MON: MISSION-OPTIMIZED OVERLAY NETWORKS

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ARCTIC OCEAN
ARCTIC SEA
GREENLAND
BAFFIN BAY
SPITZBERGEN
NORTH AMERICA
BRITISH ISLES
RUSSIAN EMPIRE
PACIFIC OCEAN
ATLANTIC OCEAN
Sahara or Great Desert
SOUTH AMERICA
AFRICA
INDIAN OCEAN
PACIFIC
OCEAN
PERSIA
Philippine Is.
Coral Sea
WESTERN AUSTRALIA
TASMANIA
NEW ZEALAND
ANTARCTIC OCEAN

SETTING

- Managed by a single organization
- Good model of underlying network
- Different types of traffic use this network
- The organization cares more about certain types of traffic

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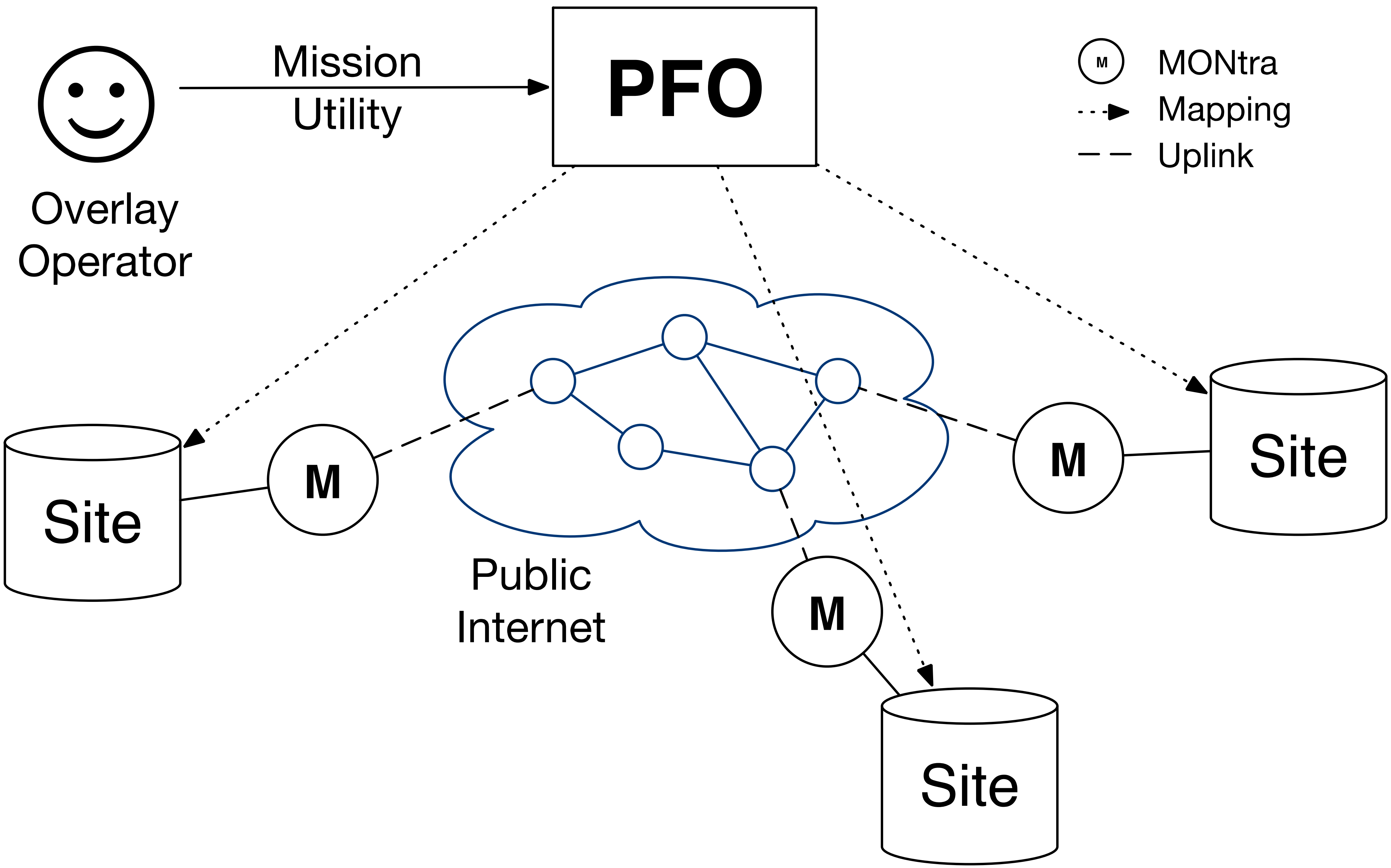


