Network Utilization: the Flow View

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Presentation:

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Overview

- Background
- Link Utilization
- Flow Utilization
- Case Study
  - Accommodating Flow Growth
  - Risk Assessment
- Practical Use of Flow Utilization
- Conclusion

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Background

- Utilization of Backbone Links
  - Of great importance to operators
  - One of the worst kept secrets: very low
  - Double-edged sword
    - Economic pressure
    - Resources wasting
    - Packet loss ratio
    - Failure resilience

high utilization

low utilization

Background

- Utilization of Backbone Links
  - Hard to measure
    - Quickly changes in time and in space
  - State of art measurement
    - Summary statistics, *i.e.*, average link utilizations
      - Hard to draw decisive conclusions
      - Lack information of utilization patterns
  - Flow utilization: a new view
    - *Generalized Flow Utilization (GFU)*
    - Flow: long lived aggregated flows, 2-tuple

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Link Utilization

- In backbone networks: poorly utilized
  - Operational constraints
  - Stable fault resilient
- Confidential by operators
  - Few public research papers
  - Andrew Odlyzko, 1999, “lightly utilized”
  - Sprint Networks, early 2000s, “very low, ~10%”
  - NANOG, 2002, maximum 75% under failure

Link Utilization

- Some more…
  - Routing scheme
  - Traffic engineering
- Recent potential improvement
  - Powerful network planning component
  - Overall view of entire networks
  - Software Defined Networking
  - Google, 2012, "close to 100% utilization"
  - However, still need more information…

Link Utilization

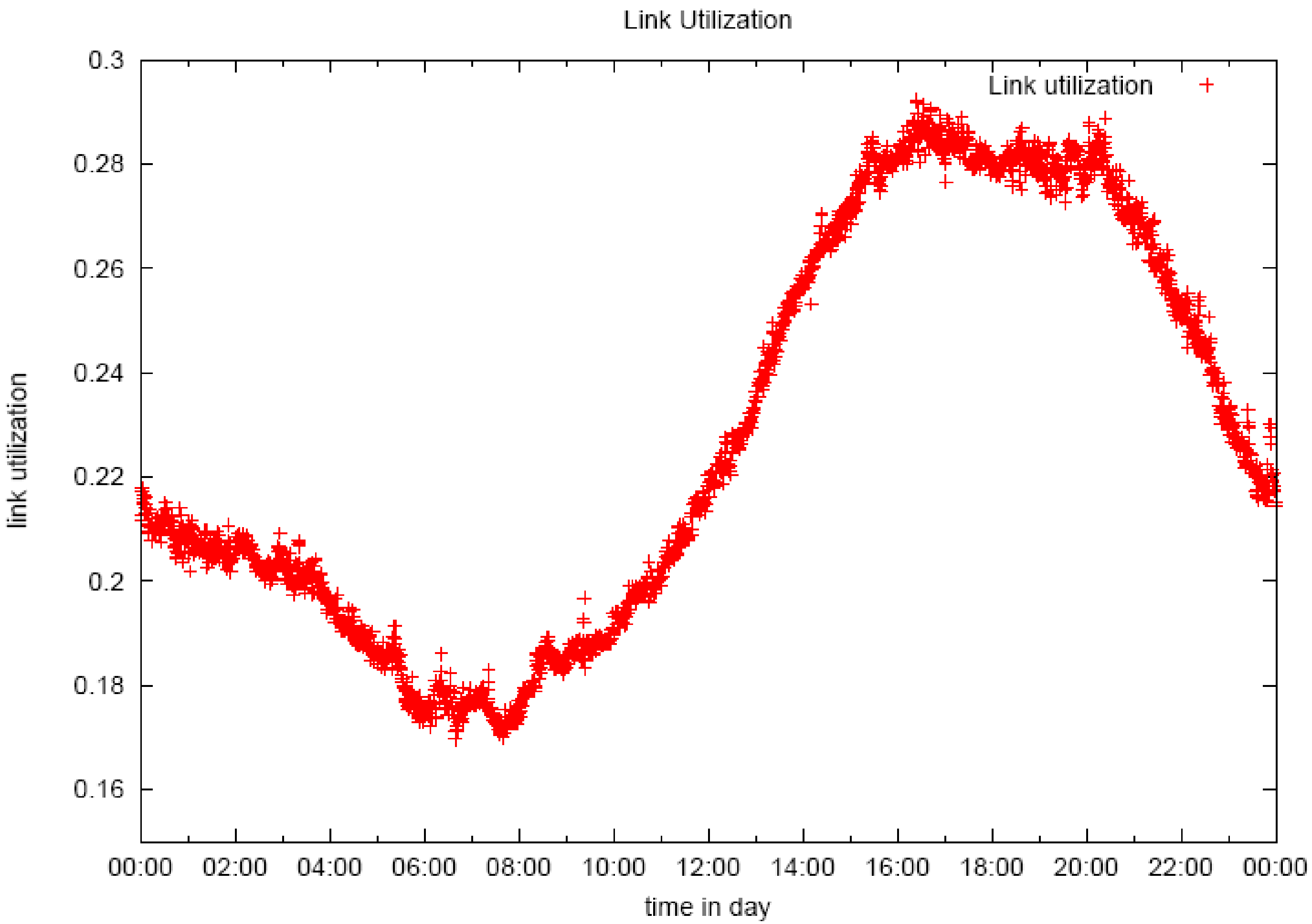

Fig. 1. Typical Backbone Link Utilization.

