Active and Passive Measurements on Campus, Regional and National Network Backbone Paths

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Topics of Discussion

- Introduction
- Motivation and Goals of our Study
- Active and Passive Measurements Toolkit
- Testbed spanning Hierarchical Network Backbone Levels – Campus, Regional, National
- Analysis of Active Measurements
- Analysis of Passive Measurements
- Conclusion

Network Measurement Infrastructures (NMIs)

- It has become a common practice for ISPs to instrument networks with NMIs that support "Active" and "Passive" measurements
- Why?
  - **Researchers**
    - Want to study the characteristics of networks that could be adopted in simulation models to develop new network protocols for advanced end-applications
  - **ISPs**
    - Determine performance bottlenecks and trends of network (network availability, loss rates, BW utilization, …) for resource capacity planning
  - **End users**
    - Would like to know about the network performance they are getting at their computer
      - *"Why is my video quality so poor in the videoconference?"*
      - BW, IPv6 capability, multicast capability, connectivity to Internet2, …
    - Advanced network-based applications such as remote scientific visualizations, collaborative tool sharing and scheduling computing jobs for clusters could be made more efficient if they had forecasted network performance data

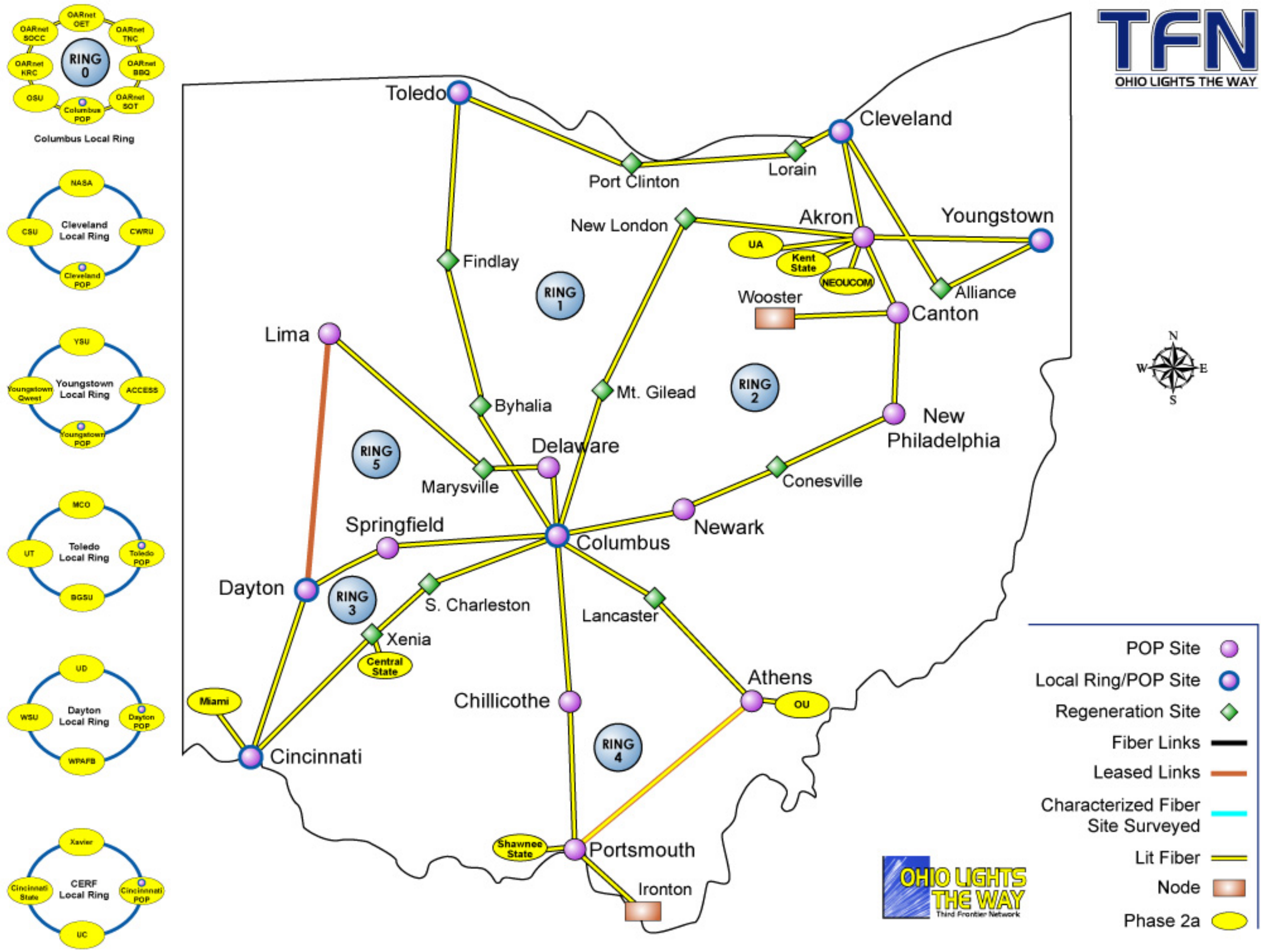
Active and Passive Measurements

- **Active Measurements**
  - Require injecting test packets into the network to determine network topology or end-to-end performance of network paths
  - +)Better characterize end-user perceived application-quality since they emulate experience of actual end-application traffic using a few test packets
  - -)They consume bandwidth required by actual application traffic
- **Passive Measurements**
  - Do not inject test packets in the network but require capturing of packets and their corresponding timestamps transmitted by applications running on network-attached devices over various network links
  - +)Do not inject test traffic and data is obtained from devices that are involved in the functioning of the network
  - -)They impose large overhead on network devices to keep track of such information in addition to their core functionality of forwarding packets

Motivation

- The **Third Frontier Network (TFN)** funded by the Ohio Board of Regents
  - A dedicated high-speed fiber-optic network linking Ohio colleges and universities with research facilities to promote research and economic development
  - Over 1,600 miles of fiber has been purchased to create a network backbone in Ohio to connect colleges and universities, K-12 schools, and communities together
- **TFN Measurement Project**
  - Started in early 2004
    - Project funding from the Ohio Board of Regents
    - To ensure that University campuses can effectively use the advanced networking services the new network provides
  - Project Partners
    - OARnet (Project Lead and Co-ordination)
    - University of Cincinnati, Cincinnati State, The Ohio State University, Kent State University, Southern State Community College, University of Toledo, Wright State University