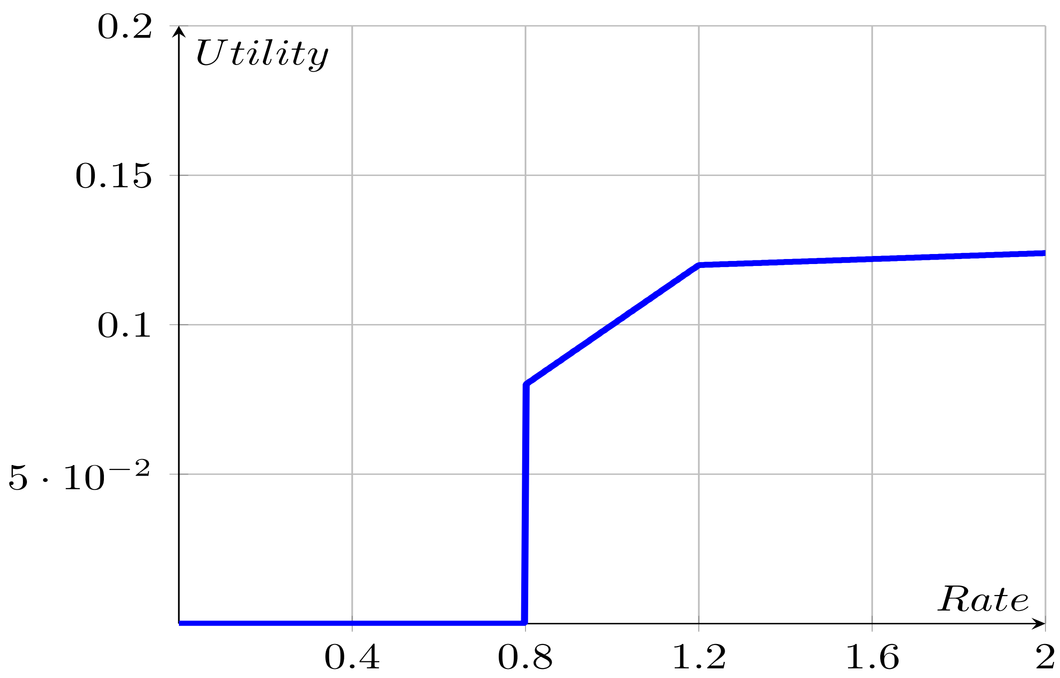
Mission
Utility
PFO
MONtra
Mapping
Uplink
Overlay
Operator
Site
M
Public
Internet
M
Site
M
Site

FLOWS

- A flow corresponds to traffic being routed between unique pair of source-destination, traffic type (ex. VOIP, Video).
- A flow could use multiple overlay paths.
- A flow could have multiple connections.
- *Example*. 10 VOIP connections from BAE to UMass

UTILITY FUNCTIONS

- **Utility Function** is a measure of "usefulness" for a certain rate (x Mbps) allocated for a single connection of the flow.
- Increasing function, possibly non-convex



$$U_A(x) = \begin{cases} 0 & , x < 0.8 \\ min(0.1x, 0.005x + 0.114) & , x \geq 0.8 \end{cases}$$

MON OPTIMIZATION PROBLEM

- k - a flow
- n_k - number of connections
- $x_{k,r}$ - rate of flow k on path r
- $U_k(x)$ - Utility of flow k
- C_l - estimated capacity
- N_k - estimated demand

$$
\begin{aligned}
\max_{n,x} \quad & \sum_{k \in K} n_k U_k\Big(\sum_{r \in \rho_k} x_{k,r}\Big) & \\
\text{subject to} \quad & \sum_{k \in K} \sum_{r \in \rho_k; l \in r} n_k x_{k,r} \leq \hat{C}_l & \forall l \in \hat{L} \\
& n_k \leq N_k & \forall k \in K \\
& x_{k,r} \geq 0 & \forall k \in K, r \in \rho_k \\
& n_k \in \mathbb{Z} & \forall k \in K
\end{aligned}
$$

PFO

Solve the problem offline using Global Optimization Techniques

$$
\begin{aligned}
\max_{n,x} \quad & \sum_{k \in K} n_k U_k\Big(\sum_{r \in \rho_k} x_{k,r}\Big) && \\
\text{subject to} \quad & \sum_{k \in K} \sum_{r \in \rho_k; l \in r} n_k x_{k,r} \leq \hat{C}_l && \forall l \in \hat{L} \\
& n_k \leq N_k && \forall k \in K \\
& x_{k,r} \geq 0 && \forall k \in K, r \in \rho_k \\
& n_k \in \mathbb{Z} && \forall k \in K
\end{aligned}
$$

MOTIVATION FOR CONGESTION CONTROL

- Solving optimization problem may take time
- What if network changes? Or demand changes?
- Quickly react to packet loss and increased bandwidth
- We use TCP for this

MONTRA OPTIMIZATION MODEL

$$
\begin{aligned}
\max_{x} \quad & \sum_{f \in \rho} n_{k(f)} V_f(x_f) & \\
\text{subject to} \quad & \sum_{k \in K} \sum_{f \in \rho_k; l \ni f} n_k x_f \leq C_l & \forall l \in L \\
& x_f \geq 0 & \forall k \in K, f \in \rho_k
\end{aligned}
$$

TCP - INCREASE/DECREASE RULES

- x_f - sending rate of flow f
- γ - stability constant
- w_f - weight

$$
\begin{aligned}
x_f &\leftarrow x_f + \gamma \cdot w_f && \text{(after each successful packet)} \\
&\leftarrow x_f - \gamma \cdot x_f && \text{(for each loss)}
\end{aligned}
$$

$$V_f(x_f) = w_f \log x_f$$

HOW TO PICK W_F?

