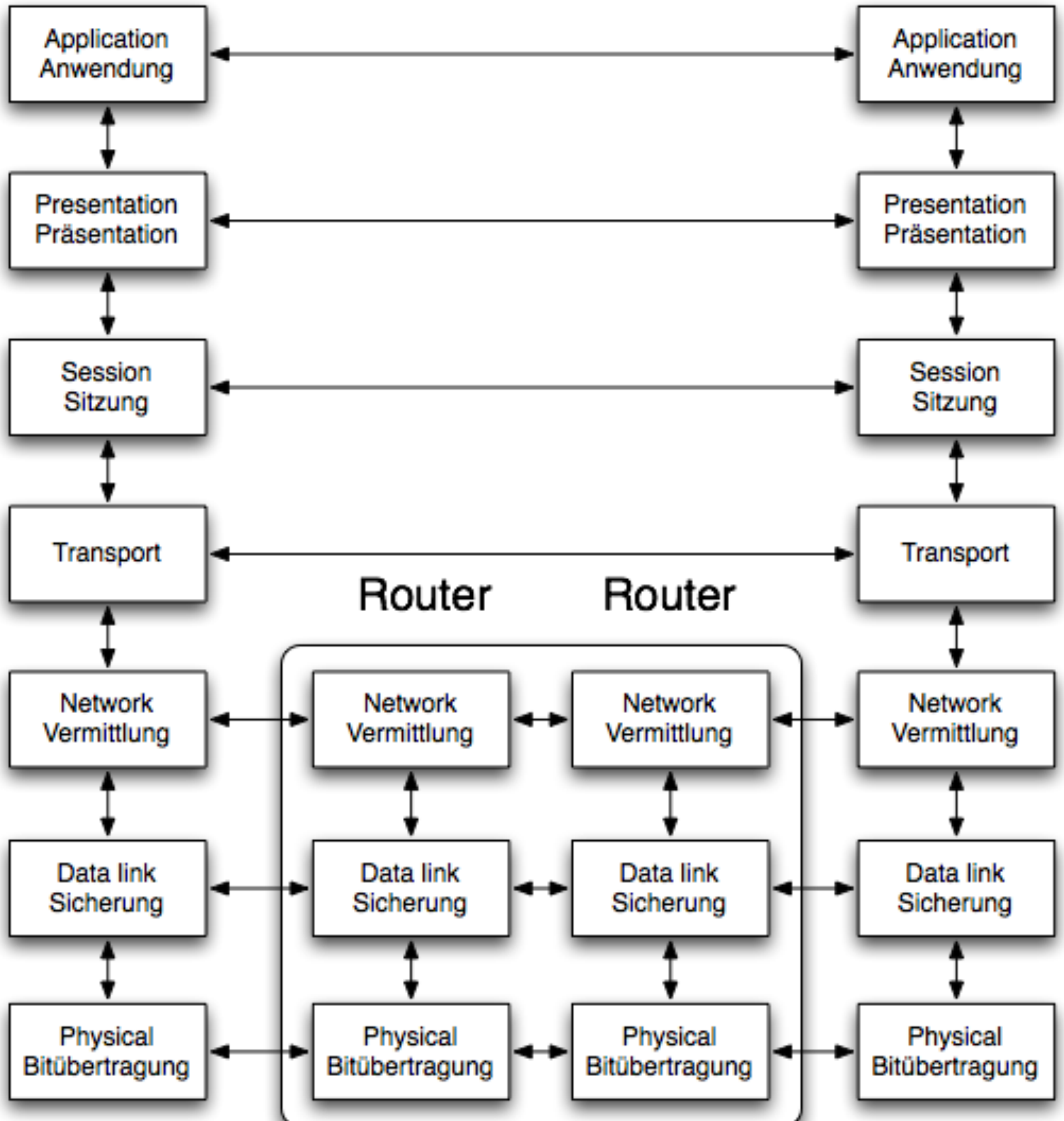
ISO/OSI Reference model

- 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



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Types of Conflict Resolution

- Conflict-free
  - TDMA, Bitmap
  - FDMA, CDMA, Token Bus
- Contention-based
  - Pure contention
  - Restricted contention
- Other solutions
  - z.B. MAC for directed antennae

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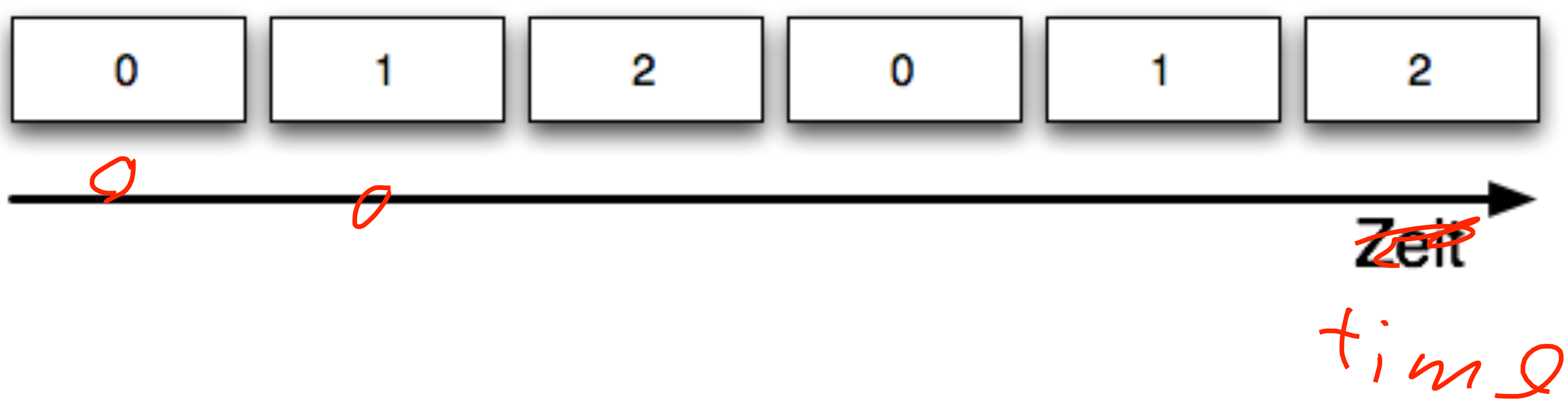
Contention Free Protocols

- Simple Example: Static Time Division Multiple Access (TDMA)
  - Each station is assigned a fixed time slot in a repeating time schedule
  - *Traffic-Bursts* cause waste of bandwidth



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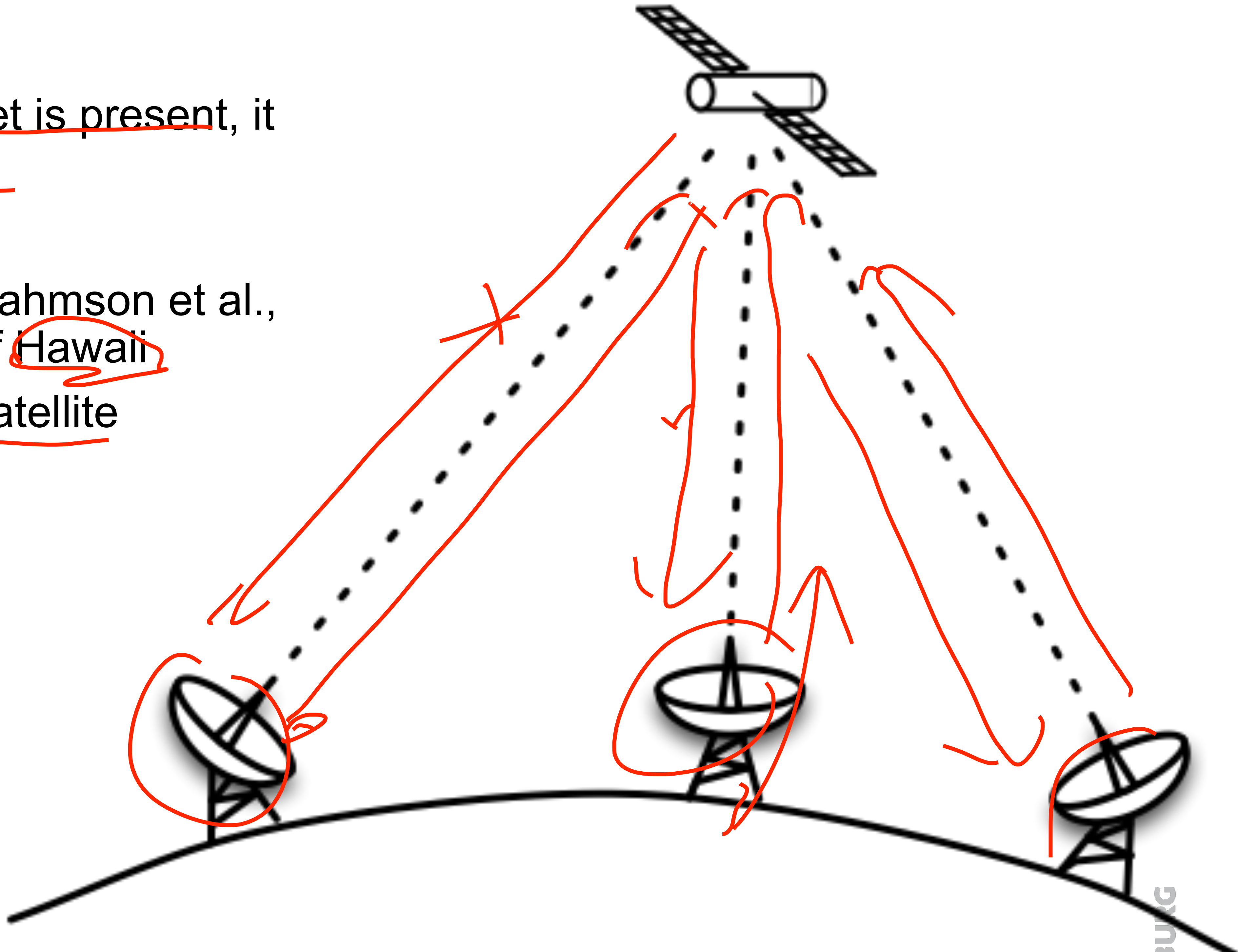
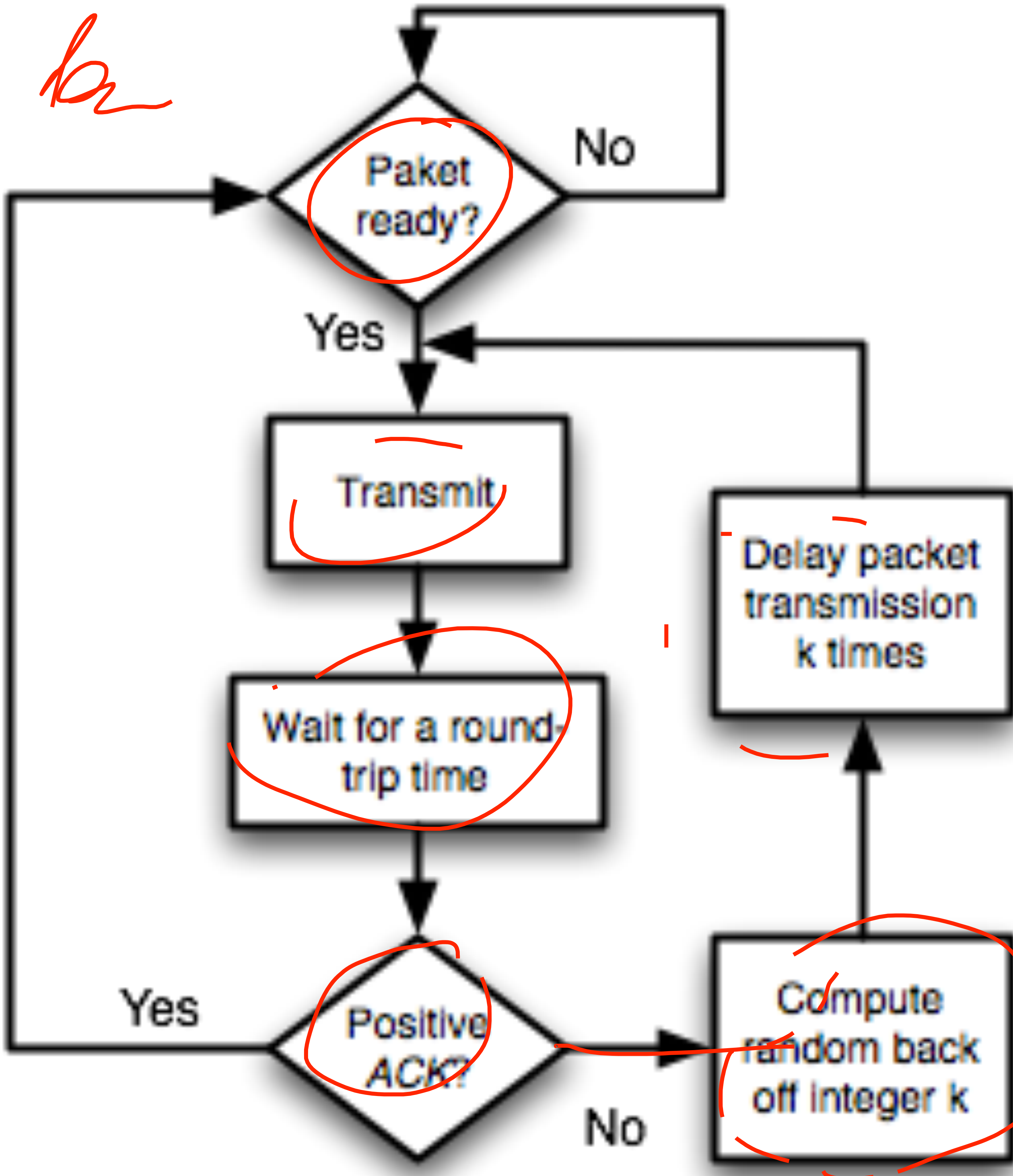
Bitmap Protokoll

