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`

time

1a. HTTP client initiates TCP connection to HTTP server (process) at www.someSchool.edu on port 80

1b. HTTP server at host www.someSchool.edu waiting for TCP connection at port 80. “accepts” connection, notifying client

2. HTTP client sends HTTP *request message* (containing URL) into TCP connection socket. Message indicates that client wants object someDepartment/home.index

3. HTTP server receives request message, forms *response message* containing requested object, and sends message into its socket

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

time

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

status line (protocol status code status phrase)

header lines

data, e.g., requested HTML file

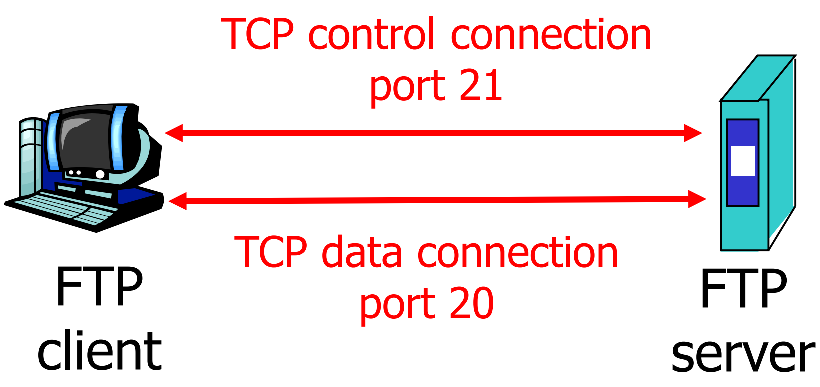
```
HTTP/1.1 200 OK
Connection close
Date: Thu, 06 Aug 1998 12:00:15 GMT
Server: Apache/1.3.0 (Unix)
Last-Modified: Mon, 22 Jun 1998 ...
Content-Length: 6821
Content-Type: text/html

data data data data data ...
```

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

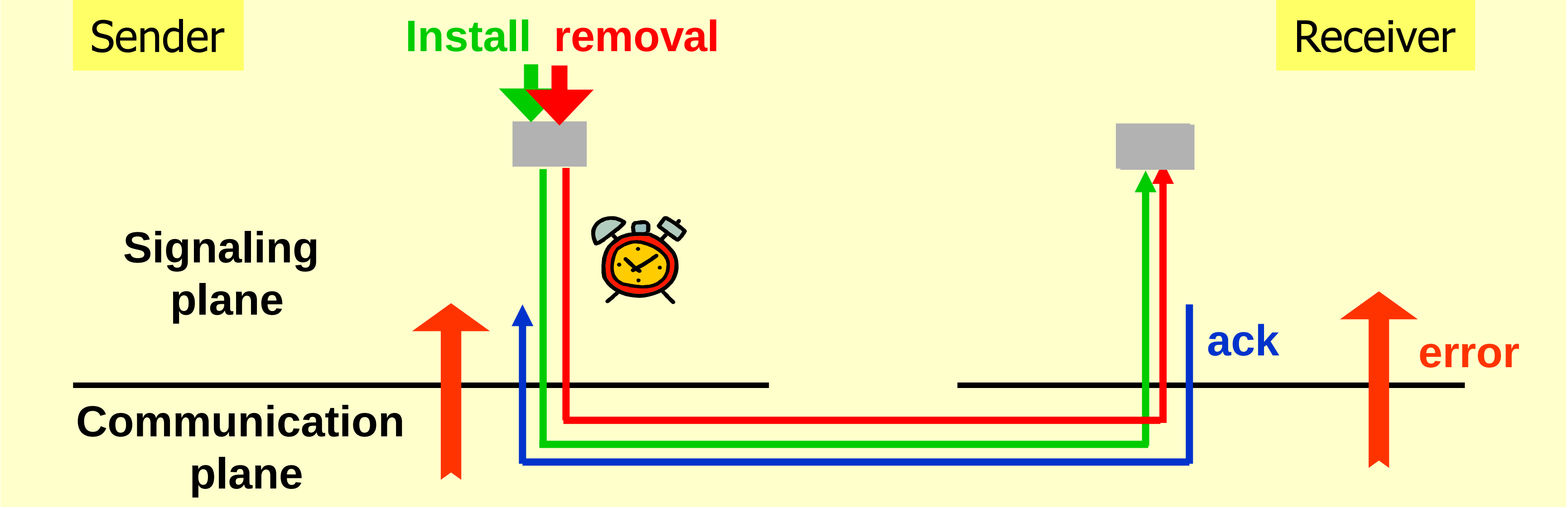
- *Default assumption:* state valid unless told otherwise
  - In practice: Failsafe-mechanisms (to remove orphaned state) in case of sender: e.g., receiver-to-sender "heartbeat": Is this state still valid?
- Examples:
  - TCP

