Design Principles

Goals:

- Identify, study common architectural components, protocol mechanisms, approaches do we find in network architectures?
- *Synthesis:* big picture

7 design principles:

- Separation of data, control
- Hard state versus soft state
- Randomization
- Indirection
- Network virtualization / overlays
- Resource sharing
- Design for scale

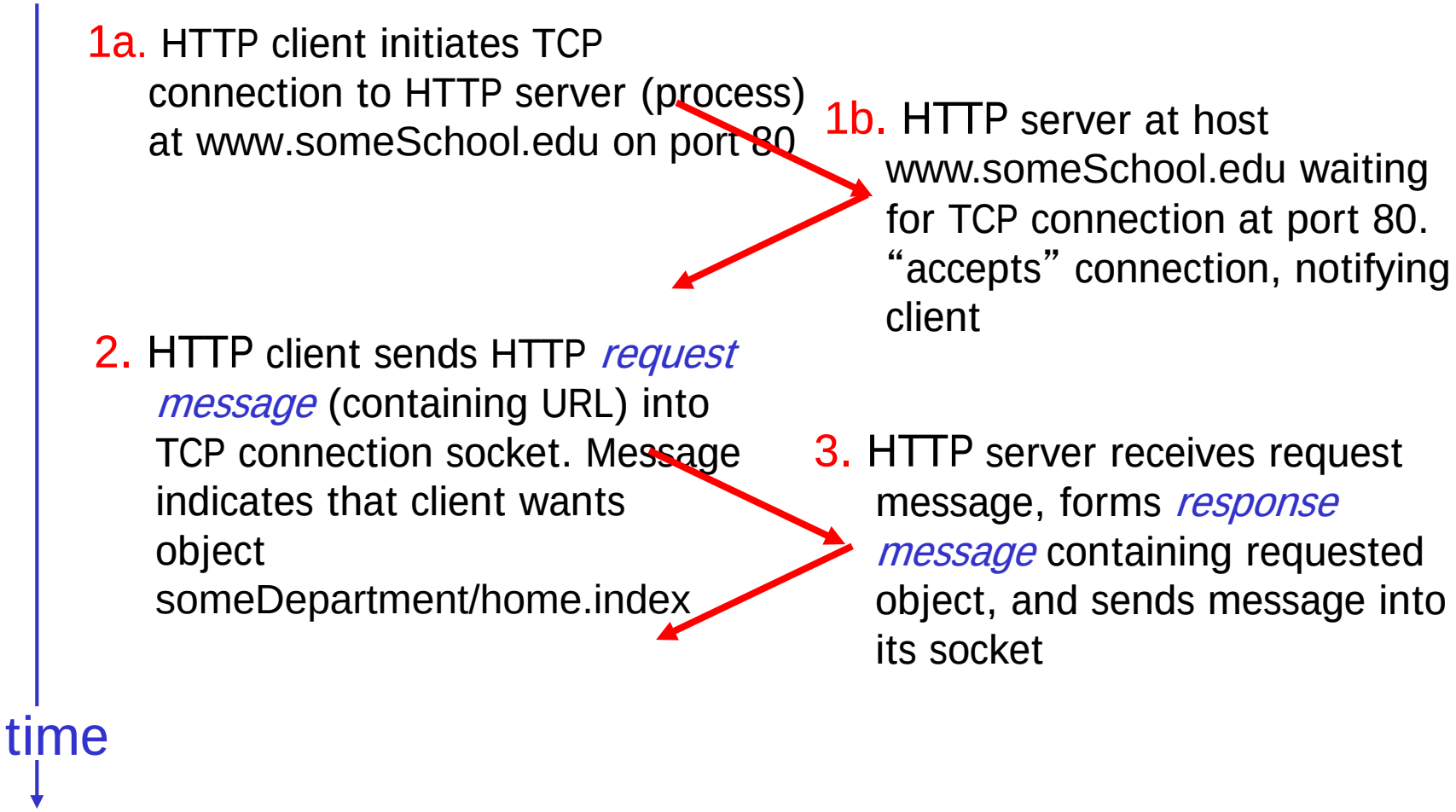
1: Separation of control and data

- PSTN (public switched telephone network):
  - SS7 (packets-switched control network) separate from (circuit-switched) call trunk lines
  - Earlier tone-based (in-band signaling)
- Internet:
  - RSVP (signaling) separate from routing, forwarding.
  - HTTP: in-band signaling
  - FTP: out-of-band signaling

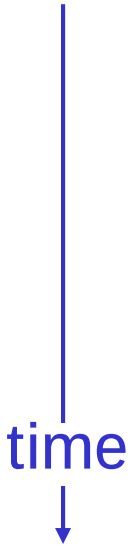
Internet: HTTP - inband signaling

Suppose user enters URL

`www.someSchool.edu/someDepartment/home.index`



Internet: HTTP - inband signaling (2)



4. HTTP server closes TCP connection.

5. HTTP client receives response message containing html file, displays html. Parsing html file, finds 10 referenced jpeg objects

6. Steps 1-5 repeated for each of 10 jpeg objects

HTTP request message

request line (GET, POST, HEAD commands)

header lines

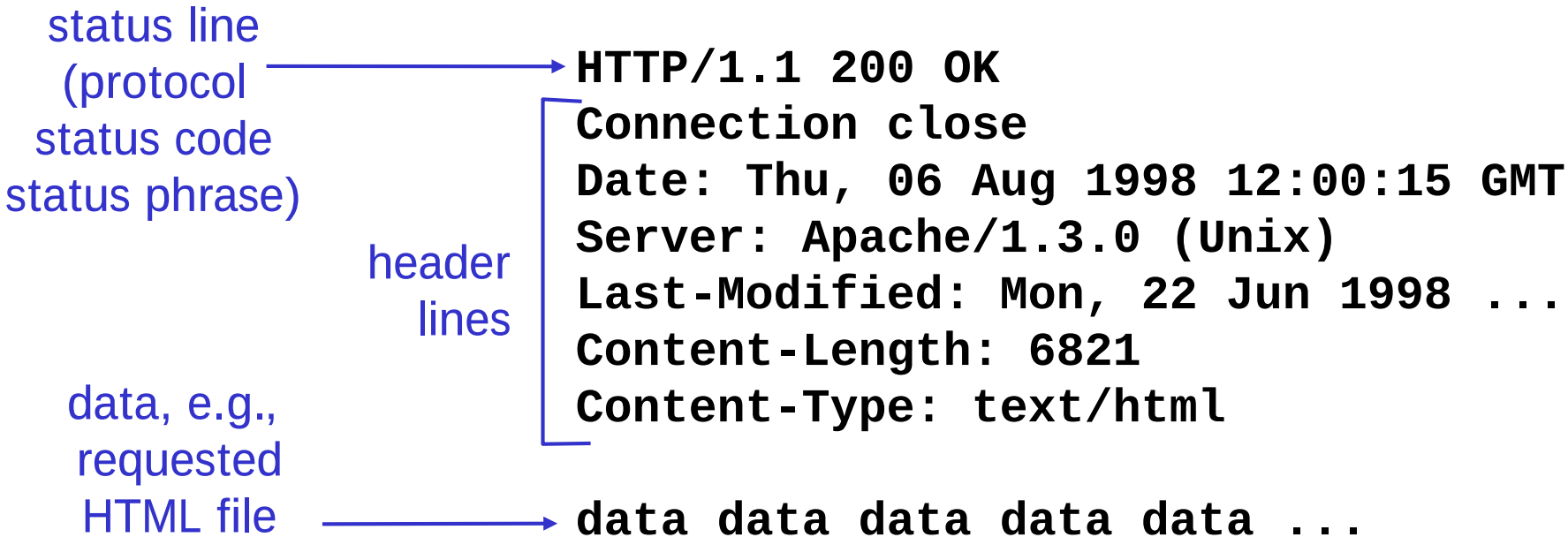
```
GET /somedir/page.html HTTP/1.1
Host: www.someschool.edu
User-agent: Mozilla/4.0
Connection: close
Accept-language:fr
```

