Network Measurement Research in a Complex Networked World (在複雜網絡世界中的網絡測量研究)

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10 July 2013

Internet Infrastructure and Security Laboratory

- Advanced Network Monitoring and Measurement Laboratory (ANEMOL)
- Internet measurement research (funded by the Innovation and Technology Commission)
  - "Design and Implementation of a Unified Box for Offering Network Path Measurement as a Service," a Tier-2 project
  - "Reliable and Accurate Bandwidth Measurement of Asymmetric Network Paths," a Tier-3 project
  - "Uncooperative Measurement and Monitoring of Internet Path Quality with Applications," a Tier-3 project
- Internet measurement services
  - "Performance Monitoring and Measurement of HARNET," Funded by The Joint Universities Computer Centre, since 2009.
  - “Performance Monitoring of Critical Network and Service Infrastructure in Hong Kong,” Funded by a government dept.
- Security projects
  - Android security and web security

Outline

A. The visions

B. The “old” network measurement field and new challenges

C. Recent network management initiatives

D. The (research) problems to solve

E. Our current projects

F. Conclusions

A. The visions

(1) Removing the information asymmetry between subscriber and provider

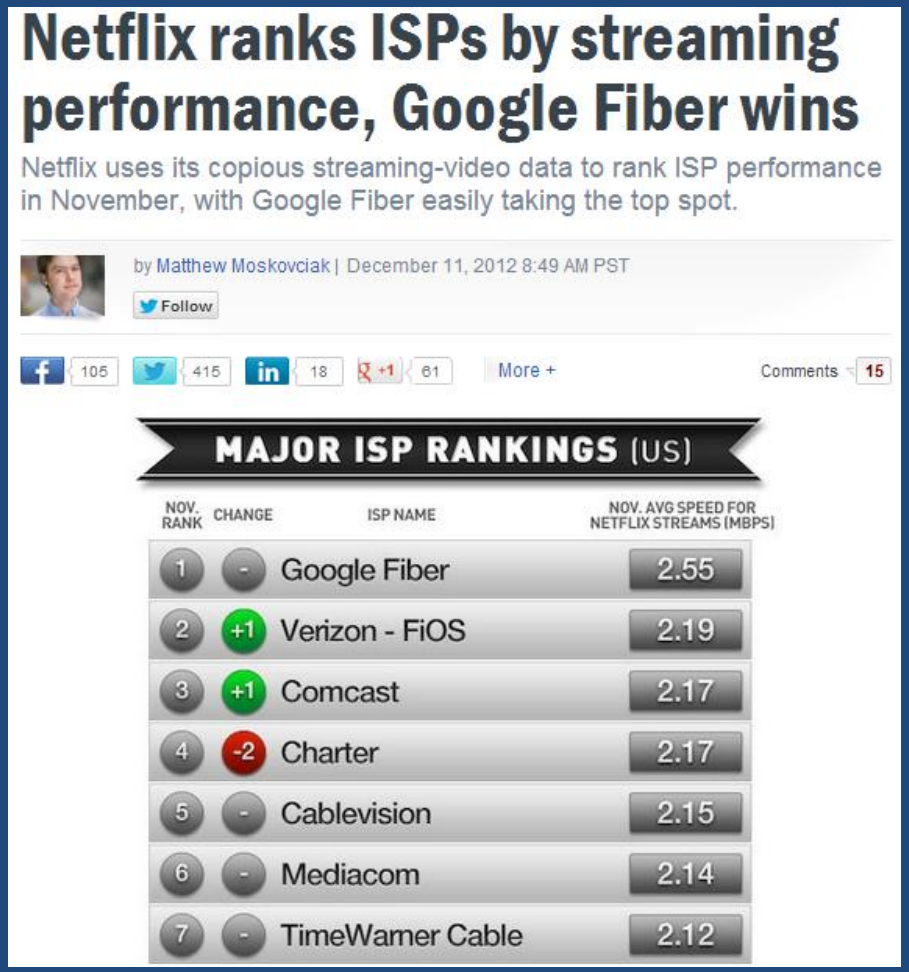
(1) HKBN fined for deceptive representations

FINAL DECISION OF THE
COMMUNICATIONS AUTHORITY

ALLEGED MISLEADING OR DECEPTIVE REPRESENTATIONS BY HONG KONG BROADBAND NETWORK LIMITED IN RELATION TO THE TRANSMISSION SPEED OF ITS BROADBAND SERVICE SET OUT IN ITS ADVERTISEMENTS AND PROMOTIONAL MATERIALS

Licensee Concerned:	Hong Kong Broadband Network Limited ("HKBN")
Issue:	The representations in relation to the transmission speed of HKBN's broadband service set out in its advertisements and promotional materials were alleged to be misleading or deceptive
Relevant Instruments:	Section 7M of the Telecommunications Ordinance ("TO") (Cap. 106)

(2) Open access to ISPs' performance



Netflix ranks ISPs by streaming performance, Google Fiber wins

Netflix uses its copious streaming-video data to rank ISP performance in November, with Google Fiber easily taking the top spot.

by Matthew Moskovciak | December 11, 2012 8:49 AM PST

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MAJOR ISP RANKINGS (US)

NOV. RANK	CHANGE	ISP NAME	NOV. AVG SPEED FOR NETFLIX STREAMS (MBPS)
1	-	Google Fiber	2.55
2	+1	Verizon - FiOS	2.19
3	+1	Comcast	2.17
4	-2	Charter	2.17
5	-	Cablevision	2.15
6	-	Mediacom	2.14
7	-	TimeWarner Cable	2.12

Source: http://reviews.cnet.com/8301-33199_7-57558483-221/netflix-ranks-isps-by-streaming-performance-google-fiber-wins/

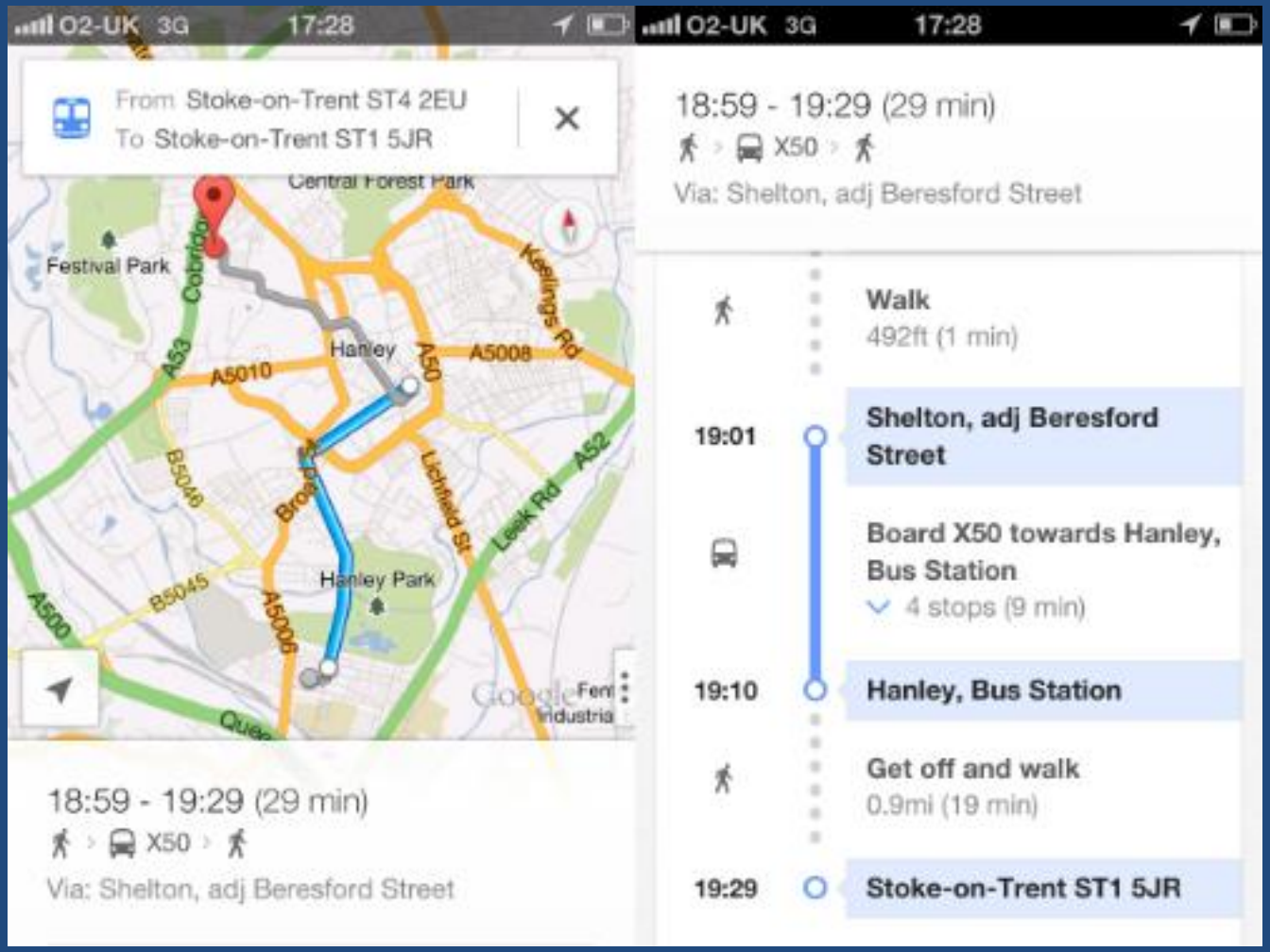
(3) Third-party performance certification and auditing