Link Utilization

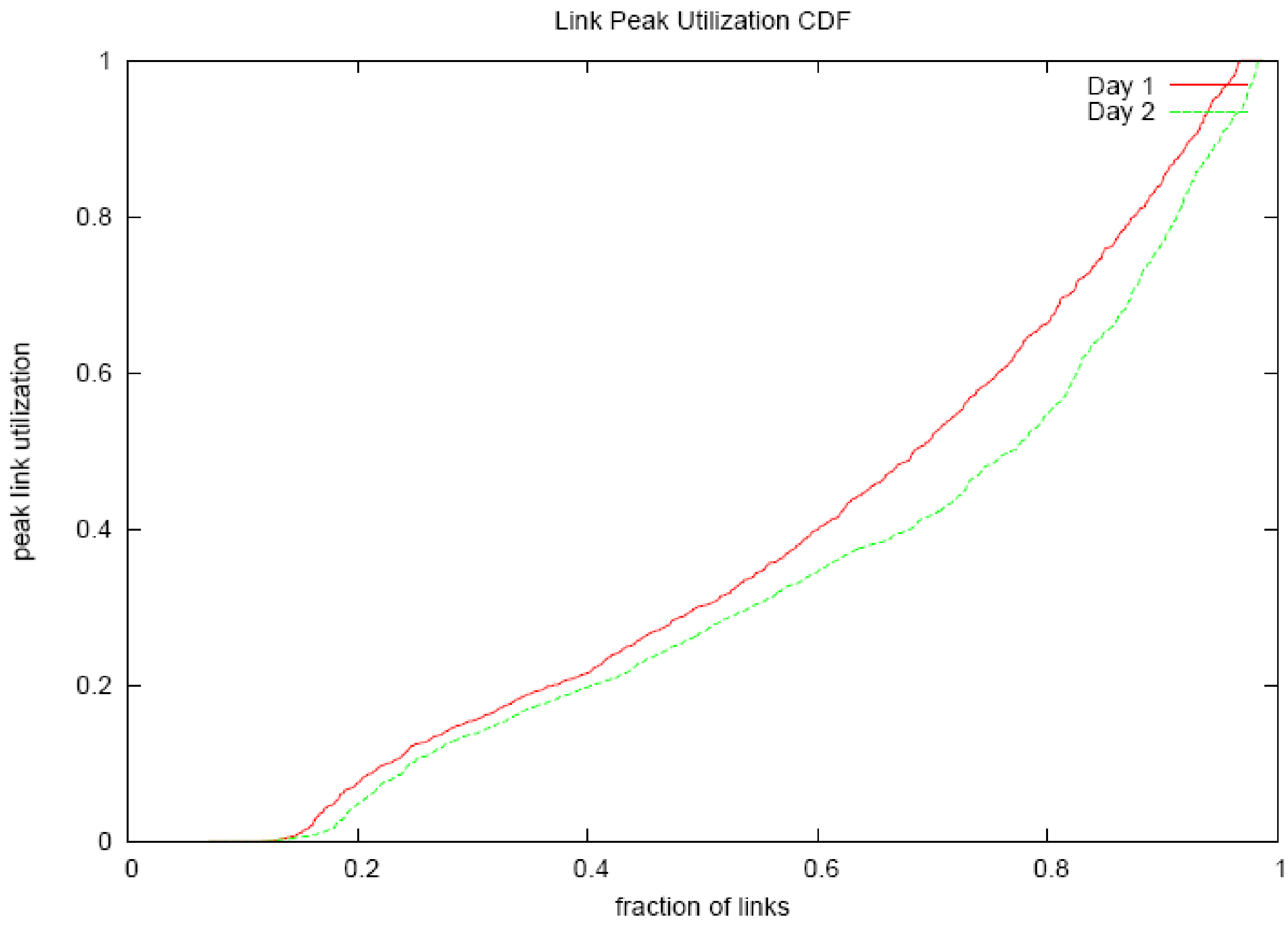

Fig. 2. Cumulative Peak Utilization.