- Problems of TDMA
  - If a station has nothing to send, then the channel is not used
- Reservation system: bitmap protocol
  - Static short reservation slots for the announcement
  - Must be received by each station
- Problem
  - Set of participants must be fixed and known a-priori
  - because of the allocation of contention slots

ALOHA

- Algorithm
  - Once a paket is present, it will be sent
- Origin
  - 1985 by Abrahmson et al., University of Hawaii
  - For use in satellite connections



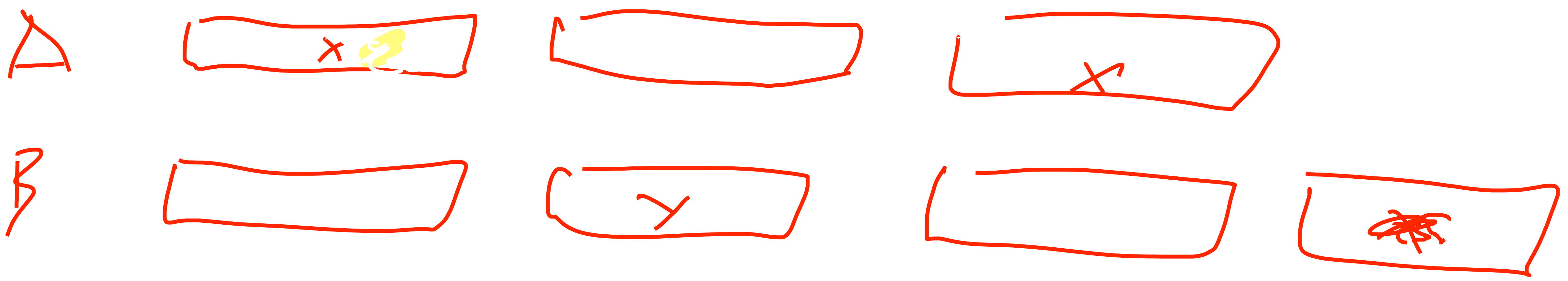

Paket ready?
No
Yes
Transmit
Delay packet transmission k times
Wait for a round-trip time
Yes
Positive ACK?
No
Compute random back off integer k

ALOHA – Analysis

- Advantage
  - simple
  - no coordination necessary
- Disadvantage
  - collisions
    - sender does not check the channel
  - sender does not know whether the transmission will be successful
    - ACKs are necessary
    - ACKs can also collide

ALOHA – Efficiency

- Consider Poisson-process for generation of packets
  - describe “infinitely” many stations with similar behavior
  - time between two transmission is exponentially distributed
  - let G be the expectation of the transmission per packet length
  - all packets have equal length
  - Then we have $$P[k \text{ transmissions}] = \frac{G^k}{k!} e^{-G}$$
- For a successful transmission, no collision with another packet may happen
  - How probable is a successful transmission?


A
x
x
B
y

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Prob p

k senders : p^k

n-k senders : $(1-p)^{n-k}$

more

Prob k messages $= p^k \cdot (1-p)^{n-k}$

$$\frac{n(n-1)(n-2)\dots(n-k+1)}{k!} = \frac{n!}{k!(n-k)!} = \binom{n}{k}$$

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$n \to \infty$

fix a random message

X_n

$$P[X_n = k] = p^n \cdot (1-p)^{n-k} \binom{n}{k}$$

$$E[X] = \sum_{k=1}^{n} P[X=k] \cdot k$$

$$E[X_1 + X_2] = E[X_1] + E[X_2]$$

1	2	3	4	5	6
$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$

$$\frac{1}{6} + \frac{2}{6} + \frac{3}{6} + \frac{4}{6} + \frac{5}{6} + \frac{6}{6}$$

$$3 \cdot \frac{7}{6} = 3{,}5$$

$$E[X_n] = n \cdot E[X_1] = pn$$

$$n\, p^1 \underbrace{(1-p)^{1-1}}_{1} \cdot \underbrace{\binom{1}{1}}_{1} = p$$

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Fix expectation $n \to \infty$

$\lambda = E[X] = n \cdot p \qquad p = \frac{\lambda}{n}$

$P[X = k] = p^k \cdot (1-p)^{n-k} \binom{n}{k}$

$= \left(\frac{\lambda}{n}\right)^k \cdot \left(1 - \frac{\lambda}{n}\right)^{n-k} \frac{n \cdot (n-1) \cdots (n-k+1)}{k!}$

$= \frac{\lambda^k}{k!} \underbrace{\left(1 - \frac{\lambda}{n}\right)^{\frac{n}{\lambda} \lambda}}_{\infty} \left(\frac{n \cdot (n-1) \cdots (n-k+1)}{n \cdot n \cdots n}\right)$

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$$\lim_{m \to \infty} \left(1 - \frac{1}{m}\right)^m = \frac{1}{e}$$

$$= \frac{\lambda^k}{k!} \left(\frac{1}{e}\right)^{\frac{\lambda}{n} \cdot (n-k)} \qquad \frac{n}{n} \cdot \frac{n-1}{n} \cdots \frac{n-k+1}{n} \;\; (\to 1)$$

$$= \frac{\lambda^k}{k!} \left(\frac{1}{e}\right)^{\lambda - \frac{\lambda \cdot k}{n}}, \qquad \frac{\lambda \cdot k}{n} \to 0$$

$$= \frac{\lambda^k}{k!} e^{-\lambda}$$

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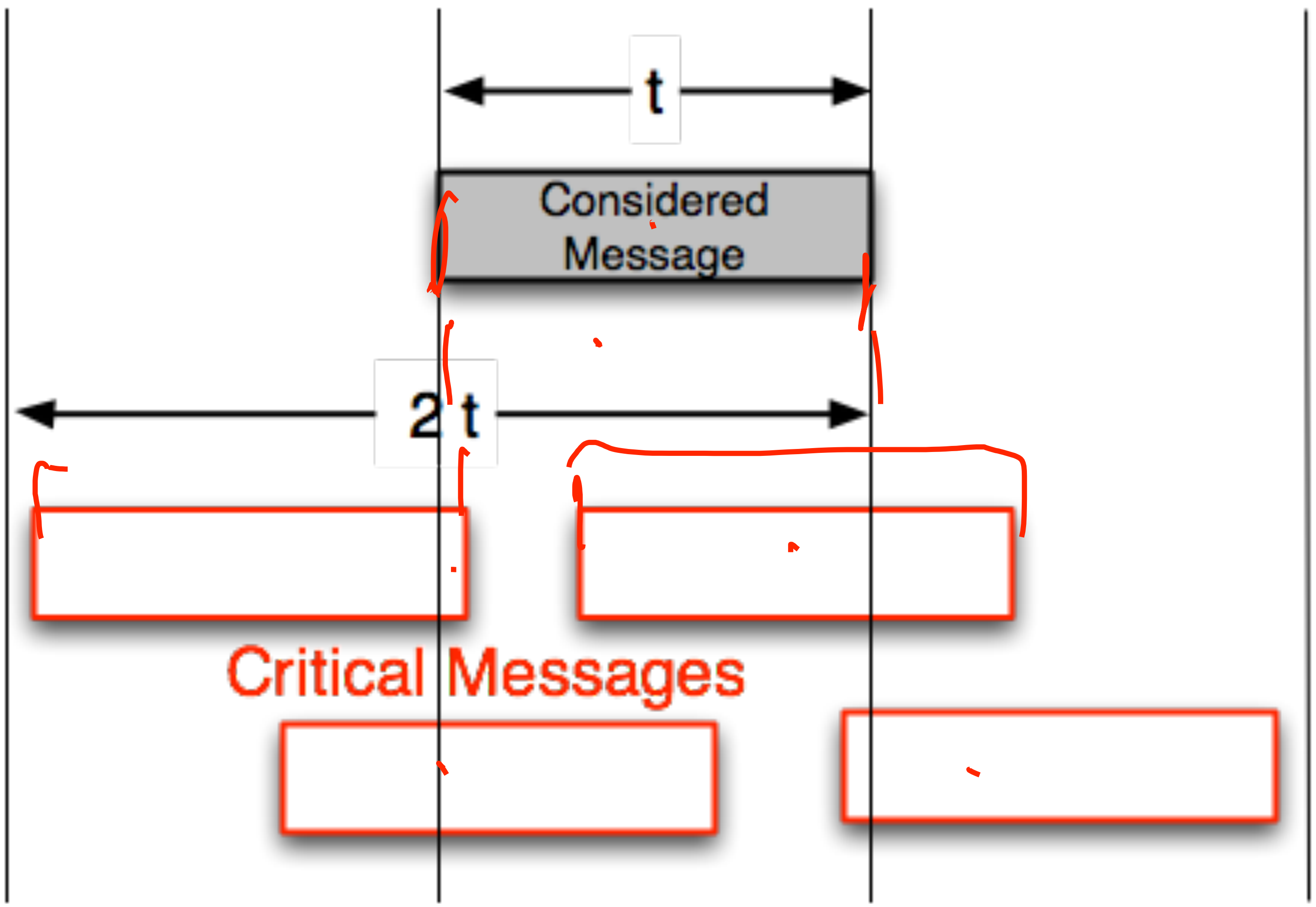
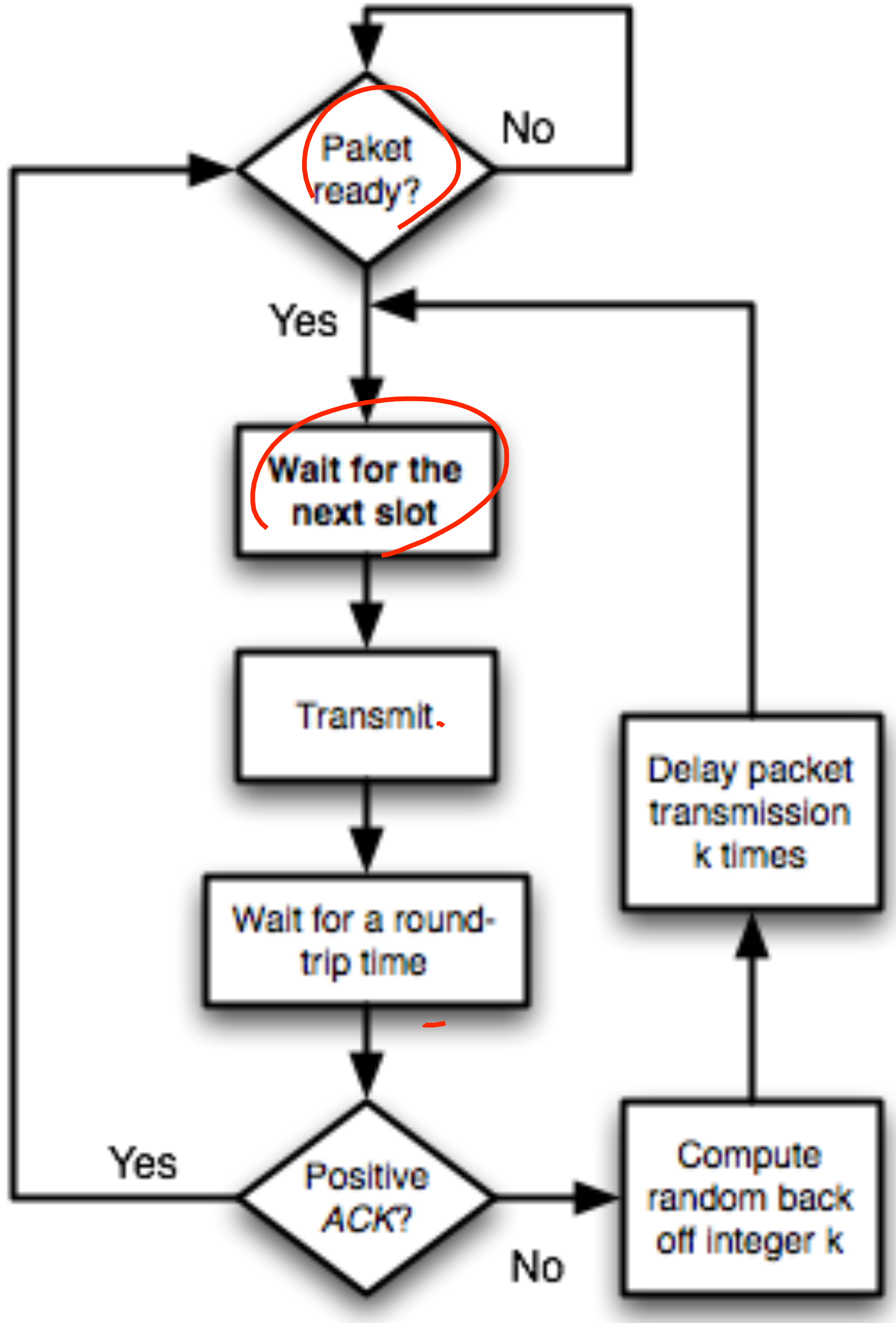
ALOHA – Efficiency