Carriage return, line feed indicates end of message

(extra carriage return, line feed)

Note: Request msg typically just a signaling msg (no data)

HTTP response message

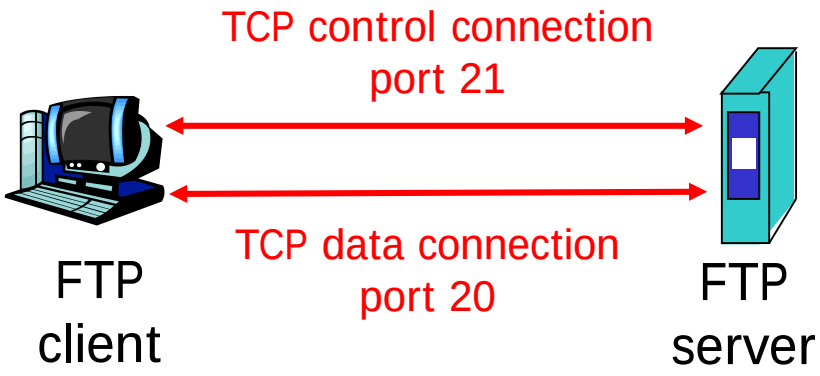


Note: Response msg mixes signaling and data

- Request, response msgs exchanged over *single* TCP connection

FTP: Separate control, data connections

- FTP client contacts FTP server at port 21
- Client obtains authorization over control connection
- Client browses remote directory via commands sent over control connection
- When server receives file transfer commend server opens new TCP data connection to client
- After transferring one file, server closes connection



- Server opens 2nd TCP data connection to transfer another file
- Control connection: “out of band” signaling
- FTP server maintains “state”: current directory, earlier authentication

Separate control, data: Why (or why not)?

Why?

- Allows concurrent control + data
- Allows perform authentication at control level
- Simplifies processing of data/control streams – higher throughput
- Provide Qos appropriate for control/data streams

Why not?

- Separate channels complicate management, increases resource requirements
- Can increase latency, e.g., http – two top connections vs. one

2: Maintaining network state

State: Information *stored* in network nodes by network protocols

- Updated when network "conditions" change
- Stored in multiple nodes
- Often associated with end-system generated call or session
- Examples:
  - RSVP router maintain lists of upstream sender IDs, downstream receiver reservations
  - TCP: Sequence numbers, timer values, RTT estimates

State: Sender, receiver

- Sender: network node that (re)generates signaling (control) msgs to install, keep-alive, remove state from other nodes
- Receiver: node that creates, maintains, removes state based on signaling msgs received from sender

Hard-state

- State *installed* by receiver on receipt of *setup msg* from sender
- State *removed* by receiver on receipt of *teardown msg* from sender

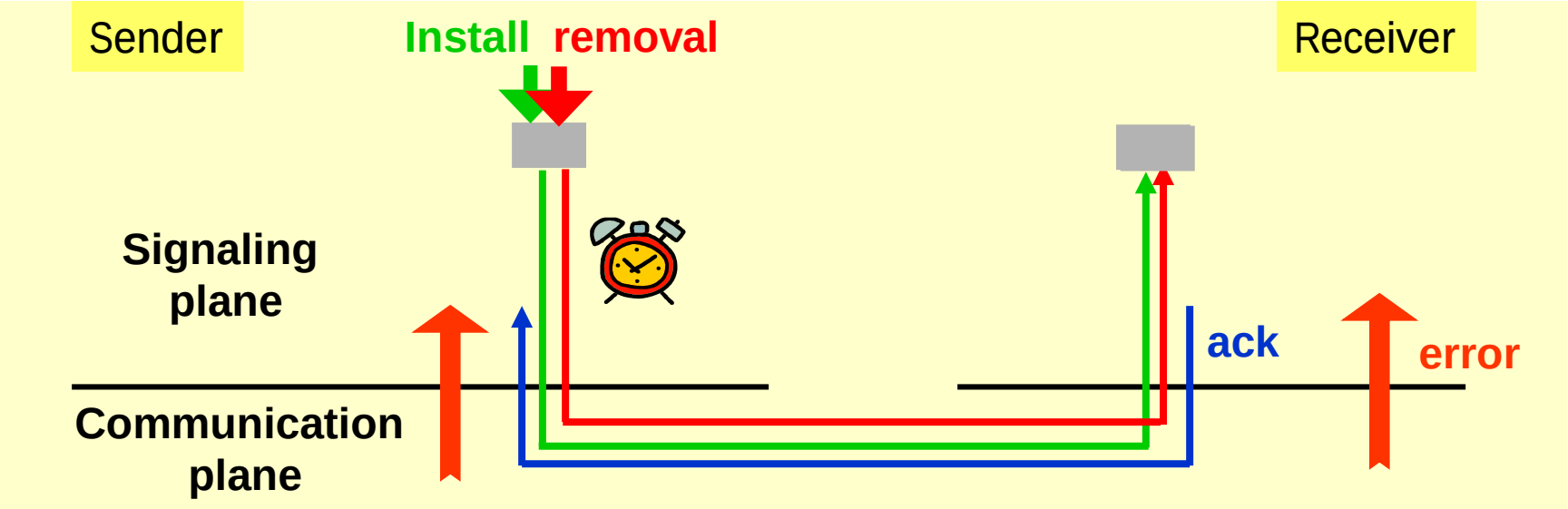
- *Default assumption:* state valid unless told otherwise
  - In practice: Failsafe-mechanisms (to remove orphaned state) in case of sender: e.g., receiver-to-sender "heartbeat": Is this state still valid?
- Examples:
  - TCP

Soft-state

- State *installed* by receiver on receipt of setup (trigger) msg from sender (typically, an endpoint)
  Sender also sends periodic *refresh msg* indicating receiver should continue to maintain state
- State *removed* by receiver via timeout, in absence of refresh msg from sender

- *Default assumption:* State becomes invalid unless refreshed
  - In practice: Explicit state removal (*teardown*) msgs also used
- Examples:
  - RSVP, RTP, IGMP

Hard-state signaling



- Reliable signaling
- State removal by request
- Requires additional error handling
  - E.g., sender failure