Link Utilization

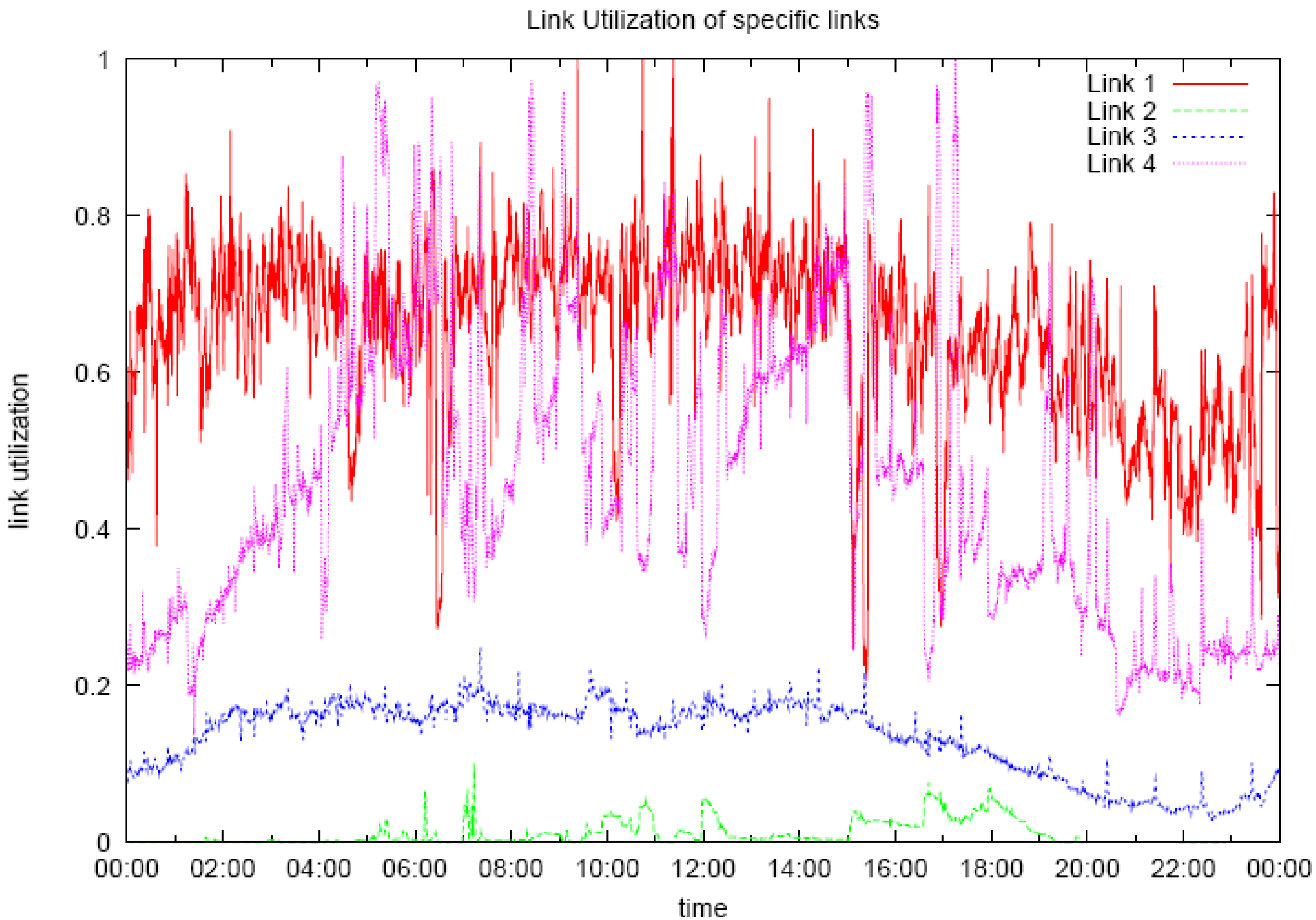

Fig. 3. Link Utilization of several links.