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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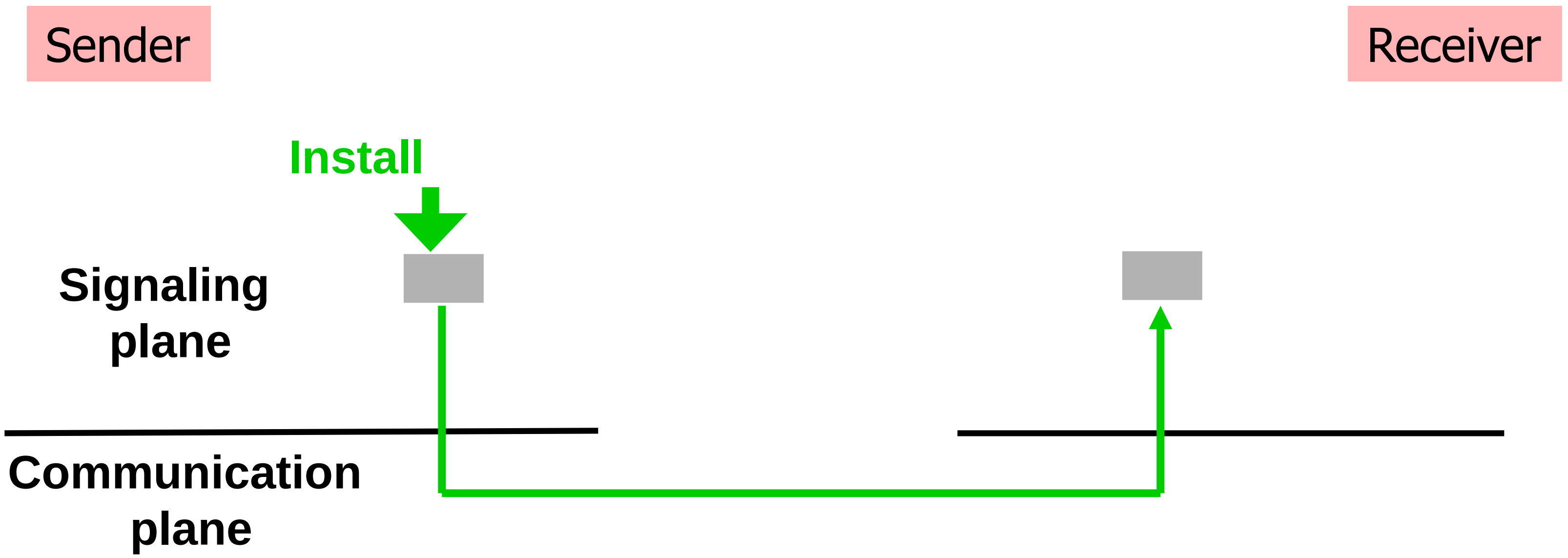
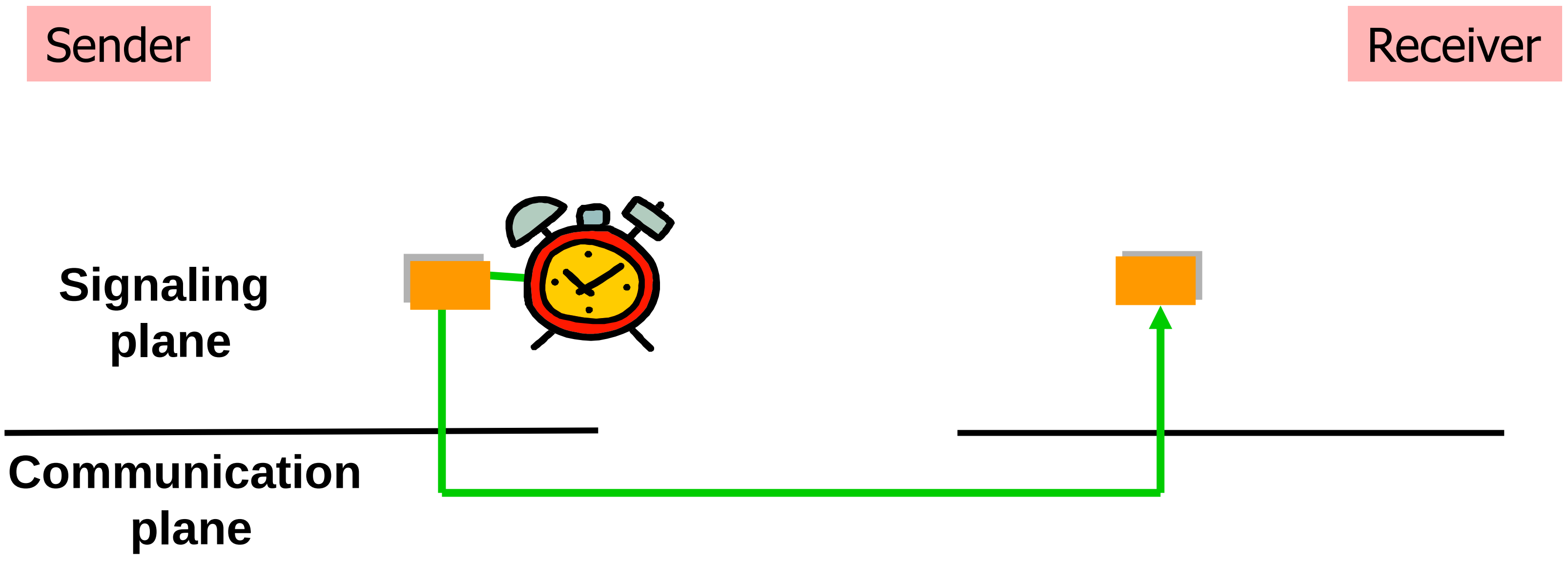
Soft-state signaling