Third Frontier Network Map



TFN MEASUREMENT PROJECT

TFN Measurement Project Objectives

- Identify end-to-end performance bottlenecks in the TFN on an ongoing fashion by building a comprehensive Network Measurement Infrastructure (NMI)
- Test new and advanced technologies and equipment before wide-scale adoption in the TFN Higher Education communities
  - Technologies: H.323/SIP based Voice and Videoconferencing, MPEG3, HDTV, Multicast, Bulk FTP
  - Equipment: Video streaming Caches, Firewalls, Intrusion Detection Systems, Traffic shapers
- Bring awareness and train campus-networking professionals to make optimum use of the capabilities of TFN so that their campus network infrastructures can be upgraded suitably

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Our TFN NMI Goals

- Goal-1:To study end-to-end network performance measurement data reported by various tools to empirically correlate network events and measurement data anomalies in a routine monitoring infrastructure

"Do measurement tools actually detect significant network events?"

- Goal-2: To analyze long-term network performance trends via statistical analysis of active and passive measurement data collected at strategic points on an ongoing basis

"What can be understood from long-term network measurements?"

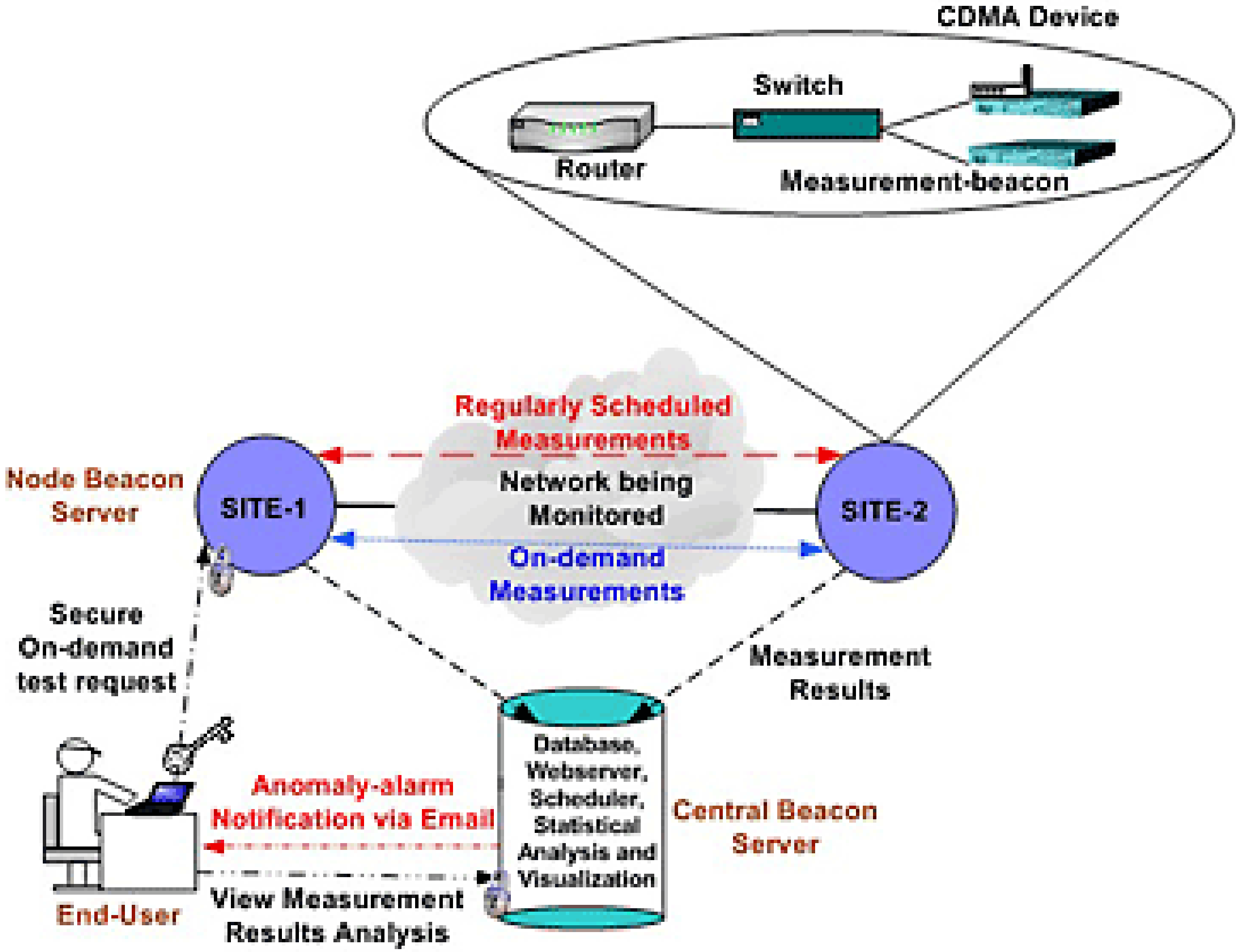
- Goal-3: To use findings obtained from fulfilling the above Goals 1 and 2, to comprehensively compare performance at campus, regional and national network backbone levels and hence to quantify end-to-end network performance stability in typical hierarchical network backbones

"How does it matter where I measure the network?"

