

Estimation of the Available Bandwidth of an E2E path

(ongoing research work)

Albert Cabellos-Aparicio, Jordi Domingo-Pascual, and Francisco Garcia

Technical University of Catalonia

Agilent Technologies

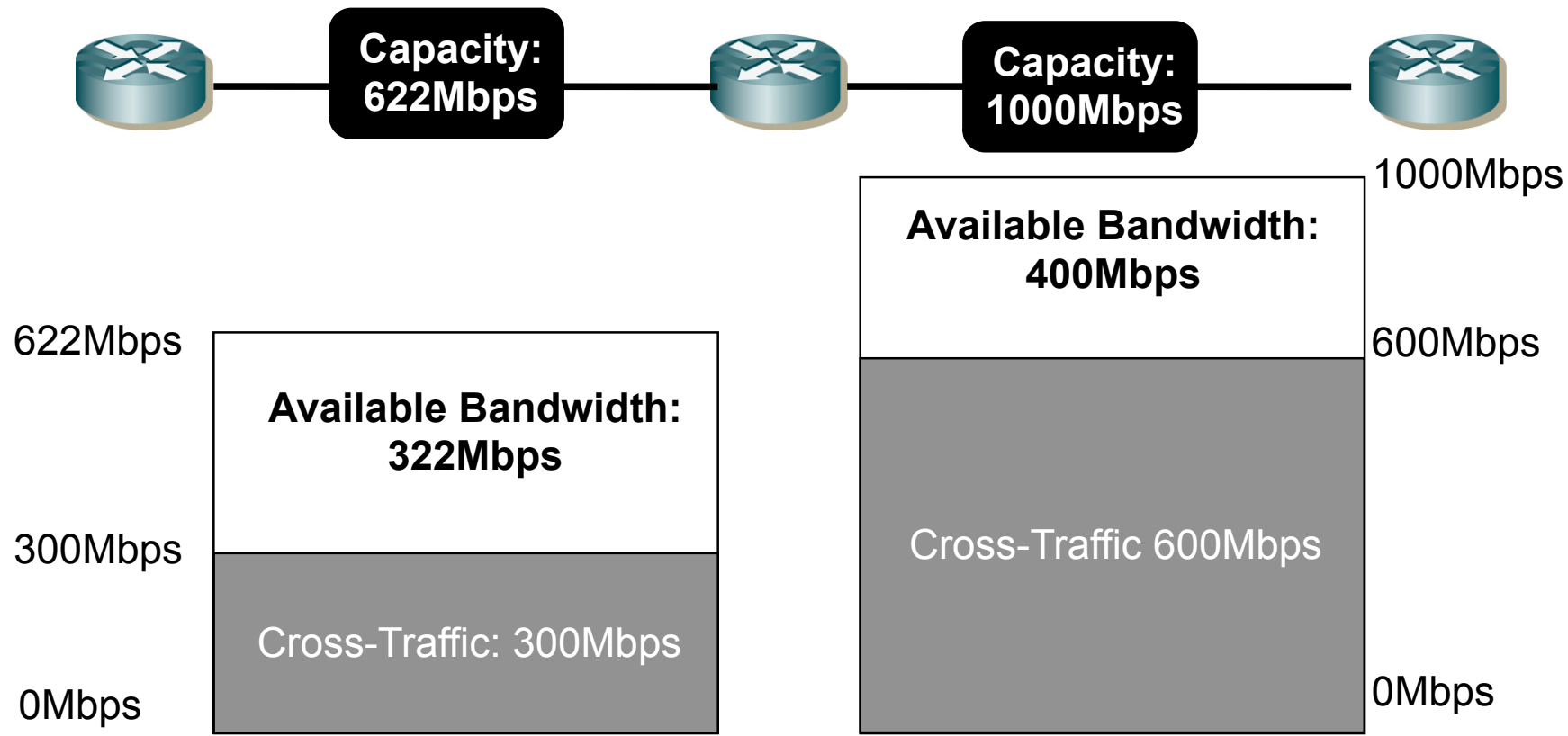


Agilent Technologies

Outline

- Introduction
- Related Work
- Objectives
- Passive Bandwidth Estimation Tool
- Results
- Conclusions

What is the Available Bandwidth?



Available Bandwidth at the E2E Path: 322Mbps

What is the Available Bandwidth?