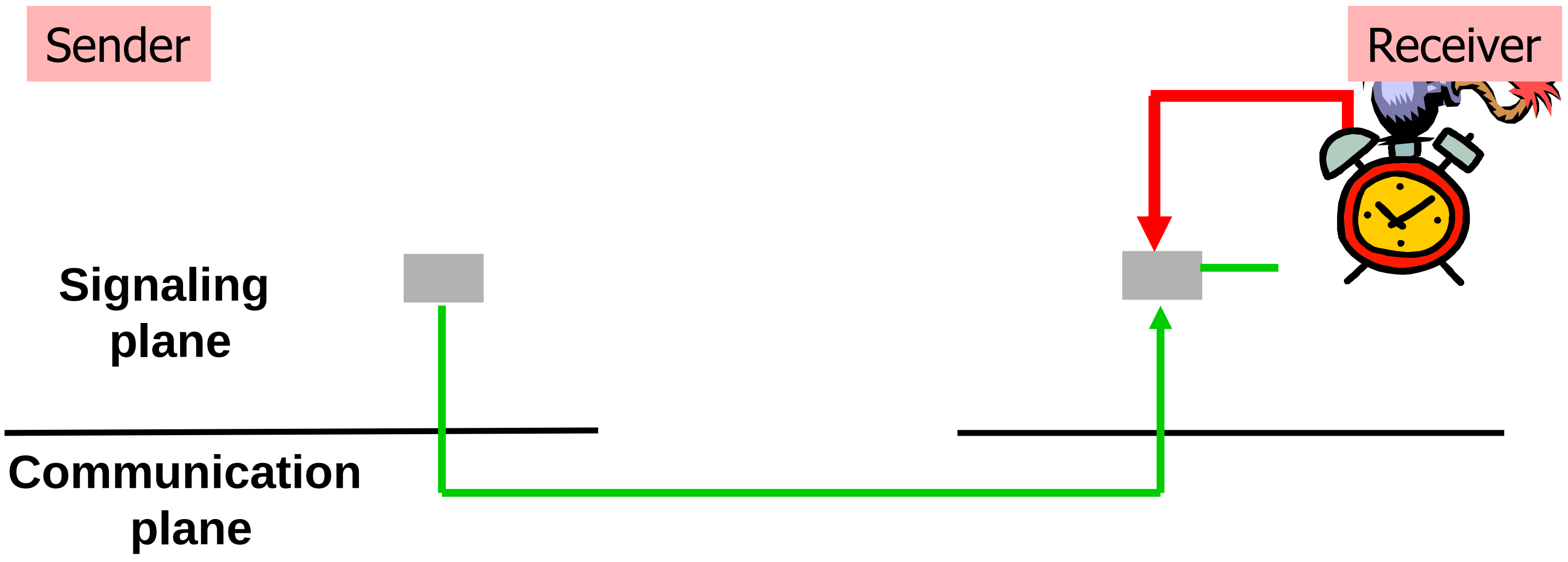
- Best effort signaling

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

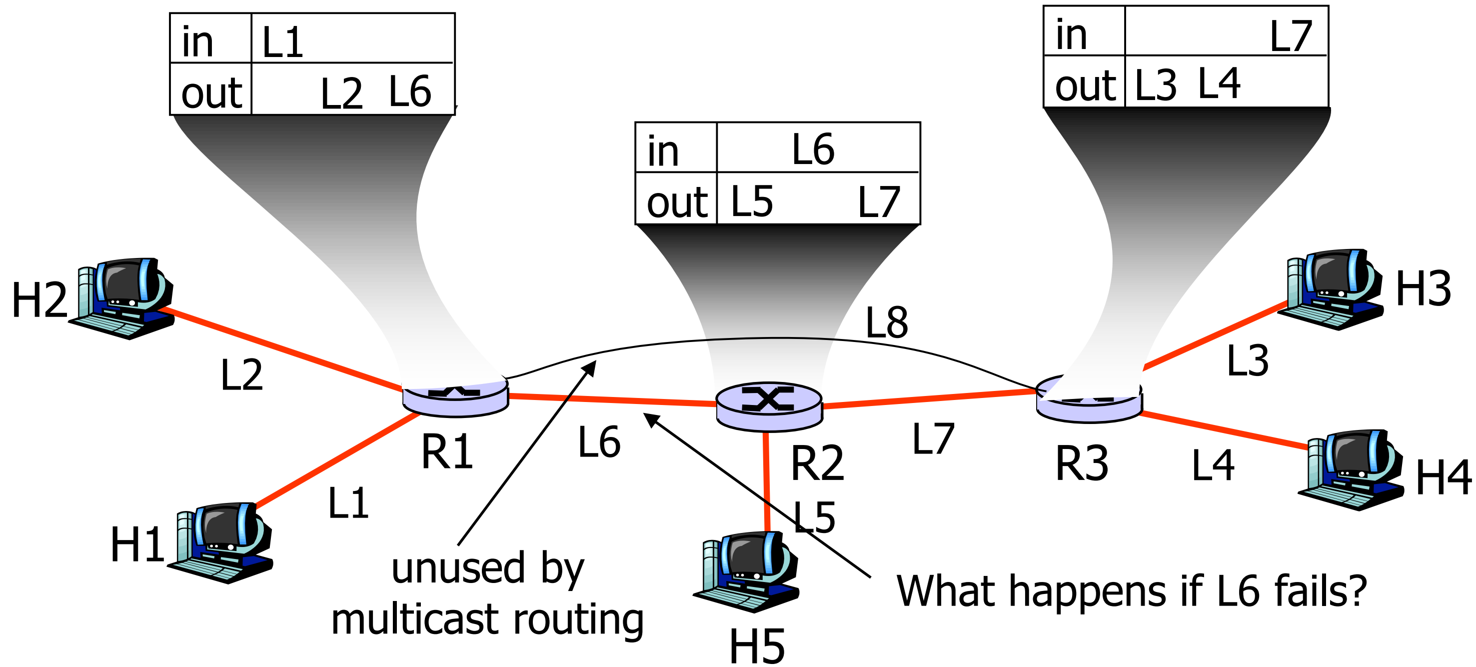
Soft-state: Claims

- “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?