Active Measurements Toolkit

- We developed and used our "ActiveMon" NMI Framework to collect and analyze active measurements
- Examples of other NMI Frameworks
  - **NIMI** (Developed by Vern Paxson), **Surveyor** (Developed by Advanced), **E2E piPES** (Developed by Internet2), **Scriptroute** (Developed by Univ. of Washington), *Many more…*
  - Why do we need a new NMI Framework?
    - Available NMI software packages are closely coupled to particular networks for which the software was originally developed
    - There is no easily customizable software package that is available to a network engineer who would like to setup a simple network measurement infrastructure
    - Existing NMI software packages have many limitations in terms of measurments scheduling, digest creation, visualization, …

ActiveMon* Architecture



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*** Project supported by The Ohio Board of Regents, OARnet**

ActiveMon Framework Features

- Data-Generator Module for an application-specific network measurement toolkit
- Central Data-Sanitizer and Data-Collector Module
- Optimized Database Schema to efficiently store massive amounts of measurement data
- Scalable Scheduler Module for handling network-wide on-demand and offline measurements
- Data-Analyzer, Digest Creator and Anomaly Detection based Alarm Generator Module with minimum false-alarms
  - Analysis and Digest creation based on “repair-rate” models
  - Sophisticated yet User-friendly Alarm Interpretation Scheme
  - Notification via email also supported!
- Easily customizable visualization Module with tabular and network health Weather map interfaces
- Security Configurations to avoid compromise of measurement infrastructure resources

Active Measurement Metrics

- Route Changes
  - Due to route flaps caused by sub optimal routing protocol behavior, network infrastructure failures, re-configuration or load balancing of networks by ISPs
- Delay
  - Delay is the time taken for a packet to traverse from a sender end-point to a receiver end-point
  - Commonly ”round-trip delay” is used to characterize network delay vs. one-way delay
- Bandwidth
  - Amount of data that can be transmitted in a fixed amount of time i.e. indicates amount of congestion or resources available the in network path
    - Measured in terms of Available / Bottleneck / Per-hop Bandwidth, TCP/UDP Throughput
- Jitter
  - Variations in network delay as seen at the receiver end (RTP- RFC 1889, IPDV – RFC 3393)
- Loss
  - Loss indicates the percentage of packets lost as observed at the receiver end-point for a given number of packets transmitted at the sender end-point.
- Mean Opinion Score
  - Used in evaluating network’s ability to support Voice and Video over IP (VVoIP) applications
    - The MOS values are reported on a quality scale of 1 to 5; 1-3 range being poor, 3-4 range being acceptable and 4-5 range being good.

ActiveMon Measurement Toolkit

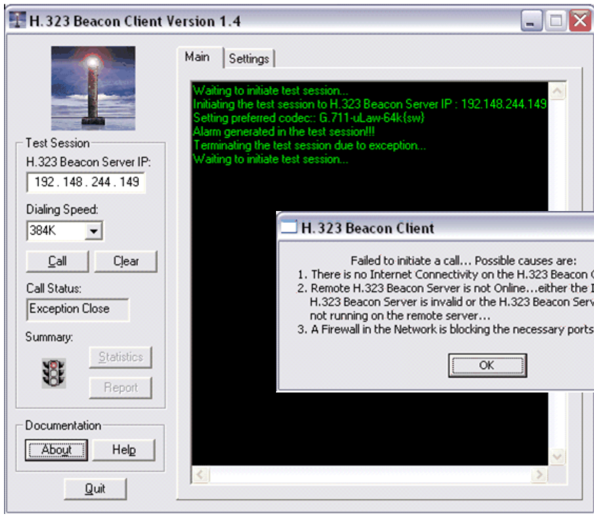
Measured Characteristics	Tool
Round-trip delay	Ping
High-precision one-way delay	OWAMP
Topology and route changes	Traceroute
Bandwidth capacity: Per-hop	Pathchar
Available bandwidth	Pathload
Bottleneck bandwidth	Pathrate
UDP transfer bandwidth, Jitter and Loss	Iperf
Performance of interactive audio/video streams (MOS)	H.323 Beacon

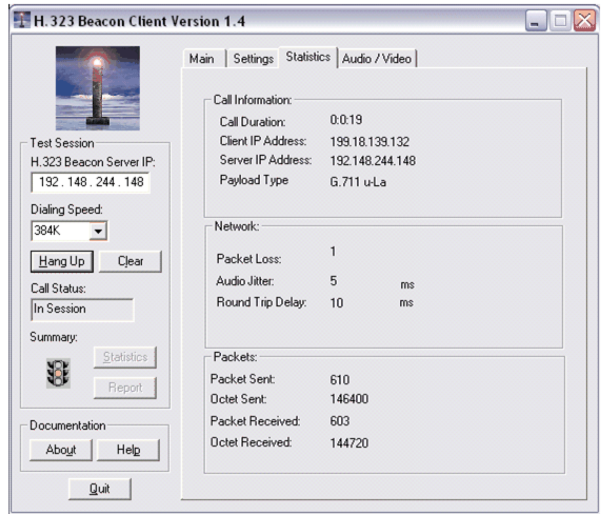
H.323 Beacon*

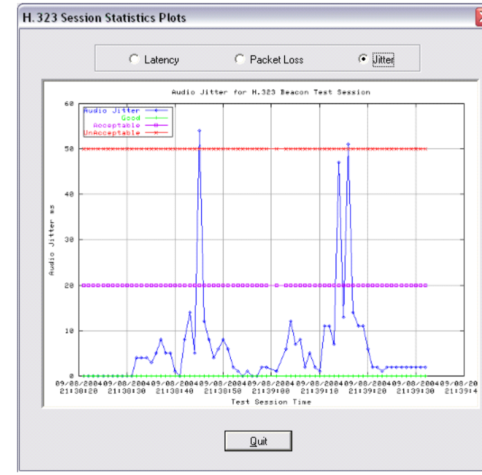
- An application-specific measurement tool
  - To monitor and qualify the performance of H.323 Videoconferencing sessions at the host and in the network (end-to-end)
- Useful to an end-user/conference operator/network engineer
- Addresses problems due to H.323 protocol-specific idiosyncrasies
  - Can be generalized to RTP packets performance over the network
  - Many in-built tools that generate various kinds of measurement data for pre/during/post Videoconference troubleshooting!
- An “easy to install and use” tool that is open source