- Controllers should match PFO's target rates
- Controllers should make good decisions if network changes

MAPPING PFO TO MONTRA

Theorem Idea: Assume PFO has an accurate model of the network. Suppose PFO picks a target rate A. If the gradient of MONtra matches the gradient of PFO at A, then MONtra will converge to A

Proof: See the paper

$$V_f(x_f) = w_f \log x_f$$

$$w_f = \left(\frac{\partial}{\partial x_r} U(A)\right) A_f$$

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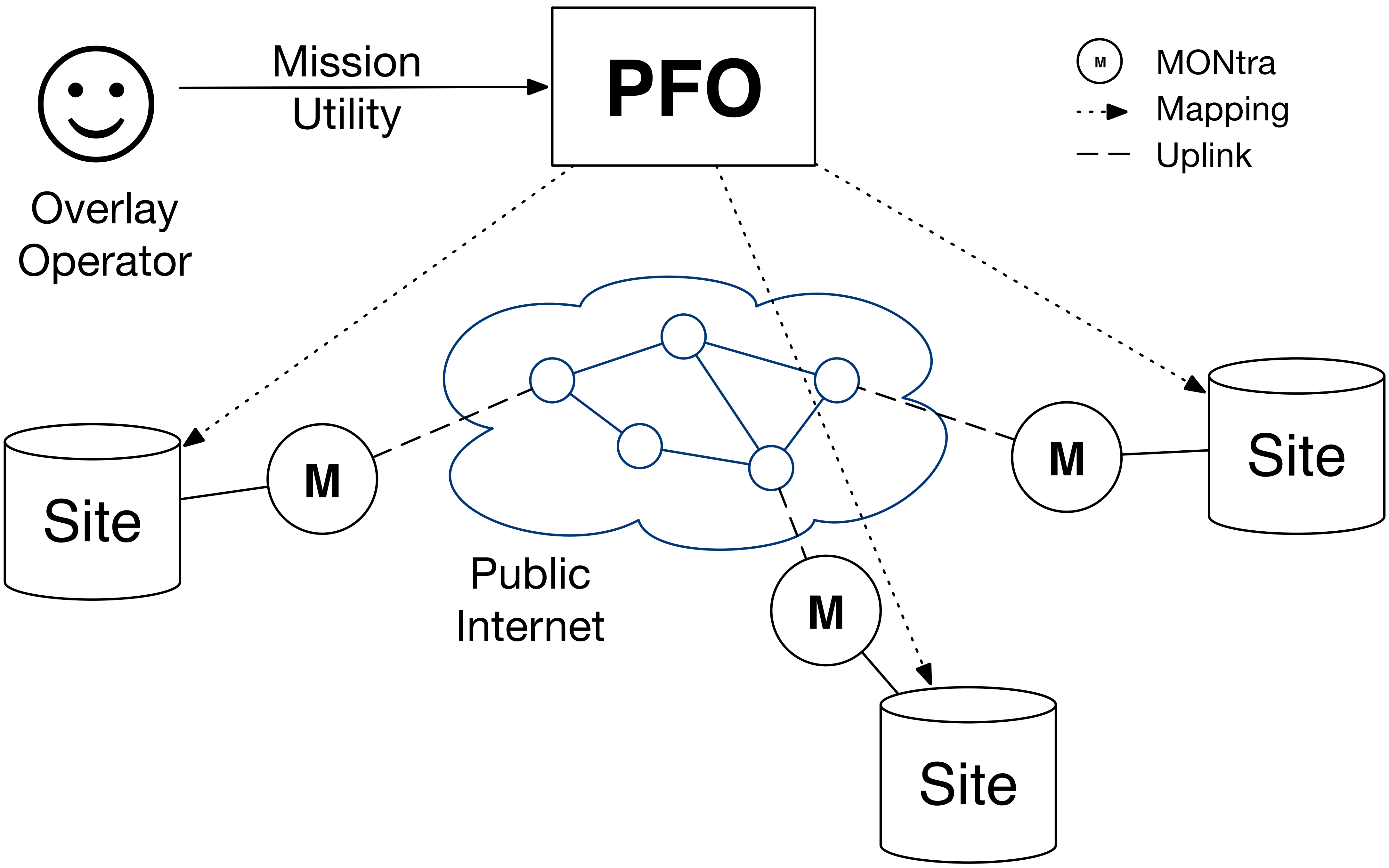

