# Real-Time Reconfiguration of MPLS/WDM Networks

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# Goal

- Develop an integrated management and control framework for MPLS/WDM networks that
  - Reconfigures both optical lightpaths and MPLS label switched paths in real-time to accommodate changes in traffic demands
  - Adapts proactively to both deterministic (time-of-day) and random traffic variations
  - Minimizes disruption to existing traffic due to adaptation

# Outline of Approach

- Control at multiple timescales
- Traffic model that includes both deterministic (time-of-day) and random variations
- Incremental reconfiguration using branch exchanges
- Formulation of Markov decision process
- Approximate solution of MDP using rollout

# Multiple Timescales

- Slow timescale: reconfiguration of logical topology (lightpaths) 2.5 minutes
- Moderate timescale: reconfiguration of MPLS label switched paths (LSPs): 30 seconds
- Fast timescale: mapping of arriving flows onto LSPs 1 second

# Traffic Model

- Calls for source-destination pair ij arrive as Poisson process with variable rate $T_{ij}(t)$ and have exponentially distributed duration
- $T(t) = Y(t)\ (1+ Z(t))$
  - Y(t) is piecewise linear function known to controller
  - Z(t) is brownian bridge approximated by $Z(t) = X(t) - t\ X(1)$, where X(t) is a generalized random walk.

# Reward Function

- Reward is accumulated based on traffic carried and delay encountered

$$R^f(r) = \sum_{i,j} \sum_{l} C u_{ij}^{l} (1 - \alpha (d_{ij}^{l}(r) - d_{0,ij}))$$

- Reward for moderate and slow timescale is sum of rewards for all fast timescale steps in corresponding moderate or slow time scale step

# Fast Timescale Policy

- Arriving call is assigned to the LSP with least total delay provided sufficient bandwidth is available
- Overloading LSP increases delay and decreases reward
  - Maximum number of calls permitted to be assigned to LSP with provisioned BW L

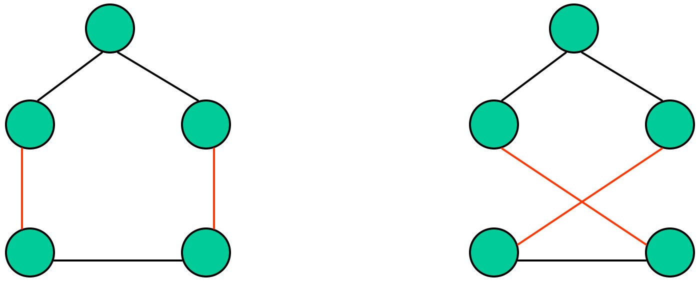
$$u_{\max} = \frac{L}{C}\left(1 - \sqrt{\frac{\alpha}{L}}\right)$$

# Moderate Timescale Policy

- Reserve BW for the existing calls in each LSP
- Estimate the number of arriving calls for each source-destination pair ij
  - Using observed number of arrivals during previous time step, estimate the random part of the arrival rate for the next time step
  - Combine random part with deterministic part to get estimate of total arrival rate
- Provisioned BW of LSPs are increased to provide for estimated number of arrivals
  - LSPs are considered in order of increasing delay
  - Source-destination pairs are considered in order of decreasing difference in delay between their best two LSPs

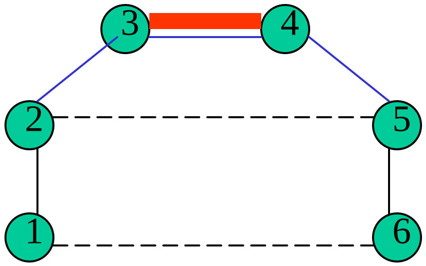
# Branch Exchanges

- Double branch exchanges permit new lightpaths to be formed when there are no free router interfaces
  - Two lightpaths are torn down and two are created
- Incremental topology changes minimize disruption of existing traffic



# Admissible Branch Exchanges

- Restrict admissible branch exchanges to those that have realistic chance of relieving congestion
- Say that a lightpath is congested if its utilization exceeds 80% of capacity
- Say that a source-destination pair ij contributes to a congested lightpath if its calls contribute load corresponding to more than 5% of lightpath capacity
- Branch exchange g is admissible if at least one of the lightpaths it creates directly  connects a source-destination pair that contributes to a congested lightpath




S-D pair 2,5 contributes to congested lightpath 3-4. BE creates lightpaths 2-5 and 1-6 offloading traffic from 3-4.

