Cache Capacity Allocation for BitTorrent-like Systems to Minimize Inter-ISP Traffic

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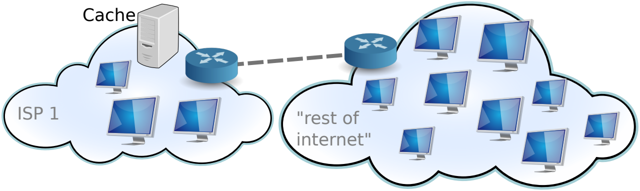
P2P Traffic

- Up to 70 % of network traffic
- Source of Inter-ISP traffic ⇒ cost for low level ISPs

Decreasing Inter-ISP traffic

1. Locality awareness
2. P2P caching



P2P Caching

Cache resource management

1. Storage capacity ⇒ cache eviction (LRU,LFU,GDS,ARC,...)
2. Bandwidth ⇒ not actively managed (e.g. Web caches)

Should bandwidth be actively managed so as to minimize the amount of Inter-ISP traffic?

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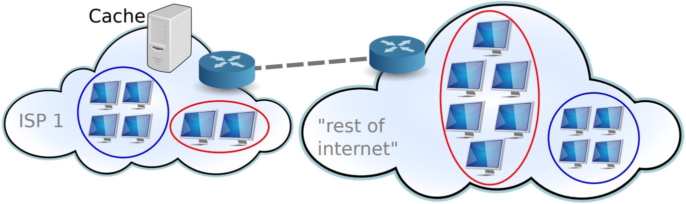
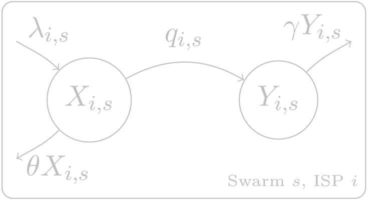


System Model without Cache

- Set of ISPs $\mathcal{I} = \{1, \ldots, I\}$, Set of swarms $\mathcal{S} = \{1, \ldots, S\}$
- Markovian model of system dynamics
  - System state $Z_{i,s}(t) = (X_{i,s}(t), Y_{i,s}(t))$
  - Parameters $(\lambda_{i,s}, \theta, \gamma, \mu, \eta)$



$$q_{i,s} = \underbrace{\frac{X_{i,s}}{X_s}\mu(\eta X_s + Y_s)}_{\text{available upload rate}}$$

- Incoming inter-ISP traffic rate $I_{i,s}(Z_s(t), .)$

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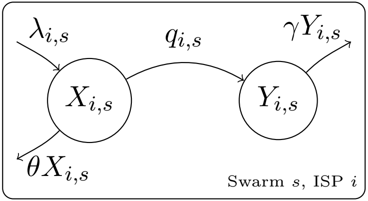

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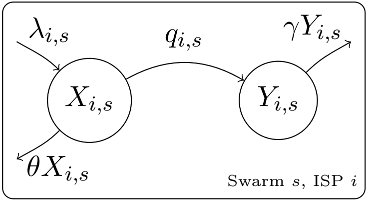
  - Parameters $(\lambda_{i,s}, \theta, \gamma, \mu, \eta, \kappa_{i,s})$
- $K_i < \infty$ bandwidth capacity of cache in ISP i



$$q_{i,s} = \underbrace{\frac{X_{i,s}}{X_s}\mu(\eta X_s + Y_s) + \kappa_{i,s}}_{\text{available upload rate}}$$

- Incoming inter-ISP traffic rate $I_{i,s}(Z_s(t), \kappa_{i,s}(t))$

Cache Bandwidth Allocation Problem

- Cache bandwidth allocation of ISP i at time t

$$\kappa_i(t) = (\kappa_{i,1}(t), \ldots, \kappa_{i,S}(t))$$

- Defined by *policy* π: $\kappa_i(t) = \mathcal{F}^{\pi}\left(\left(Z(u)\right)_{u<t}, \left(\kappa_i(u)\right)_{u<t}\right)$

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- Expected incoming inter-ISP traffic under allocation policy π

$$C_i^\pi(Z(0), T) = E_{Z(0)}^\pi\left[\int_0^T \sum_{s\in\mathcal{S}} I_{i,s}(Z_s(t), \kappa_{i,s}(t))dt\right]$$

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Find the optimal policy $\pi^* \in \Pi$ s.t.

$$\inf_{\pi\in\Pi} C_i^\pi(Z(0)) = \inf_{\pi} \limsup_{T\to\infty} \frac{1}{T} C_i^\pi(Z(0), T).$$

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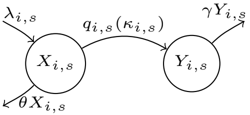
Existence of Optimal Stationary Policy