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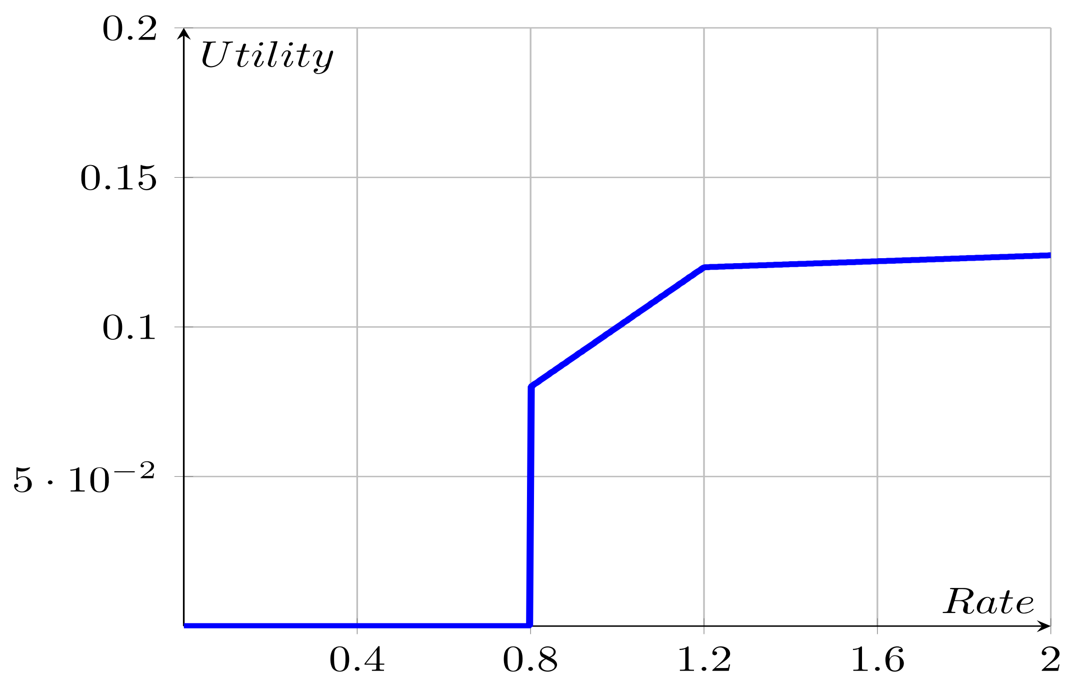
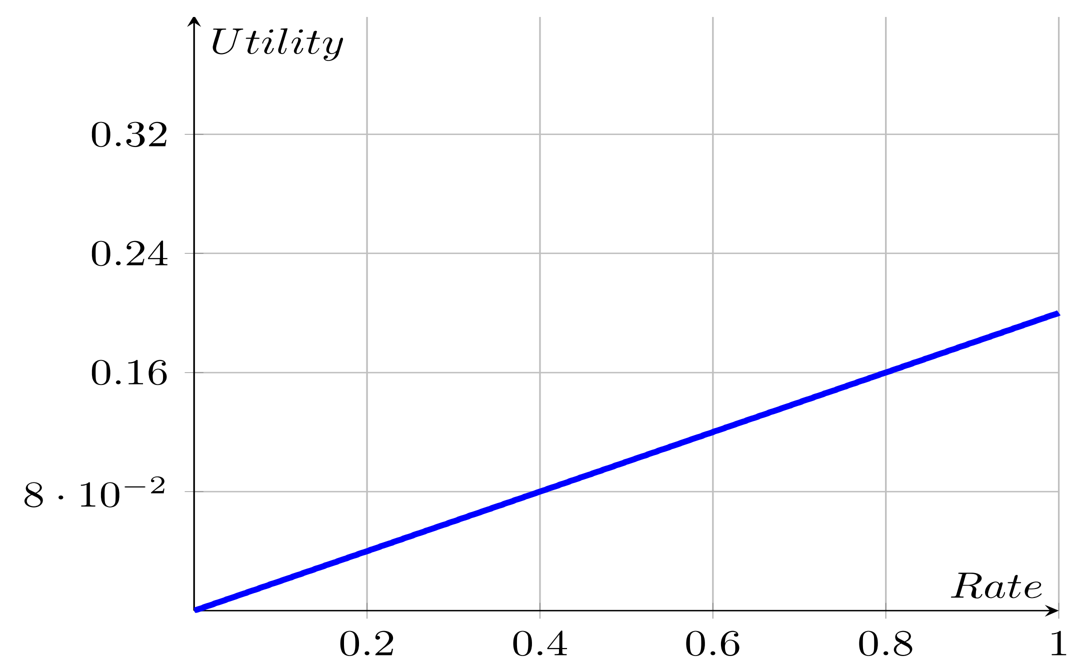
UTILITY FUNCTIONS AND FLOWS

- Used following utility functions:

Flow A



Flow B



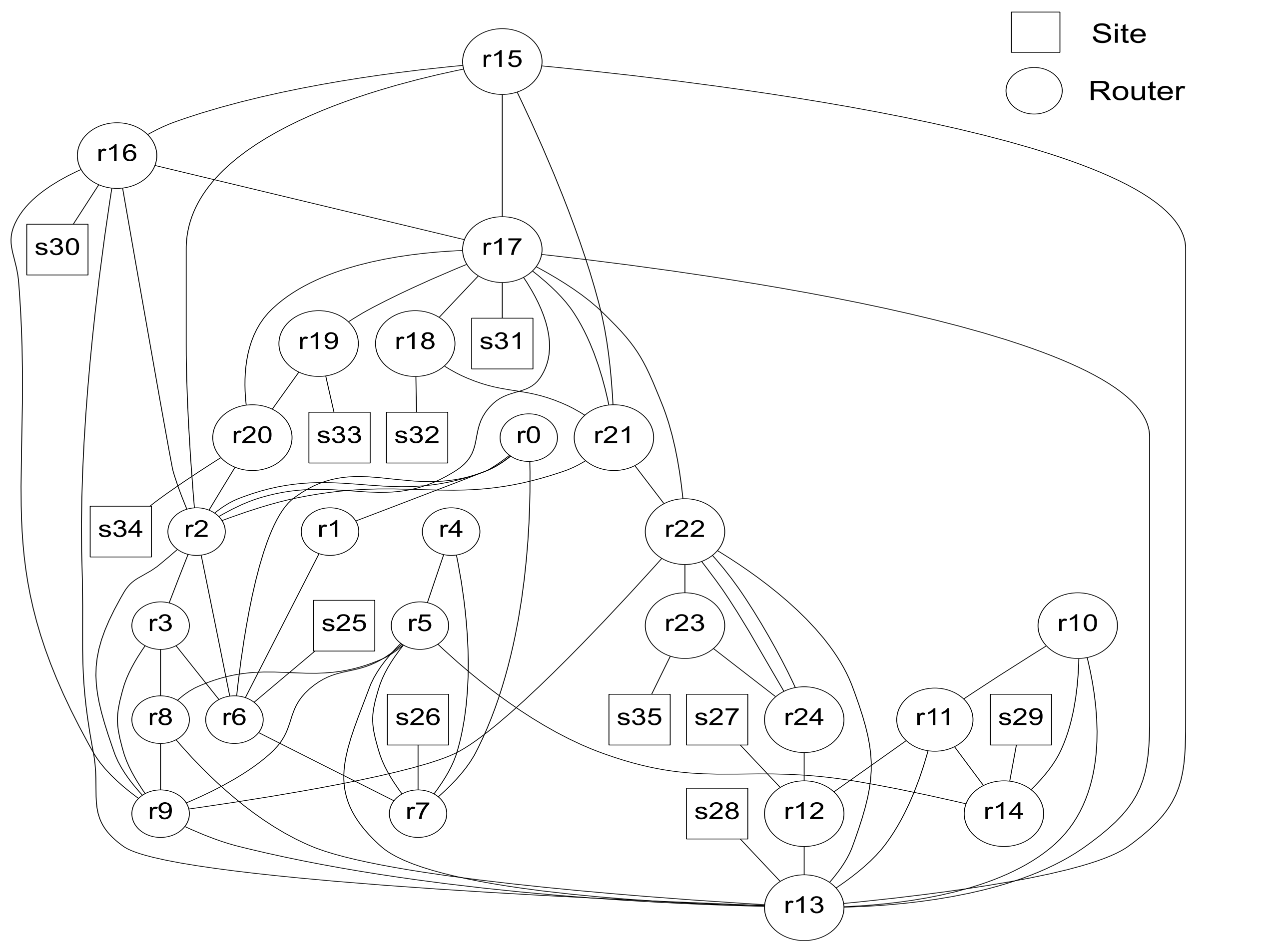
$$U_A(x) = \begin{cases} 0 & , x < 0.8 \\ min(0.1x, 0.005x + 0.114) & , x \geq 0.8 \end{cases}$$

$$U_B(x) = 0.2x$$

- Generated random flows

DOES MONTRA SEND AT THE CORRECT RATE?

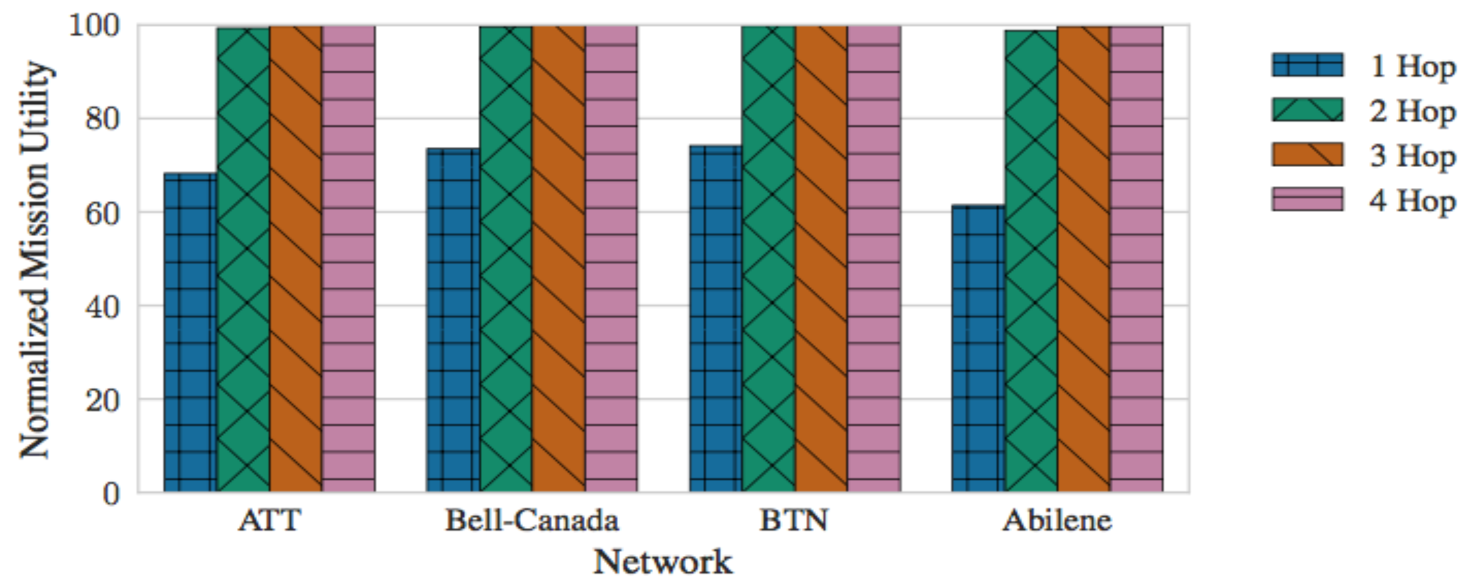
Path	Target	Actual
$E35 \rightarrow E26$	10.0	9.24
$E29 \rightarrow E31$	10.0	9.24
$E33 \rightarrow E35$	10.0	9.24
$E31 \rightarrow E33$	10.0	9.23
$E34 \rightarrow E32$	6.0	5.9
$E26 \rightarrow E34$	6.0	5.68
$E32 \rightarrow E29$	6.0	4.4
$E32 \rightarrow E34$	4.0	3.55
$E26 \rightarrow E32$	4.0	3.4
$E34 \rightarrow E29$	4.0	3.24