# Slow Timescale Heuristic Policy

- For each admissible branch exchange, perform the following computation using the new topology
  - Determine the 3 least delay LSPs for each source-destination pair
  - If an existing LSP no longer exists, migrate the calls to the active LSPs
  - Reprovision the bandwidth of the active LSPs taking into account the calls that must be migrated as well as the estimated number of new arrivals during the next slow time step
  - Based on the number of calls assigned to each LSP (including migration and new arrivals), determine the expected reward over the next slow time step
- Choose the branch exchange that gives the maximum expected reward over the next slow time step

# Concept of Rollout

- Starts with a heuristic policy $u = \pi(x)$ where u is the action in state x
- Creates an improved 'rollout' policy $u = \pi_r(x)$ as follows
  - For each possible action u in state x, evaluate the expected reward of taking u in x and following policy $\pi$ starting in the next state x'.
  - Let $\pi_r(x)$ be the action that maximizes the expected reward.
- The action $\pi_r(x)$ can be computed online when state x is visited using simulation to compute the expected reward for each possible action

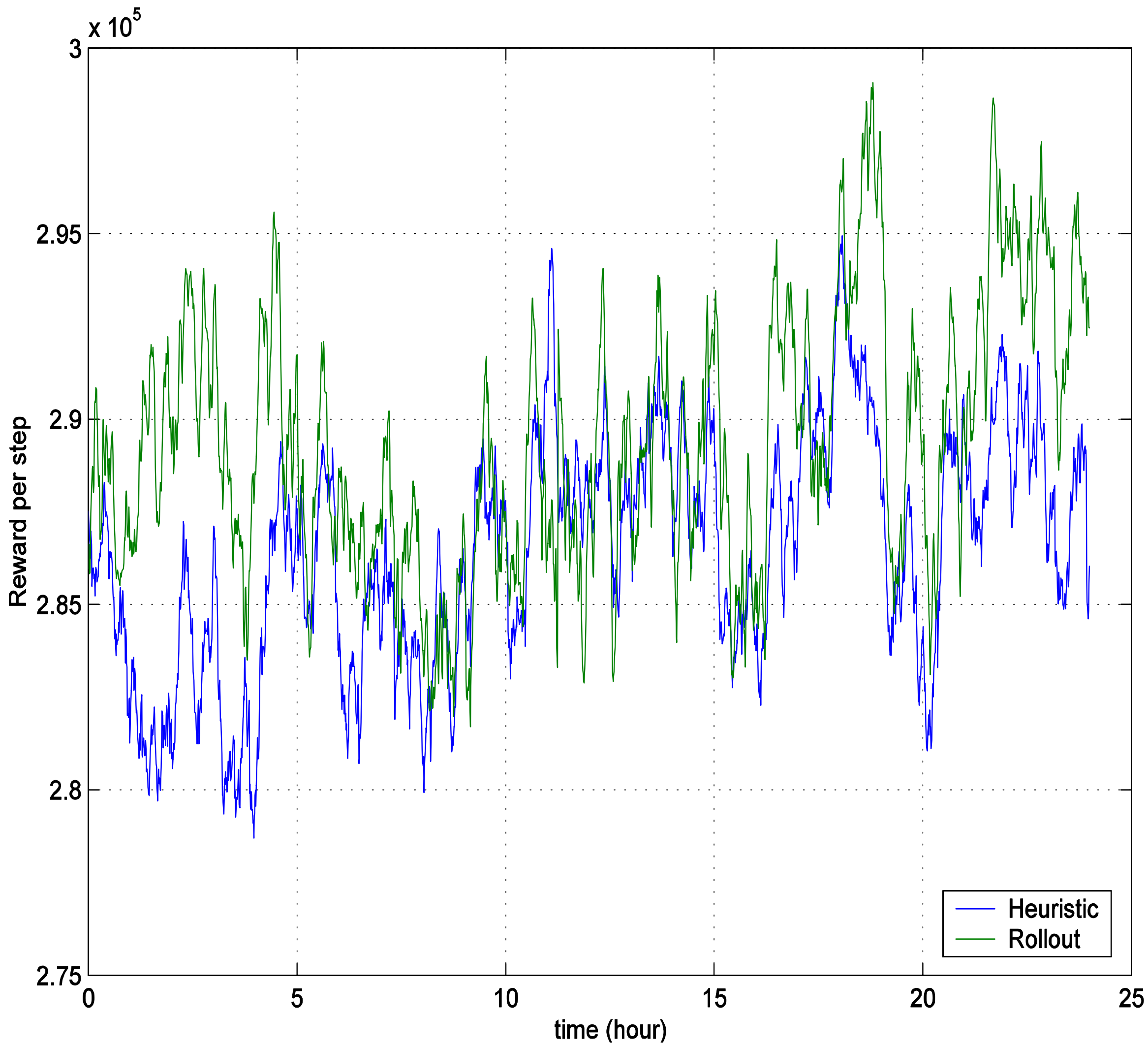
# Milestones Achieved

- Heuristic policy developed improved
- Rollout policy implemented
- Started from a simplistic traffic pattern and reached a more realistic one.
- Implemented a policy similar to Mukherjee’s to compare it to our policy.

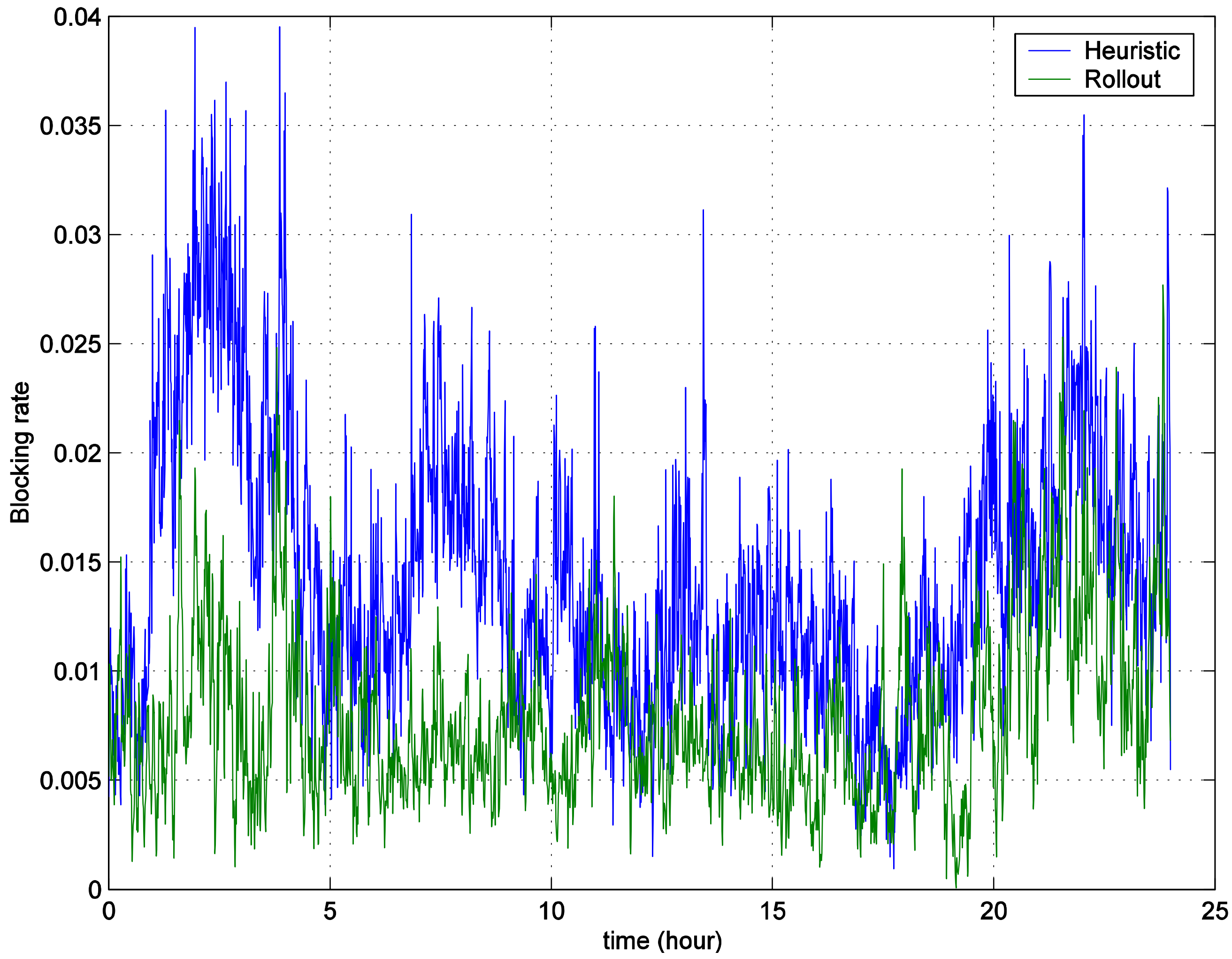
# Results

- The next few slides compares rollout algorithm to heuristic, open loop and no-action policies.