- A packet X is disturbed if
  - a packet starts just before X
  - a packet starts shortly after X starts
- A packet is successfully transmitted,
  - if during an interval of two packets no other packets are transmitted



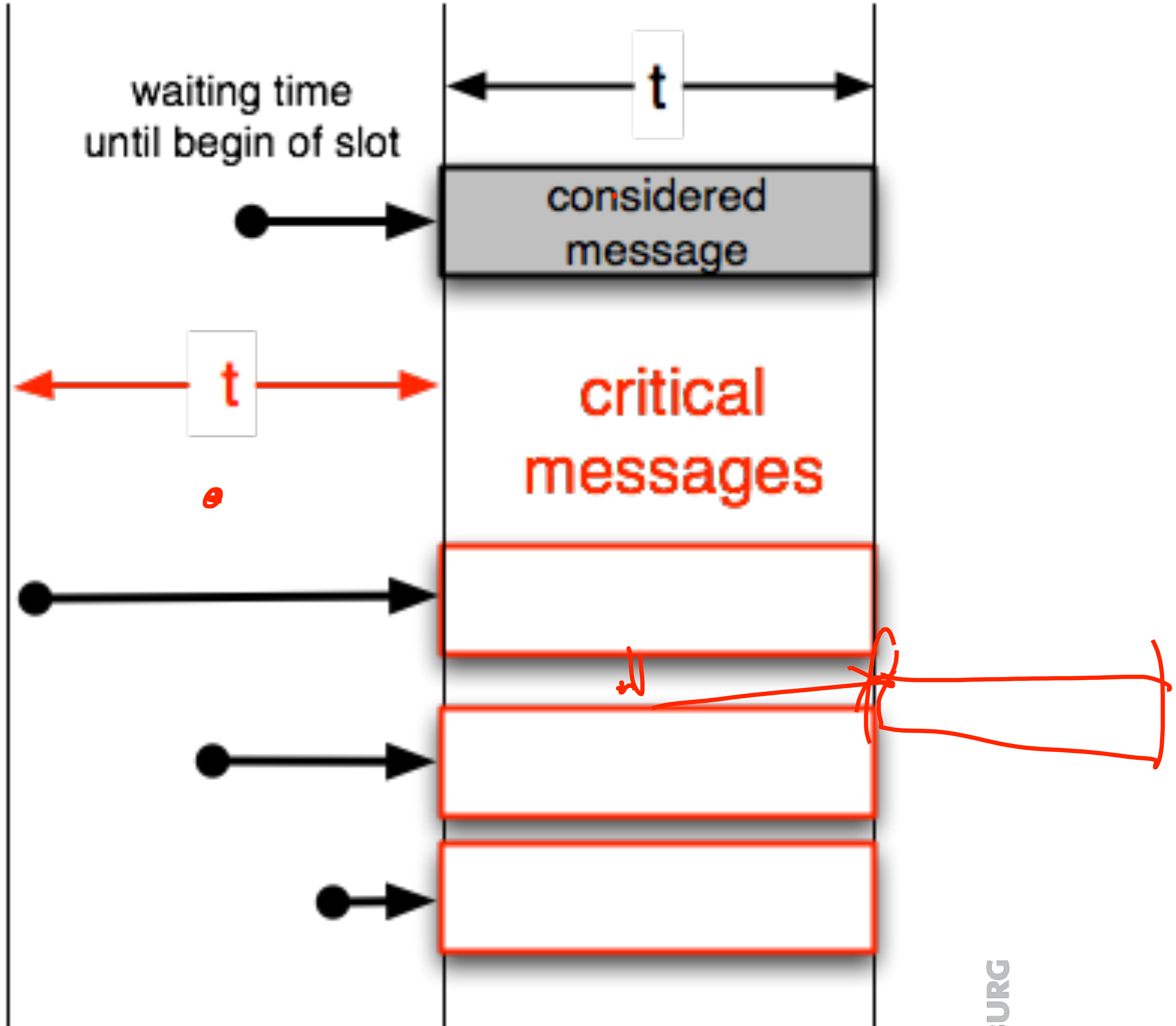

Paket ready?
No
Yes
Wait for the next slot
Transmit.
Wait for a round-trip time
Positive ACK?
Yes
No
Compute random back off integer k
Delay packet transmission k times

Slotted ALOHA

- ALOHA‘s problem
  - long vulnerability of a packet
- Reduction through use slots
  - synchronization is assumed
- Result
  - vulnerability is halved
  - throughput is doubled
    - $S(G) = Ge^{-G}$
    - optimal for G=1, S=1/e

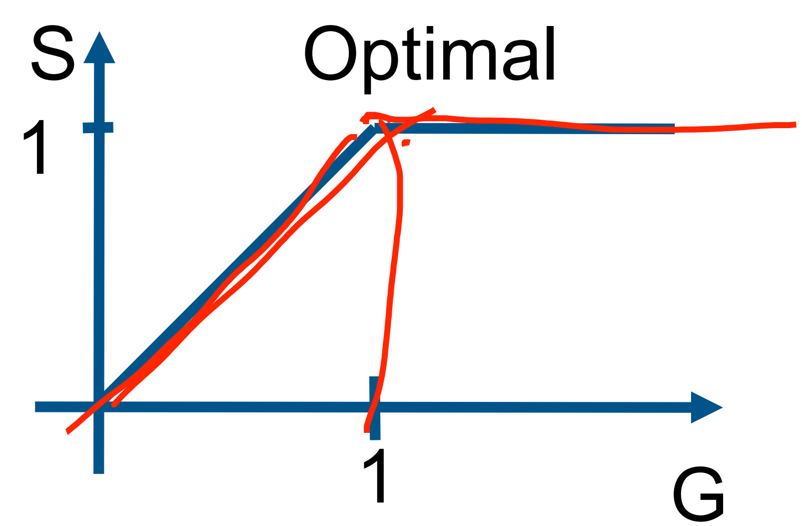
Slotted ALOHA – Effizienz

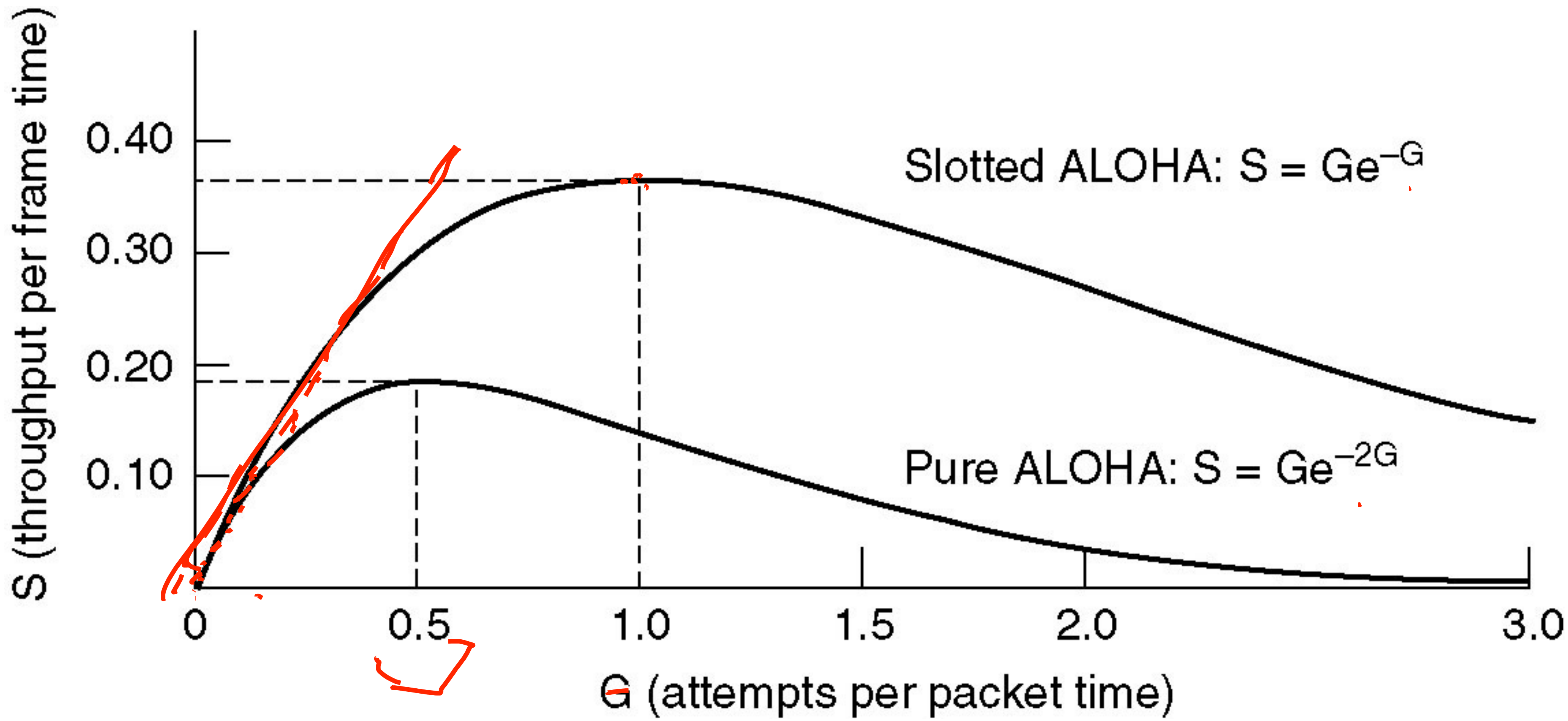
- A packet X is disturbed if
  - a package starts just before X
- The packet is successfully transmitted,
  - when transmitting over a period of **one** packets no (other) packets appears