Soft-state

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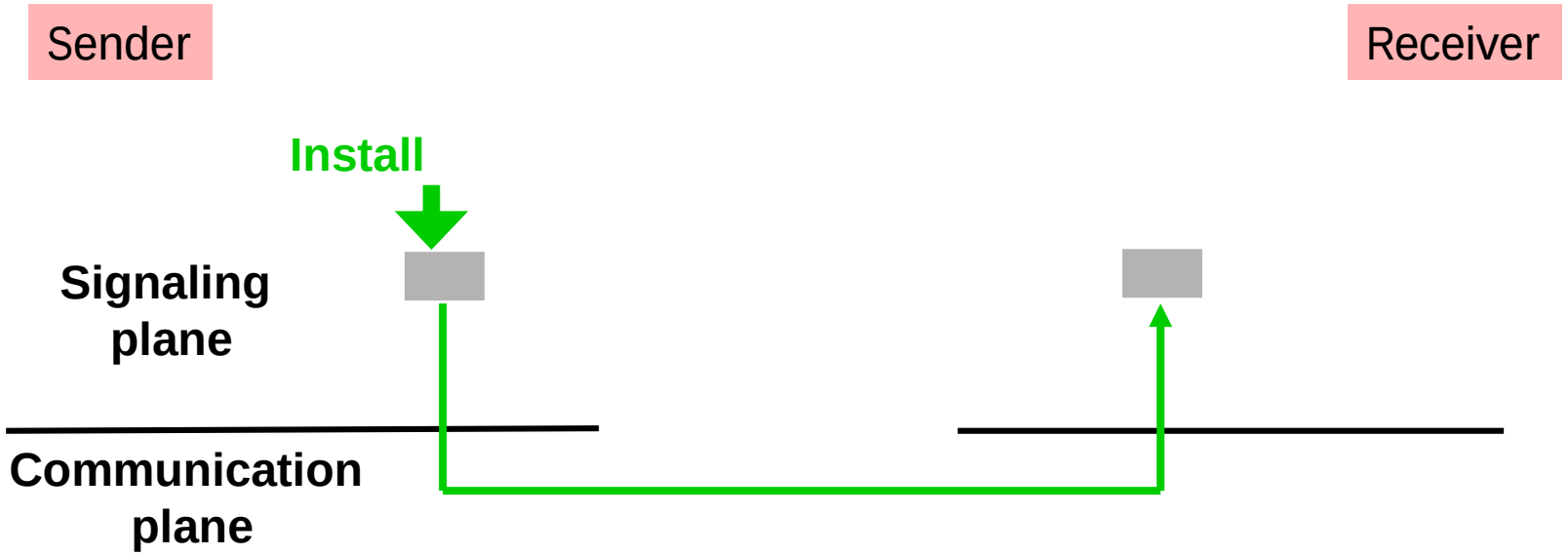
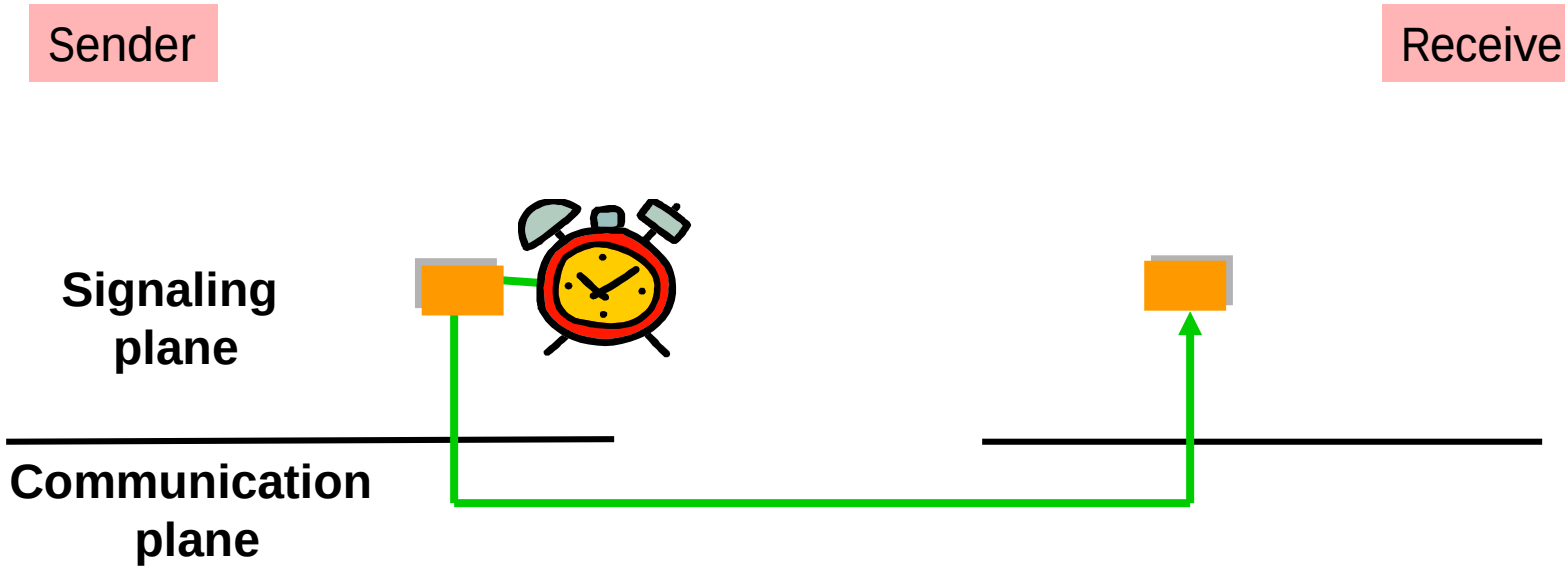
Soft-state signaling



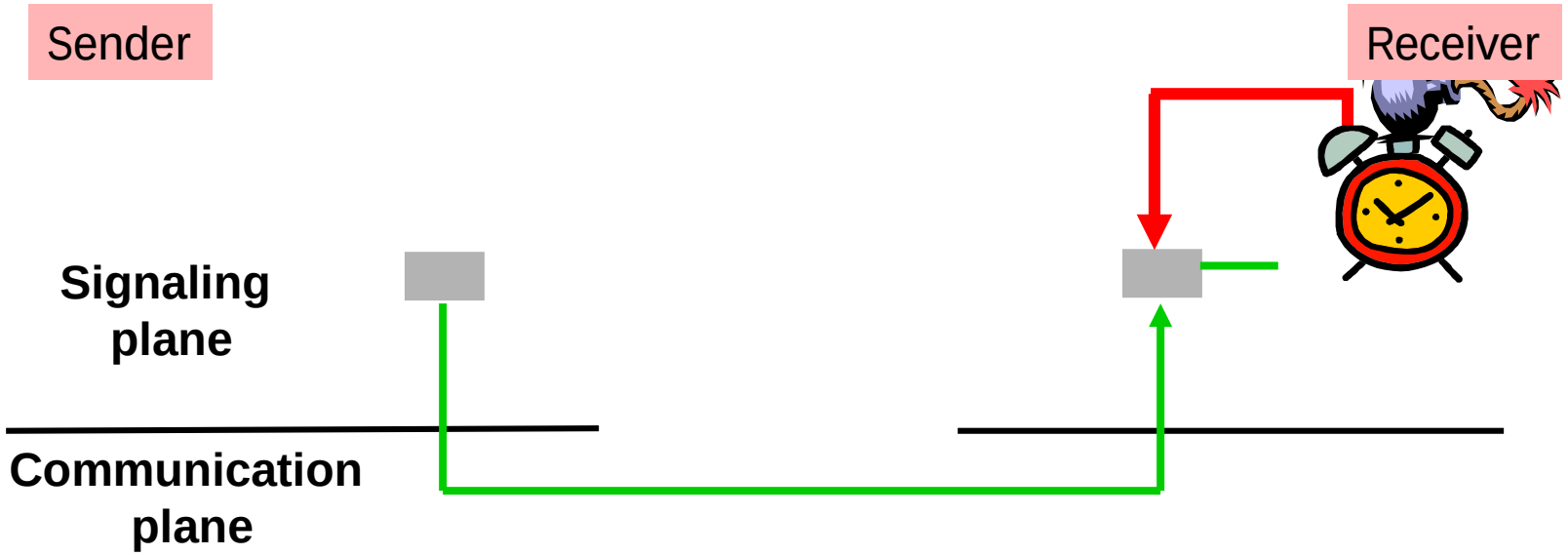
- Best effort signaling

Soft-state signaling



- Best effort signaling
- Refresh timer, periodic refresh

Soft-state signaling



- Best effort signaling
- Refresh timer, periodic refresh
- State time-out timer, state removal only by time-out