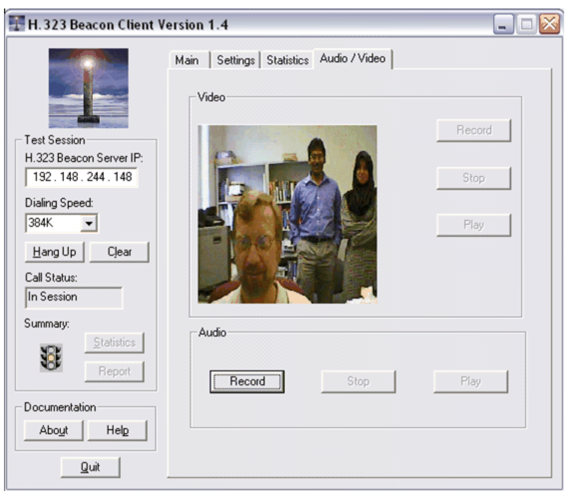
*** Project supported by Internet2, The Ohio Board of Regents, OARnet***

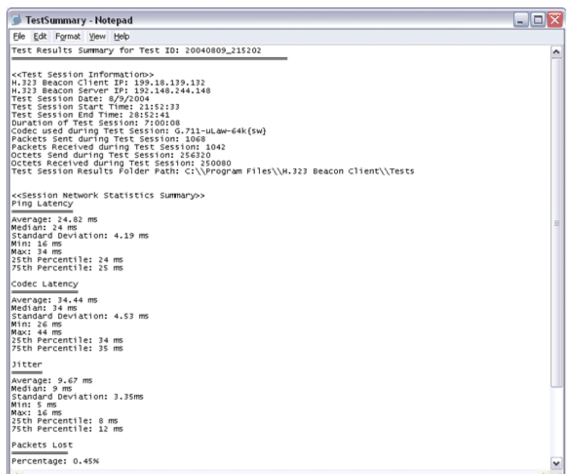
A few H.323 Beacon screenshots…

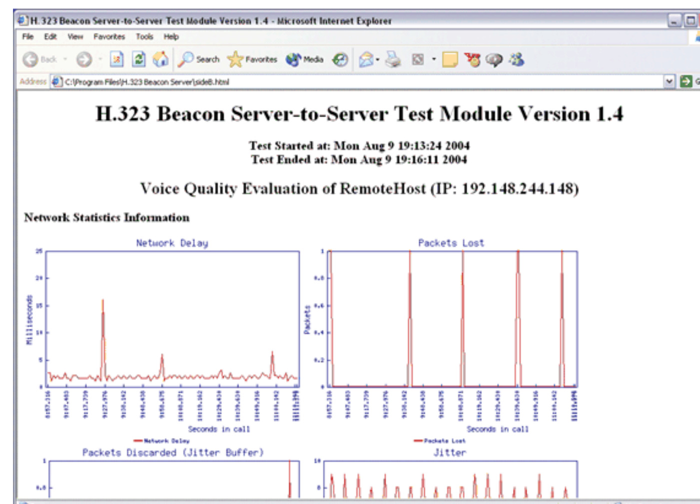












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http://www.itecohio.org/beacon

Passive Measurement Metrics

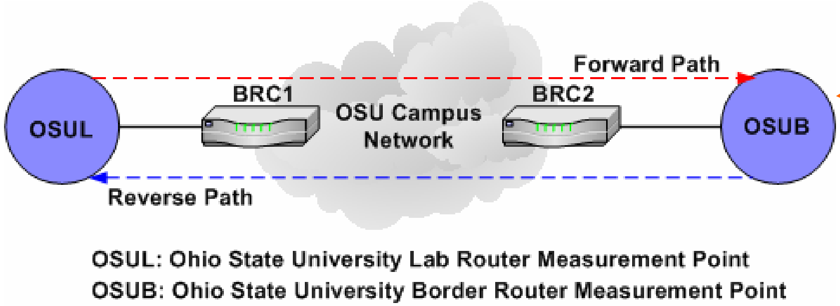
- Availability
  - It is calculated by measuring the uptime or downtime of a network device or service using passive measurements
  - Scheduled outages (e.g. network devices or services are shutdown for maintenance purposes) are not considered while calculating availability
- Discards
  - It is an SNMP metric that indicates the number of packet discarded for a particular network interface.
- Errors
  - It is an SNMP metric that indicates the number of interface errors (e.g., Frame Check Sequence (FCS) errors)
    - Large values of discards and errors are an indication of excessive network congestion at any given point of time
- Utilization
  - It is an SNMP metric that compares the amount of inbound and outbound traffic versus the bandwidth provisioned on a link in a network path
- Flow Information
  - It provides bandwidth/link utilization information at flow-levels between network backbone routers
    - This information could be used to determine the flow-level type, duration and amount of application traffic traversing the network

Passive Measurements Toolkit

- Standards-compliant Commercial Software

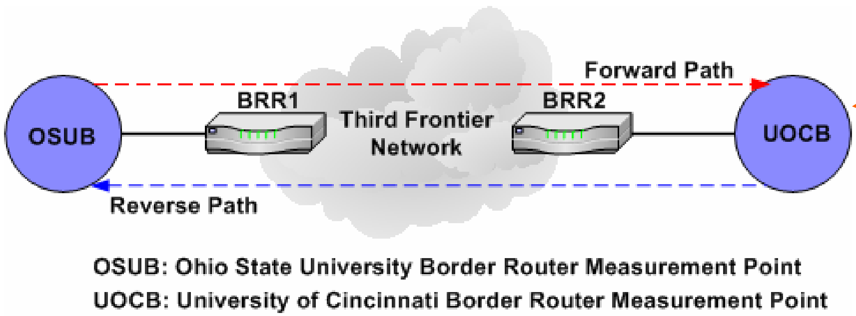
Measured Characteristics	Tool
Availability	Nagios, Syslog
Errors and Discards	Statscout
Bandwidth Utilization	MRTG
Description of traffic flows	NetFlow

Testbed spanning Hierarchical Network Backbone Levels – Campus, Regional, National