Source: http://www.certifiedhph.com/

(4) Instantaneous Internet traffic reporting

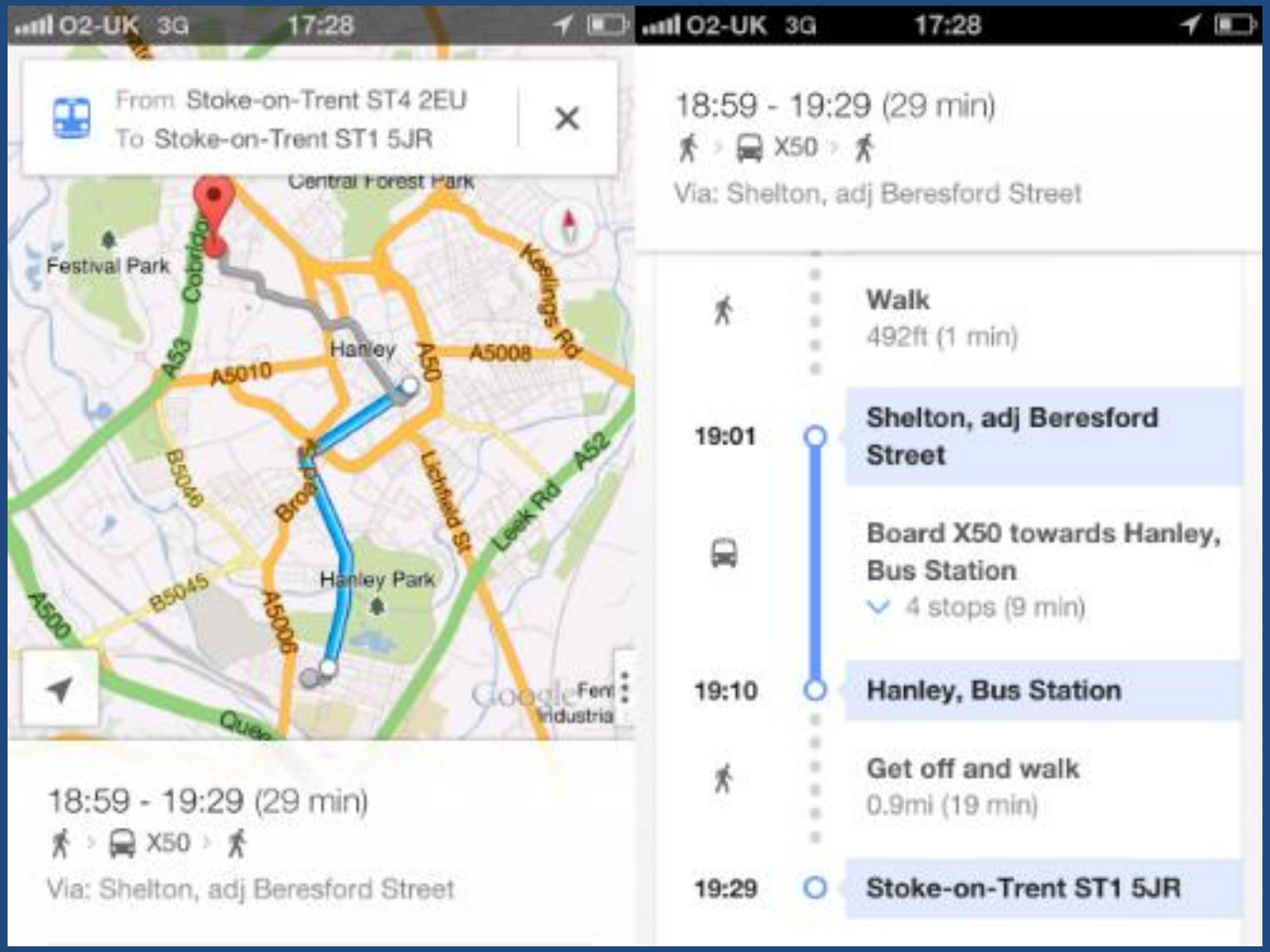
Source: http://forums.macrumors.com/showthread.php?t=788472

(5) Server optimizing the data path



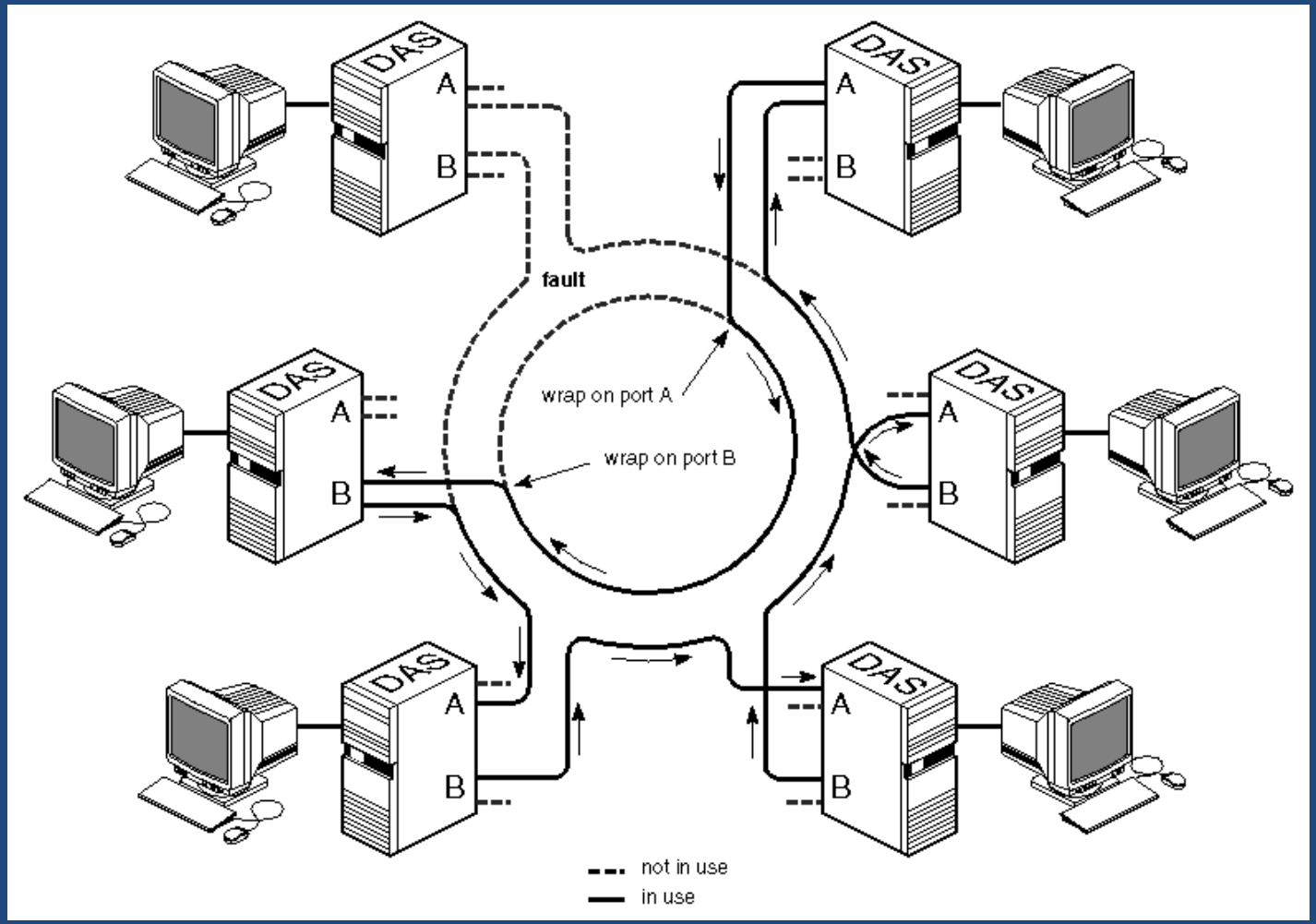
Source: http://www.dialaphone.co.uk/blog/2013/05/11/best-public-transport-apps/