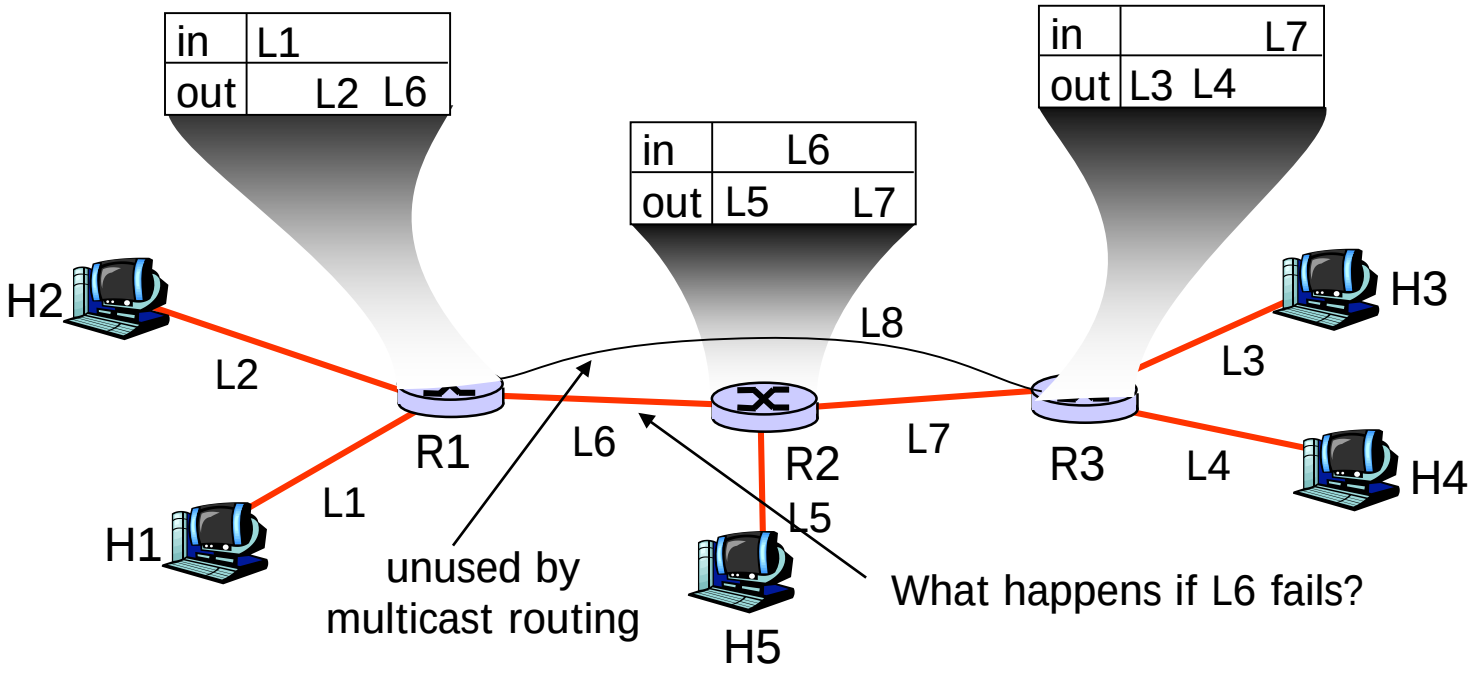
Soft-state: Claims

- "Systems built on soft-state are robust" [Raman 99]
- "Soft-state protocols provide … greater robustness to changes in the underlying network conditions ..." [Sharma 97]
- "Obviates the need for complex error handling software" [Balakrishnan 99]

What does this mean?

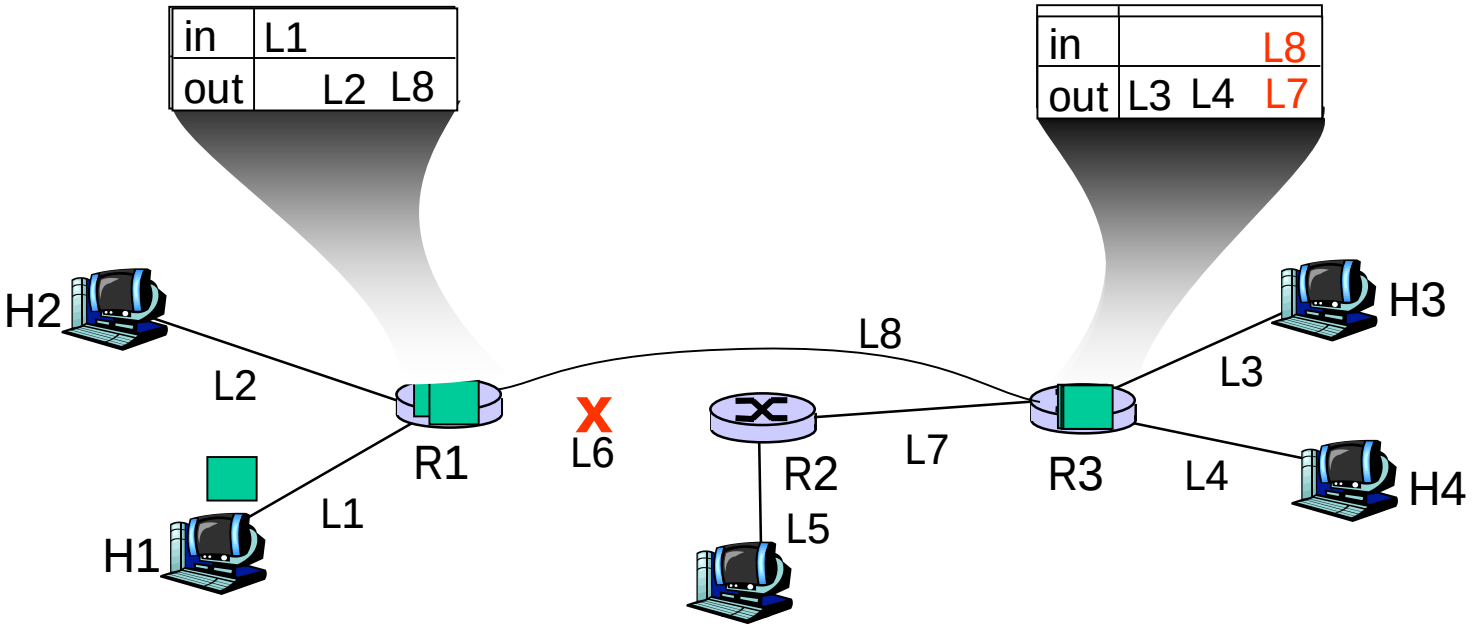
Soft-state: "Easy" handling of changes

- Periodic refresh: If network "conditions" change, refresh will re-establish state under new conditions
- Example: RSVP/routing interaction: if routes change (nodes fail) RSVP PATH refresh will *re-establish* state along new path