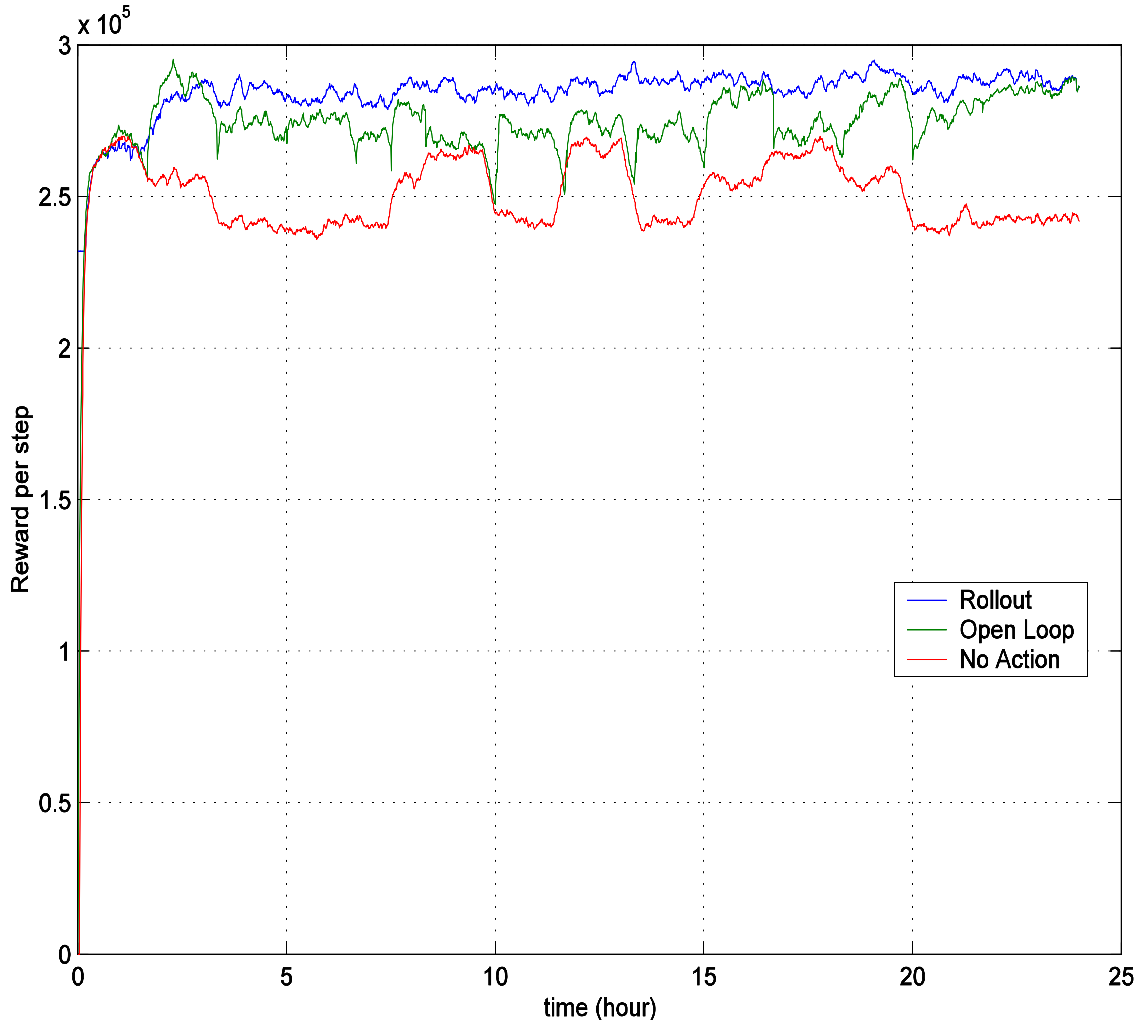
# Rollout vs. Heuristic: Reward per Step