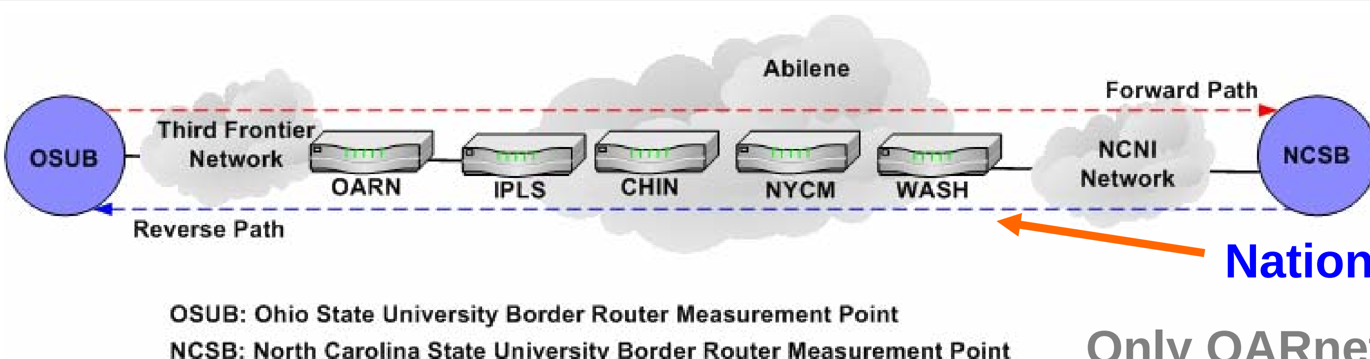
Campus - Level Path

Only OSU Campus Backbone Routers were present along the path



Regional - Level Path

Only OARnet Backbone Routers were present along the path



National - Level Path

Only OARnet Backbone Routers, Abilene Routers, NCNI Routers were present along the path

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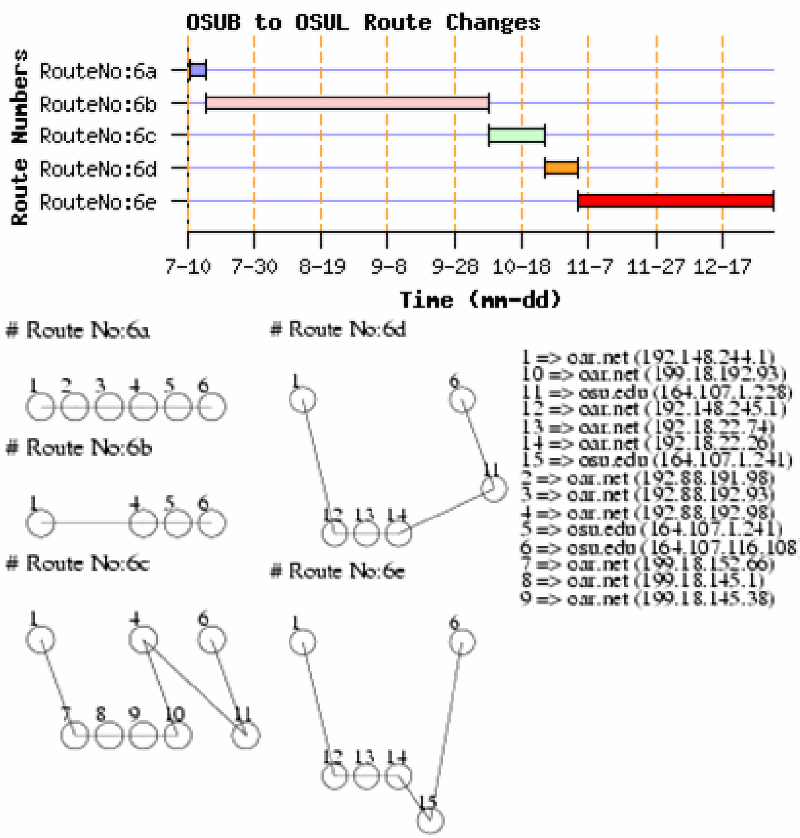
Analysis of Active Measurements
(July 2004 – December 2004 Measurements Data)

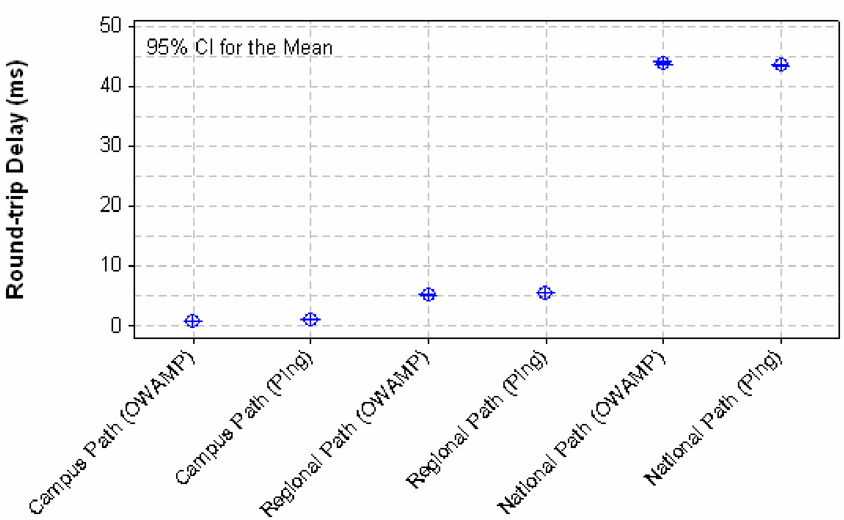
- Route Changes
  - 4 in Campus path, 2 in Regional path, 0 in National path
    - Mainly due to network management while transitioning from our old ATM network to our TFN
    - Otherwise, stable routing!