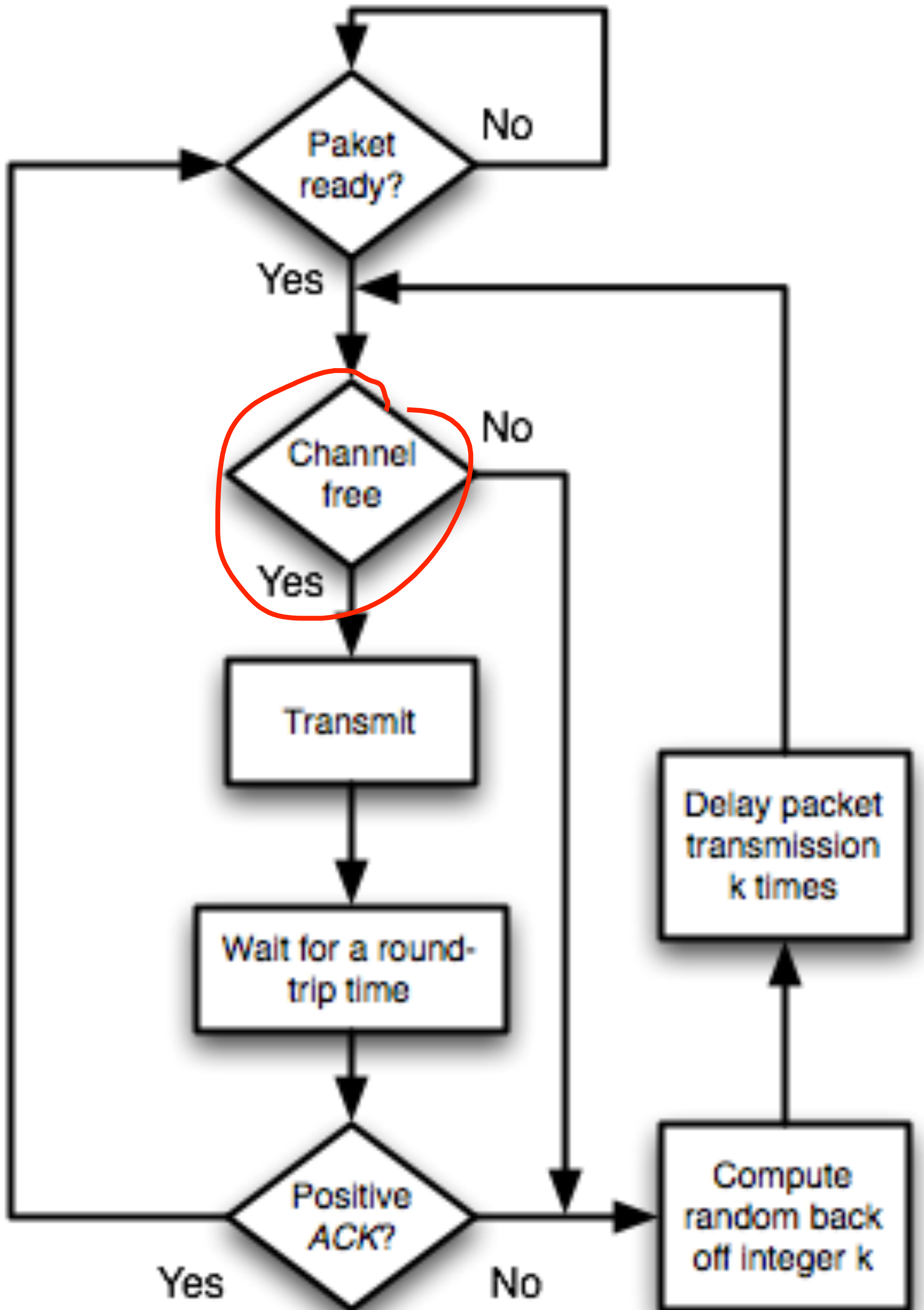


Throughput with respect to the Load

- (Slotted) ALOHA
  - not a good protocol
  - Throughput breaks down for increasing demand



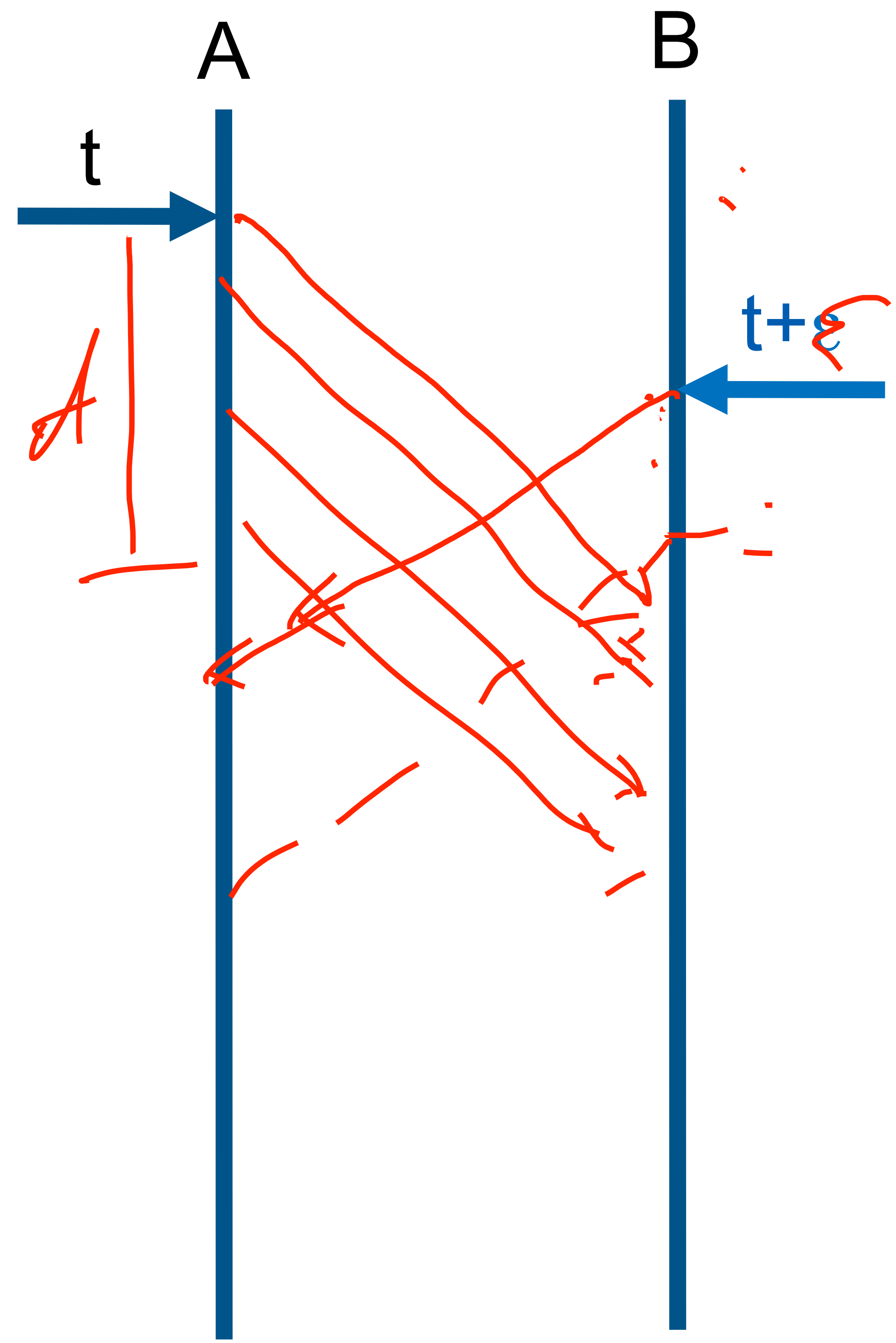




Paket ready?
No
Yes
Channel free
No
Yes
Transmit
Wait for a round-trip time
Positive ACK?
Yes
No
Delay packet transmission k times
Compute random back off integer k