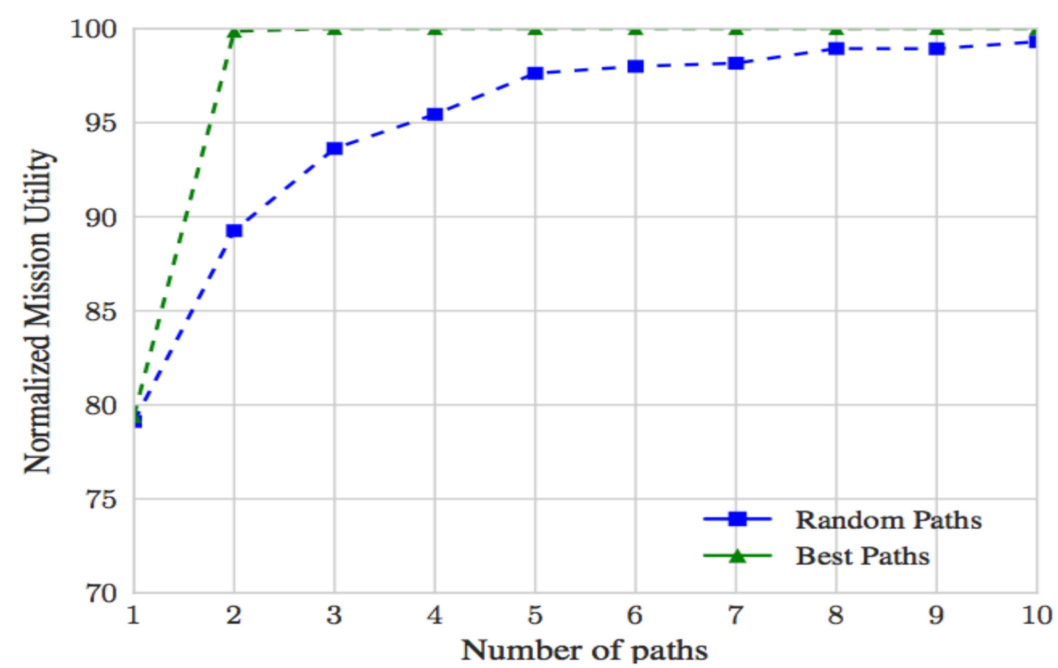
MONtra converges to PFO’s rates on a complex network

BENEFITS OF OVERLAY ROUTING

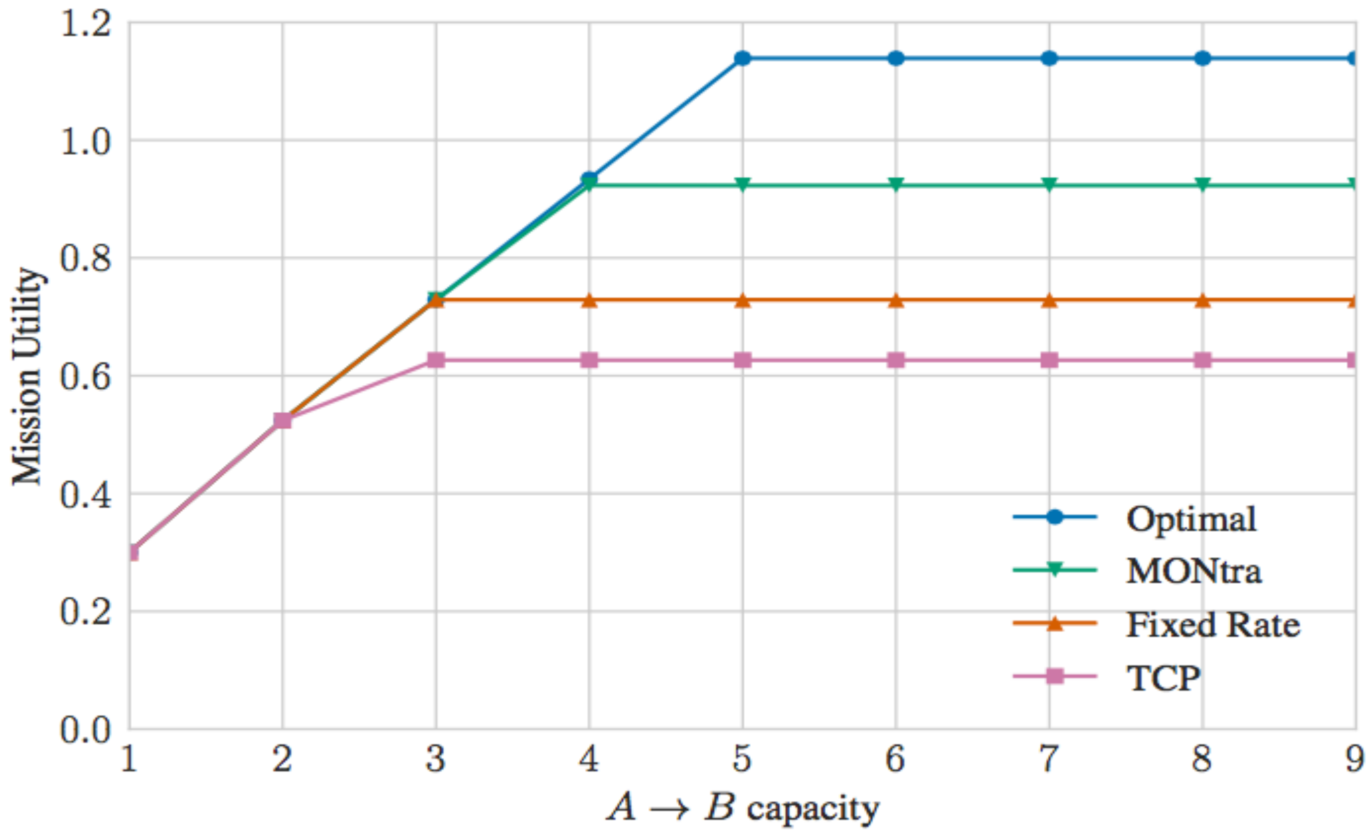
Number of hops: Mission utility increases with number of hops

