Performance Analysis of Soft-State Lightpath Management in GMPLS-Based WDM Networks

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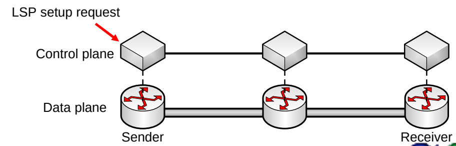
Signaling in wavelength routed networks

- GMPLS (Generalized Multi-Protocol Label Switching)
  - Protocol suite to control wavelength routed networks
  - RSVP-TE (Resource reSerVation Protocol – Traffic Engineering)
    - Soft-state signaling protocol for GMPLS
- RSVP-TE controls Path and Resv states in soft-state
  - Control states are deleted when they are **timeout**
  - Control states are held by **refresh**
    - State timeout timer is reset by receiving a refresh message



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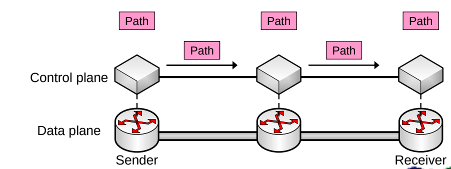

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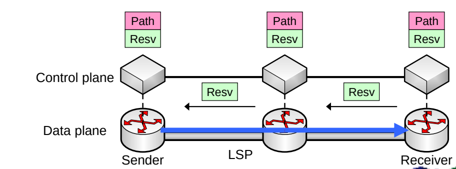

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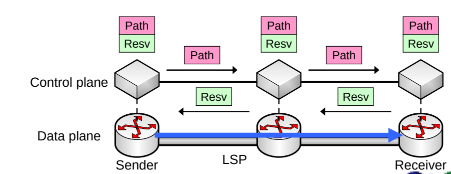

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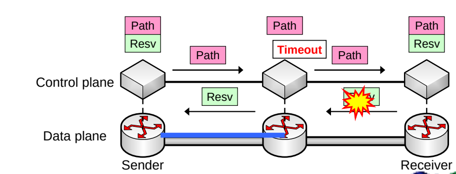

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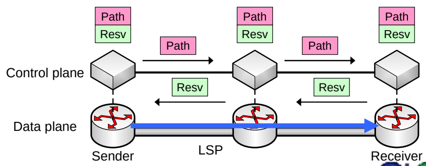

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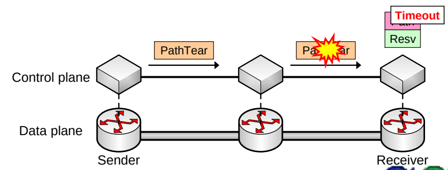

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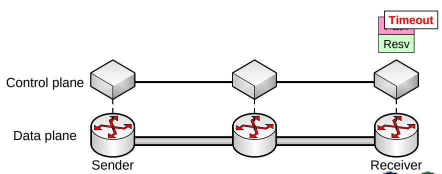


Previous studies on signaling in wavelength routed networks

- They assume no signaling message losses
  - Signaling protocols are evaluated as hard-state signaling
    - Control states are explicitly configured by signaling messages
- Signaling messages would be lost in real networks
  - Failures in the control plane, buffer overflow, software bug, etc…
  - Hard-state signaling cannot deal with signaling message losses
    - Cannot update control states without messages
  - Soft-state mechanism is indispensable
- But…
  - The performance of soft-state signaling protocols for wavelength routed networks is not revealed

Objectives of our research

- Our objective is to investigate
  - How control parameters of RSVP-TE affect the network performance
  - When the message retransmission of RSVP-TE works effectively
- Control parameters we are interested in
  - State lifetime
    - The period of time that states are held without refresh
  - Refresh interval
    - The time interval between the previous and the next refresh messages
  - Number of refreshes
    - The number of refresh messages sent during a state lifetime
- Signaling protocols for comparison
  - RSVP-TE: The standard RSVP-TE
  - RSVP-TE/Ack: The standard RSVP-TE + message retransmission
  - HS-BR: A hard-state signaling protocol for backward reservation

Model of RSVP-TE for single-hop LSP (1)

- Modeling the process of RSVP-TE for single-hop LSP
  - Extend the Markov model in [6]
- Assumptions to model RSVP-TE with Markov chain
  - For network
    - Holding times of LSPs follow an exponential distribution
    - Propagation delays of signaling messages follow an exponential distribution
    - Delay of message processing at nodes is 0
    - Blocking probability of wavelength reservation is constant
  - For RSVP-TE operation
    - Timeout intervals follow exponential distributions
    - Average timeout intervals of refresh timer, state-timeout timer, and retransmission timer are constant

[6] P. Ji, Z. Ge, J. Kurose, and D. Towsley, "A Comparison of Hard-state and Soft-state Signaling Protocols," in Proceedings of ACM SIGCOMM '03, August 2003.