(5) Server optimizing the data path



Source: http://www.dialaphone.co.uk/blog/2013/05/11/best-public-transport-apps/

(6) Auto-reconfiguration to bypass faults



Source: http://techpubs.sgi.com/library/dynaweb_docs/0530/SGI_Admin/books/FDDIX_AG/sgi_html/ch03.html

(7) Network measurement as a service

Source: http://blog.evaria.com/2007/next-gen-broadband-speed-test/

B. The “old” network measurement field and new challenges

Internet measurement research

- Devising sound and pragmatic methodologies for measuring different aspects (infrastructure, traffic and applications) of the Internet
  - Network traffic measurement
  - Network topology measurement
  - Network performance measurement
  - …
- Measurement methodology, metrics, experiments, tools, data analysis, calibration, …

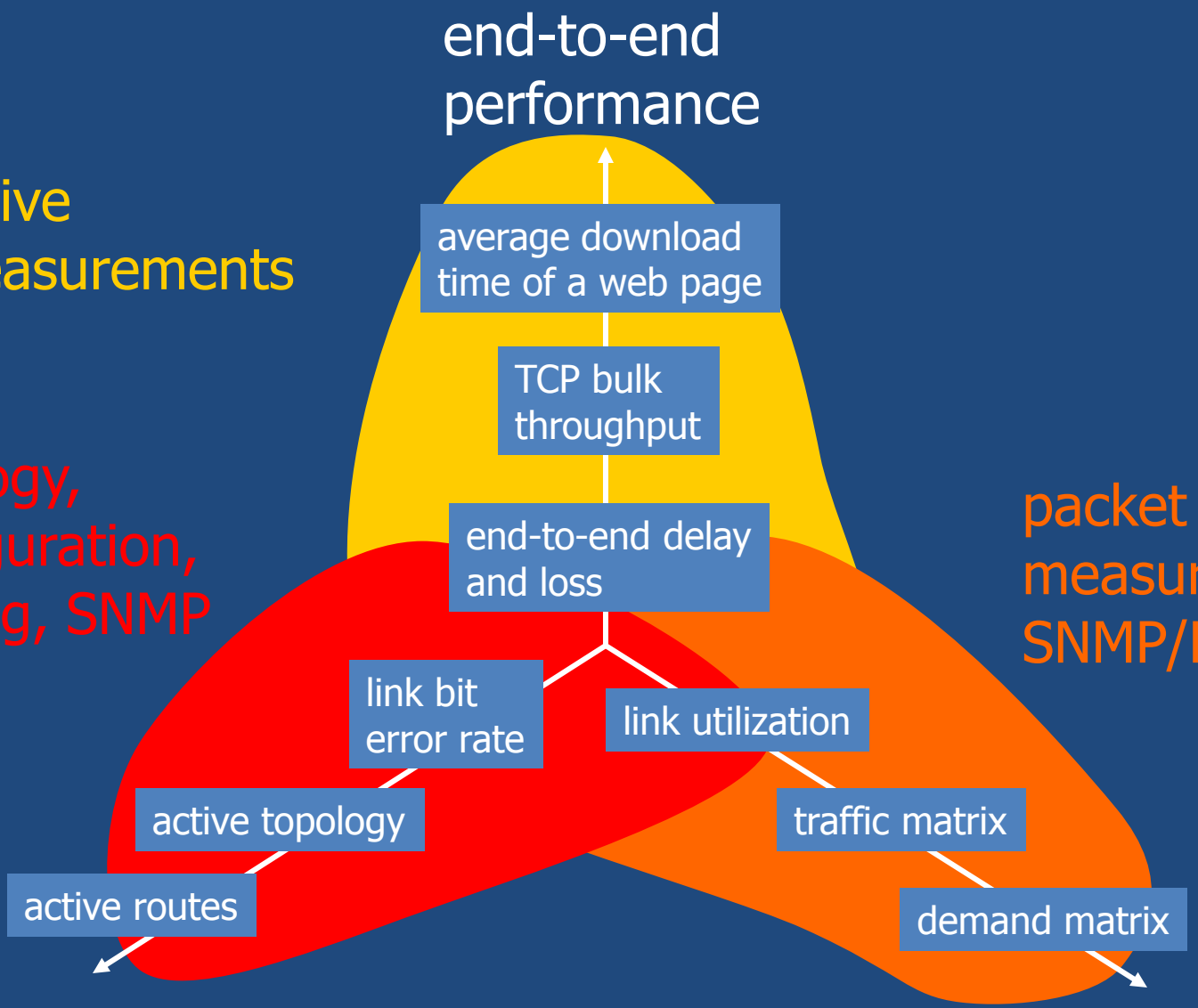
Seminal works

- Walter Willinger on self-similar traffic
  - "On the Self-Similar Nature of Ethernet Traffic", 1994
  - Many papers followed: http://www.informatik.uni-trier.de/~ley/pers/hd/w/Willinger:Walter.html
- Paxson on measuring IP network performance
  - "Growth Trends in Wide-Area TCP Connections" 1994
  - "Wide-Area Traffic: The Failure of Poisson Modeling", 1995
  - "Measurements and Analysis of End-to-End Internet Dynamics", 1997

Research efforts

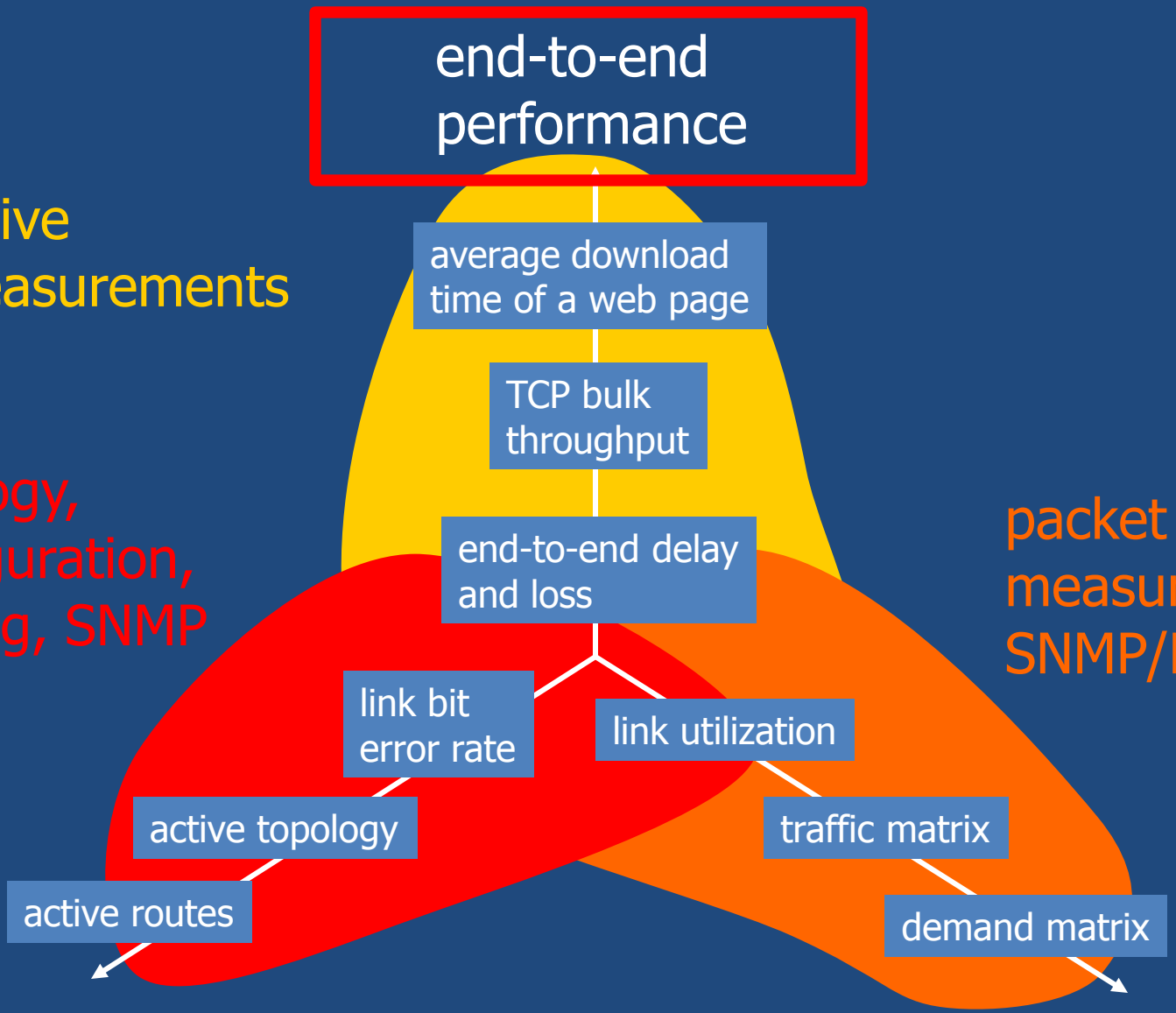
- The first PAM workshop in 2000, Hamilton, New Zealand
  - The 2nd organized by RIPE NCC, …
  - The 14th by our research group
- The first IMC workshop in 2001, San Francisco, California, USA, organized by netVMG and Sprint
- Others: SIGCOMM, CoNEXT, SIGMETRICS, etc
- Internet Measurement: Infrastructure, Traffic and Applications by Mark Crovella, June 2006.
- CAIDA, RIPE NCC, IETF's IPPM WG, M-Lab (Google), Internet's perfSONAR, MPlane