- Markov Decision Process
  $< \mathcal{Z}, \mathcal{K}, \underline{\underline{Q}}(\kappa), I(z,\kappa) >$



Theorem

There exists an optimal stationary policy $\pi^* \in \Pi$ *that minimizes* $C_i^\pi(Z(0))$

The optimal policy π^*

- Stationary: $\kappa_i(t)$ is only a function of the system state $Z(t)$
- Calculation requires steady state probabilities
  - Prohibitive even for few ISPs and swarms
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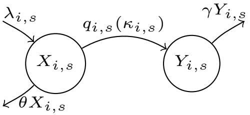

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One-Step Look Ahead (OLA)

- Minimize the incoming inter-ISP traffic rate given the system state

$$\kappa_i(t) = \arg\min_{\kappa_i \in \mathcal{K}_i} \sum_{s \in \mathcal{S}} I_{i,s}(Z_s(t), \kappa_{i,s})$$

- Short term approximation → disregards system dynamics

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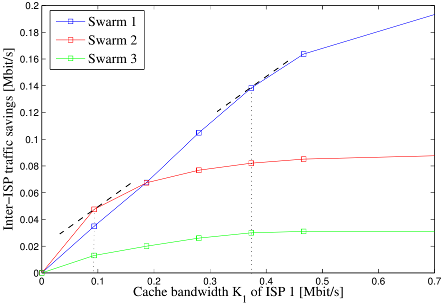

Optimal $\kappa_i(t)$ leads to equal marginal traffic saving for every swarm

$$\kappa_{i,s} > 0 \quad \Rightarrow \quad \frac{\partial I_{i,s}(z_s, \kappa_{i,s})}{\partial \kappa_{i,s}} = \zeta$$

$$\kappa_{i,s} = 0 \quad \Rightarrow \quad \frac{\partial_{-} I_{i,s}(z_s, \kappa_{i,s})}{\partial \kappa_{i,s}} \geq \zeta$$

Steady-State Optimal (SSO)

- Minimize the incoming inter-ISP traffic rate at steady state

$$\overline{\pi}^* = \arg\min_{\kappa_i \in \mathcal{K}_i} \sum_{s \in \mathcal{S}} \overline{I}_{i,s}(\kappa_{i,s})$$

- Long term approximation $\rightarrow$ non adaptive policy
- $\overline{I}_{i,s}(\kappa_{i,s}) = I\left(\overline{x}^{\overline{\pi}}_{i,s}(\kappa_{i,s}), \overline{y}^{\overline{\pi}}_{i,s}(\kappa_{i,s}), \kappa_{i,s}\right)$
- Based on fluid model [1] of cache impact on system state

$$\begin{aligned}
\overline{x}^{\overline{\pi}}_{i,s} &= \frac{\lambda_{i,s}}{\nu\left(1+\frac{\theta}{\nu}\right)} - \frac{\kappa_{i,s}}{\mu\eta\left(1+\frac{\theta}{\nu}\right)} - \Delta_i(\mathbf{x},\mathbf{y},\kappa) \\
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Smallest-Ratio Priority (SRP)

- Approximation of SSO for small cache bandwidth
  - For two ISPs at steady state:

$$\overline{I}_1(\kappa_1) \approx \frac{\overline{x}_1}{\overline{x}_1 + \overline{x}_2}\mu(\eta\overline{x}_2 + \overline{y}_2)$$

  - $\frac{\partial \overline{I}_1(\kappa_1)}{\partial \kappa_1}\Big|_{\substack{\kappa_1=0 \\ \kappa_2=0}} < 0$ and decreases monotonically in $r = \frac{\lambda_2}{\lambda_1}$
- Swarms with lowest ratio $\frac{\lambda_i}{\sum_{j \neq i} \lambda_j}$ have highest priority
- Practical implementation $\hat{r}_{i,s} = \frac{x_{i,s}(t)}{\sum_{j \neq i} z_{j,s}(t)}$
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Evaluation Methodology

- Model of the incoming inter-ISP traffic for OLA and SSO policies

Simulations

- Flow level simulation in the ProtoPeer framework
- 6.5 hours of simulated time, up to 12.000 BitTorrent peers