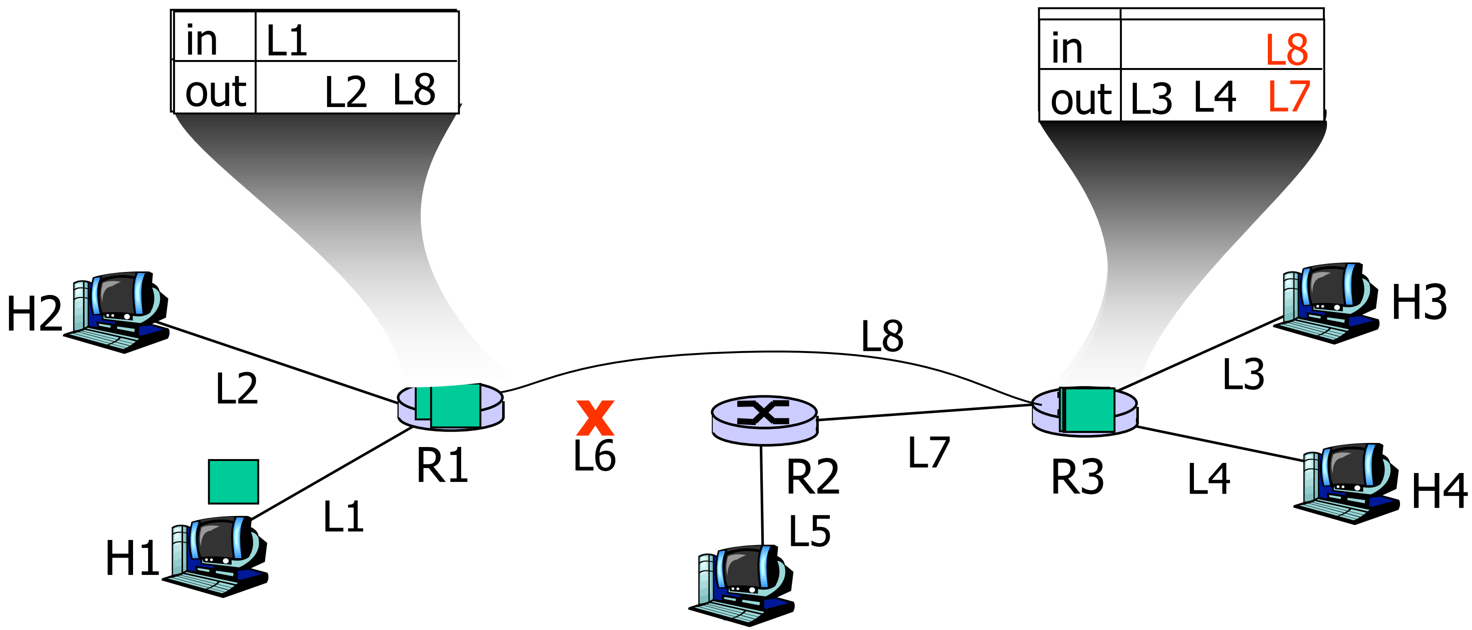
Soft-state: "Easy" handling of changes

- 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
  - Long timers: slow response to changes, less signaling
- Ultimately: Consequence of slow/fast response, msg loss probability will dictate appropriate timer values

Signaling spectrum

periodic refresh

Soft-state

SS + explicit removal
IGMPv2/v3

SS + reliable trigger
RSVP new version

SS + reliable trigger/removal
ST-II

Hard-state

- 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?