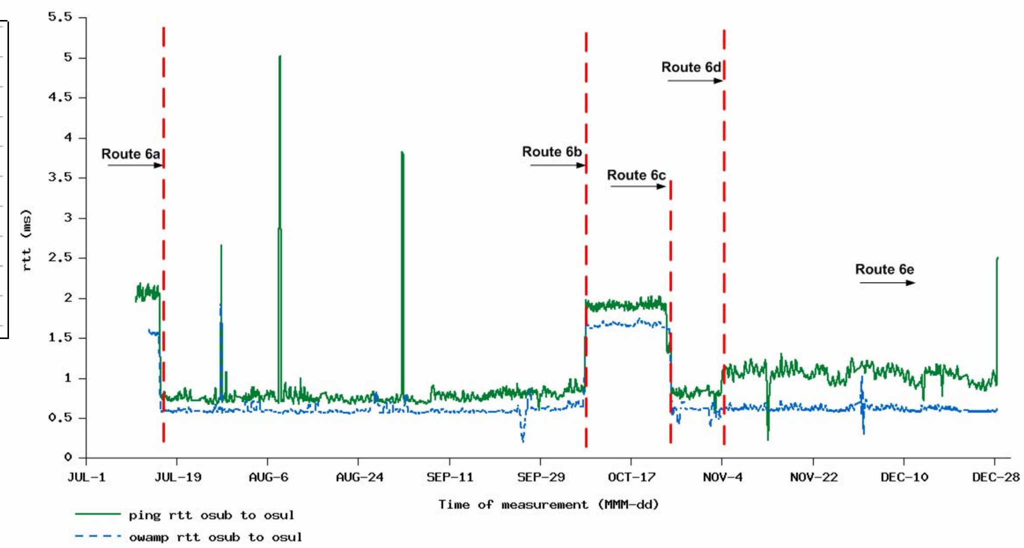


Analysis of Active Measurements

(July 2004 – December 2004 Measurements Data)

- Delay
  - We found that combined one-way delays (A→B+B→A) along a path with ends A and B are comparable to round trip delays (A↔B) in all the three paths
  - Significant anomalies due to route changes (each time!)
  - Short-lived dips and peaks due to miscellaneous temporal network dynamics
  - Magnitudes based on hop-count





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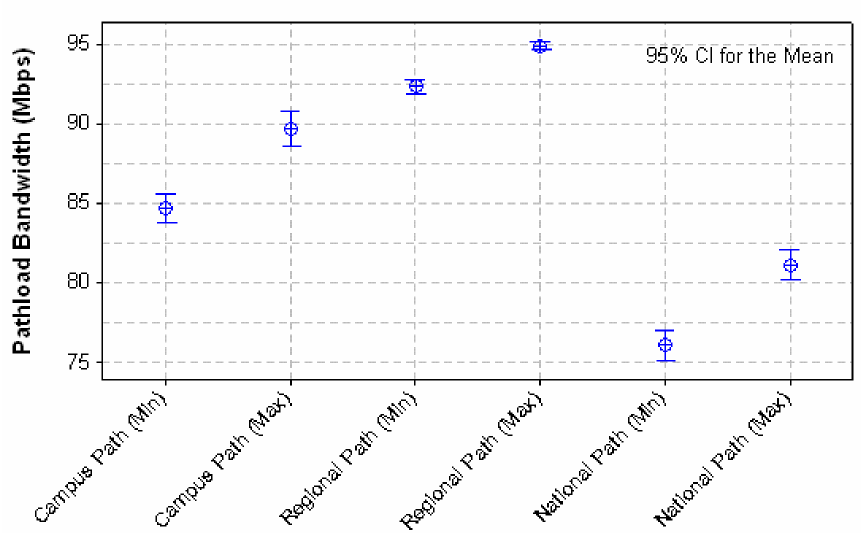
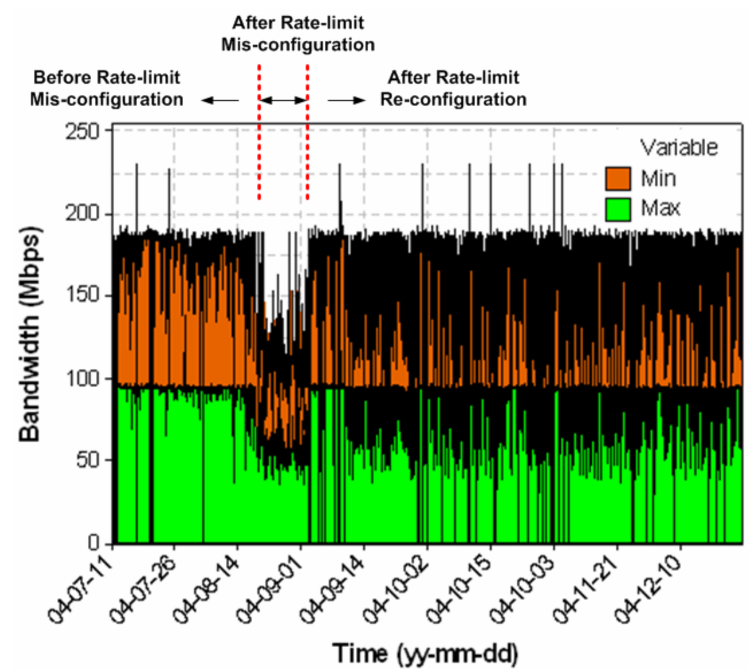
Analysis of Active Measurements
(July 2004 – December 2004 Measurements Data)

- Bandwidth
  - Router mis-configuration anomaly with three distinct trends
  - Regional path was the least congested and most provisioned path
  - National path traffic spanning multiple-ISPs experiences most congestion and is the least provisioned path
    - Traffic management policies, heterogeneity in infrastructure