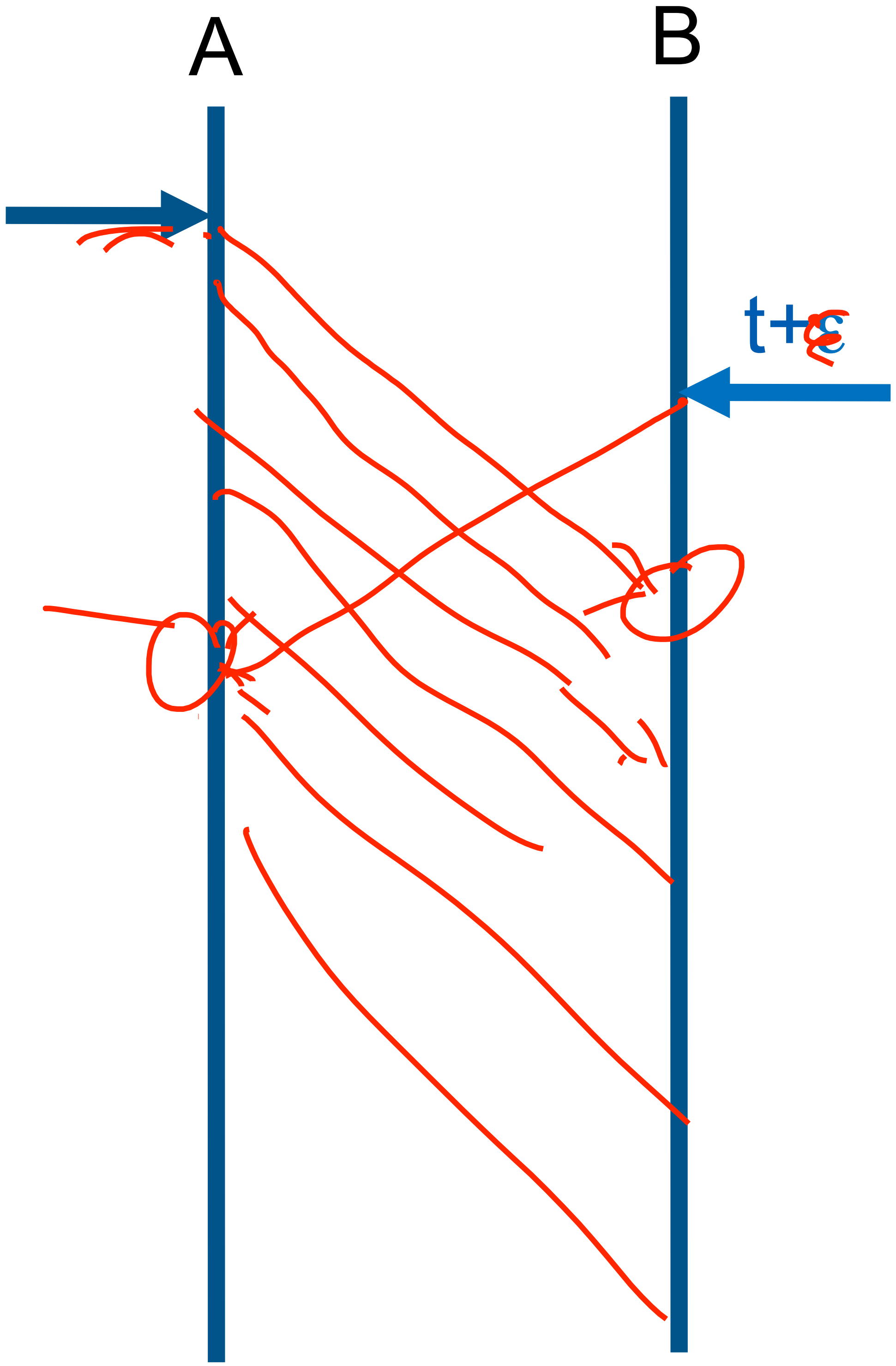
CSMA und Transmission Time

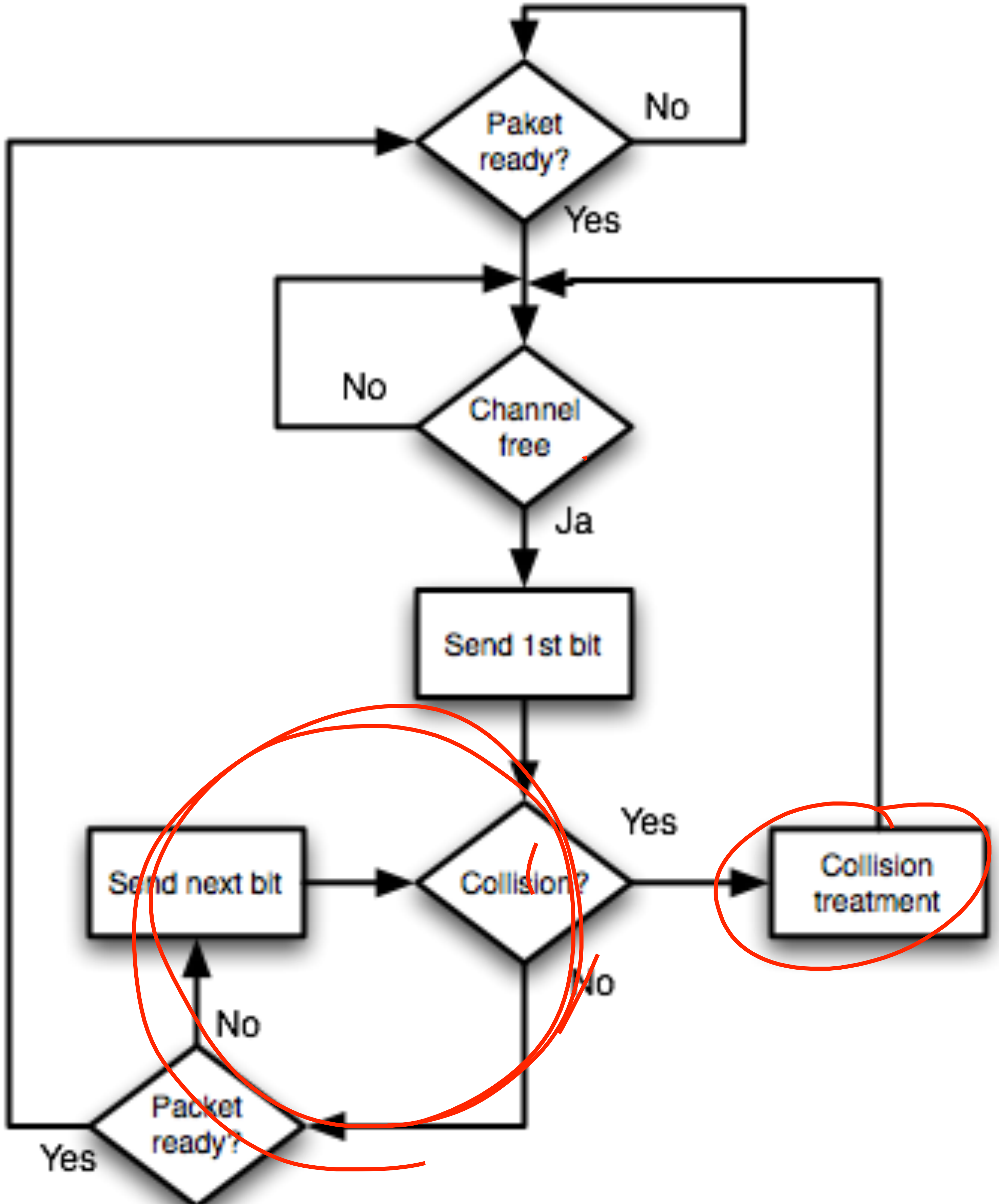
- CSMA-Problem:
  - Transmission delay d
- Two stations
  - start sending at times t and t + ε with ε <d
  - see a free channel
- 2nd Station
  - causes a collision



Collision Detection in Ethernet – CSMA/CD

- CSMA/CD – Carrier Sense Multiple Access/Collision Detection
  - Ethernet
- If collision detection during reception is possible
  - Both senders interrupt sending
  - Waste of time is reduced
- Collision Detection
  - simultaneously listening and sending must be possible
  - Is that what happens on the channel that's identical to the message?



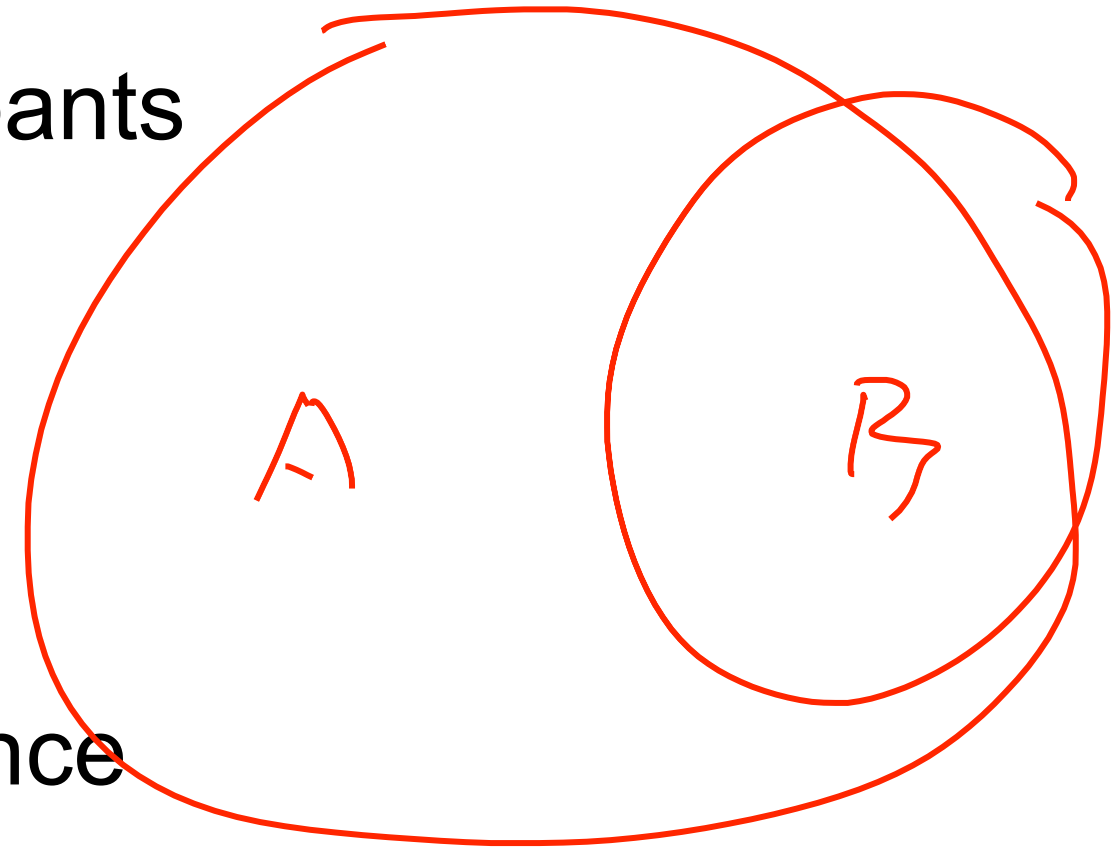

Paket ready?
No
Yes
No
Channel free
Ja
Send 1st bit
Yes
Send next bit
Collision?
Collision treatment
No
No
Packet ready?
Yes

Computation of the Backoff

- Algorithm: Binary Exponential Backoff
  - k:=2
  - While a collision has occurred
    - choose t randomly uniformly from {0,...,k-1}
    - wait t time units
    - send message (terminate in case of collision)
    - k:= 2 k
- Algorithm
  - waiting time adapts to the number of stations
  - uniform utilization of the channel
  - fair in the long term

Problem of Wireless Media Access

- Unknown number of participants
  - broadcast
  - many nodes simultaneously
  - only one channel available
  - asymmetric situations
- Collisions produce interference
- Media Access
  - Rules to participate in a network



Aims

- Delay
- Throughput
- Fairness
- Robustness and stability
  - against disturbances on the channel
  - against mobility
- Scalability
- Energy efficiency

Methods

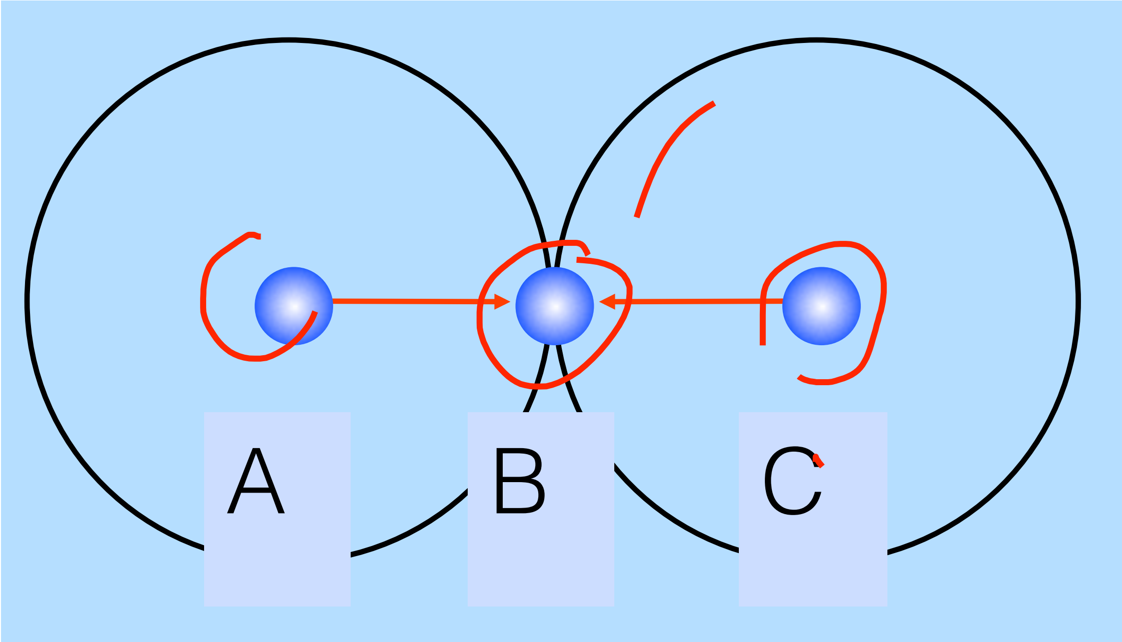
- Organisation
  - Central control
  - Distributed control
- Access
  - without contention
  - with contention

Problem of Media Access

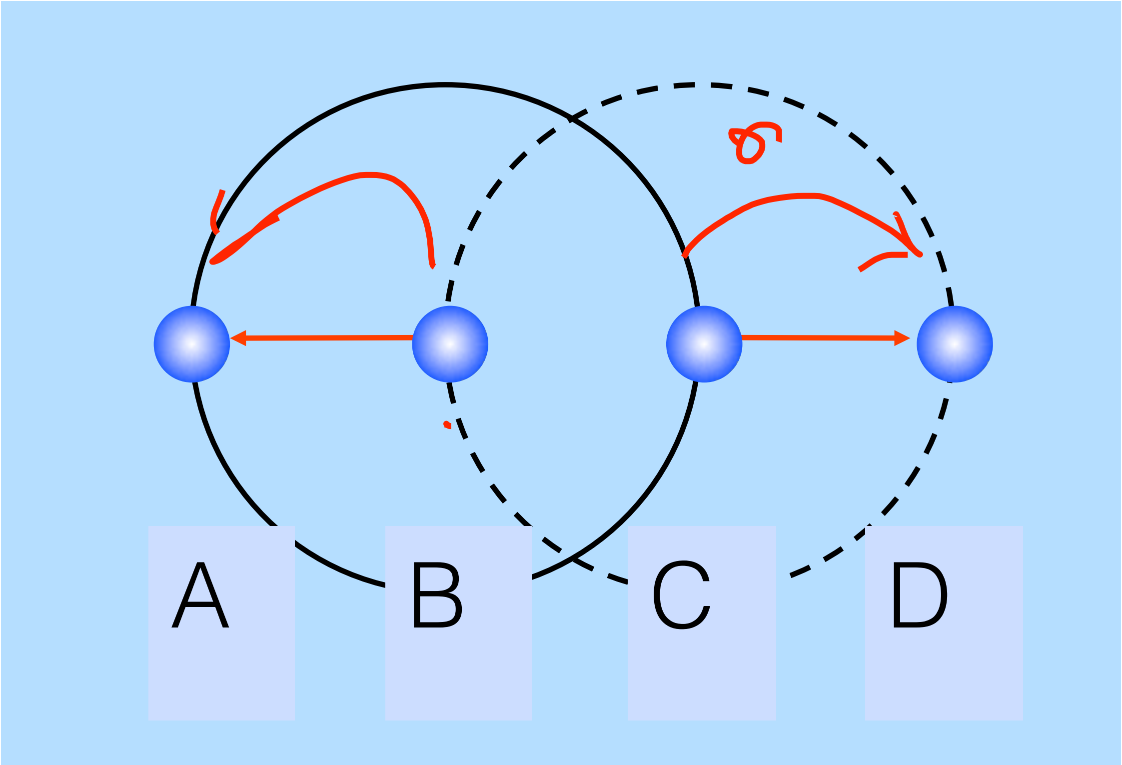
- CSMA/CD not applicable
  - Media is only locally known
  - Bounded range
- Hidden Terminal
  - Receiver collision despite *carrier sensing*
- Exposed Terminal
  - Opportunity costs of unsent messages because of *carrier sensing*

Hidden Terminal and Exposed Terminal

- Hidden Terminal Problem



- Exposed Terminal Problem



Alternative Solutions

- Extended hardware
  - Addition carrier signal blocks and ensures transmission
- Centralized solution
  - Base station is the only communication partner
  - Base station coordinates the media access