Model of RSVP-TE for single-hop LSP (2)

- Parameters in this model
  - Propagation delay of signaling messages: D
  - Timeout interval of refresh timer: T
  - Refresh time: k
  - Timeout interval of state-timeout timer: $X = kT$
  - Average holding time of an LSP: $1/\mu$
  - Loss probability of signaling messages: p_l
  - Blocking probability of wavelength reservation: p_b
  - Retransmission interval: R
  - Retransmission times: m
  - Probability of false removal:

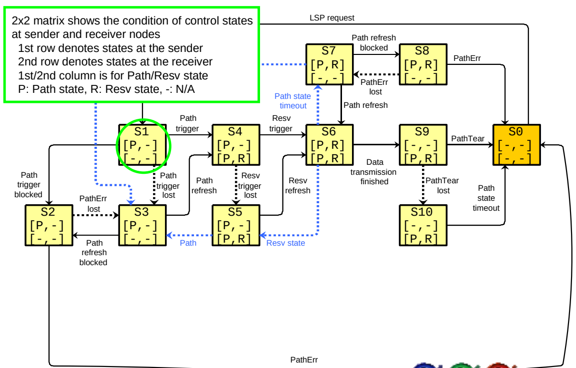
    RSVP-TE: $\lambda_f = p_l^{\,k} / X$

    RSVP-TE/Ack: $\lambda_f = p_l^{\,(k-1)(m+1)+1} / X$

Model with control plane failure

- Add states of the control plane failure to our model
  - Assumptions for the control plane failure
    - Signaling message transmission is impossible during the control plane failure
    - RSVP-TE deletes LSPs after failures (does not recovery the control states)
    - Control plane failures occurs in accordance with a Poisson process
    - Recovery time follows an exponential distribution
  - Additional parameters
    - Rate of the control plane failure: ϕ
    - Average recovery time: $1/\gamma$

State transition of RSVP-TE for a single-hop LSP



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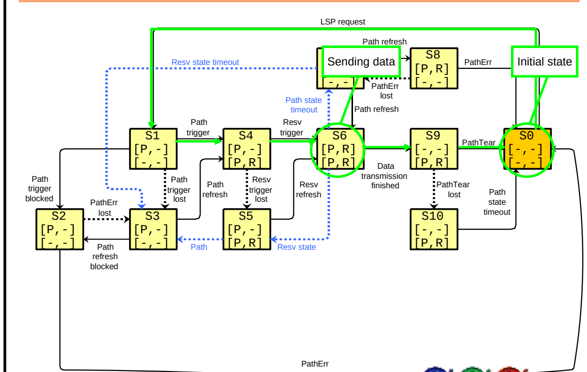

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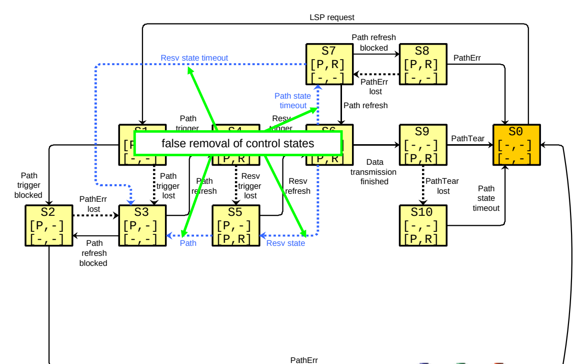

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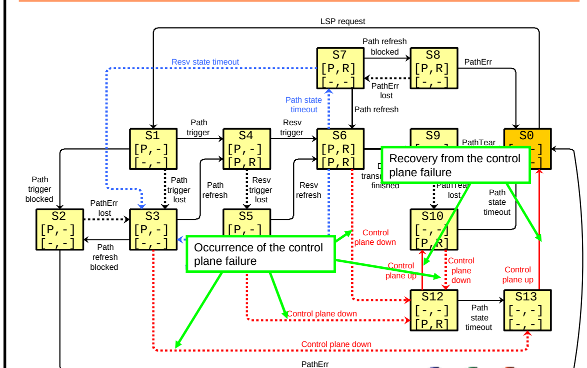