Soft-state: “Easy” handling of changes

- L6 goes down, multicast routing reconfigures but ...
- H1 data no longer reaches H3, H3, H5 (no sender or receiver state for L8)
- H1 refreshes PATH, establishes *new* state for L8 in R1, R3
- H4 refreshes RESV, propagates upstream to H1, establishes new receiver state for H4 in R1, R3



Soft-state: “Easy” handling of changes

- “Recovery” performed transparently to end-system by normal refresh procedures
- No need for network to signal failure/change to end system, or end system to respond to specific error
- Less signaling (volume, types of messages) than hard-state from network to end-system but...
- More signaling (volume) than hard-state from end-system to network for refreshes

Soft-state: Refreshes

- Refresh msgs serve many purposes:
  - Trigger: first time state-installation
  - Refresh: refresh state known to exist ("I am still here")
  - <Lack of refresh>: Remove state ("I am gone")
- Challenge: All refresh msgs unreliable
  - Would like triggers to result in state-installation asap
  - Enhancement: add receiver-to-sender refresh_ACK for triggers
  - E.g., see "Staged Refresh Timers for RSVP"

Soft-state: Setting timer values

Q: How to set refresh/timeout timers

- State-timeout interval = n * refresh-interval-timeout
  - What value of n to choose?
- Will determine amount of signaling traffic, responsiveness to change
  - Small timers: fast response to changes, more signaling
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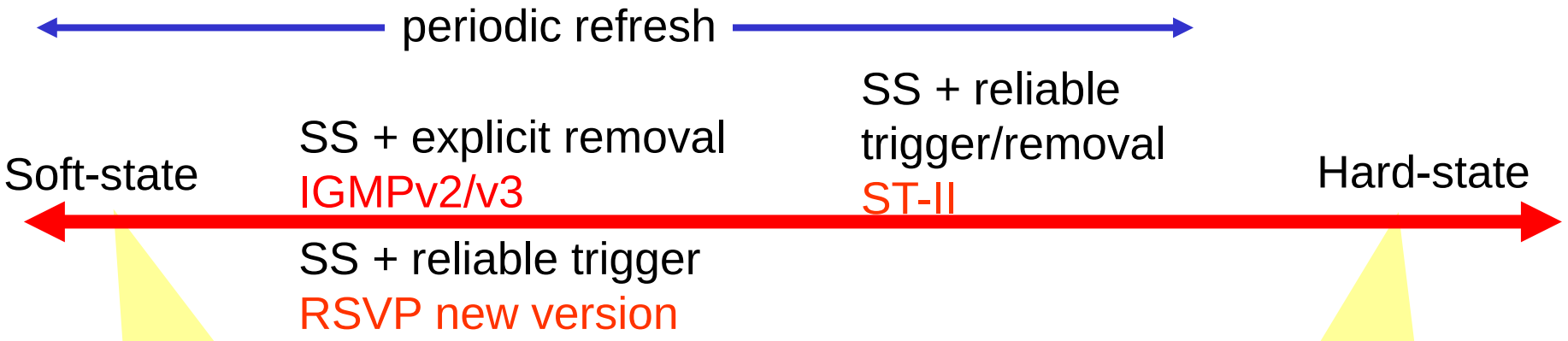
- Ultimately: Consequence of slow/fast response, msg loss probability will dictate appropriate timer values

Signaling spectrum



- Best effort periodic state installation/refresh
- State removal by time out
- RSVP, IGMPv1

- Reliable signaling
- Explicit state removal
- Requires additional mechanism to remove orphan state
- SS7, TCP

How do we model/evaluate?

Metrics

- Inconsistency ratio – fraction time participating nodes disagree
- Signaling overhead – average # of messages during session lifetime

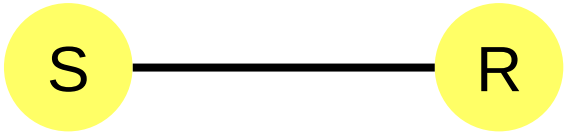
Measures of robustness?

- Convergence time

Complexity?

Single hop model

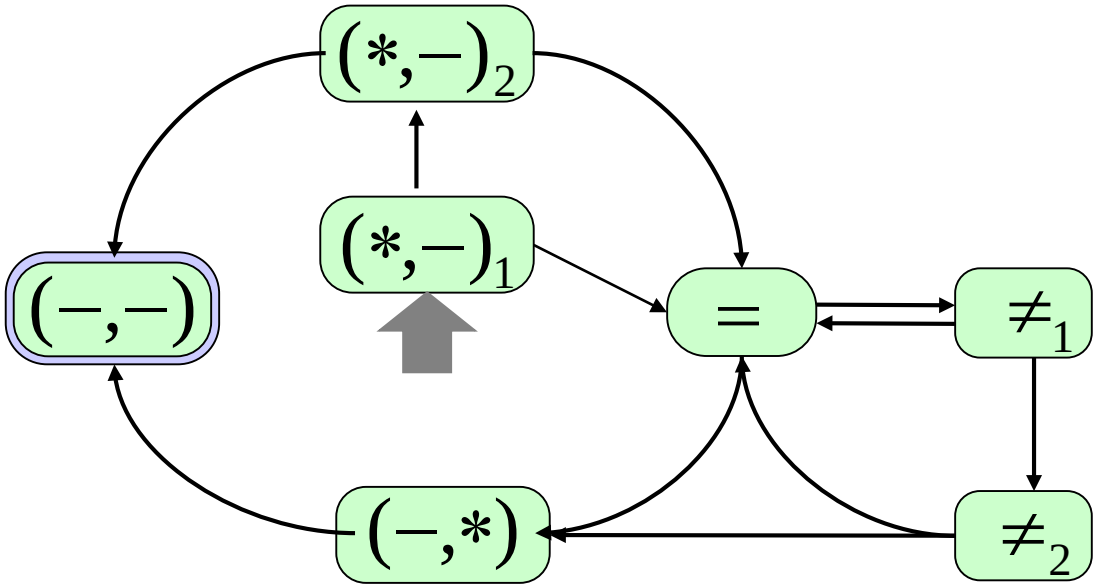
- Sender, receiver
- Single state variable
- State lifetime – exp(μ)
- Updates – Poisson(λ)
- Timers – exponentially distributed
  - Refresh - 1/T
  - State expiration – 1/X
- Link: Delay exp(1/D), loss prob. p