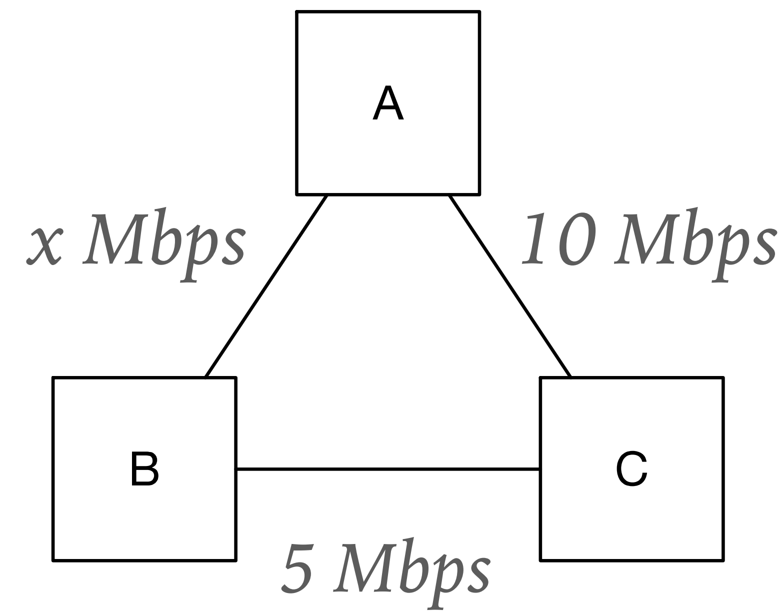


Number of paths: Allowing more paths increases utility



HOW DOES MONTRA REACT TO SLIGHT CHANGES IN NETWORK?