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- 500 PlanetLab nodes running BitTorrent
  - BitTorrent Mainline client 4.4.0
  - 4 hours experiments, 1 hour of warm-up period
  - Up to 8400 peers distributed among 12 swarms
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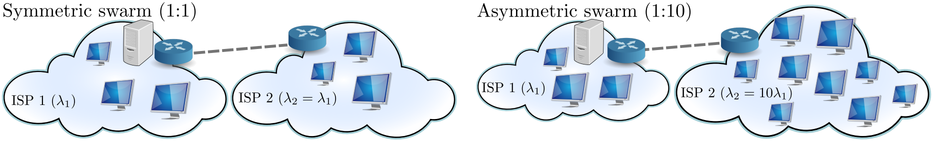
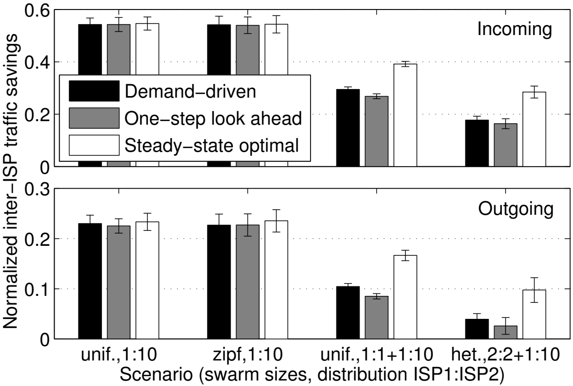
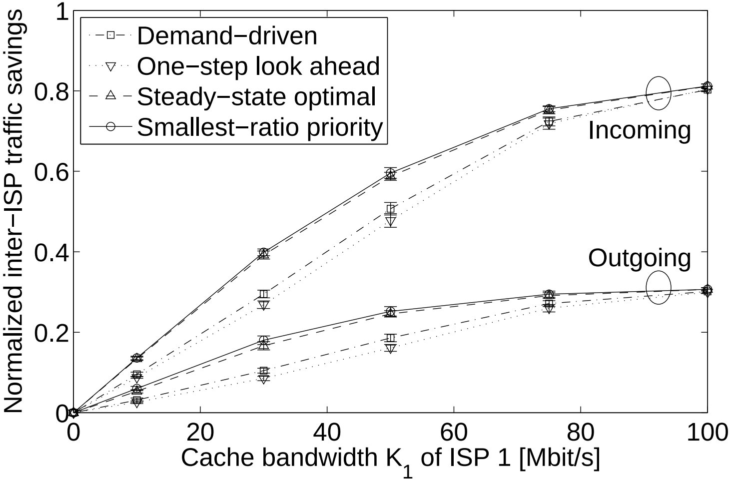
When Bandwidth Allocation Matters - Simulations



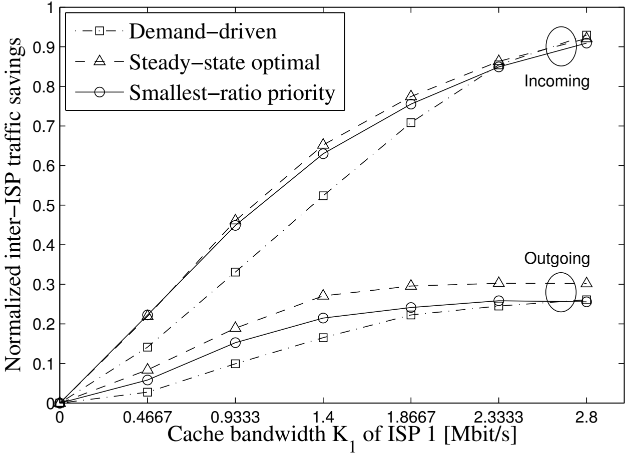


Bandwidth Allocation Policies Evaluation - Simulations

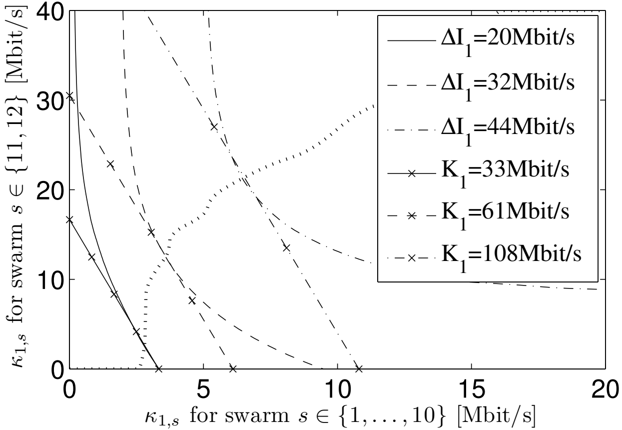
- Scenario *unif.,1:1+1:10*:



Validation - Experiments on PlanetLab



Indifference Map - Simulations



Conclusions

- Cache upload bandwidth allocation problem
- Existence of a stationary bandwidth allocation policy
- Various adaptive bandwidth allocation policies

Main observations

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- Difference in swarms symmetry is the key
- Significant traffic savings possible
  - ~60% improvement in incoming inter-ISP traffic saving
  - ~250% improvement in outgoing inter-ISP traffic saving

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