Link Utilization

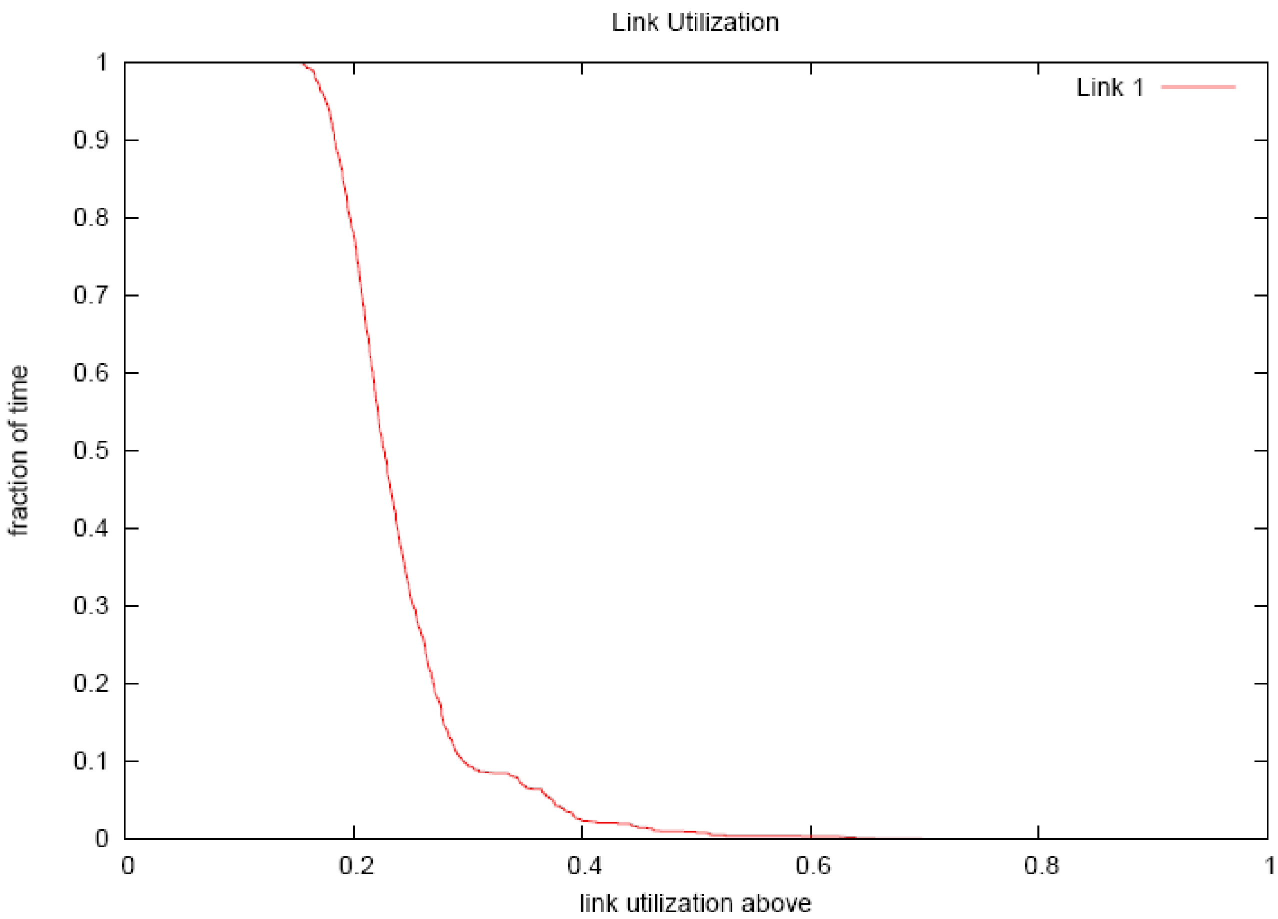

Fig. 4. Link Utilization Distribution of a specific link over one day.

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Flow Utilization

- Link Utilization
  - Based on link data, infrastructure point of view
- An alternative definition
  - Flow perspective
    - Ability to distinguish between different types of flow
    - Satisfy required weight to the more important flows
  - Constraint Conditions
    - Measuring utilization across the board
    - Getting to the sweet spot
    - Computability

Flow Utilization

- Definition
  - Feasible flows $f_1, f_2, \ldots, f_m$
    - Can be routed under capacity constraints
  - Admissible vector $\alpha_1, \alpha_2, \ldots, \alpha_m$
    - Flows $\alpha_1 f_1, \alpha_2 f_2, \ldots, \alpha_m f_m$ are feasible
    - Clearly, if $\forall i,\ \alpha_i = 1$, the vector is admissible
  - Analogy
    - Link utilization: $u = (u_1, u_2, \ldots, u_n)$
    - Flow utilization: $\alpha = (\alpha_1, \alpha_2, \ldots, \alpha_m)$

Flow Utilization

- Definition
  - Generalized Flow Utilization (GFU)

$$\mathrm{GFU} = 1/F \sum_{i=1}^{k} f_i U(1/\alpha_i),$$

    - Where *U(·)* is a nondecreasing utilization function
    - *E.g.*, $U(x) = x$, the weighted average of $1/\alpha_i$

Flow Utilization

- Properties
  - Let the set *V(k, α)*
    - Be the set of vectors with *k* entries equal to α for some value α > 1, and others equal to 1.
  - *V(0.95n, 1.2)*
    - Packet loss in most flows should not be too high
  - *V(0.8n, 4)*
    - The network is underutilized

Flow Utilization

- Properties
  - We have:

Lemma 1: For any $\alpha > 1$ and $\epsilon > 0$, it is NP hard to distinguish between a network of n flows in which $V(n^{1-\epsilon}, \alpha)$ is admissible and a network in which $V(n^{\epsilon}, \alpha)$ is admissible. In particular, for $k = \Omega(n)$ it is NP hard to approximate $V(k, \alpha)$ to within a factor of $n^{1-\epsilon}$.

Lemma 2: Let $U_p(x) = x^p$ for some $p \geq 1$. Given a network with flows $f_1, f_2, \ldots, f_m$ one can efficiently find an admissible vector $\alpha_1, \alpha_2, \ldots, \alpha_m$ minimizing:

$$1/F \sum_{i=1}^{k} f_i U_p(1/\alpha_i) = 1/F \sum_{i=1}^{k} f_i/\alpha_i^p.$$

Flow Utilization

Lemma 1: For any $\alpha > 1$ and $\epsilon > 0$, it is NP hard to distinguish between a network of n flows in which $V(n^{1-\epsilon}, \alpha)$ is admissible and a network in which $V(n^{\epsilon}, \alpha)$ is admissible. In particular, for $k = \Omega(n)$ it is NP hard to approximate $V(k, \alpha)$ to within a factor of $n^{1-\epsilon}$.

Proof: The proof is by reduction from independent set. Let $H = \langle V_H, E_H \rangle$ be a graph, where we want to know if H has an independent set of size k. We build a new graph G, where all the capacities of all edges in G are exactly $1 + \alpha$. The graph G will have $|V_H| + 2|E_H| + 1$ vertices:

1) It will have one target vertex t.
2) It will have $|V_H|$ source vertices, denoted s_h for every $s \in V_H$. Each of these vertices will originate a flow to t.
3) For every edge $e \in E_H$, it will have two vertices e_{in} and e_{out}.