- The Available Bandwidth is remaining capacity of a path = The amount of traffic that can be sent without congesting the path

$$A = \min_{i=0..H} [C_i (1 - u_i)]$$

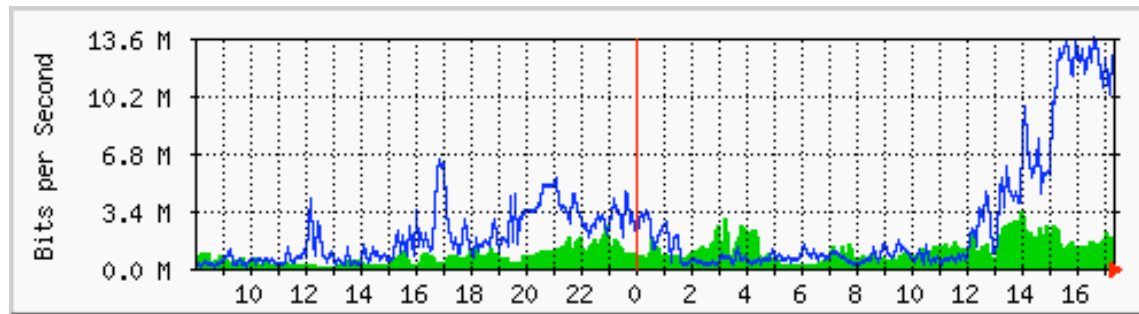
- It is one of the most **important** metrics and it is very **complex** to estimate

What is the Available Bandwidth?

- The AB may be used for:
 - Monitoring clouds by ISP
 - Overlay Networks
 - P2P networks
 - Routing Protocols
 - Service Level Agreement verification
 - Server Selection
 - Rate adaptative flows
 - ...

How does the industry monitor the AB?

- The Multi-Router Traffic Grapher



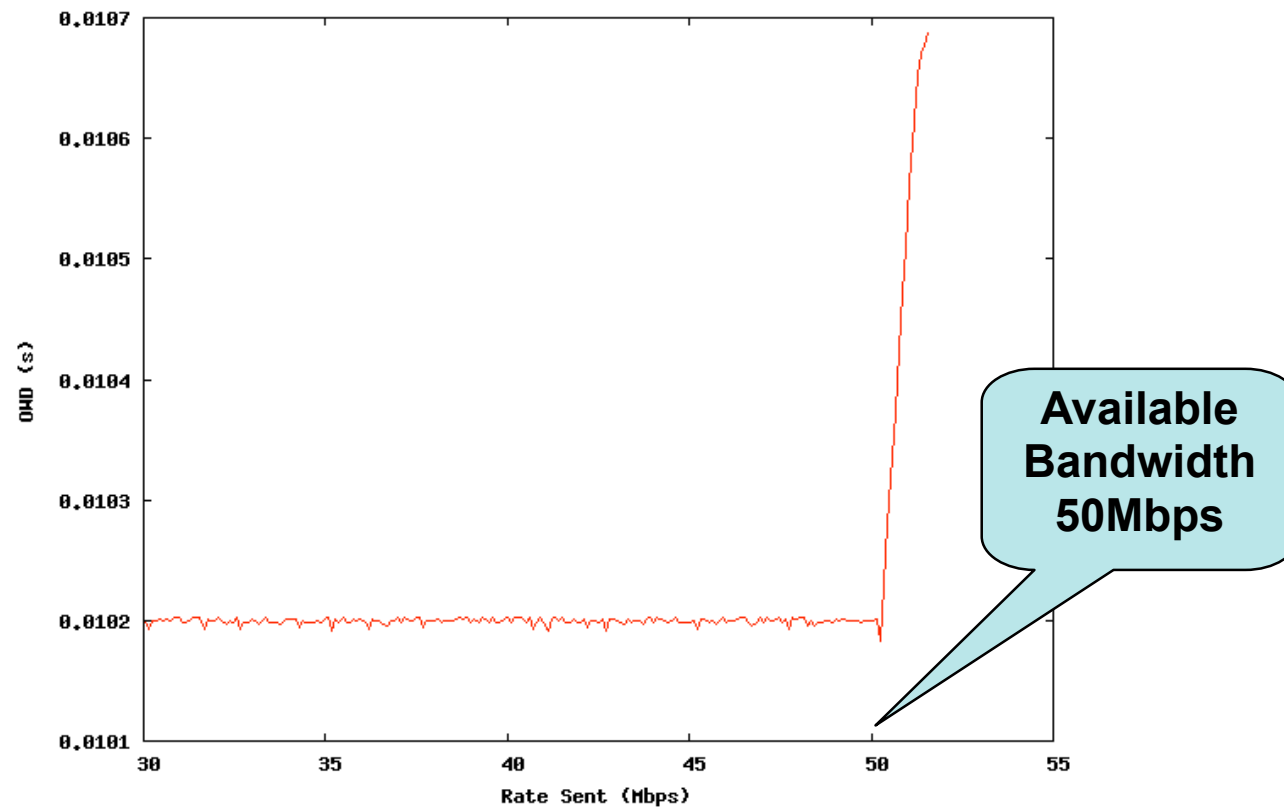
- This tool is very useful BUT:
 - It requires administrator access to the routers
 - Computes the Available Bandwidth per link, not per path