Transient Markov model

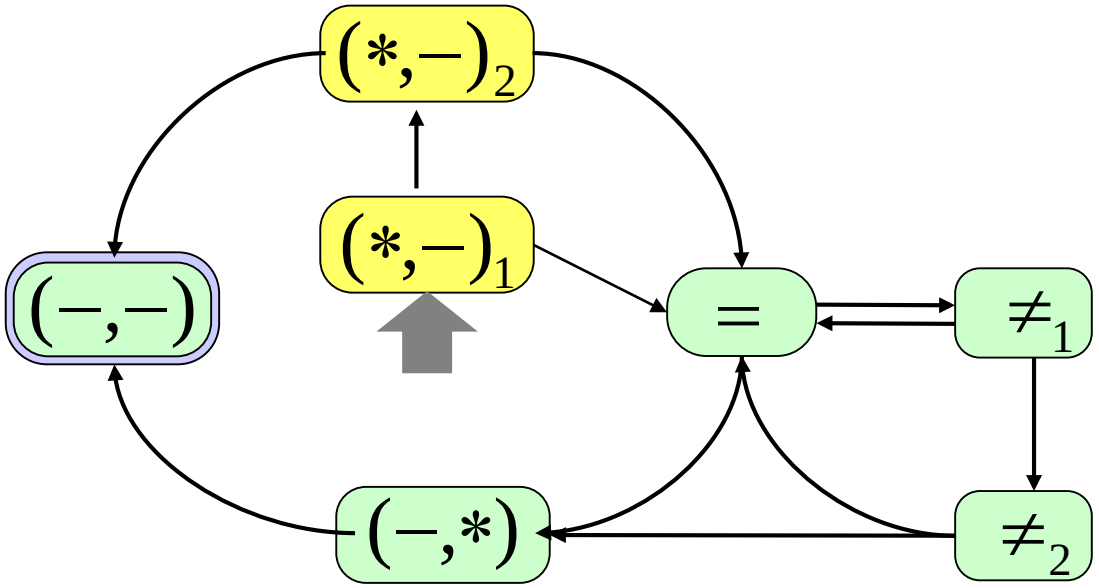
Model for SS

(Ji, Ge, Kurose and Towsley. A Comparison of Hard-state and Soft-state Signaling Protocols. SIGCOMM 2003)



Model for SS

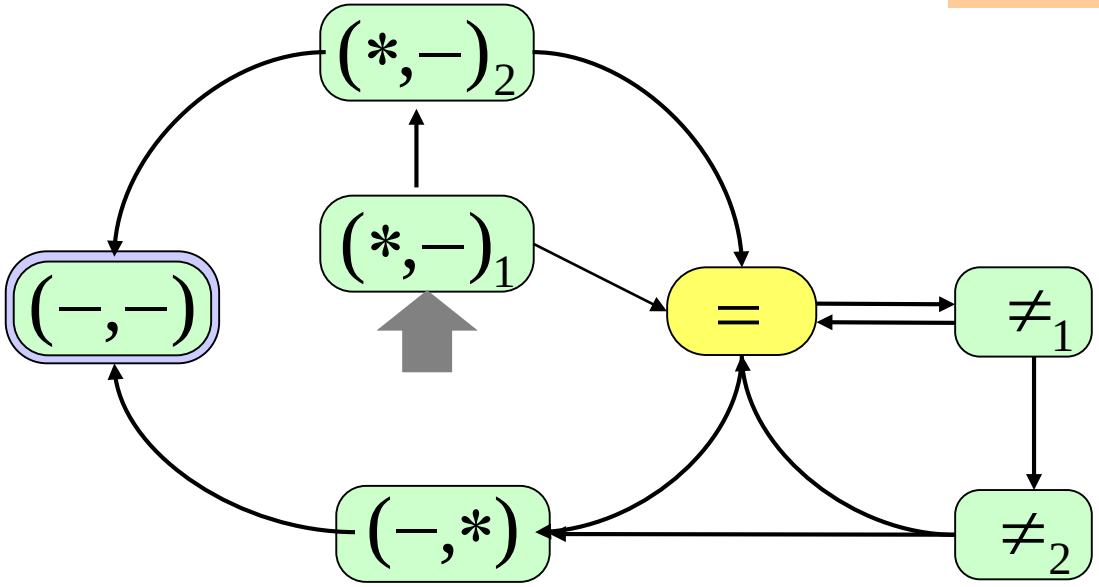
$(*,-)$: signaling state generated at sdr, not installed at rcvr



Model for SS

$(*,-)$ signaling state generated at sdr, not installed at rcvr

$=$: signaling state consistent at sdr/rcvr

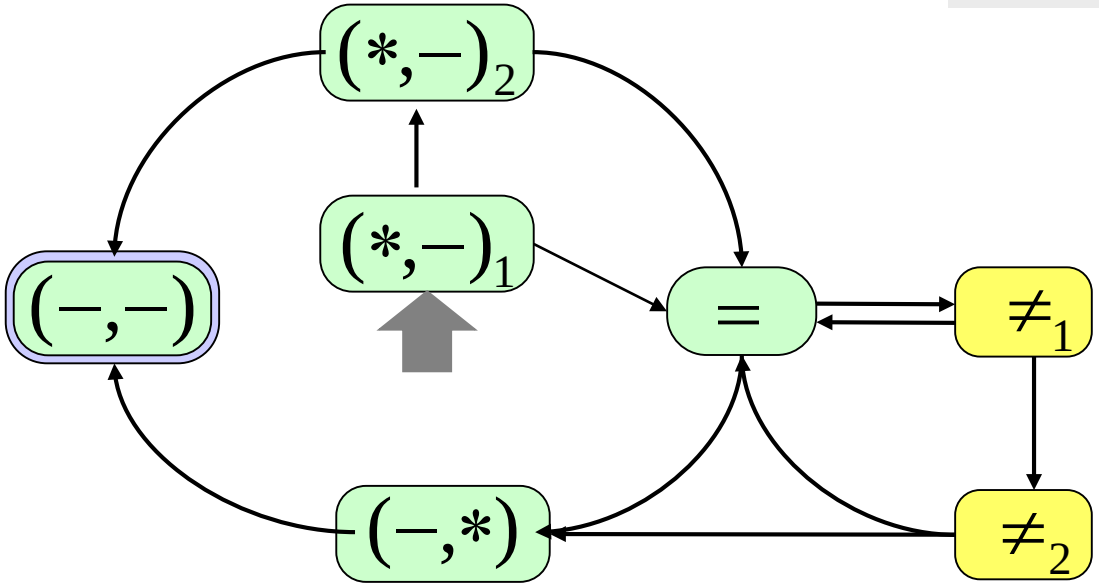


Model for SS

$(*,-)$ signaling state generated at sdr, not installed at rcvr

$=$: signaling state consistent at sdr/rcvr

$\neq$: signaling state inconsistent at sdr/rcvr



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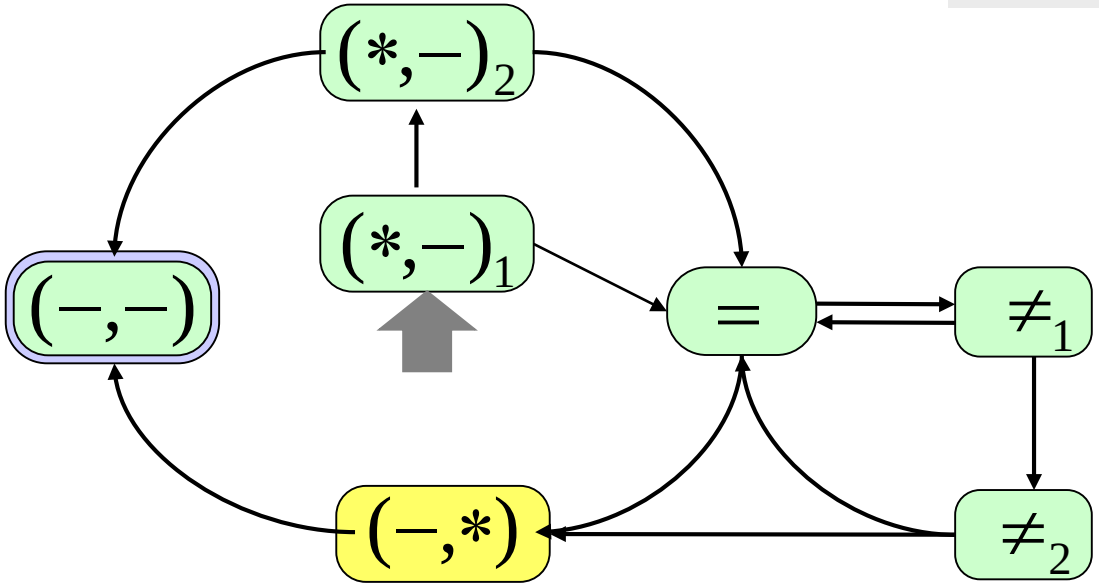