Flow Utilization

Lemma 1: For any $\alpha > 1$ and $\epsilon > 0$, it is NP hard to distinguish between a network of n flows in which $V(n^{1-\epsilon}, \alpha)$ is admissible and a network in which $V(n^{\epsilon}, \alpha)$ is admissible. In particular, for $k = \Omega(n)$ it is NP hard to approximate $V(k, \alpha)$ to within a factor of $n^{1-\epsilon}$.

Each flow can only use one specific path, and the edges of G are the edges of all the these paths. For each source vertex s_h where $h \in V_H$ we define a flow: Let $e^1, e^2, \ldots, e^h$ be the edges adjacent to the vertex h in the original graph H. The path of the flow which starts from s_h is

$$s_h \to e^1_{in} \to e^1_{out} \to e^2_{in} \to e^2_{out} \ldots \to e^h_{in} \to e^h_{out} \to t$$

The flow f_i will consist of s_i passing one unit to the target. The following claim is easy:

Flow Utilization

Lemma 1: For any $\alpha > 1$ and $\epsilon > 0$, it is NP hard to distinguish between a network of n flows in which $V(n^{1-\epsilon}, \alpha)$ is admissible and a network in which $V(n^{\epsilon}, \alpha)$ is admissible. In particular, for $k = \Omega(n)$ it is NP hard to approximate $V(k, \alpha)$ to within a factor of $n^{1-\epsilon}$.

Claim 1: The graph H has an independent set of size k if and only if $V(k, \alpha)$ is admissible for G.

Proof: Suppose that H has an independent set U of size k. For every $h \in U$ increase the flow from s_h by a factor of α. Given $h, u \in U$ the paths they have to t do not intersect.

For the other direction, if $V(k, \alpha)$ is admissible, let U be the set of flows which are increased. For any $s_h, s_u \in U$ their paths to the source do not intersect, and thus u, h are not neighbors in H. Therefore, we can let $U_H = \{h : \; s_h \in U\}$ be an independent set in H. ■

This concludes the proof of the lemma. ■

Flow Utilization

Lemma 2: Let $U_p(x) = x^p$ for some $p \geq 1$. Given a network with flows $f_1, f_2, \ldots, f_m$ one can efficiently find an admissible vector $\alpha_1, \alpha_2, \ldots, \alpha_m$ minimizing:

$$1/F \sum_{i=1}^{k} f_i U_p(1/\alpha_i) = 1/F \sum_{i=1}^{k} f_i/\alpha_i^p.$$

Proof: We find the vector $\alpha_1, \ldots, \alpha_m$ by using convex optimization methods. We write a convex program with m variables, $x_1, x_2, \ldots, x_m$. The constraints are the flow constraints, where x_i corresponds to flow i. We also add the constraint that $x_i \geq f_i$. The target function to minimize is:

$$\sum_{i=1}^{k} f_i (\frac{f_i}{x_i})^p$$

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Case Study

- Accommodating Flow Growth

$$\alpha_1^{\text{Growth}} = \ldots = \alpha_{l_1}^{\text{Growth}} = \beta_1$$

$$\alpha_{l_1+1}^{\text{Growth}} = \ldots = \alpha_{l_1+l_2}^{\text{Growth}} = \beta_2;$$

Case Study

- Accommodating Flow Growth

$$c_i(l) = c(l) - \sum_{\substack{l \in \text{path}(f): \\ \exists j < i : f = b_j}} \alpha_f^{\text{Growth}} \cdot f,$$

where $c(l)$ is the capacity of link l and f is the flow value
Similarly, define the *residual utilization* of link l at step i as

$$u_i(l) = \sum_{\substack{l \in \text{path}(f): \\ \forall j < i : f \neq b_j}} f.$$

At step i, define a growth factor for each flow f as

$$g_{f,i} = \min_{l \in \text{path}(f)} \frac{c_i(l)}{u_i(l)}.$$

Select a flow f with minimal $g_{f,i}$, and set

$$\alpha_i^{\text{Growth}} = \alpha_f^{\text{Growth}} = g_{f,i}$$
$$b_i = f$$

Case Study

- Risk Assessment

$$\alpha^{\text{Risk}}(f_j) = \frac{1}{\max\{\text{util}(e_i) | e_i \in \text{path}(f_j)\}},$$

where $c(e)$ is the capacity of e and

$$\text{util}(e) = \frac{\sum_{i=1}^{m} f_i(e)}{c(e)}.$$

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Practical Use of Flow Utilization