MACA

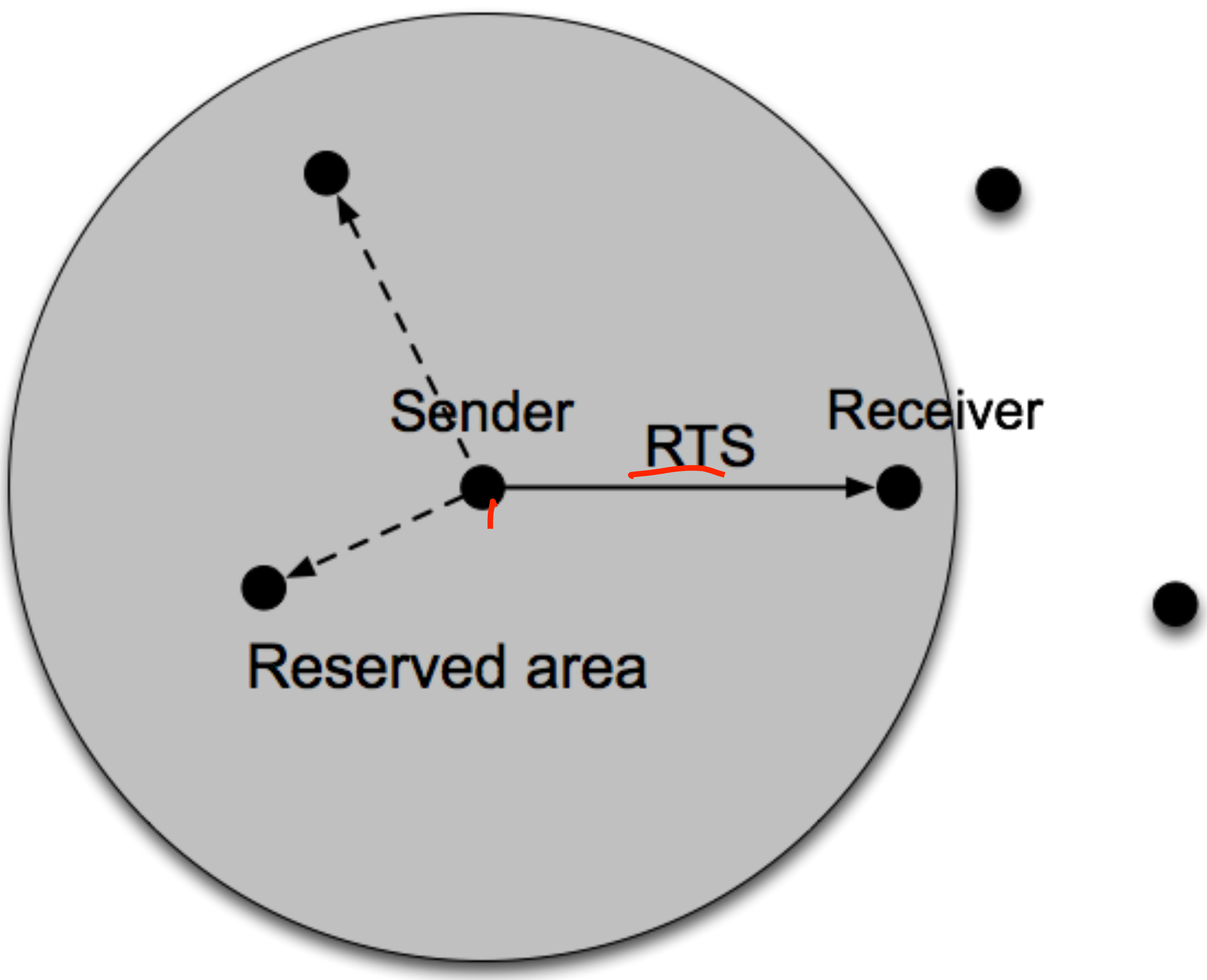
RTS/CTS

- **Phil Karn**
  - MACA: A New Channel Access Method for Packet Radio 1990
- **Alternative names:**
  - Carrier Sensing Multiple Access / Collision Avoidance (CSMA/CA)
  - Medium Access with Collision Avoidance (MACA)
- **Aim**
  - Solution of the Hidden and Exposed Terminal Problem
- **Idea**
  - Channel reservation before the communication
  - Minimization of collision cost

Request to Send

(a) A sends Request to Send (RTS)

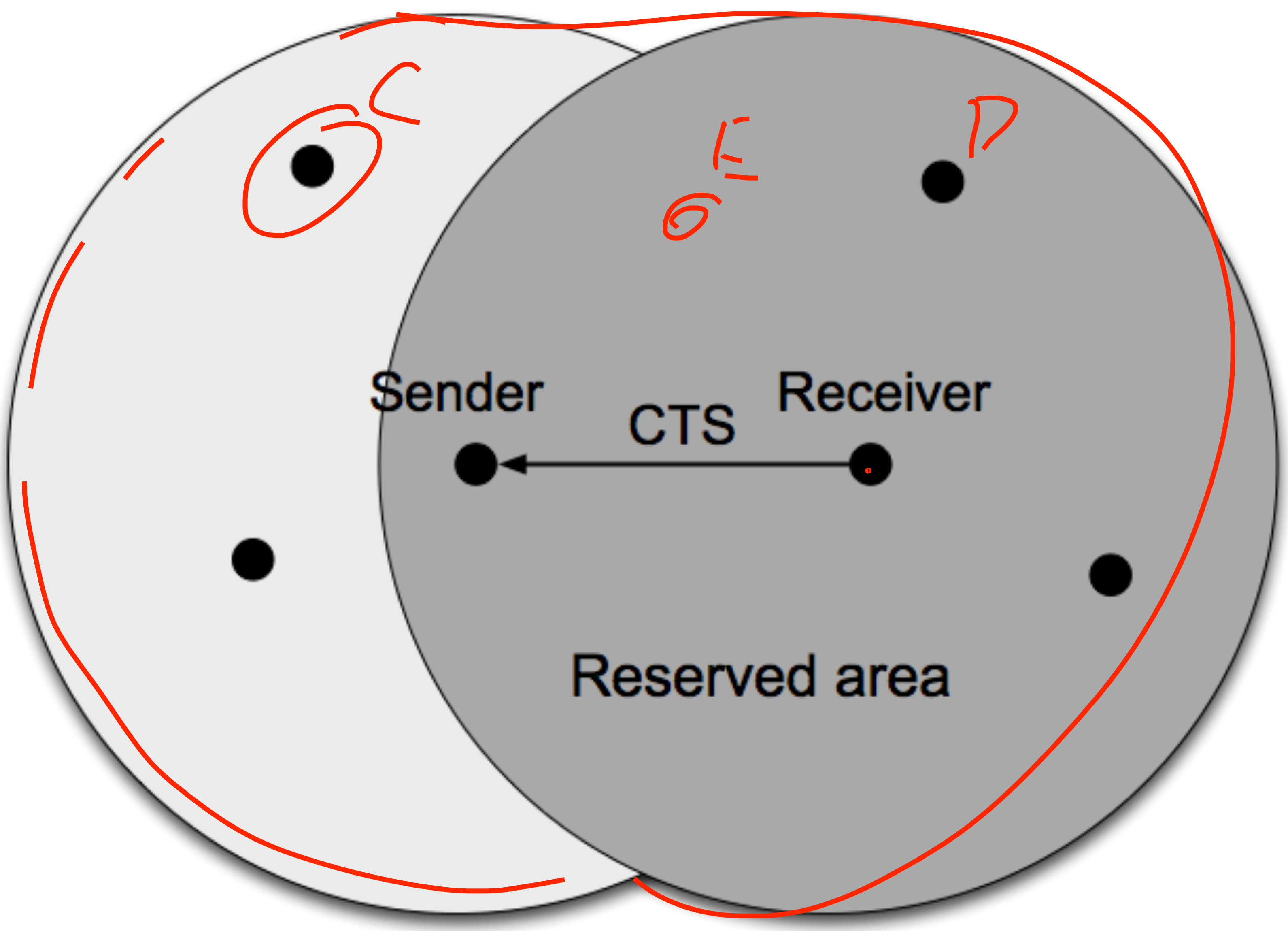
(b) B answers with Clear to Send (CTS)

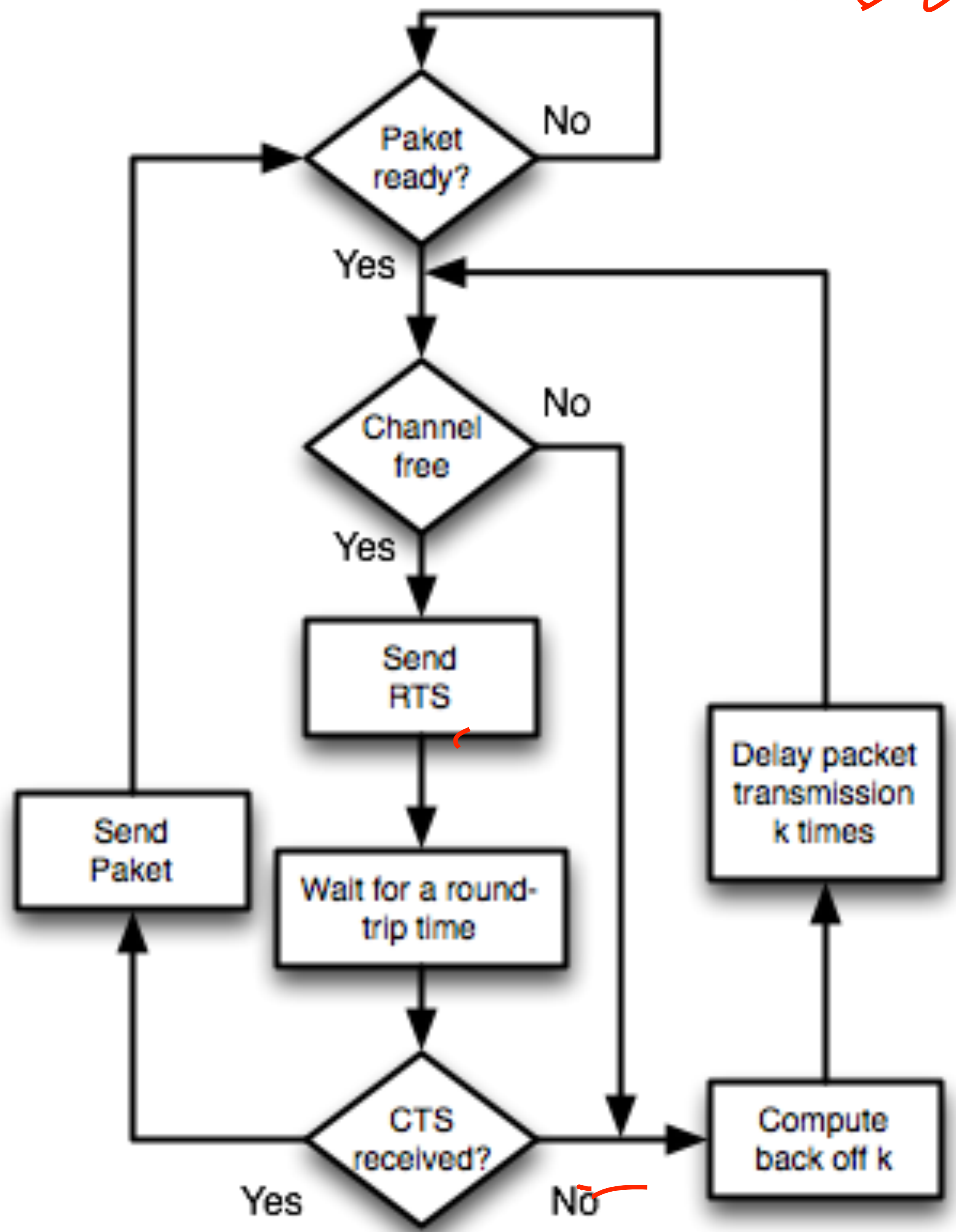


Clear to Send

(a) A sends Request to Send (RTS)

(b) B answers with Clear to Send (CTS)




Paket ready?
No
Yes
Channel free
No
Yes
Send RTS
Send Paket
Wait for a round-trip time
Delay packet transmission k times
CTS received?
Yes
No
Compute back off k

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Details for Sender

- A sends RTS
  - waits certain time for CTS
- If A receives CTS in time
  - A sends packet
  - otherwise A assumes a collision at B
    - doubles *Backoff*-counter
    - and chooses a random waiting time from {1,...,*Backoff* }
  - After the waiting time A repeats from the beginning

Details for Receiver

- After B has received RTS
  - B sends CTS
  - B waits some time for the data packet
  - If the data packet arrives then the process is finished
    - Otherwise B is not blocked