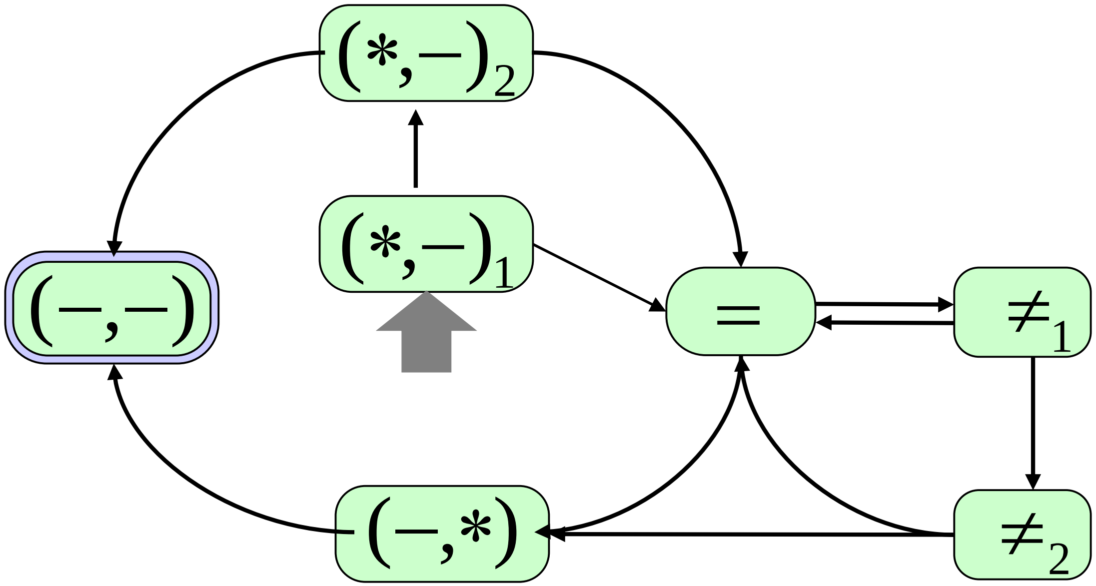
Single hop model

- 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

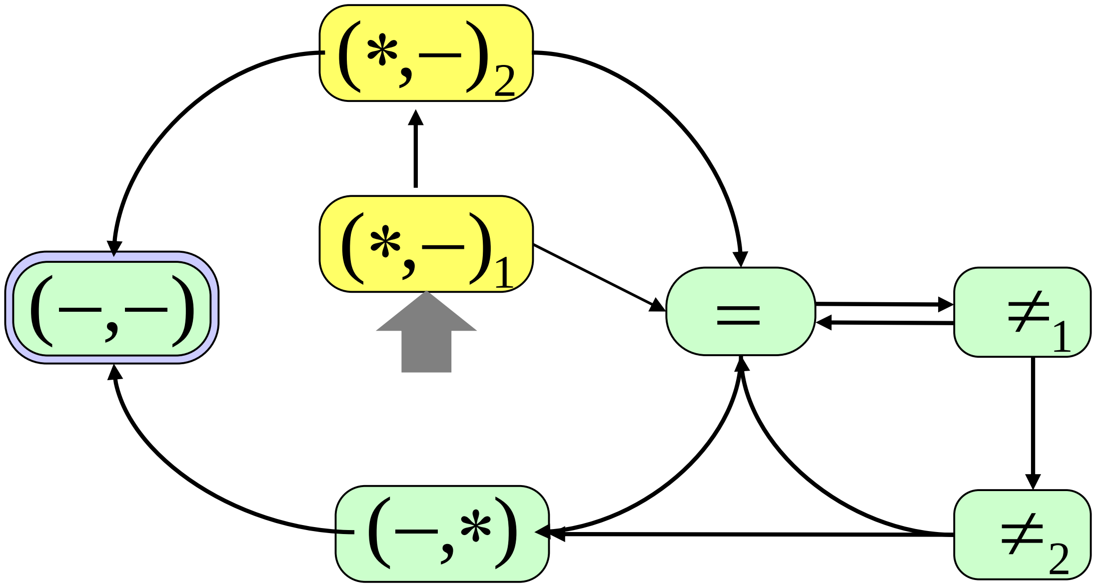
Model for SS

(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

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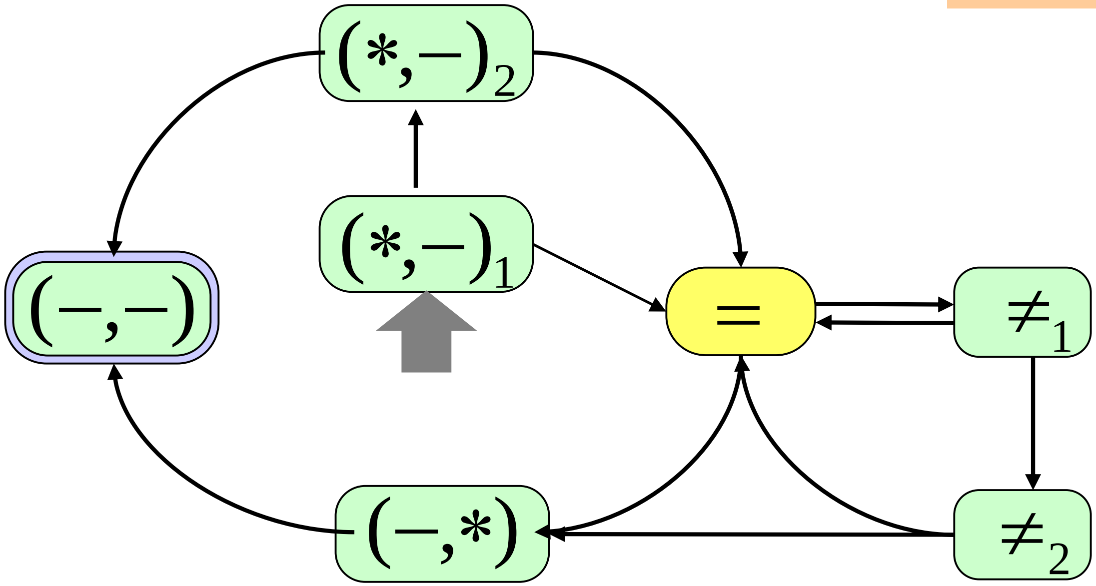
= : signaling state consistent at sdr/rcvr