$(-,*)$: signaling state removed at sender, present at receiver

Model for SS

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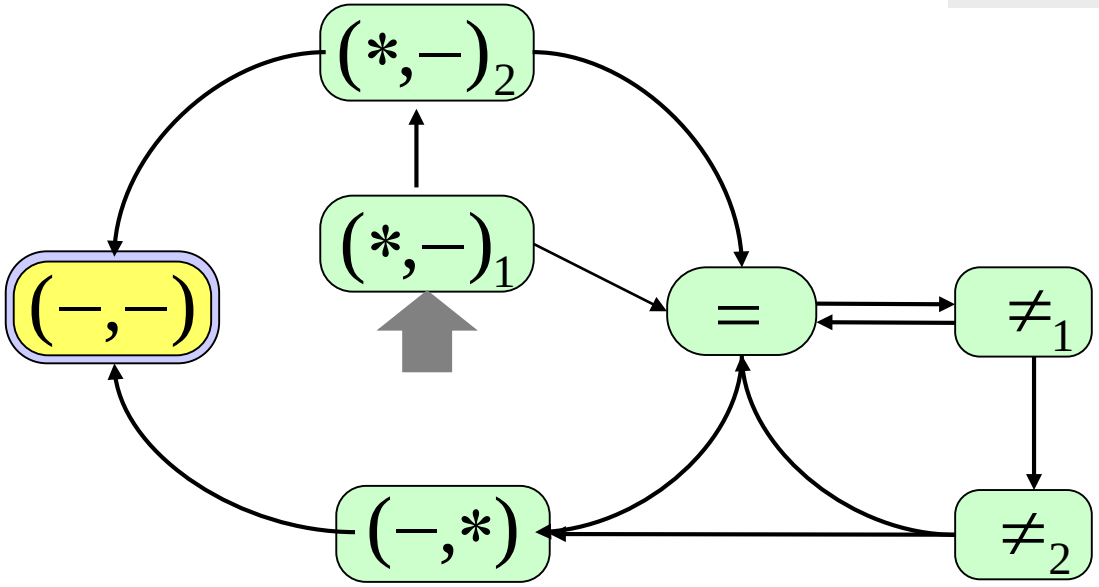

$\neq$: signaling state inconsistent at sdr/rcvr

$(-,-)$: signaling state removed at sdr/rcvr

$(-,*)$: signaling state removed at sender, present at receiver

Model for SS

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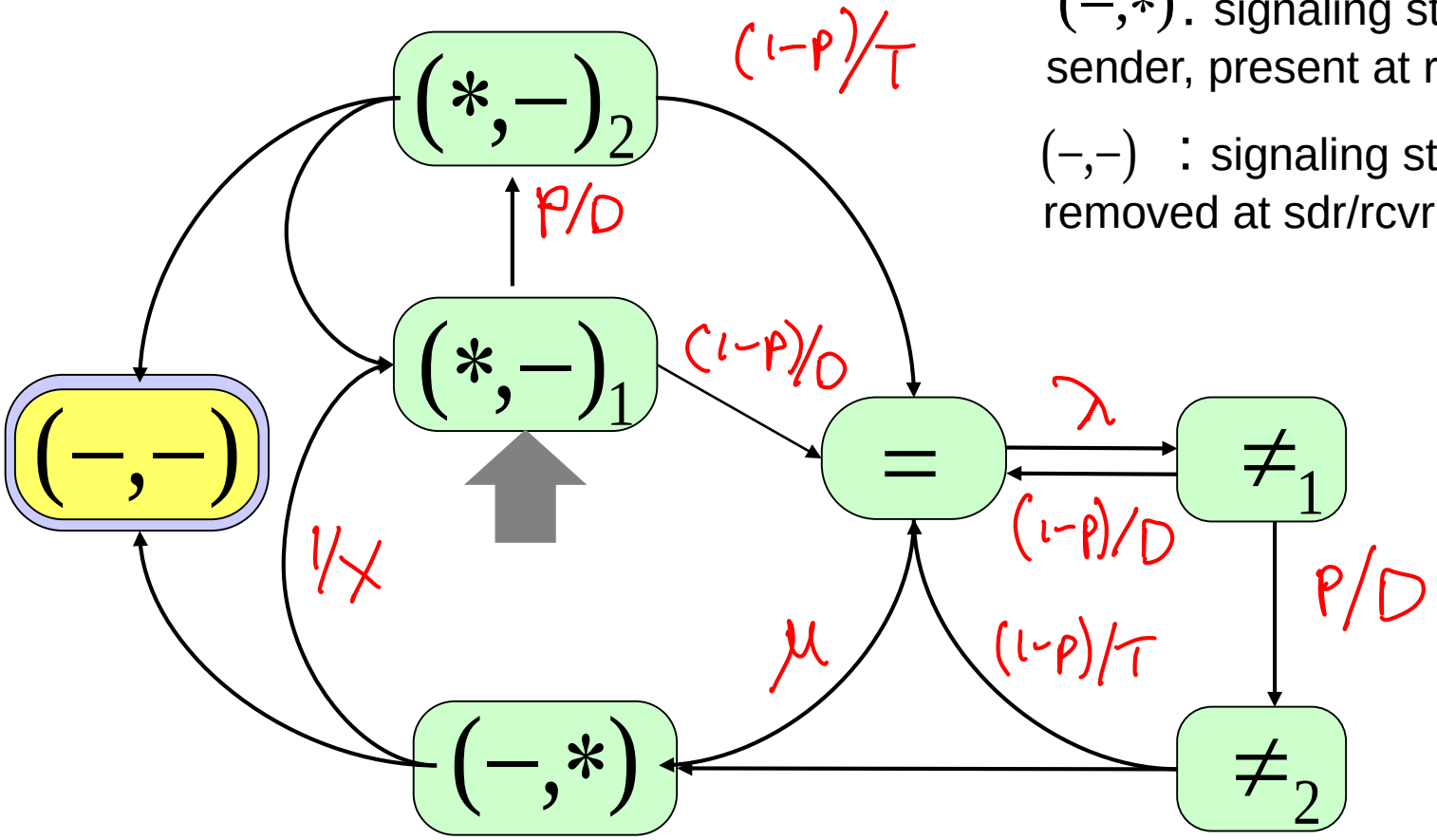


Performance metrics (SS)