Outline

- Introduction
- **Related Work**
- Objectives
- Passive Bandwidth Estimation Tool
- Results
- Conclusions

Related Work

- Probe Rate Model (Packet Trains)



Related Work

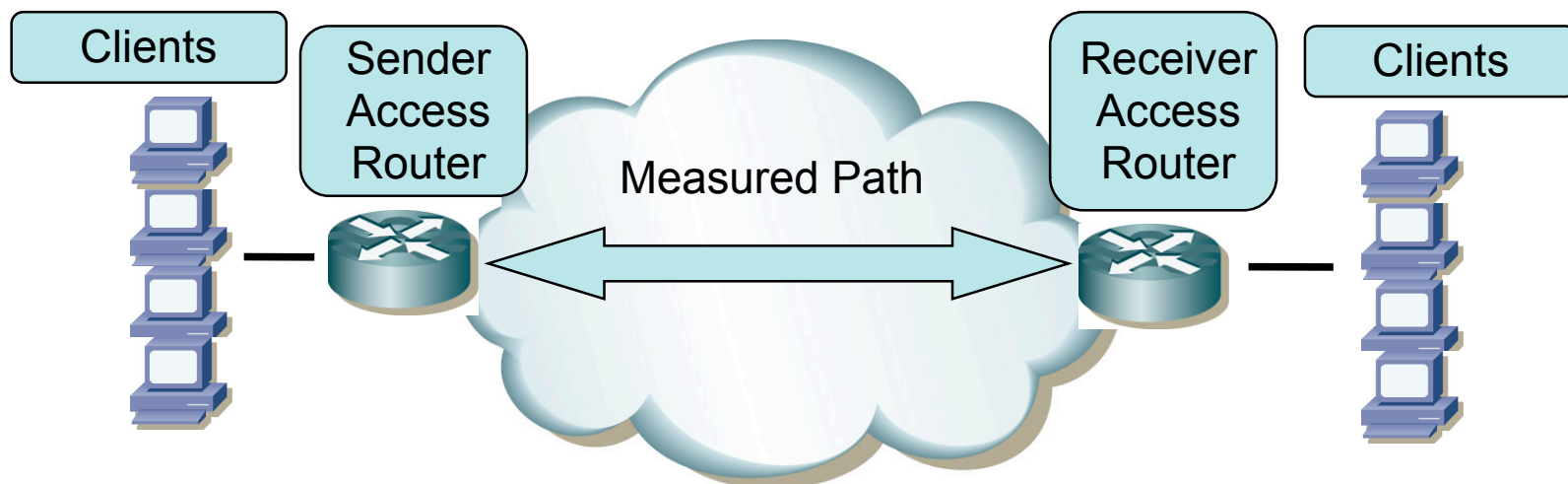
- The Probe Rate Model and other techniques causes congestion in order to estimate the AB.
- These techniques send sequences of packets (packet rates) at a higher rate than the AB
- This impact TCP flows and reduces the performance of the Network

Outline

- Introduction
- Related Work
- **Objectives**
- Passive Bandwidth Estimation Tool
- Results
- Conclusions