Types of measurement



Source: Tutorial on "Traffic Measurement for IP Operations" (Grossglauser and Rexford) at ACM SIGCOMM'01 and IEEE INFOCOM'02

Cross-domain active e2e



Source: Tutorial on "Traffic Measurement for IP Operations" (Grossglauser and Rexford) at ACM SIGCOMM'01 and IEEE INFOCOM'02

New challenges

- Scale of the Internet
- Many middleboxes
- Security alerts
- Different application requirements
- User's QoE, instead of network's QoS

Challenges to e2e active measurement

- Measurement scalability
  - Measure many network paths
- Measurement reliability
  - Measurement will not be interfered or interrupted
- Measurement representativeness
  - Measurement traffic representing the traffic of interest
- Measurement accuracy
  - Measurement results are accurate statistically.
- Bi-directional measurement
  - Measure both directions
- Measuring multiple metrics

Challenges to e2e active measurement

- Measurement scalability
  - Cooperative measurement paradigm (e.g., OWAMP) not scalable
- Measurement reliability
  - Interference from various middleboxes and firewalls
- Measurement representativeness
  - Using control channel to measure data channel
- Measurement accuracy
  - Sampling rate and patterns
- Bi-directional measurement
  - Measure from both directions
- Measuring multiple metrics
  - Need multiple tools

B. The recent network measurement initiatives

MPlane: a major effort in Europe

mPlane

Building an Intelligent Measurement Plane for the Internet

Public

- ABOUT MPLANE
  - CONSORTIUM
  - Collaborating Institutions
  - WORK PACKAGES
  - Gantt
- NEWS
- EXTERNAL ADVISORY BOARD
- PUBLIC DELIVERABLES
- PUBLICATIONS
- TALKS
- STANDARDIZATION
- CALENDAR & EVENTS
- CONCERTATION ACTIVITIES
- CONTACTS

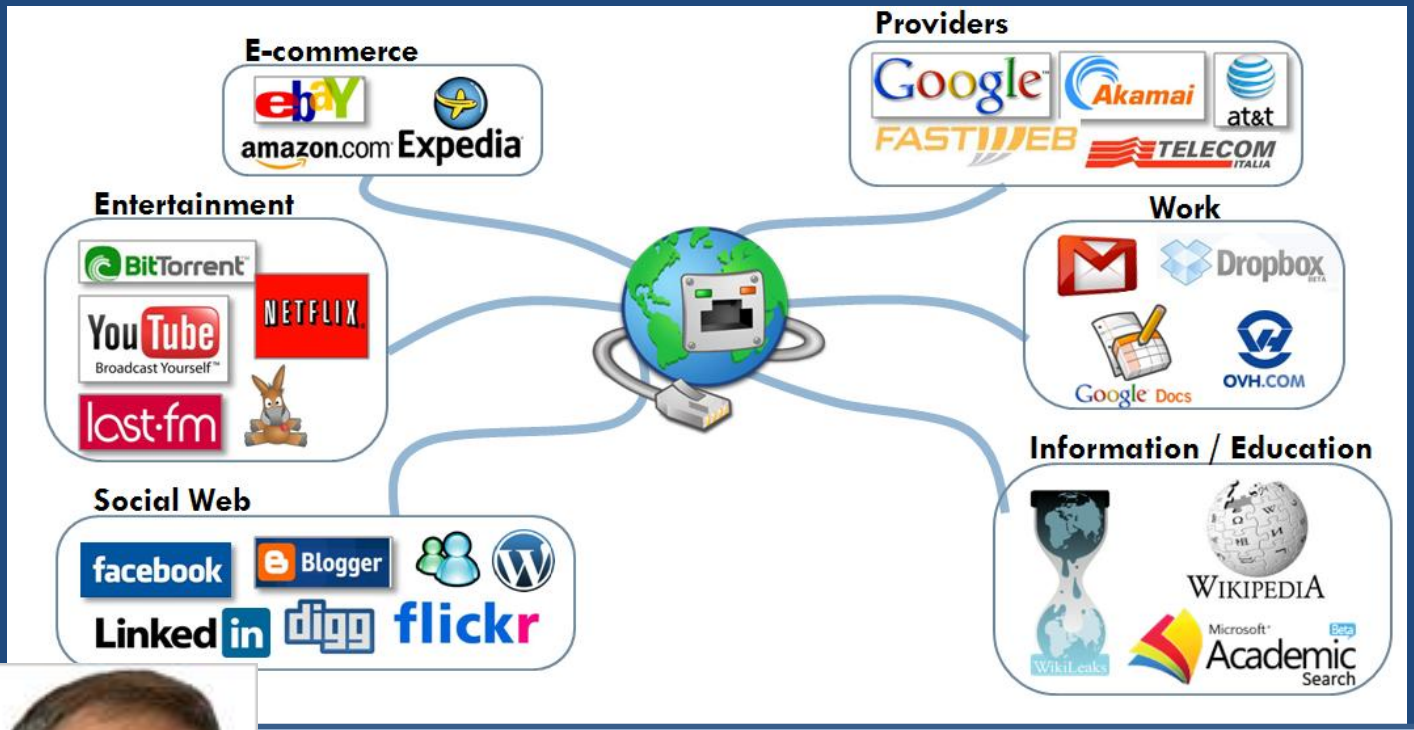
mPlane – an Intelligent Measurement Plane for Future Network and Application Management

Decentralized and diverse, the Internet is resilient and universal. However, its distributed nature leads to operational brittleness and difficulty in identifying and tracking the root causes of performance and availability issues. **The first step to improve this fragmentation is measurement: illuminating the currently obscure dynamics of the Internet**. To address this, we advocate a measurement plane, or mPlane alongside the Internet's data and control planes.

mPlane consists of a **Distributed Measurement Infrastructure to perform active, passive and hybrid measurements**; it operates at a wide variety of scales and dynamically supports new functionality. **A Repository and Analysis layer collects, stores, and analyses the collected data** via parallel processing and data mining. Finally, an **Intelligent Reasoner iteratively drills down into the cause of an evidence**, determining the conditions leading to given issues, and supporting the understanding of problem origins.

Source: http://www.ict-mplane.eu/

The nowadays Internet



*"The Internet is the first thing that humanity has built that humanity doesn't **understand**, the largest experiment in **anarchy** that we have ever had."*

Eric Schmidt – ex Google Exec. Chairman

Source: http://www.ict-mplane.eu/

A complicated technology…

The internet is a key infrastructure where different technologies are combined to offer a plethora of services. It's horribly complicated and we sorely miss the technology to understand what is happening in the network and thus to optimize its performance and utilization.