- Inconsistency ratio:

$$\delta = 1 - \pi_{=}$$

- Signaling overhead

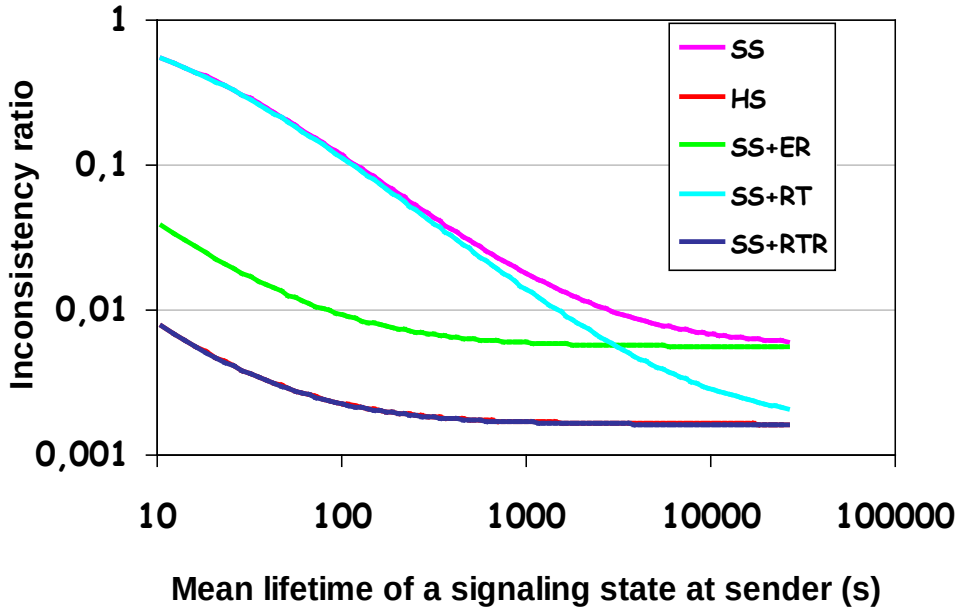
$$\Gamma = (1+\lambda +1/T) /\mu$$

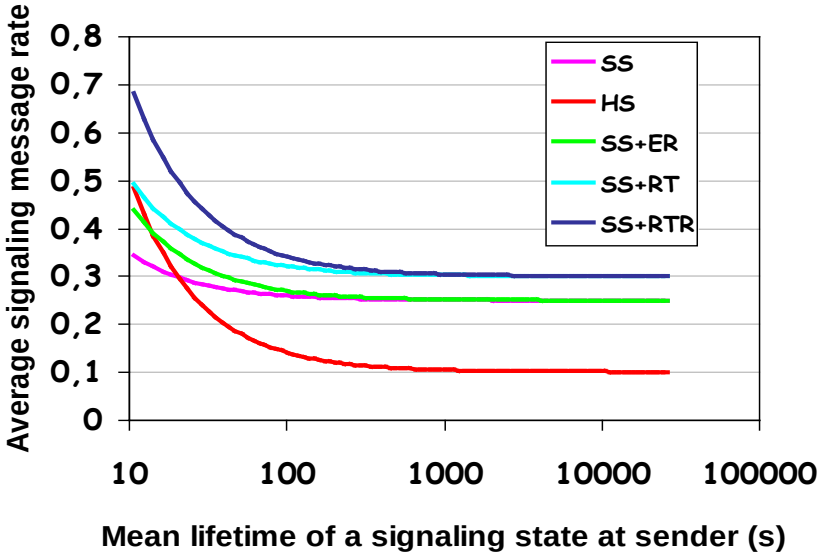
Parameter settings

- Mean lifetime – 30 min.
- Refresh timer, T = 5sec
- State timer, X = 15 sec
- Update rate – 1/20sec
- Signal loss rate – 2%

Motivated by Kazaa

Impact of state lifetime





- Inconsistency, overhead decrease as state life-time increases
- Explicit removal improves consistency with little additional overhead

Soft-state: Setting timer values

Q: How to set refresh/timeout timers

- State-timeout interval = n * refresh-interval-timeout
  - What value of n to choose?
- Will determine amount of signaling traffic, responsiveness to change
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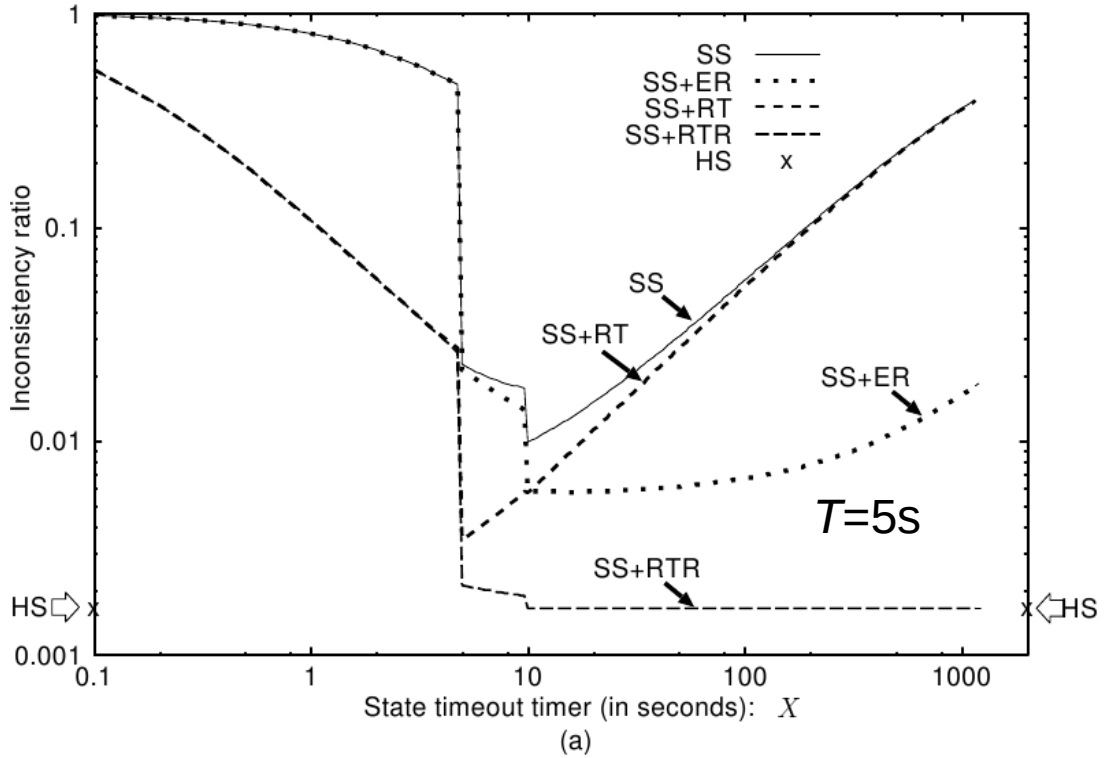
Impact of state timeout timer



- $X < T$: inconsistency high (premature state removal)
- $X > 2T$: increasing $X \Rightarrow$ increasing inconsistency for SS, SS+ER, SS+RT (due to orphan state)
- $X = 2T$: sweet spot

Hard-state versus soft-state: Discussion

Q: Which is preferable and why?

Hard state:

- Better if message OH really high
- Potentially greater consistency
- System wide coupling -> difficult to analyze

Soft state:

- Robustness, shorter convergence times
- Implicit reliability
- Easier error recovery
- Easily decomposed -> simpler analysis