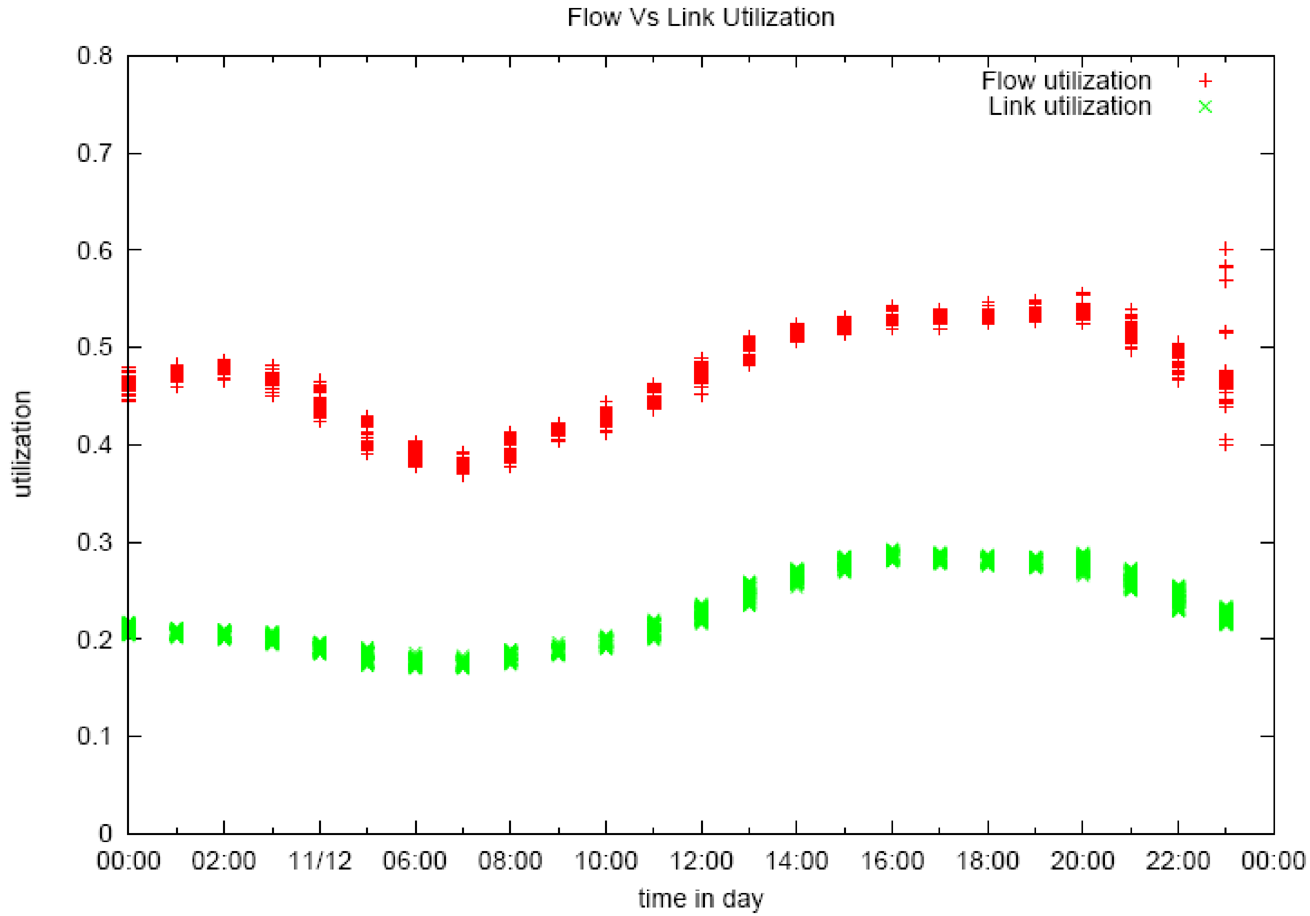

Fig. 6. Flow vs. Link Utilization.