Objectives

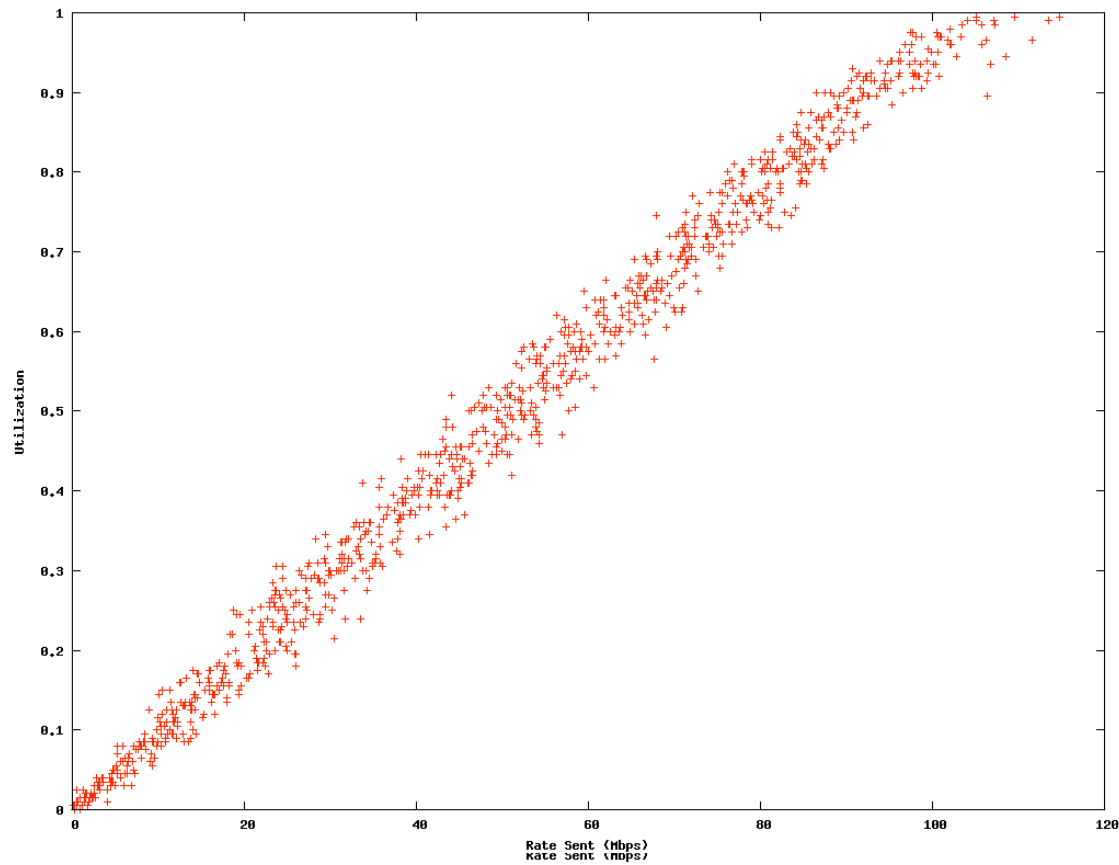
- Design an end-to-end Available Bandwidth estimation tool that do not send packet trains at a higher rate than the AB
- Passive Available Bandwidth estimation tool:



Outline

- Introduction
- Related Work
- Objectives
- **Passive Bandwidth Estimation Tool**
- Results
- Conclusions