Source: http://www.ict-mplane.eu/

A complicated technology…

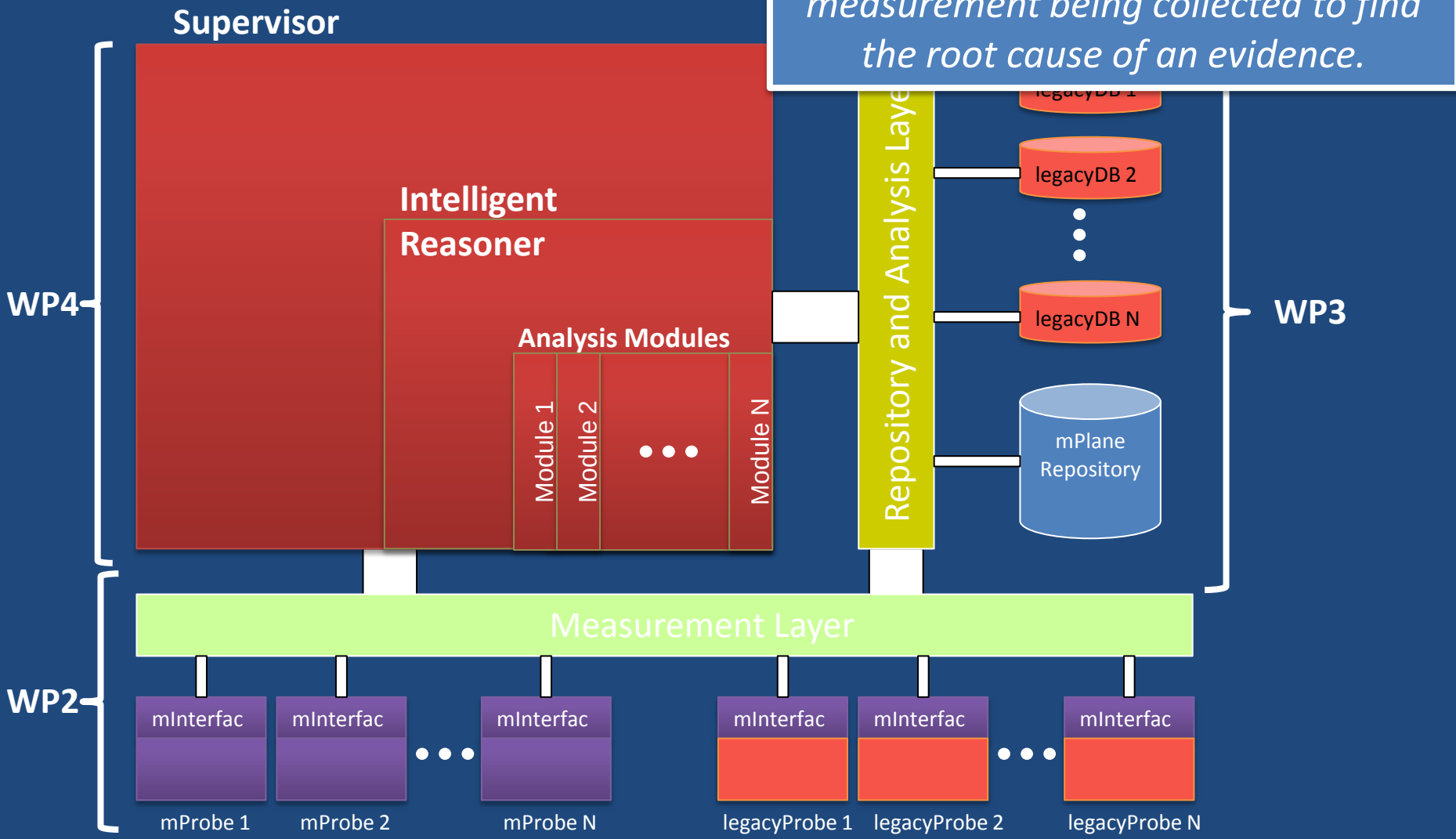
…that no one controls and understands

- Why skype is not working?
- Which is the best ISP in my area?
- Where is YouTube traffic coming from?
- How to optimize my Lte network for facebook?

Source: http://www.ict-mplane.eu/

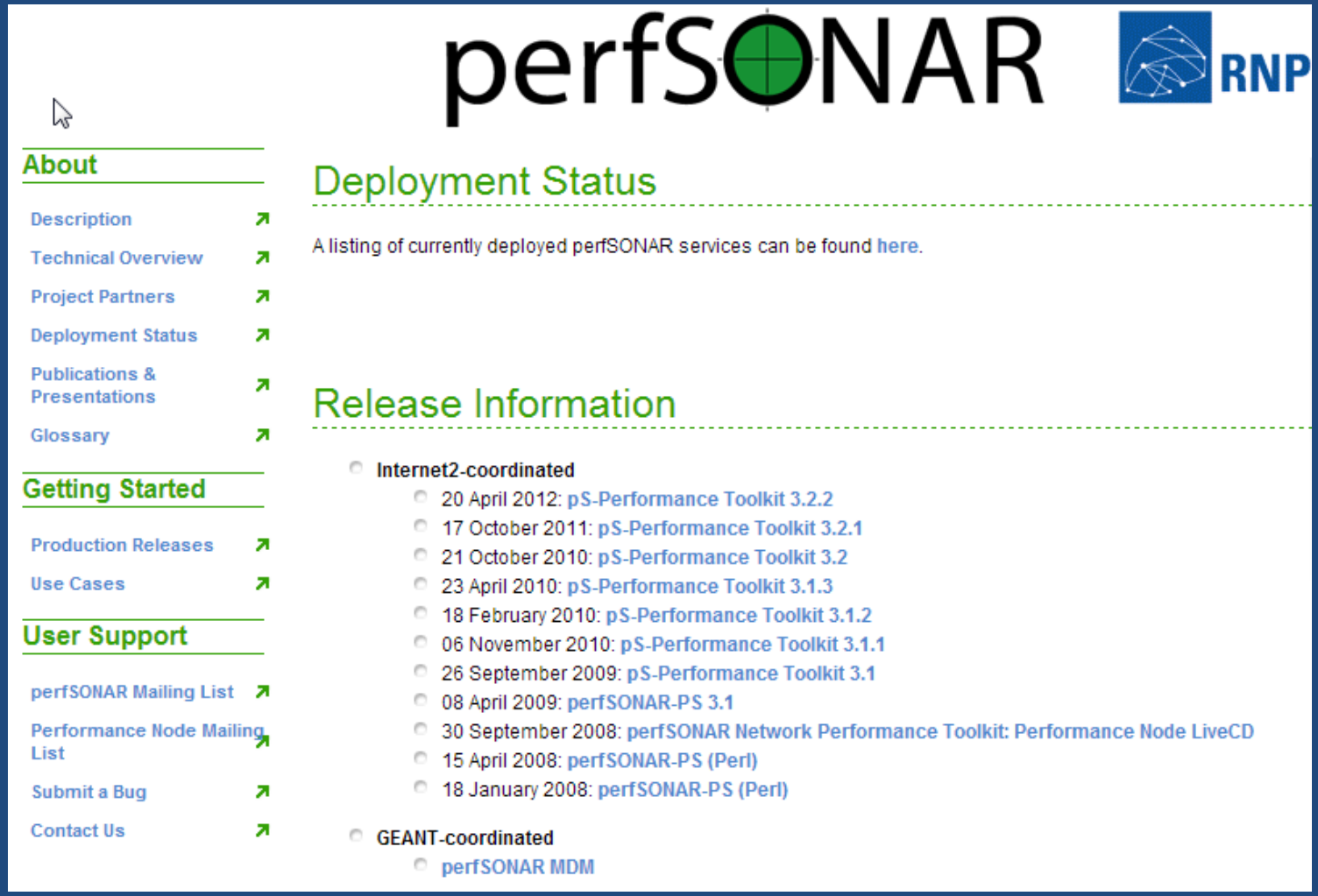
mPlane in

The mPlane architecture will allow to iteratively drill down into the measurement being collected to find the root cause of an evidence.