Practical Use of Flow Utilization

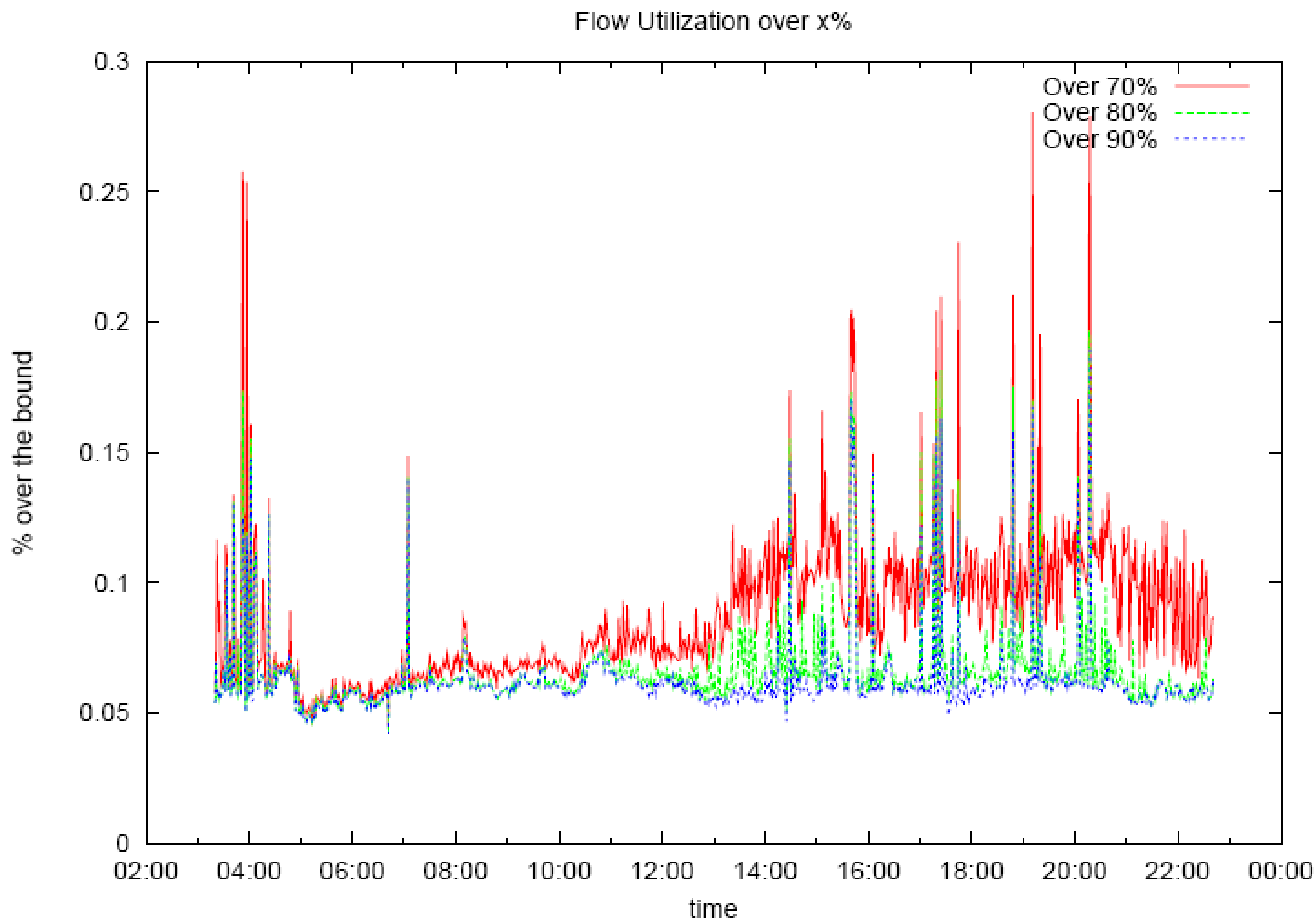

Fig. 7. Traffic at risk over a day.