Our Mathematical Model



$$utilization(r) \approx \min(1, a + br)$$

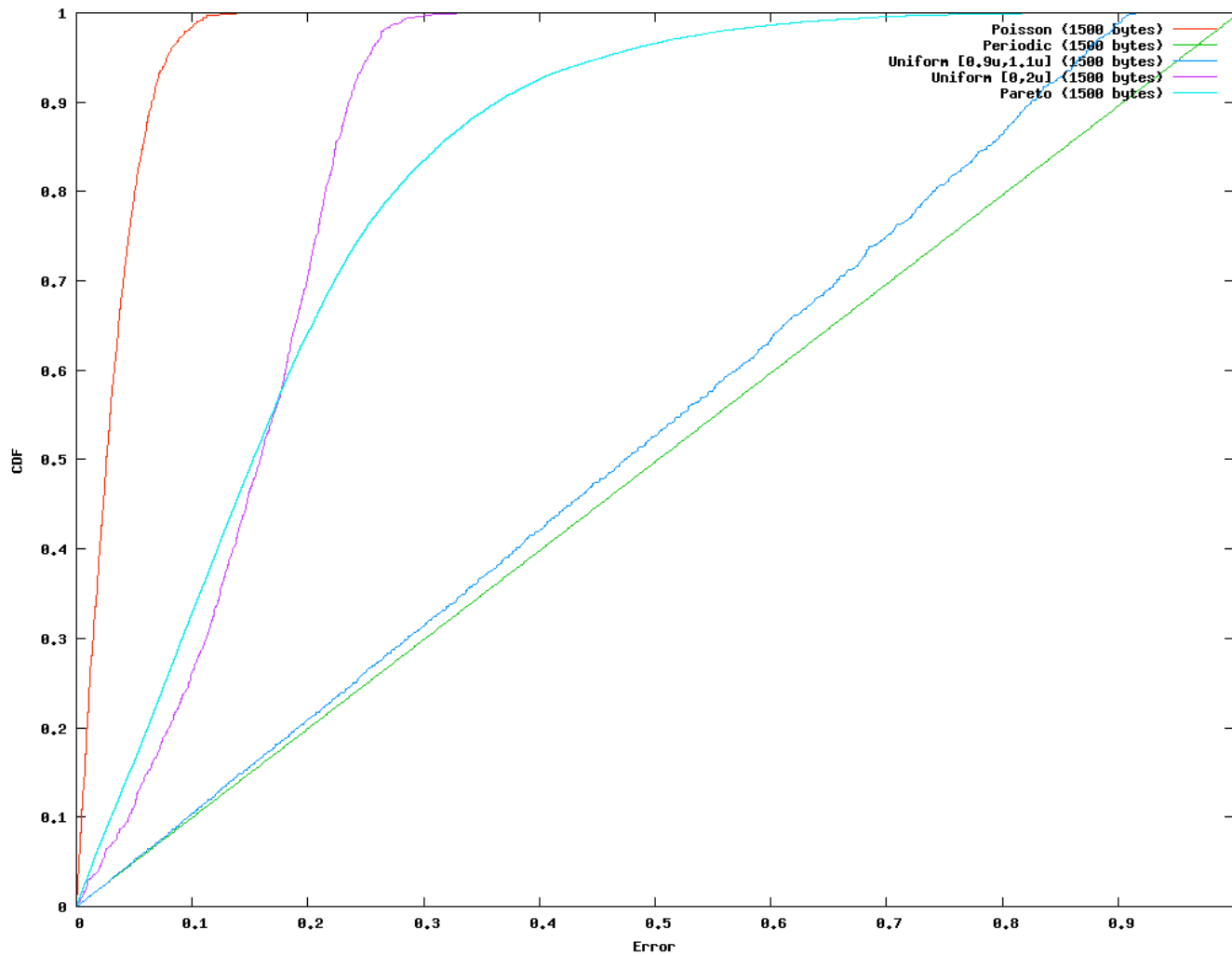
Our Mathematical Model

- Our Mathematical Model allows us to estimate the Available Bandwidth with packet trains at a lower rate than the AB
- To estimate the utilization we compute how many packets have been delayed:

$$owd_i > \min_{j=0\dots P} (owd_j)$$

- Utilization = Number of packets above the minimum delay/Total number of packets