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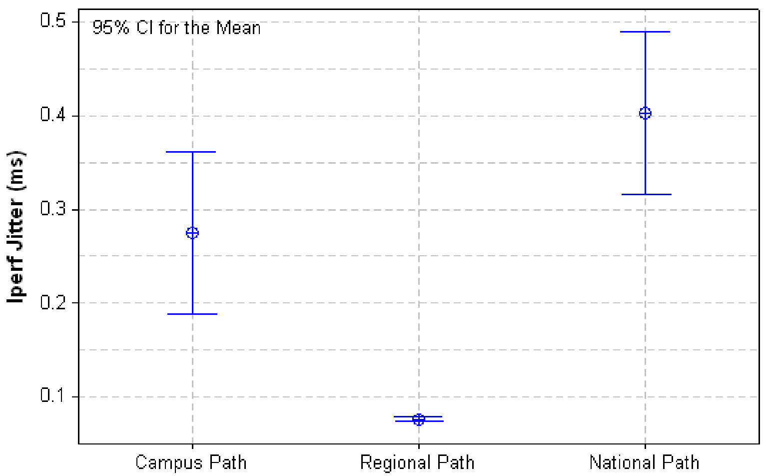
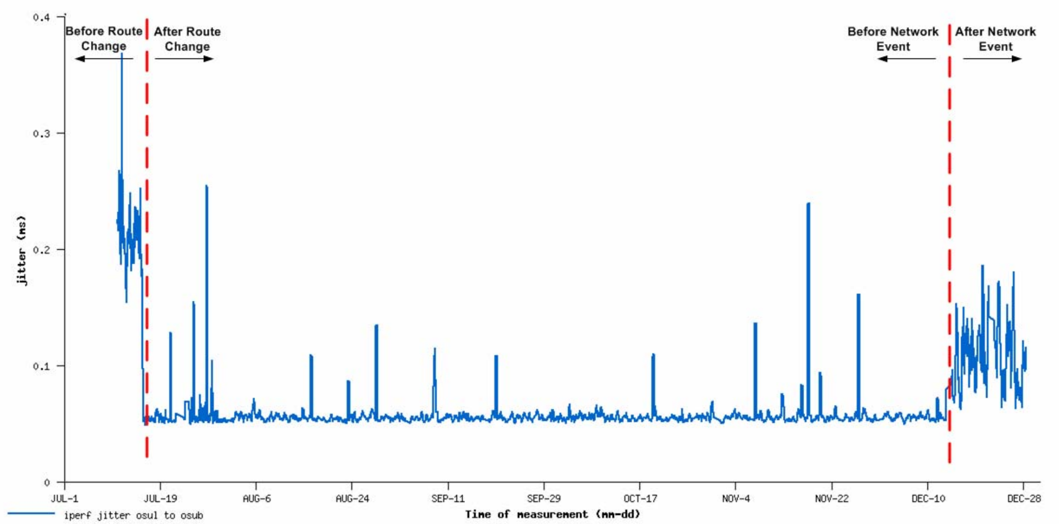
Analysis of Active Measurements

(July 2004 – December 2004 Measurements Data)

- Jitter
  - Not all route changes cause jitter anomalies
  - Jitter magnitudes and spread are higher on more congested and less provisioned paths
  - Short-lived dips and peaks due to miscellaneous temporal network dynamics

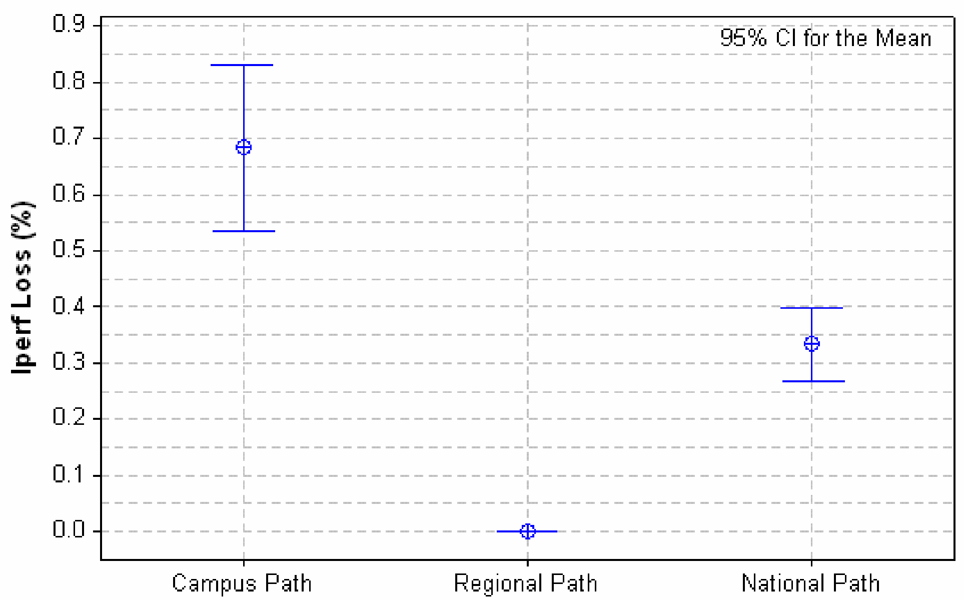




Analysis of Active Measurements

(July 2004 – December 2004 Measurements Data)

- Loss
  - No noticeable effects of route changes on loss anomalies
  - Loss magnitude and spread higher for last-mile bottleneck Campus path
  - Short-lived dips and peaks due to miscellaneous temporal network dynamics



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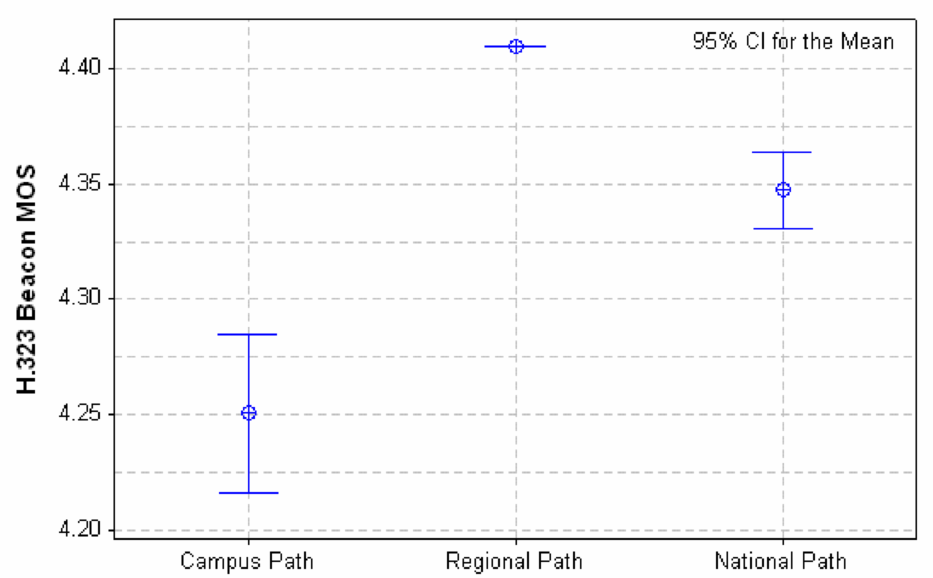
Analysis of Active Measurements
(July 2004 – December 2004 Measurements Data)