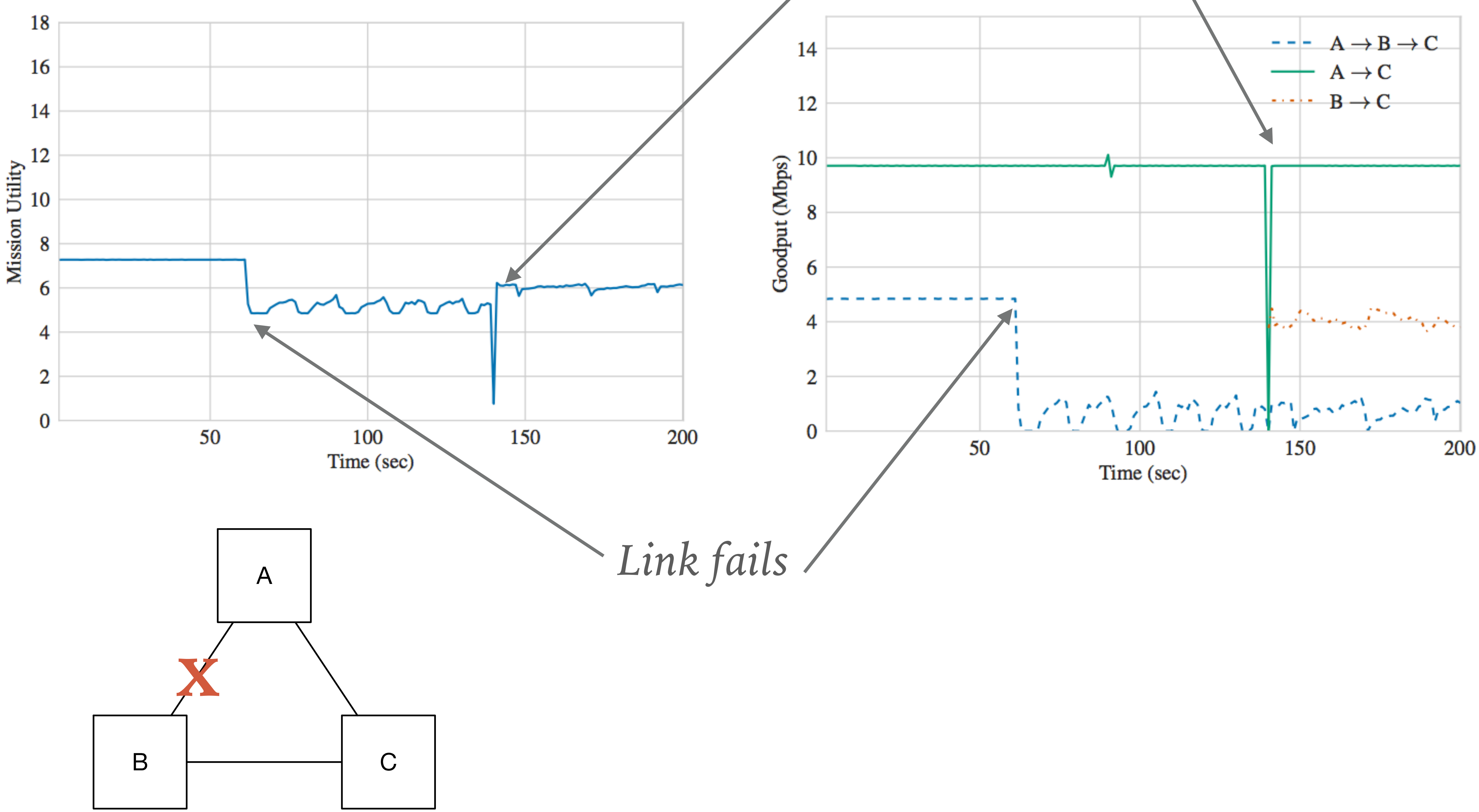


- Ran PFO with *x=3 Mbps*
- Adjusted capacity from 1 to 9 Mbps.
- MONtra does better than baselines

HOW DOES MONTRA REACT TO NETWORK FAILURES?

Triangle topology:

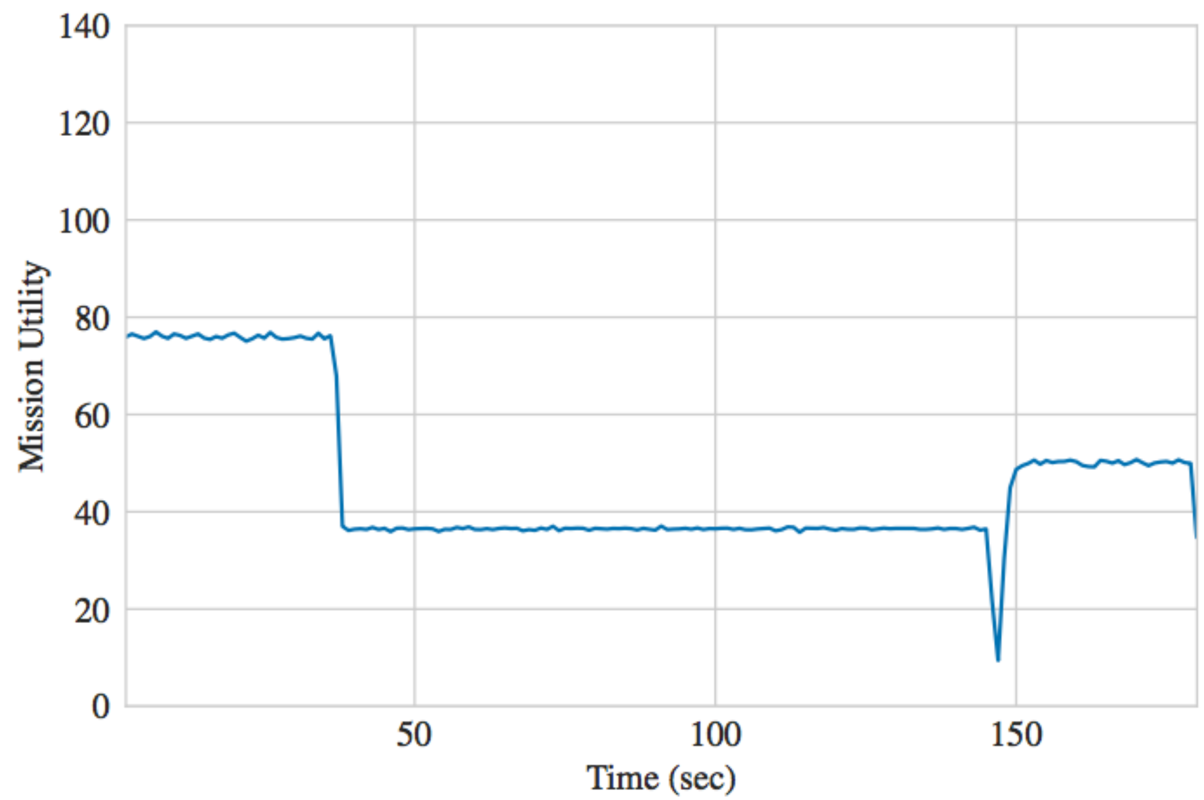
PFO recovers



Link fails

HOW DOES MONTRA REACT TO NETWORK FAILURES?

AT&T topology:



- Link failure decreases utility
- PFO recovers utility

SUMMARY

- Overlay network architecture
- Optimally route flows
- Resilient to changes to inputs

THANKS!

QUESTIONS?