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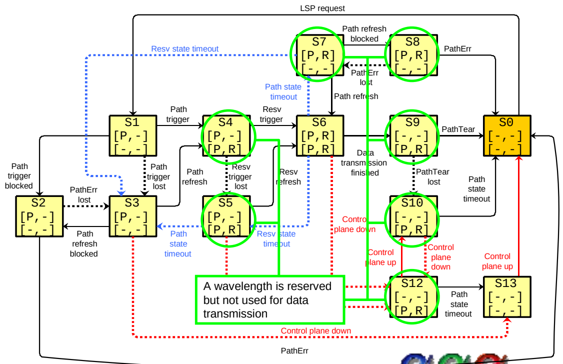
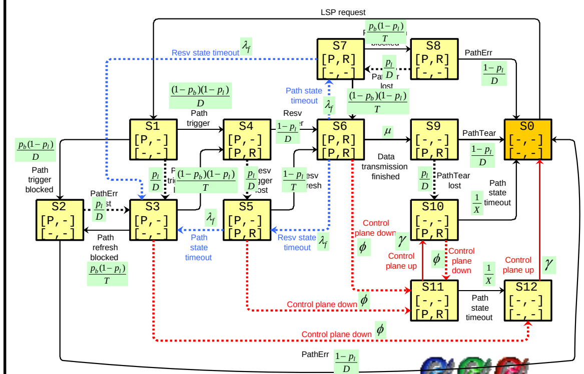


State transition rates



State transitions of RSVP-TE/Ack and HS-BR

- RSVP-TE/Ack
  - Retransmit signaling messages if they were lost
    - Retransmission rate is $1/R$
  - Replace transition rates of RSVP-TE state transition as follows

$$\frac{1}{T} \rightarrow \frac{1}{T} + \frac{1}{R}$$

$$\frac{1}{X} \rightarrow \frac{1}{X} + \frac{1-p_l}{R}$$ (for only the transition from S_{10} to S_0)

- HS-BR
  - No timers and no refreshes
  - Change the state transition of RSVP-TE/Ack as follows
    - Remove transitions associated with state timeout and refresh timeout
    - Remove unreachable states

Calculating unoccupied time

- Unoccupied time
  - The time a wavelength is reserved but not used for data transmission
  - The longer the unoccupied time is, the less resource utilization becomes
- Unoccupied time is obtained with the ratio of steady-state probability
  - π_i : steady-state probability of S_i
  - Unoccupied time T' is given as follows
    - Average communication time is $1/\mu$

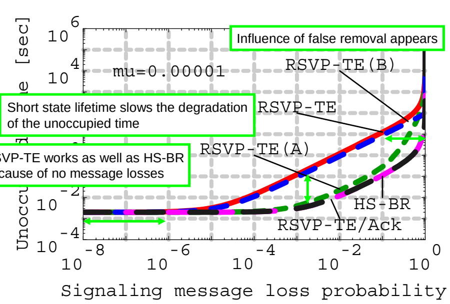
$$T' = \frac{\pi_4+\pi_5+\pi_7+\pi_8+\pi_9+\pi_{10}+\pi_{11}}{\mu\pi_6}$$

Analysis of RSVP-TE for single-hop LSP

- Unoccupied time against signaling message loss probability
  - Parameter settings
    - Propagation delay: 0.001 sec
    - Average communication time: 100000 sec (about 28 hours)
    - Blocking probability of wavelength reservation: 0.001
- Compare the unoccupied time among 5 types of signaling
  - RSVP-TE: *standard*
    - Refresh interval = 30sec* / number of refreshes = 3* (state lifetime = 90sec)
  - RSVP-TE(A): *short lifetime*
    - Refresh interval = 0.5sec / number of refreshes = 3* (state lifetime = 1.5sec)
  - RSVP-TE(B): *frequent refresh*
    - Refresh interval = 0.5sec / number of refreshes = 180 (state lifetime = 90sec)
  - RSVP-TE/Ack: *message retransmission*
    - Refresh interval = 30sec* / number of refreshes = 3* (state lifetime = 90sec)
    - Retransmission interval = 0.5sec** / retransmission times = 3**
  - HS-BR: *hard-state*
    - Retransmission interval = 0.5sec / retransmission times = unlimited

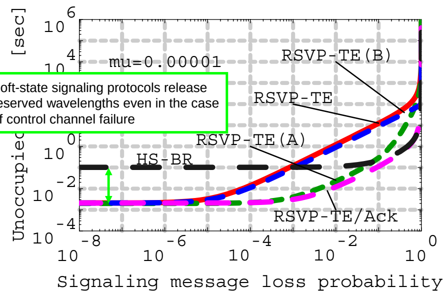
*: RFC2205
**: RFC2961

Unoccupied time vs message loss probability (without failure)