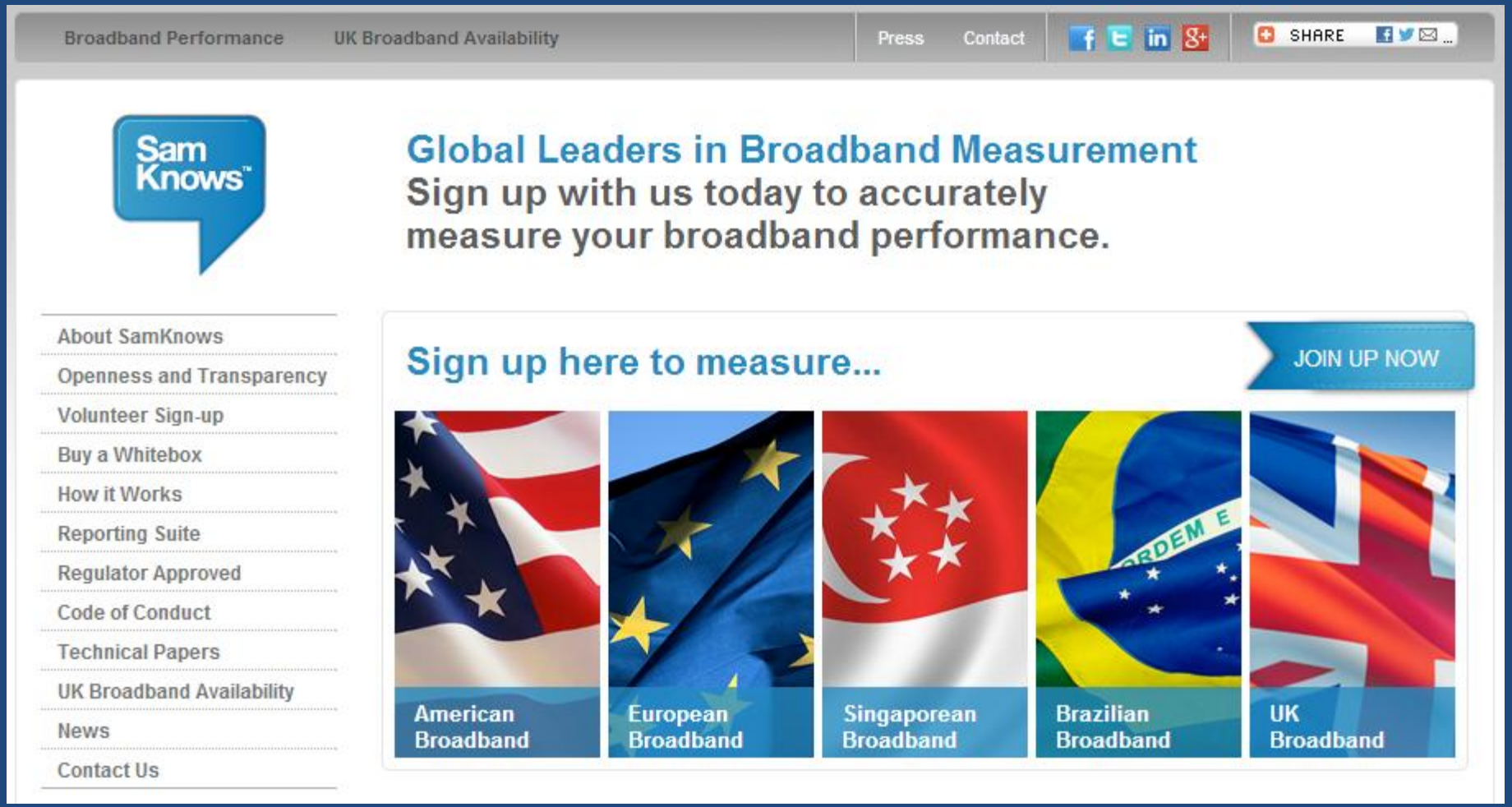
Source: http://www.ict-mplane.eu/

Internet2 and SamKnows in the US



Services Offered	
Bandwidth Test Controller (BWCTL)[1] • tcp://perfsonar.ucar.edu:4823	Running
Lookup Service[1] • http://perfsonar.ucar.edu:9995/perfSONAR_PS/services/hLS	Running
Network Diagnostic Tester (NDT)[1] • tcp://perfsonar.ucar.edu:3001 • http://perfsonar.ucar.edu:7123	Running
Network Path and Application Diagnosis (NPAD)[1] • tcp://perfsonar.ucar.edu:8001 • http://perfsonar.ucar.edu:8000	Running
One-Way Ping Service (OWAMP)[1] • tcp://perfsonar.ucar.edu:861	Running
perfSONAR-BUOY Regular Testing (Throughput)[1]	Running
perfSONAR-BUOY Measurement Archive[1] • http://perfsonar.ucar.edu:8085/perfSONAR_PS/services/pSB	Running
perfSONAR-BUOY Regular Testing (One-Way Latency)[1]	Not Running
PingER Measurement Archive and Regular Tester[1] • http://perfsonar.ucar.edu:8075/perfSONAR_PS/services/pinger/ma	Running
SNMP Measurement Archive[1] • http://perfsonar.ucar.edu:9990/perfSONAR_PS/services/SNMPMA	Running
Traceroute Measurement Archive[1] • http://perfsonar.ucar.edu:8086/perfSONAR_PS/services/tracerouteMA	Running
Traceroute Regular Testing[1]	Running

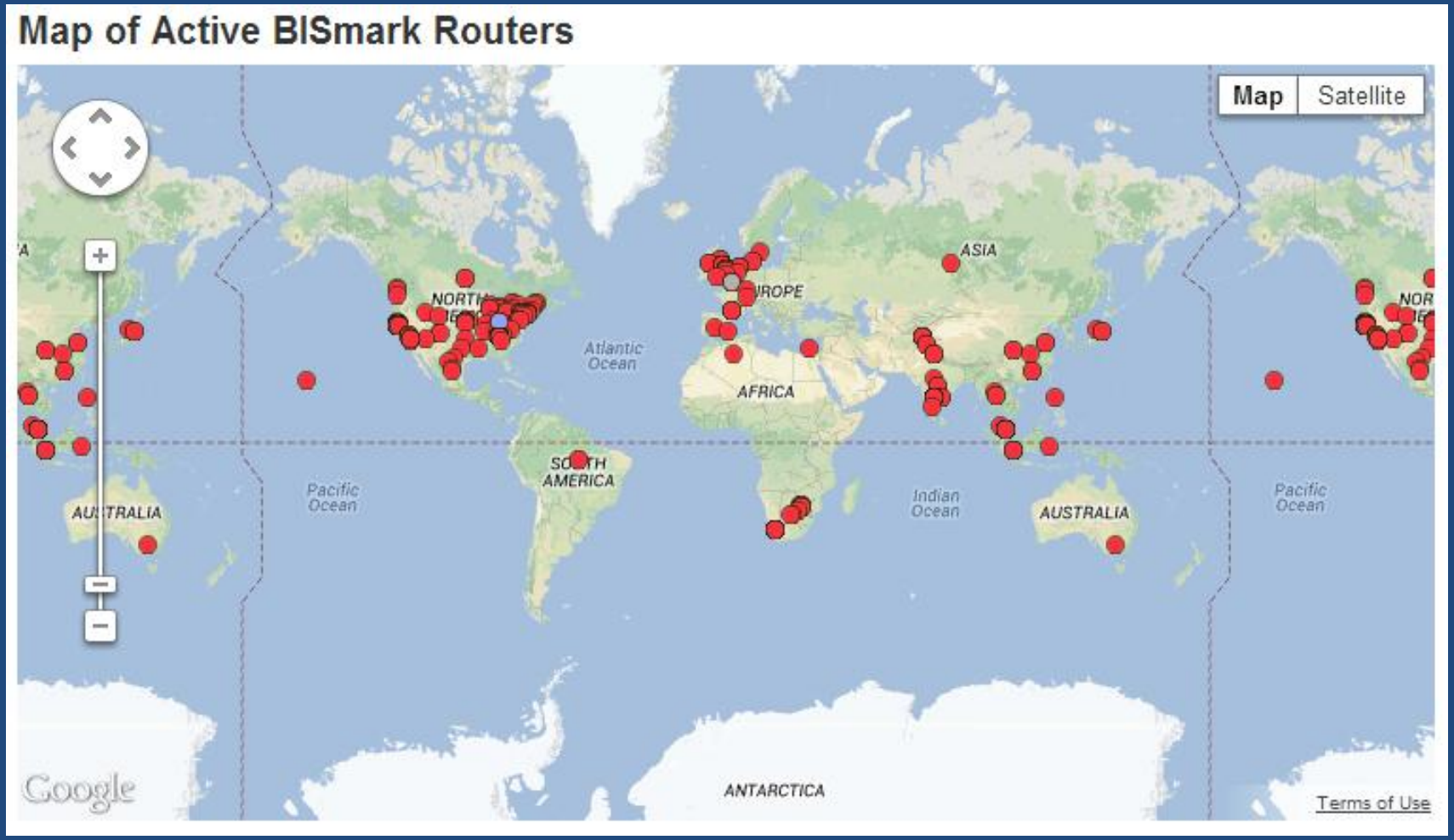
SamKnows and Bismark



Active measurement in Bismark

Parameter	Type	Prot.	Freq.	Comments
BISMark: 17 devices, 3 ISPs				
Latency	End-to-end	ICMP	5 min	Host
	Last-mile	ICMP	5 min	First IP hop
	Upstream load	ICMP	30 min	During upload
	Downstream load	ICMP	30 min	During download
Packet loss	End-to-end	UDP	15 min	D-ITG
Jitter	End-to-end	UDP	15 min	D-ITG
Downstream Throughput	Single-thread HTTP	TCP	30 min	curlget to Host
	Passive throughput	N/A	30 min	/proc/net/dev
	Capacity	UDP	12 hrs	ShaperProbe
Upstream Throughput	Single-thread HTTP	TCP	30 min	curlput to Host
	Passive throughput	N/A	30 min	/proc/net/dev
	Capacity	UDP	12 hrs	ShaperProbe