Packet Trains



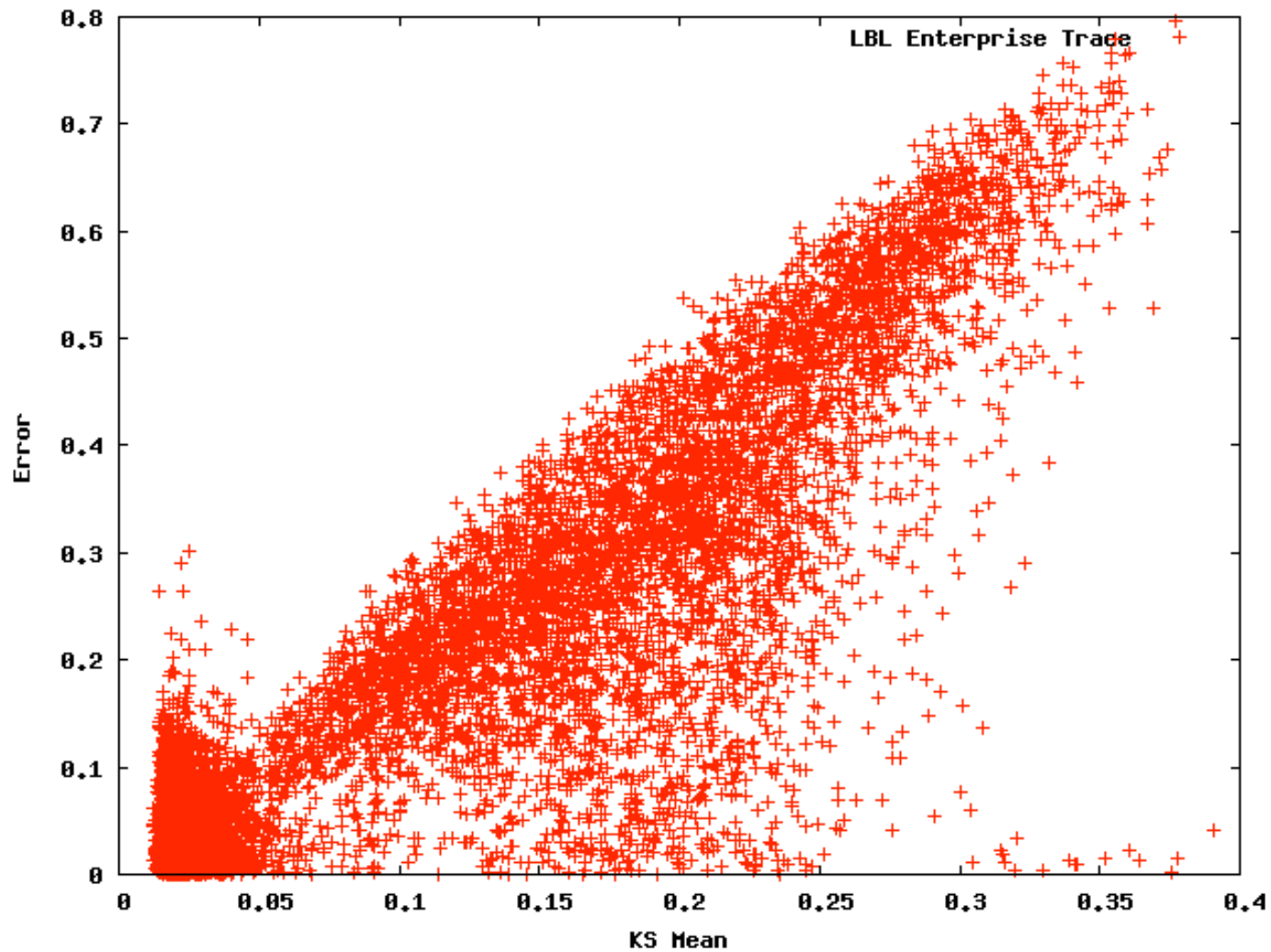
Passive Tool

- Instead of artificial traffic, this tool uses real traffic as packet trains to estimate the AB
- We need to differentiate “good” packet trains from “bad” packet trains
- We have researched many metrics:
 - Autocorrelation function
 - Multiple Linear Regression
 - ...

Passive Tool

- **BUT**, the only metric that provides good results is the *Kolmogorov-Smirnov* Test for the *Poisson* distribution
- The *Kolmogorov-Smirnov* Test is a goodness-of-fit test for many distributions, including *Poisson*
- This test uses the maximum distance between the theoretical distribution and the empirical distribution
- **However**, a more **generic** metric may exist

Kolmogorov-Smirnov Test



Passive Tool

- Sender-Side:
 - Timestamp (using In-Line Measurements 1000) packets (5 packet trains)
 - If low rate variability is detected, inject artificial traffic at the last packet train
 - Worst case: 1ms
- Receiver-Side:
 - Compute the KS-test for each packet train
 - If the $KS\text{-mean} < 0.05$ compute Utilization and Rate
 - Feed the Mathematical Model with the (Utilization, Rate)
 - Obtain an estimation of the AB

Outline

- Introduction
- Related Work
- Objectives
- Passive Bandwidth Estimation Tool
- **Results**
- Conclusions

Results – (Semi)Passive Tool

Scenario I	AB	
1	10	Min: 8.39 Mean: 10.33 Max: 13.35
2	8	Min: 4.25 Mean: 7.57 Max: 12.25
3	5	Min: 1.57 Mean: 5.02 Max: 21.96
Scenario II	AB	
1	100	Min: 67.45 Mean: 95.72 Max: 109.65
2	50	Min: 18.50 Mean: 52.22 Max: 96.63
3	80	Min: 5.71 Mean: 45.46 Max: 96.33
Scenario III	AB	
1	51	Min: 43.85 Mean: 54.62 Max: 66.12
2	25	Min: 11.31 Mean: 29.35 Max: 44.39
3	30	Min: 9.09 Mean: 30.83 Max: 55.71

Outline

- Introduction
- Related Work
- Objectives
- Passive Bandwidth Estimation Tool
- Results
- **Conclusions**

Advantages/Drawbacks

Simple Implementation

- No special hardware
- No clock synchronization
- Runs at the user-space

 Packet trains at lower data rates than the AB

 High variability on highly congested paths

  Lots of parameters to tune