Unoccupied time vs message loss probability (with failure)

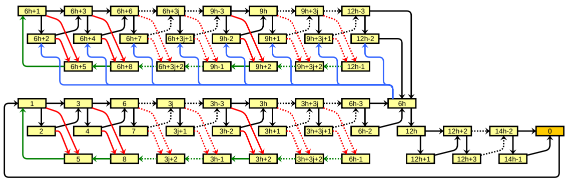
Control plane failure rate: 0.00000001 /s (about once every 3 years)
Average recovery time: 100000 s (about 28 hours)



Soft-state signaling protocols release reserved wavelengths even in the case of control channel failure

Model of RSVP-TE for multi-hop LSP

- Extend the Markov model for a single-hop LSP
  - Assume false removals never occur during LSP setup and recovery
    - To avoid the rapid increase of the number of states
    - LSP holding time is enough long to omit those removals
  - The number of states is $14h$ for h hop LSP

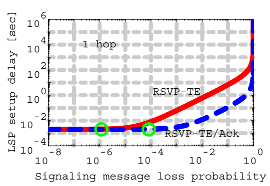


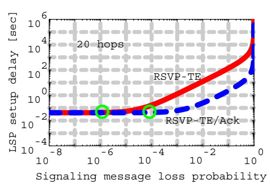
Analysis of RSVP-TE for multi-hop LSP

- LSP setup delay against signaling message loss probability
  - LSP setup delay is given as follows

$$T_S = \frac{\sum_{j=1}^{6h-1} \pi_j}{\mu \pi_{6h}}$$

- Tendency of LSP setup delay is not dependent on the length of LSP





Effectiveness of message retransmission

- When the message retransmission is efficient / inefficient
  - The amount of signaling messages in RSVP-TE/Ack is greater than in RSVP-TE
  - The signaling message loss probability in RSVP-TE/Ack must be greater than in RSVP-TE
- From these assumptions, the message loss probability is described with M/M/1/K queuing model
  - Message losses occur only by buffer overflow
  - Signaling messages arrive according to a Poisson process
  - The processing times of signaling messages follow an exponential distribution

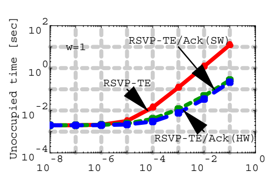
$$P_{b_2} = \frac{(1 - w\rho_2)(w\rho_2)^K}{1 - (w\rho_2)^{K+1}} \qquad K = \frac{\log\left[\frac{P_{b_1}}{1-(1-P_{b_1})w\rho_1}\right]}{\log[w\rho_1]}$$

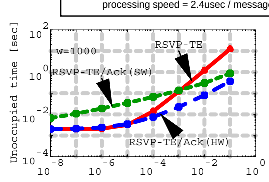
P_{b_1} : message loss probability in RSVP-TE
P_{b_2} : message loss probability in RSVP-TE/Ack

Numerical examples

- Message retransmission may degrade the resource utilization
  - When the number of sessions is 1000, the unoccupied time of RSVP-TE is shorter than that of RSVP-TE/Ack(SW)

SW: implemented with software
processing speed = 0.1msec / message [9]
HW: implemented with hardware
processing speed = 2.4usec / message [10]





[9] Z. Zhou and D. Gao, "An efficient adaptation of RSVP-TE in GMPLS," in Proceedings of the 2004 International Symposium of Performance Evaluation of Computer and Telecommunication Systems (SPECTS 2004), July 2004.
[10] H. Wang, R. Karri, M. Veeraraghavan, and T. Li, "A hardware-accelerated implementation of the RSVP-TE signaling protocol," in Proceedings of IEEE International Conference of Communications (ICC 2004), June 2004.

Summary

- Summary
  - We developed Model of GMPLS RSVP-TE by Markov chain
    - For single-hop LSP with/without control plane failure
    - For multi-hop LSP
  - We analyzed the performance of GMPLS RSVP-TE with those models
    - Low signaling message loss probability lets RSVP-TE works as well as hard-state signaling protocols
    - Soft-state signaling protocols are stable to control channel failures
  - We evaluated the effectiveness of the signaling message retransmission
    - The message retransmission may result in poor resource utilization when there are thousands of sessions
- Future work
  - Analysis of other signaling protocols for wavelength routed networks
    - e.g. Parallel reservation
  - Comparison of the performance between soft-state and hard-state signaling protocols in transient state