Details for Third Parties

- C receives RTS of A
  - waits certain time for CTS of B
- If CTS does not occur
  - C is free for own communication
- If CTS of B has been received
  - then C waits long enough such that B can receive the data packet

Details for Third Parties

- D receives CTS of B
  - waits long enough such that B can receive the data packet
- E receives RTS of A and CTS of B
  - waits long enough such that B can receive the data packet

MACAW

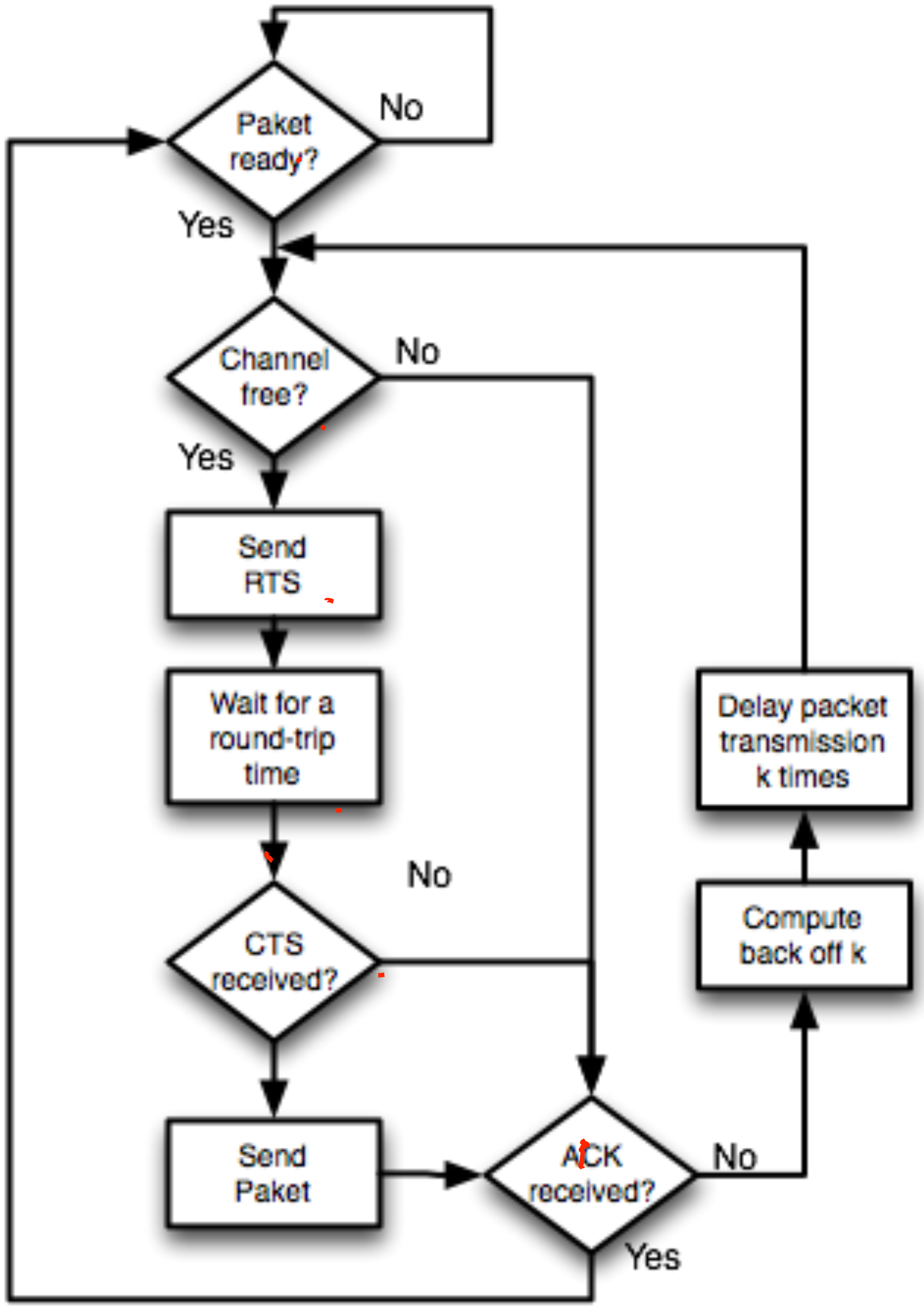
- Bharghavan, Demers, Shenker, Zhang
  - MACAW: A Media Access Protocol for Wireless LAN‘s, SIGCOMM 1994
  - Palo Alto Research Center, Xerox
- Aim
  - Redesign of MACA
  - Improved backoff
  - Fairer bandwidth sharing using *Streams*
  - Higher efficiency
    - by 4- and 5-Handshake

Acknowledgment in the Data Link Layer

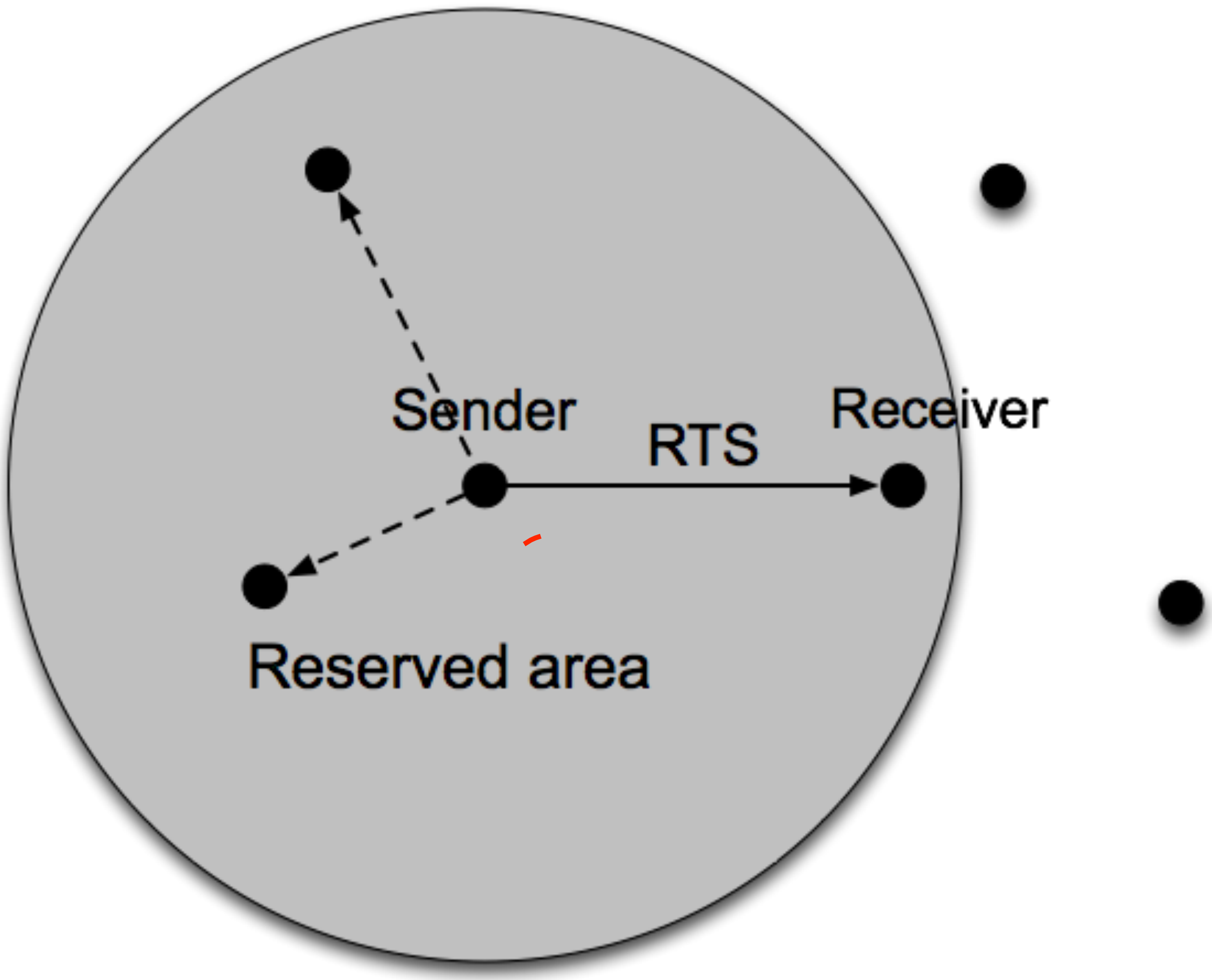
- MACA
  - does not use Acks
  - initiated by Transport Layer
  - very inefficient
- How can MACA use Acks?

MACAW
4 Handshake

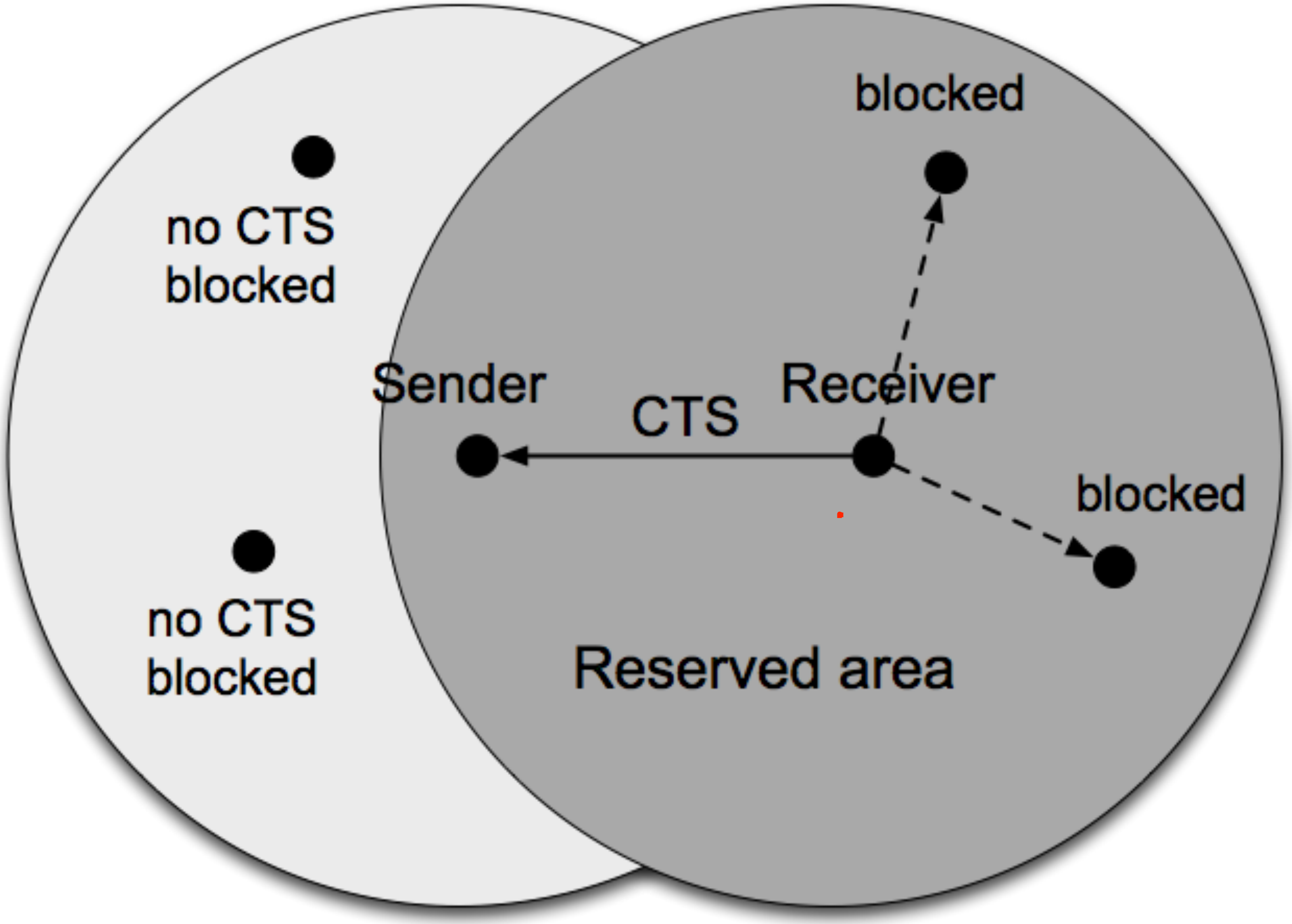
- Participants
  - Sender sends RTS
  - Receiver answers with CTS
  - Sender sends data packet
  - Receiver acknowledges (ACK)
- Third parties
  - Nodes receiving RTS or CTS are blocked for some time
  - RTS and CTS describe the transmission duration
- Sender repeats RTS, if no ACK has been received
  - If receiver has sent ACK
  - then the receiver sends (instead of CTS) another ACK