Practical Use of Flow Utilization

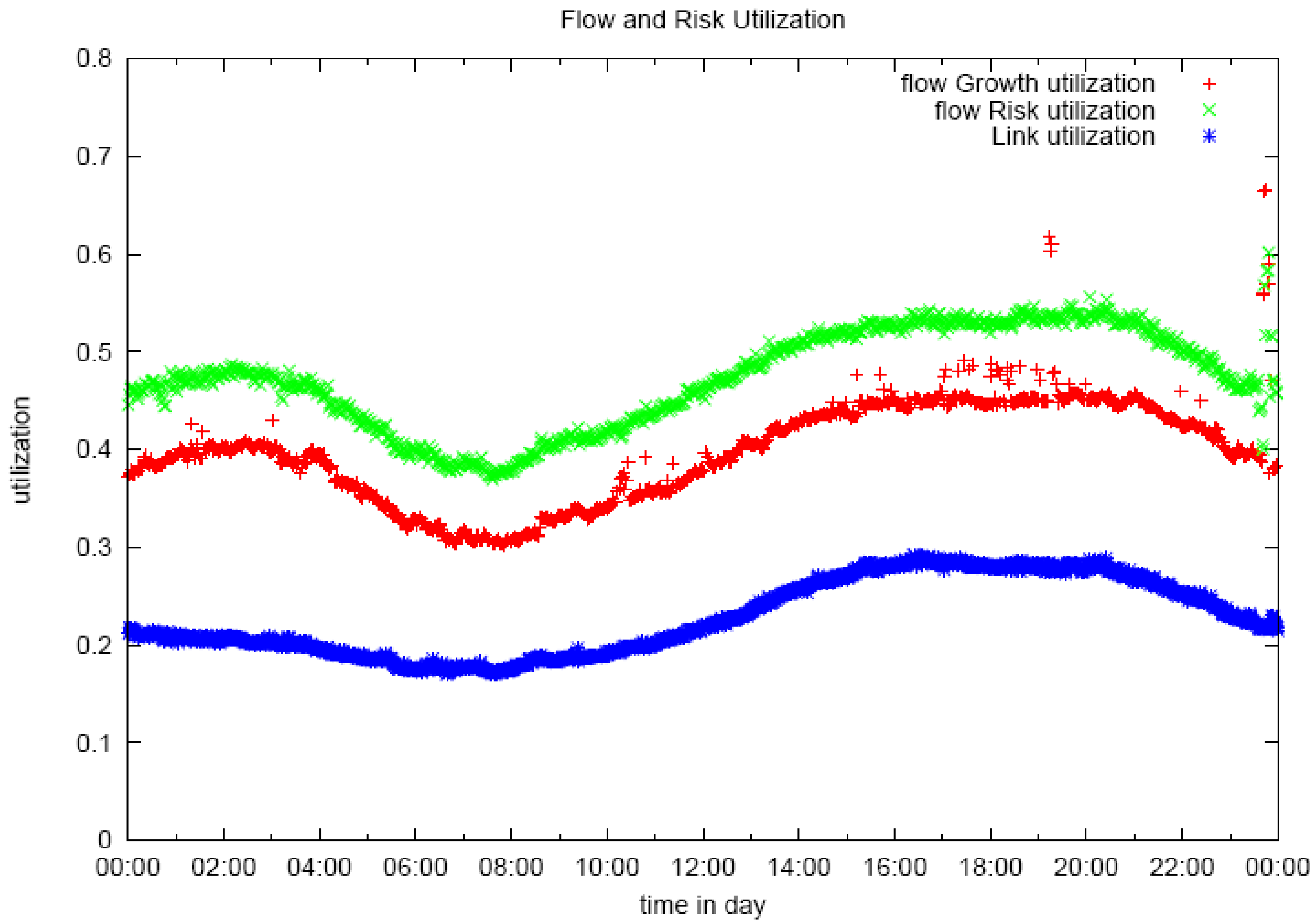

Fig. 9. Empirical gap between α^{Growth} and α^{Risk} on the Google backbone.

Practical Use of Flow Utilization

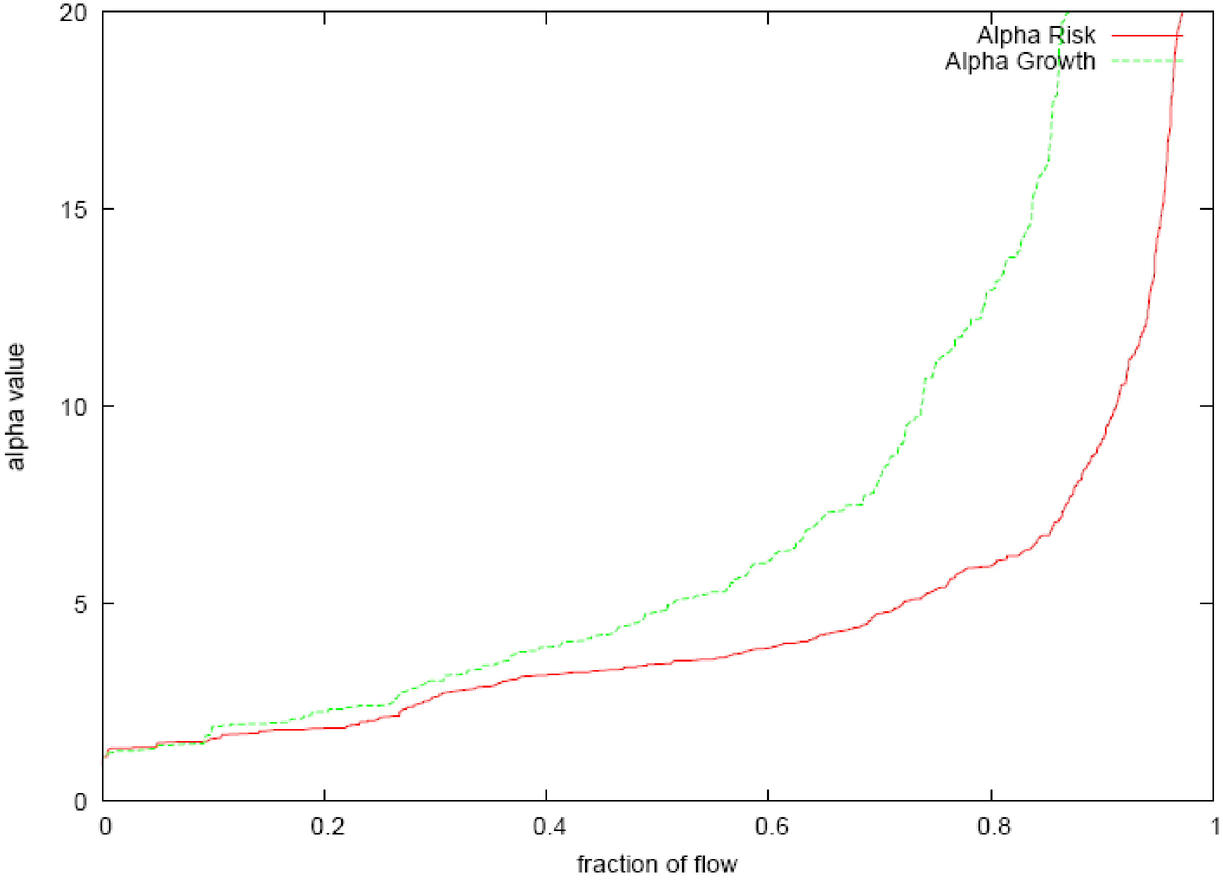

Fig. 10. α^{Growth} and α^{Risk} on the Google backbone at a specific timestamp.

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Conclusion

- A new view of network utilization
    - Take the user perspective, and understand how she experiences the network.
    - Focus the attention on the traffic at risk.
    - Tune the network to be in the sweet spot, where it is not under utilized and not over utilized.
- What remain…
    - Link failure
    - Capacity planning and network upgrades

Thank you!
Q & A