Bismark deployment



C. The (research) problems to solve

(1) Measuring network path properties

- Cooperative vs uncooperative
- Forward-path, reverse-path, both
- Data channel vs control channel

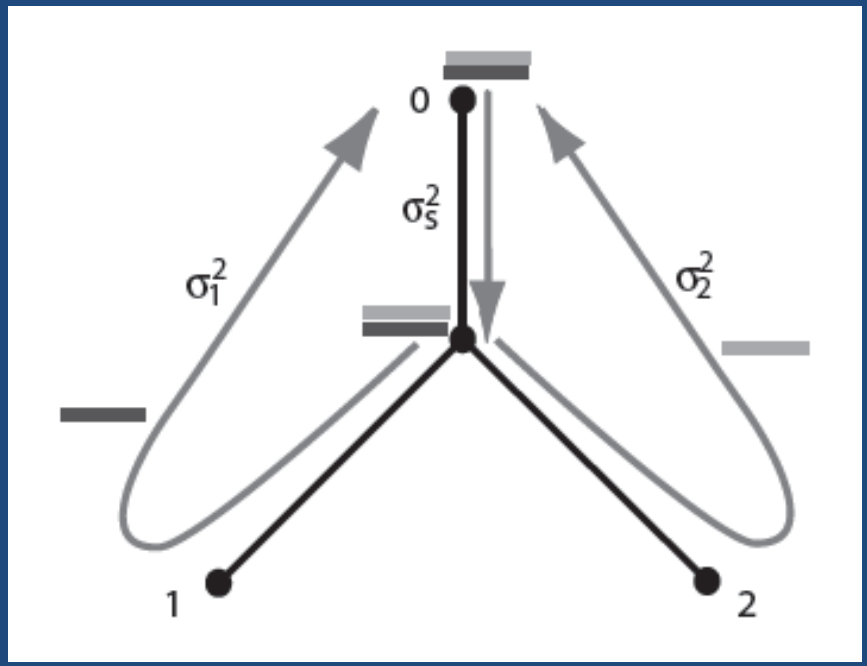
Tools	Mode	Direction	Probing method	Probing packets
Packet loss:				
Sting [21]	Uncoop.	F, B	Induce different TCP ACKs	TCP data segments in a single connection
BADABING [22]	Coop.	F	Improved probing algorithm	Packet trains
Packet reordering:				
Single connection test [2]	Uncoop.	F, B, D	Induce different ACK pairs	Three TCP data segments in a single connection
Dual connection test [2]	Uncoop.	F, B, D	Induce different ACK pairs with IPIDs	Two TCP data segments in two connections
SYN test [2]	Uncoop.	F, B, D	Induce different SYN-RST pairs	Two TCP SYNs in two connections
TCP data transfer test [2]	Uncoop.	B	Request for TCP data download	TCP data in a single connection
POINTER [12]	Uncoop.	F, B, D	Induce different TCP data and ACKs	Two TCP data/ACKs in a single connection
Reordering, loss and queueing delay:				
tulip [13]	Uncoop.	F, B, D	Induce ICMP replies with IPIDs	Two/three ICMP timestamp requests
Available bandwidth:				
pathload [10]	Coop.	F	Self-loading periodic streams	Periodic UDP packet trains
IGI, PTR [7]	Coop.	F	Self-loading periodic streams	Periodic UDP packet trains
pathChirp [19]	Coop.	F	Self-Loading packet chirps	Exponentially spaced UDP packet trains
abget [1]	Uncoop.	B	Self-loading periodic streams	Pure TCP ACK trains
ImTCP [23]	Uncoop.	F	Self-loading periodic streams	TCP data packet trains
Capacity:				
SProbe [20]	Uncoop.	F, B	Induce RST pairs	Two TCP SYN segments
pathrate [5]	Coop.	F	Packet pairs and trains	UDP packet pairs and trains
CapProbe [11]	Coop.	F	Packet pairs	UDP/ICMP packet pairs

(1) Measuring network path properties (cont'd)

- How to measure capacity without flooding?
  - Packet-pair measurement, machine learning?
- How stable is the available bandwidth for an e2e path?
- How to sample packet losses without self-inducing losses?
- How to sample the path performance per application flow?
  - Inband vs out-of-band, existing protocol vs new protocol
- How to mitigate the influence of middleboxes?
- Our works: HTTP/OneProbe (USENIX ATC'09), MDDIF (CoNEXT'09), Loss-pair analysis (IMC'10), TRIO (CoNEXT'11), Irate (NSDI'13 poster/demo)

(2) Fault diagnosis

- Network tomography: Inferring link-level characteristics (e.g., loss, delay) from a set of e2e path measurement
- Active vs passive tomography
- Unicast vs multicast probes



Source: "Network Radar: Tomography from Round Trip Time Measurements"

(2) Problems with network tomography

- The knowledge of an IP-level network topology
- Multicast probes are not widely supported
- Exponential increase in e2e path measurement if unicast is used.
- Our works: using coordinated measurement to diagnose faults (HotDep'10 poster, PAM'11, Networking'12, IM'13)

(3) Cross-domain network diagnosis

Call for Papers

IEEE Communications Magazine

Monitoring and Troubleshooting Multi-domain Networks using Measurement Federations

Aims and Scope

In both the scientific and corporate worlds, users, resources, and data are often physically distributed, making networks increasingly important for all operations. Enormous progress has been made in increasing the capacity and accessibility of networking infrastructures, which in turn has fostered wider adoption of Cloud and Grid environments. Unfortunately, these advances have not directly translated into improved performance for all applications and users; instead, network performance problems become even more subtle and detrimental as the capacity of the network increases, and troubleshooting them on multi-domain network paths is highly challenging. These problems may be as benign as congestion from other network users, or as serious as packet loss caused by one or more intermediate-domain infrastructure and architectural flaws.

Troubleshooting performance problems on multi-domain networks requires a great deal of effort and expertise, as well as measurement policy agreements that mutually benefit domains within measurement federations. Novel approaches are needed to foster wider adoption of explicit measurement federations such as perfSONAR, SamKnows, Grenouille and M-Lab involving co-operating agents in collaborating vendor organizations as well as user communities. These approaches may also be suitable for implicit measurement federations seen in content-delivery networks involving multiple service providers that co-operate to reduce operating costs, while providing satisfactory end-user experience. Building upon current end-to-end measurement federation related standards-development efforts - at Open Grid Forum (OGF), IETF IP Performance Metrics (IPPM), IEEE 802.1 ag, ITU-T Y.1731, and Metro Ethernet Forum (MEF) - can benefit the interoperability and sustainability of explicit and implicit measurement federations.

In addition, sophisticated tools are required to monitor multi-domain networks and to detect, localize and diagnose performance problems in real-time. As networks increase in capacity, and new paradigms such as Software Defined Networking emerge to aid in traffic management, performance monitoring tools must be scalable and capable of detecting performance issues in a timely manner. The monitoring and diagnosing tools must comply with measurement federation policies, and aid network operators when troubleshooting perceived abnormalities, as well as help network middleware and intelligent applications to work around problems, ultimately minimizing the impact to end users.