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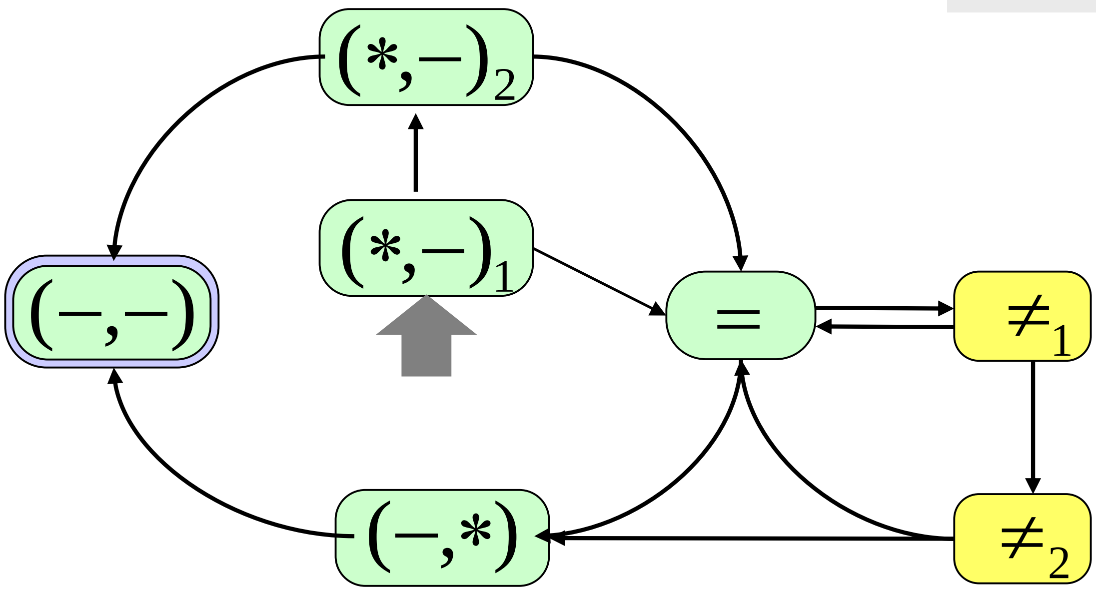
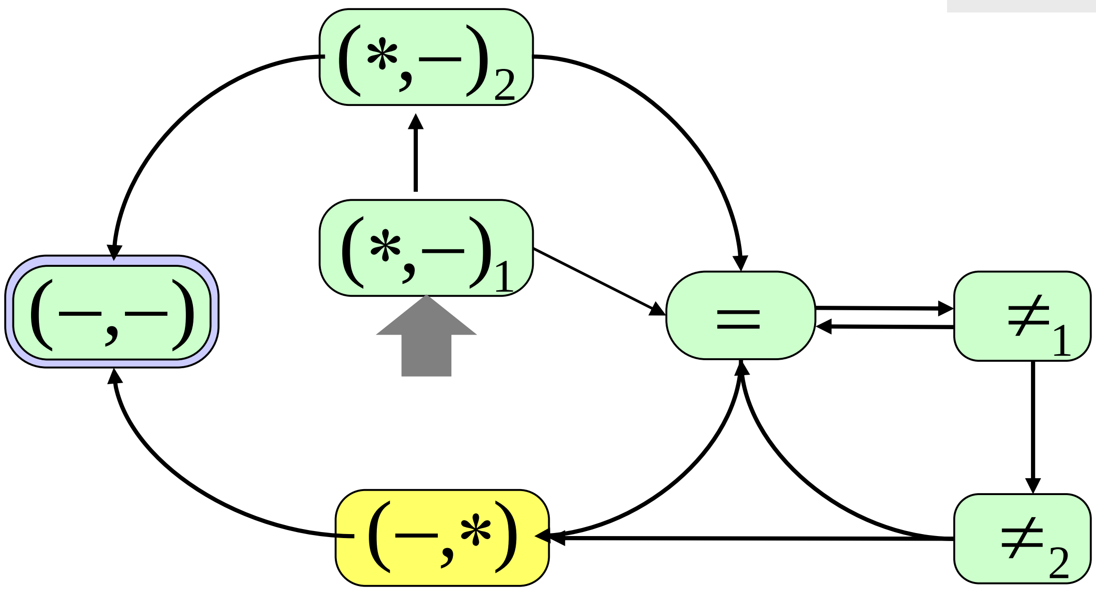


Model for SS

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

$=$: signaling state consistent at sdr/rcvr

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



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

Model for SS

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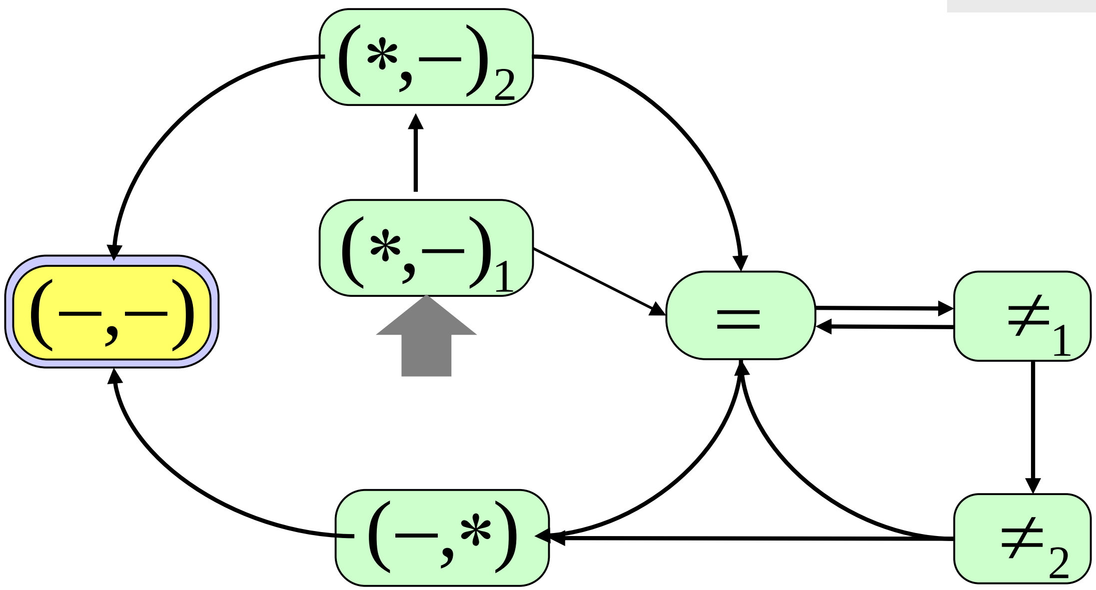