# Rollout vs. Heuristic: Call Blocking Rate



# Rollout vs. Open Loop & Static: Reward per Step



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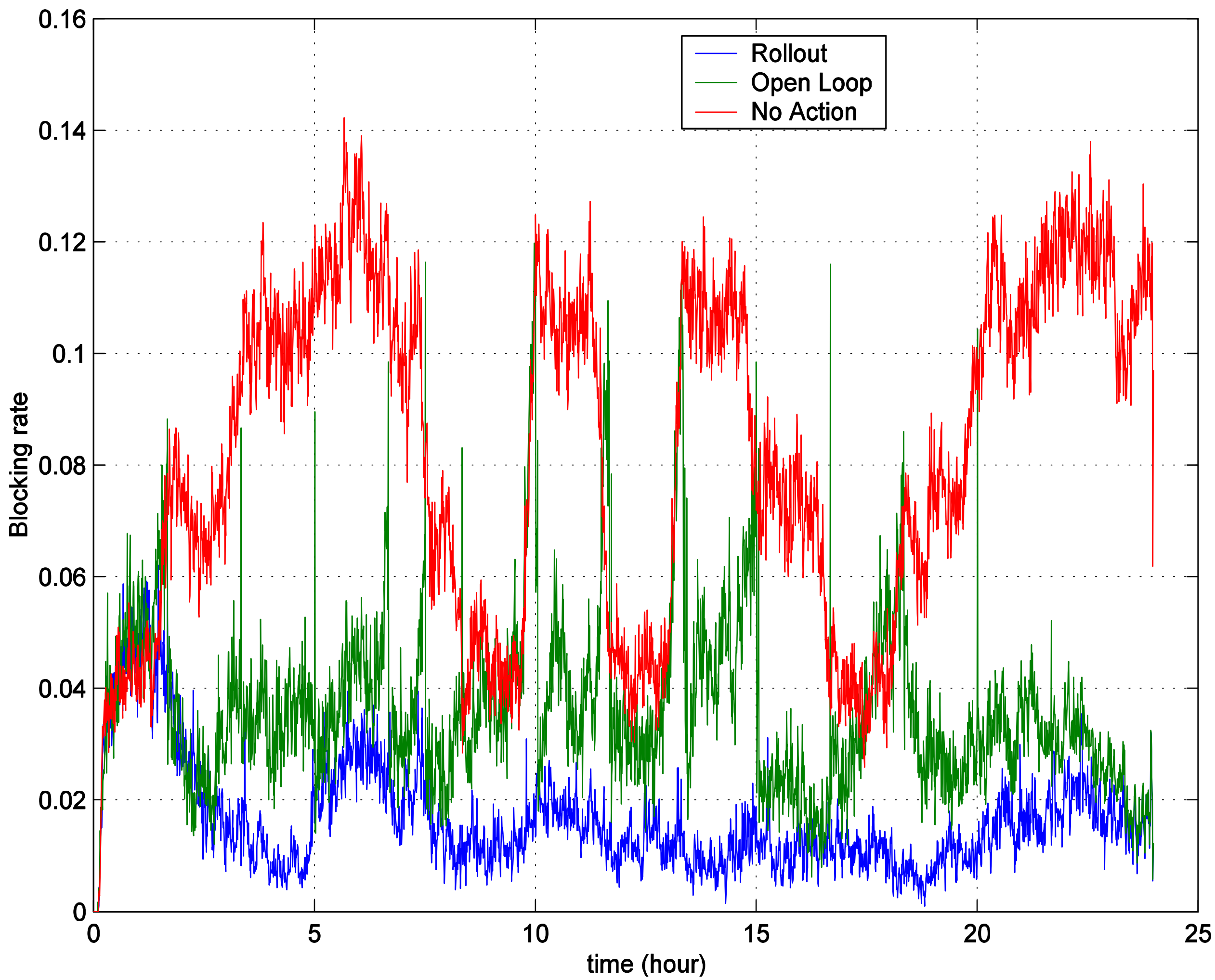

# Proposed Plans/Milestones

- Completed work does not model optical resources
  - Can be implemented using overlay model
    - All decisions can be made by MPLS service provider
    - Branch exchanges are requested from WDM service provider
- Future work
  - Add model of optical network: physical topology, wavelength converters
  - Develop control algorithm for augmented model
    - WDM SP informs MPLS SP of number of wavelengths available between each pair of routers
  - Develop control algorithm for peer model
    - Using integrated extended routing algorithm, MPLS is aware of the wavelengths available on each fiber and the physical path and wavelengths used on each lightpath

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