- Mean Opinion Score (MOS)
  - No noticeable effects of route changes on MOS anomalies
  - MOS measurement anomalies were partially influenced by the varying degrees of delay, jitter and loss in the paths
  - All Paths suitable for VVoIP applications deployment (MOS >4.2)



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Analysis of Active Measurements

(July 2004 – December 2004 Measurements Data)

- Stability Analysis using statistical co-efficient of variation (ρ)
  - Lesser ρ indicates better stability
- Regional path most stable; Campus path least stable

$$\rho = \frac{S}{\bar{X}} * 100$$

where -

$$S = \sqrt{\frac{\sum (x_i - \bar{X})^2}{X}}; \bar{X} = \sum \frac{x_i}{N}$$

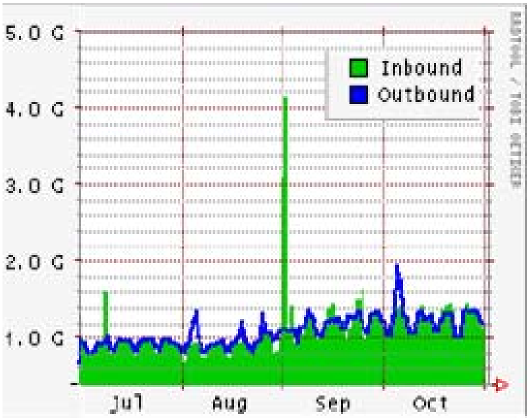
Here: x_i is the i^{th} observation, N is the number of non-missing observations, $\bar{X}$ is the Mean and S is the standard deviation.

Tool Characteristic	Campus	Regional	National
Pathrate Max. Bandwidth (Mbps)	24.23	5.5	6.74
Iperf Jitter (ms)	745.95	45.1	499.89
Iperf Loss (%)	517.63	62.48	127.43
H.323 Beacon MOS	18.48	0.03	9.63
OWAMP Delay (ms)	52.87	10.64	13.47
Ping Delay (ms)	58.52	5.65	24.4

Analysis of Passive Measurements

(July 2004 – October 2004 Measurements Data)

- Not common to find notable correlations between active and passive measurements
  - Provide good context to interpret active measurements
  - Another perspective in evaluating end-to-end network performance
- Measured at core routers
  - BRC1, BRC2, BRR1, BRR2, OARN, IPLS, CHIN, NYCM, WASH
- Availability
  - All core routers in the hierarchical paths showed 100% availability
- Discards and Errors
  - Very low or close to zero
- Utilization
  - About (10-20)% in general



Utilization between IPLS and CHIN

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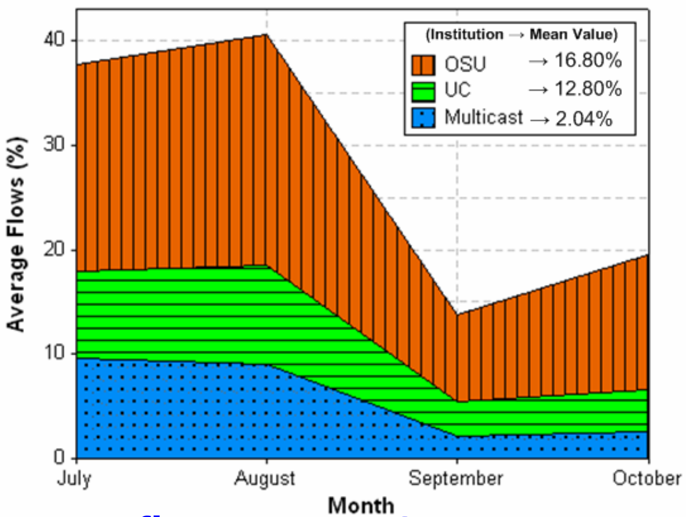
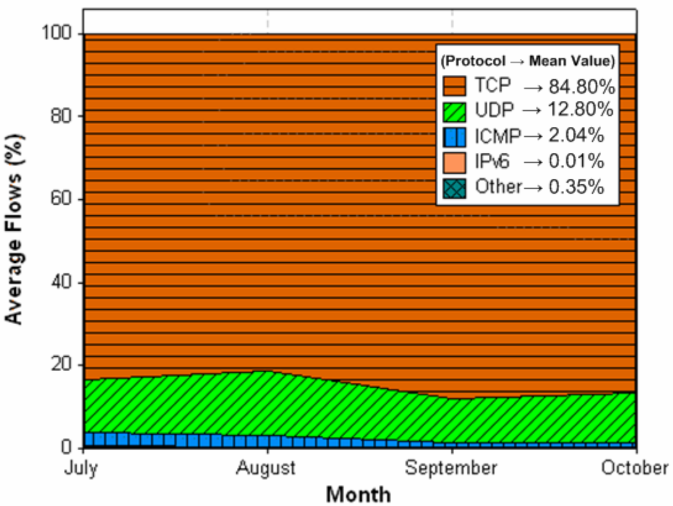
Analysis of Passive Measurements

(July 2004 – October 2004 Measurements Data)

- Flow Information
  - Considered UC and OSU Traffic
    - Effect of "Summer Break"
    - They together contribute to about 30% of Abilene traffic originating from Ohio
  - Considered Protocol distribution in Traffic at WASH
    - 80% TCP, 10-15% UDP, 1-3% ICMP, 0.01% IPv6



Netflow Data at OARN Router



Netflow Data at WASH Router

Work in Progress…

- Using our valuable measurement data sets to develop better “on-line anomaly detection schemes” for routine ISP monitoring
- Extensive performance stability analysis and visualization over multi-resolution timescales
- Extending ActiveMon with our lessons learnt from our measurements analysis studies…

Thanks!

- ActiveMon Scripts Development and Data Analysis
  - Mukundan Sridharan, Dima Krymskiy, Phani Kumar Arava
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  - Jeff Boote (OWAMP)
  - Leandro Lustoza (H.323 Beacon E-Model implementation)

Questions?

TFN Measurement Project Reference:

http://tfn.oar.net/measurement