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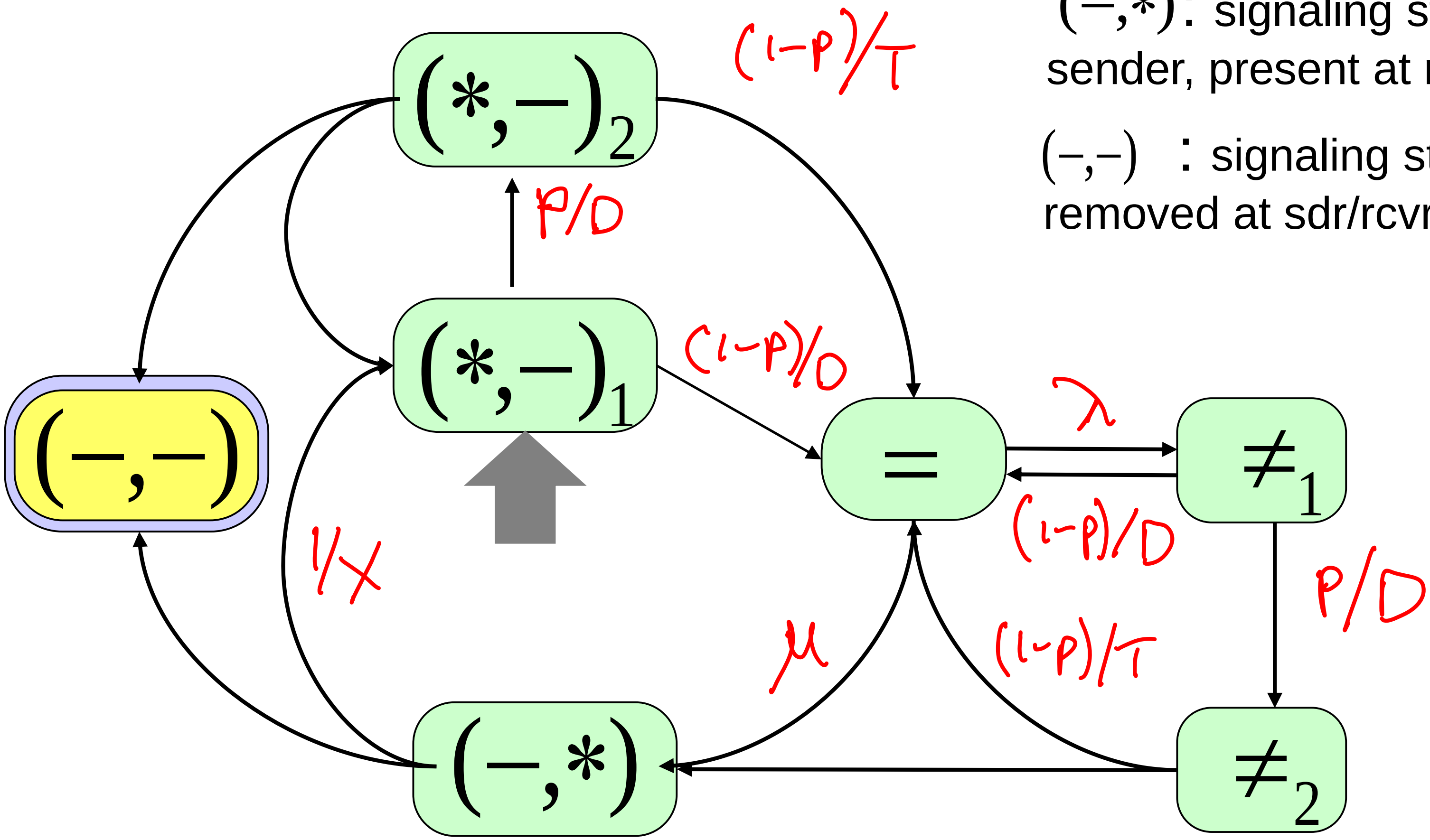


Performance metrics (SS)

- Inconsistency ratio:

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

- Signaling overhead

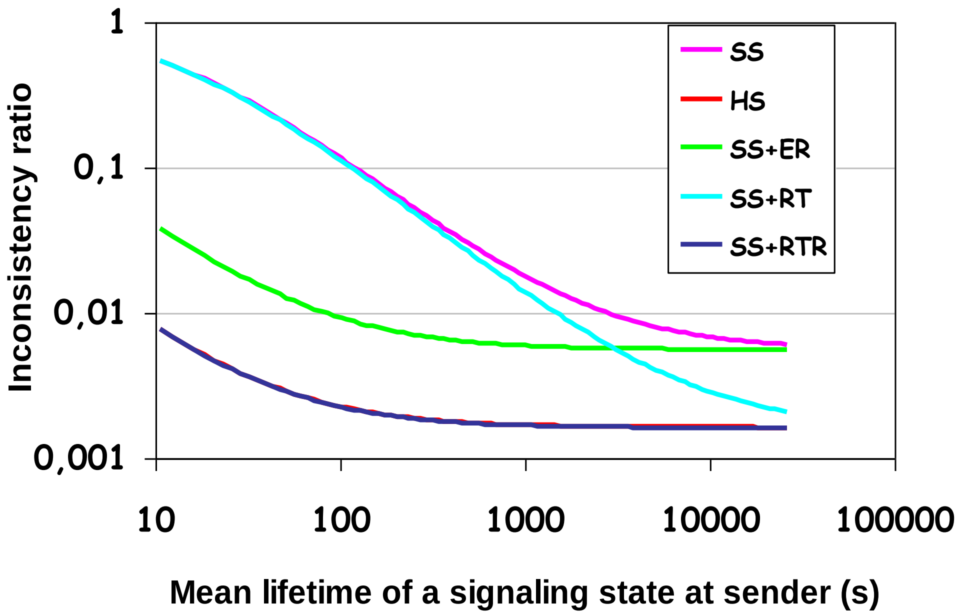
$$\Gamma = (1+\lambda + 1/T) / \mu$$

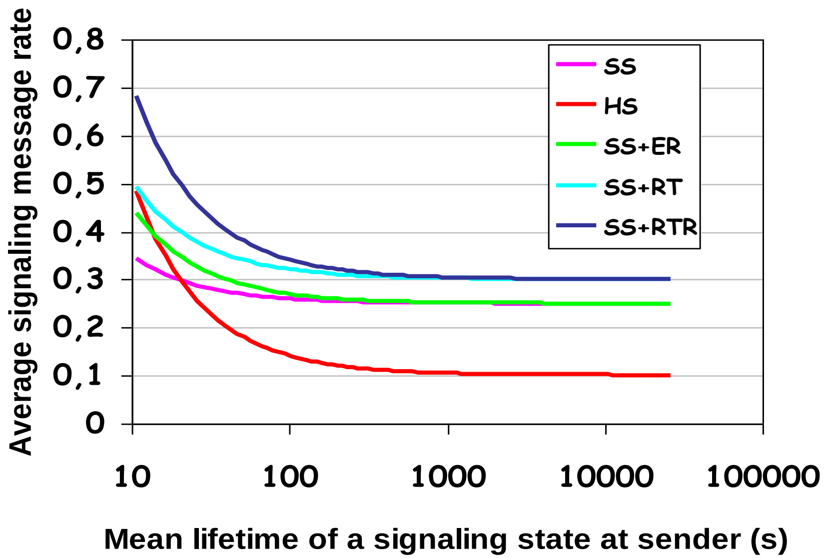
Parameter settings

- 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

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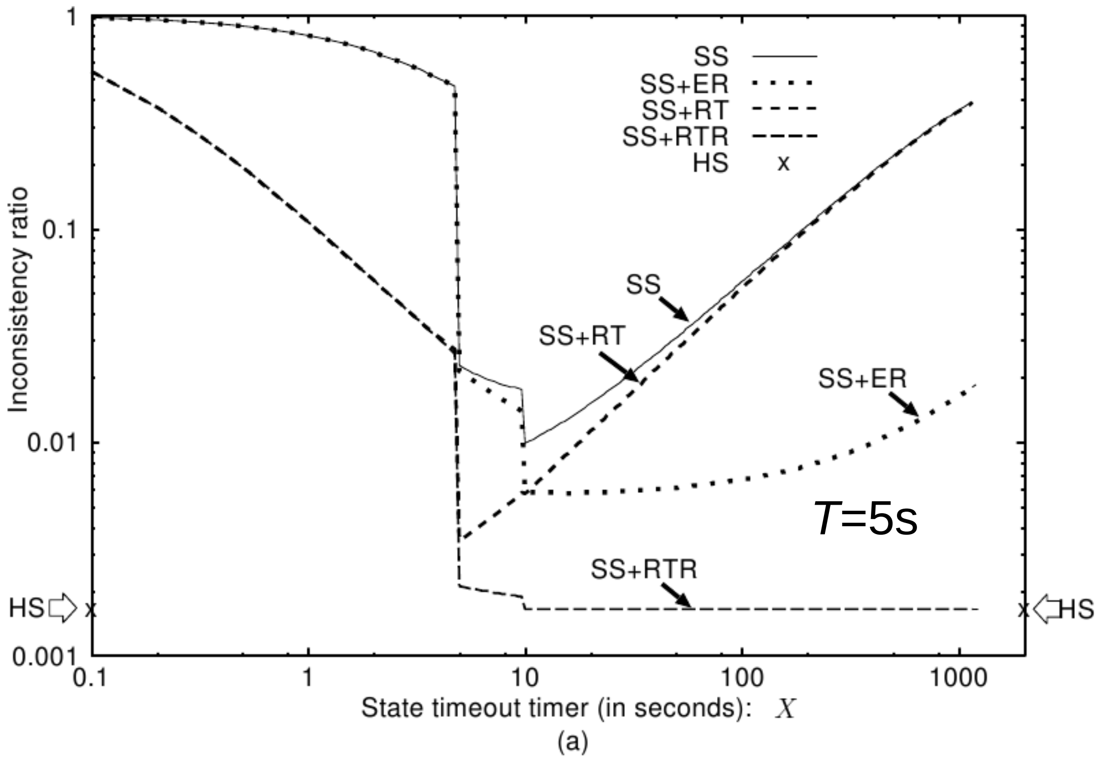
Impact of state timeout timer



- $X < T$: 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