Paket ready?
No
Yes
Channel free?
No
Yes
Send RTS
Wait for a round-trip time
No
CTS received?
Send Paket
ACK received?
No
Yes
Compute back off k
Delay packet transmission k times

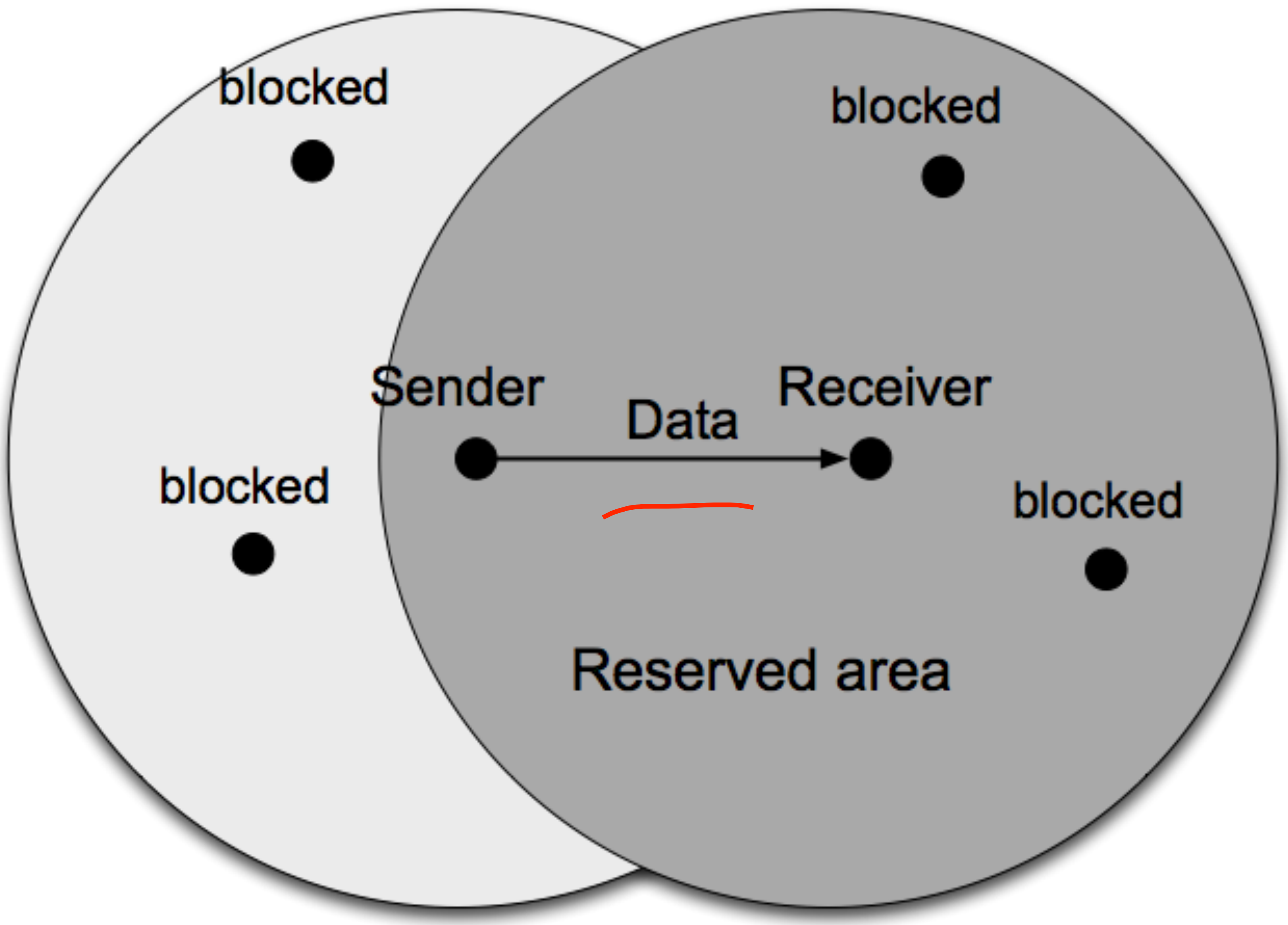
MACA 4-Handshake
RTS



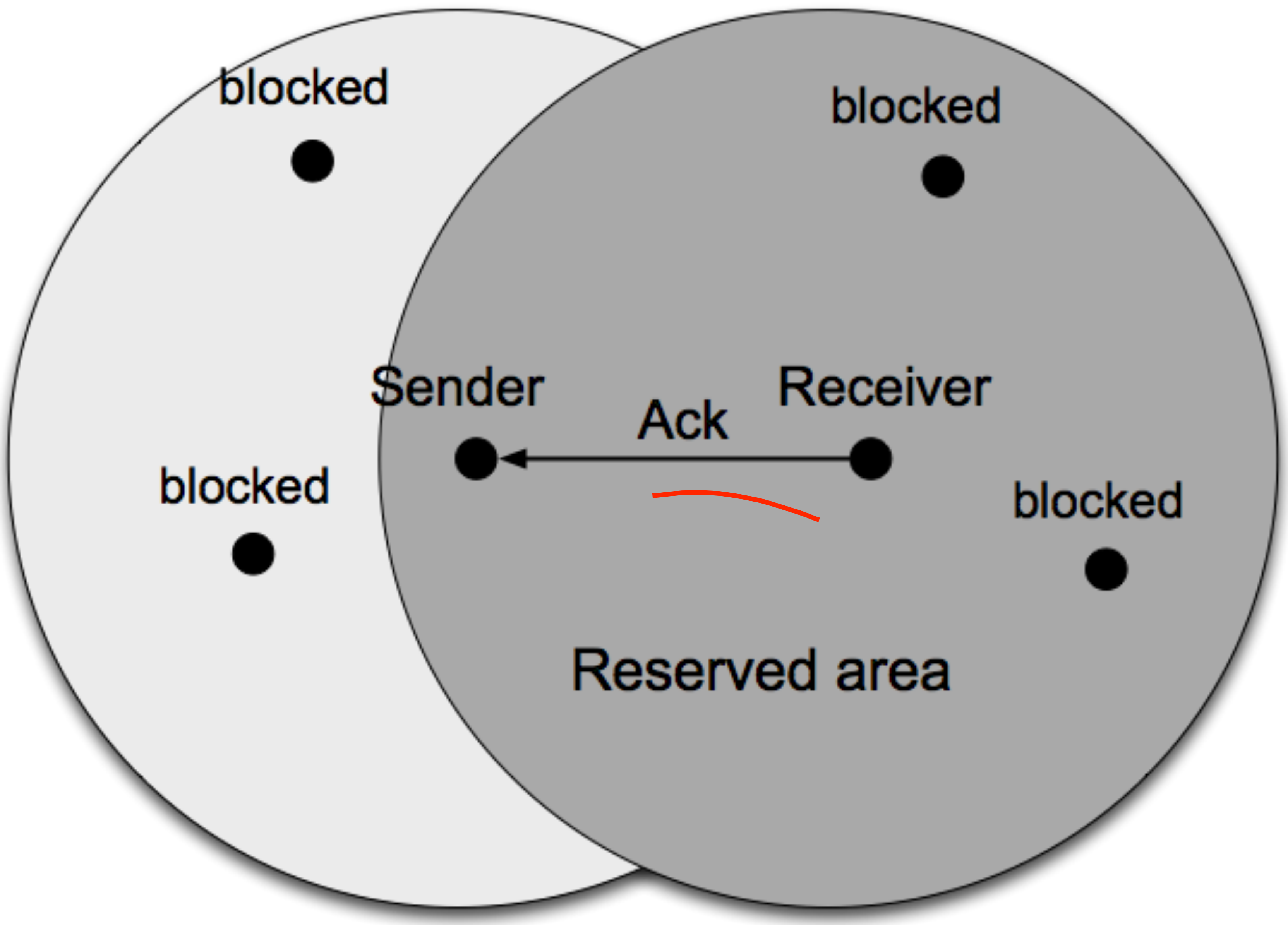
MACAW 4-Handshake
CTS



MACAW 4-Handshake
Data



MACAW 4-Handshake
Ack



Acknowledgments

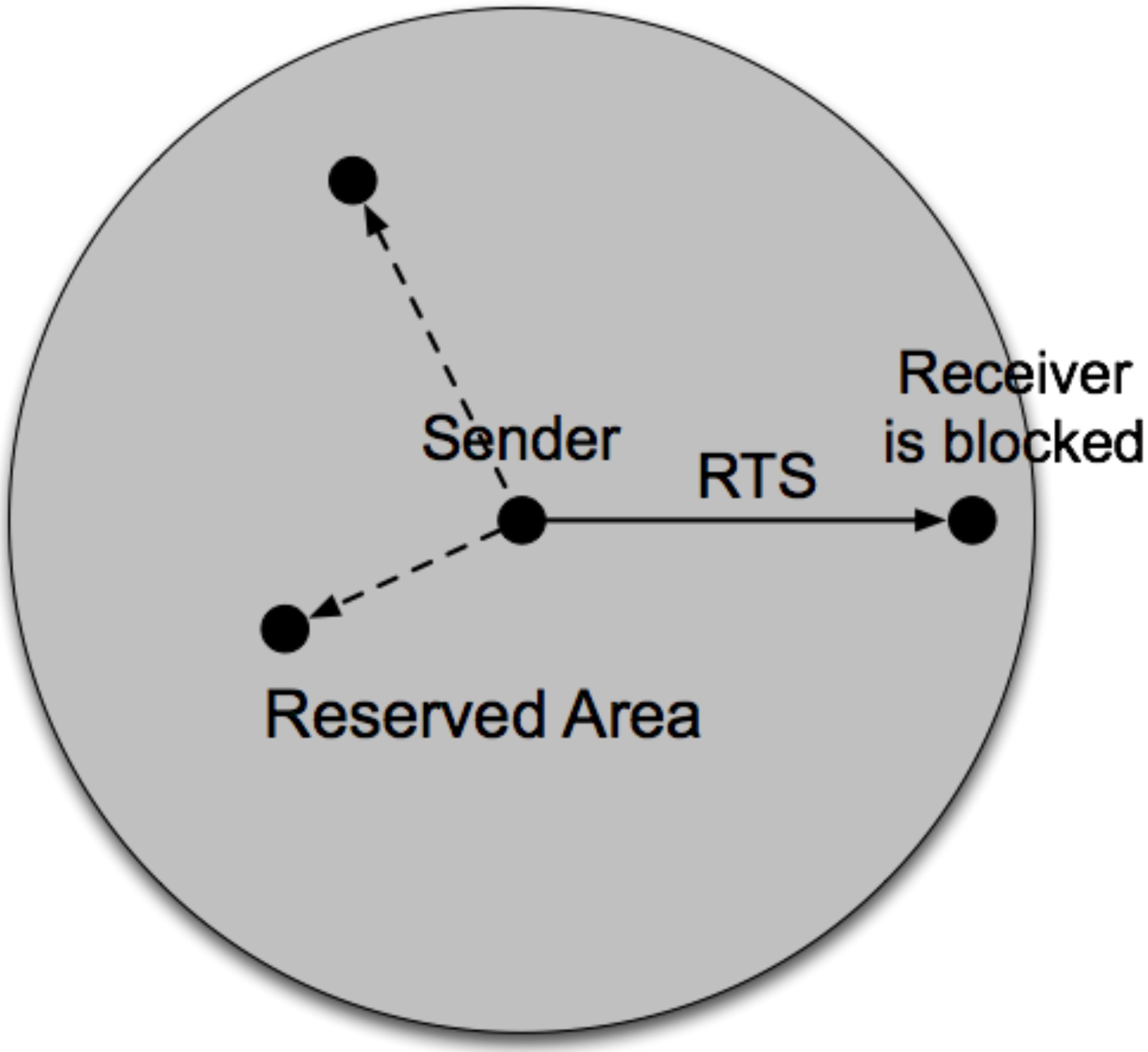
- Adding ACKs to MACA
  - In MACA done by transport layer
- leads to drastical improvements of throughput even for moderate error rates

error rate	throughput	
	RTS-CTS-DATA	RTS-CTS-DATA-ACK
0	40	37
0,001	37	37
0,01	17	36
0,1	2	10

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