This special issue will cover novel techniques and standardization efforts in the area of monitoring and troubleshooting of multi-domain networks using measurement federations. Topics to be covered include, but are not limited to:

- Algorithms and Techniques for Automated Network Troubleshooting
- Architectures for Federated Measurement Collection and Sharing
- Intra and Inter Domain Monitoring Strategies
- Measurement Federation related Standards-development Efforts
- Monitoring of Software Defined, Content-delivery and Overlay Networks
- Troubleshooting of Hybrid Packet and Circuit Networks
- Network-aware Middleware for High Speed Networks
- Measurements from Cloud and Grid Environments
- Security and Policy Considerations for Federated Measurements
- New Policy-based Network Monitoring/Analysis Tools and Paradigms
- End-to-End ("Disk-to-Disk") Performance Problem Troubleshooting
- Scalability of Measurement Methods and Infrastructures
- Embedded Active Monitoring based Collaborative Management
- Case Studies of End-to-End or Network Performance Troubleshooting
- Federations to jointly troubleshoot Home-area and Wide-area Networks

(3) Cross-domain network diagnosis (cont'd)

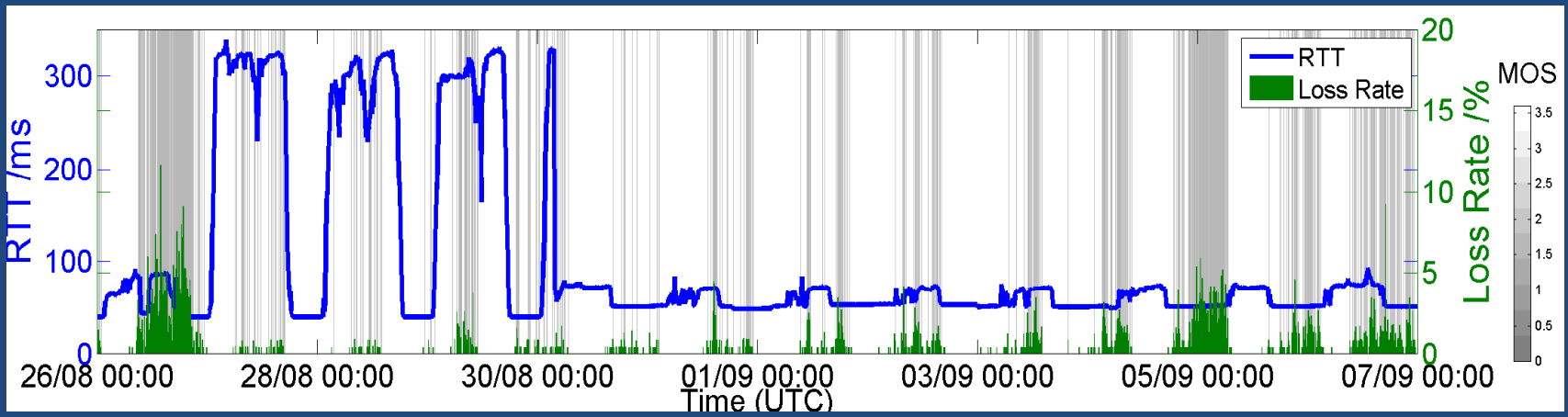
- Network tomography without fixed topology
- A "sufficient" number of probes "strategically" distributed
- Coordinated and adaptive probing
- E2e measurement with traceroute facility
- Federated network measurement
- Our work: "Four-Year Experience of Monitoring and Troubleshooting Multi-domain Networks from a Local Federation" under review for a SI in the *IEEE Commun. Mag*.

(3) Cross-domain cont'd: Existing platforms

- iPlane (providing accurate predictions of Internet path performance for emerging overlay services)
- Scriptroute (allowing any user to connect to any server and execute any safe network measurement)
- Dipzoom (using P2P concepts to bring together experimenters in need of measurements with external measurement providers)
- Crowdsourcing (e.g., Portolan, a crowdsourcing-based system that uses smartphones as mobile measuring elements)
- Edge measurement (e.g., Dasu, a measurement experimentation platform for the Internet's edge)
- Etomic (closed?)
- Our work: Open Measurement Platform

(4) Measuring user's QoE

- Network QoS, application QoS and user's QoS (QoE)
- MOS vs network QoS for HTTP streaming



- Our works: IM'11 (pre-conf), W-MUST'11, MMSys'12, NSDI'13 poster/demo

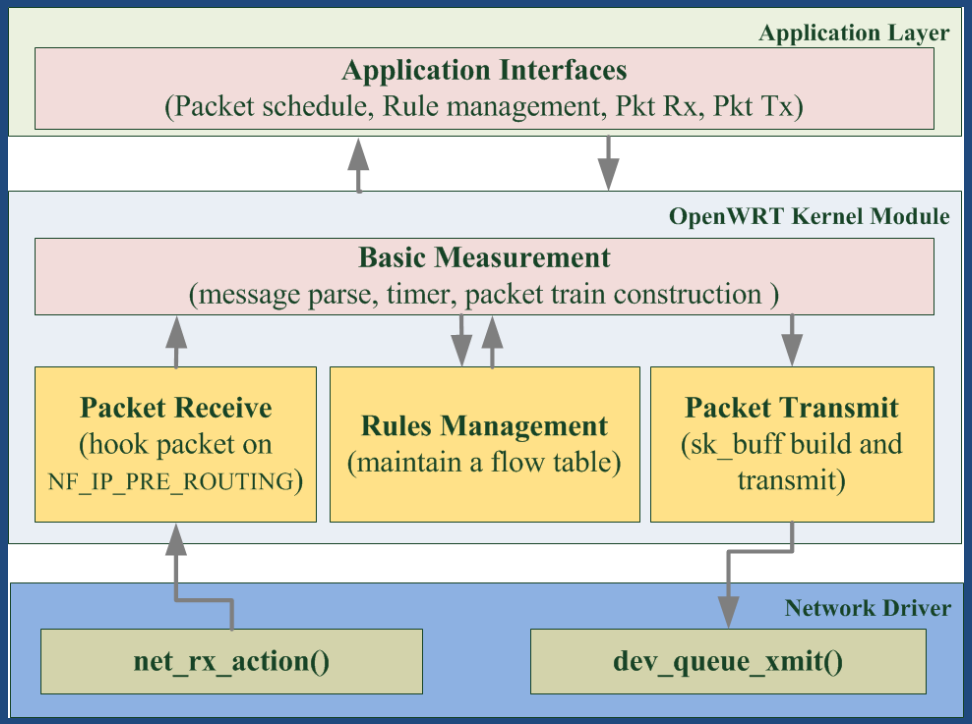
(5) Scientific study of network properties

- Power-law relationship in the Internet topology discovered around 15 years ago
- Route asymmetry in the Internet discovered around 10 years ago
- Delay asymmetry in the Internet
- “Network science”
- Our work: “Characterizing Inter-domain Rerouting by Betweenness Centrality after Disruptive Events” (JSAC 2013)

D. Our current projects

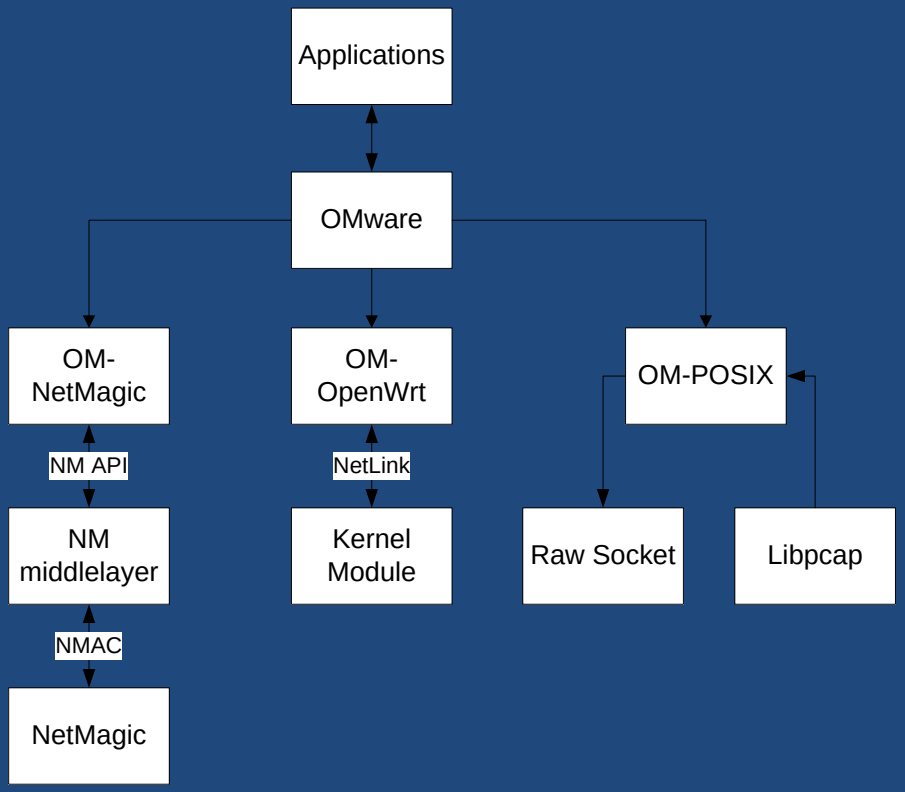
(1) Residential broadband measurement platform

- Enabling users with network diagnosis capability
- Performing cooperative network measurement
- HTTP/OneProbe in OpenWrt routers
- “OMware: An Open Measurement Ware for Stable Residential Broadband Measurement" SIGCOMM'13 poster/demo



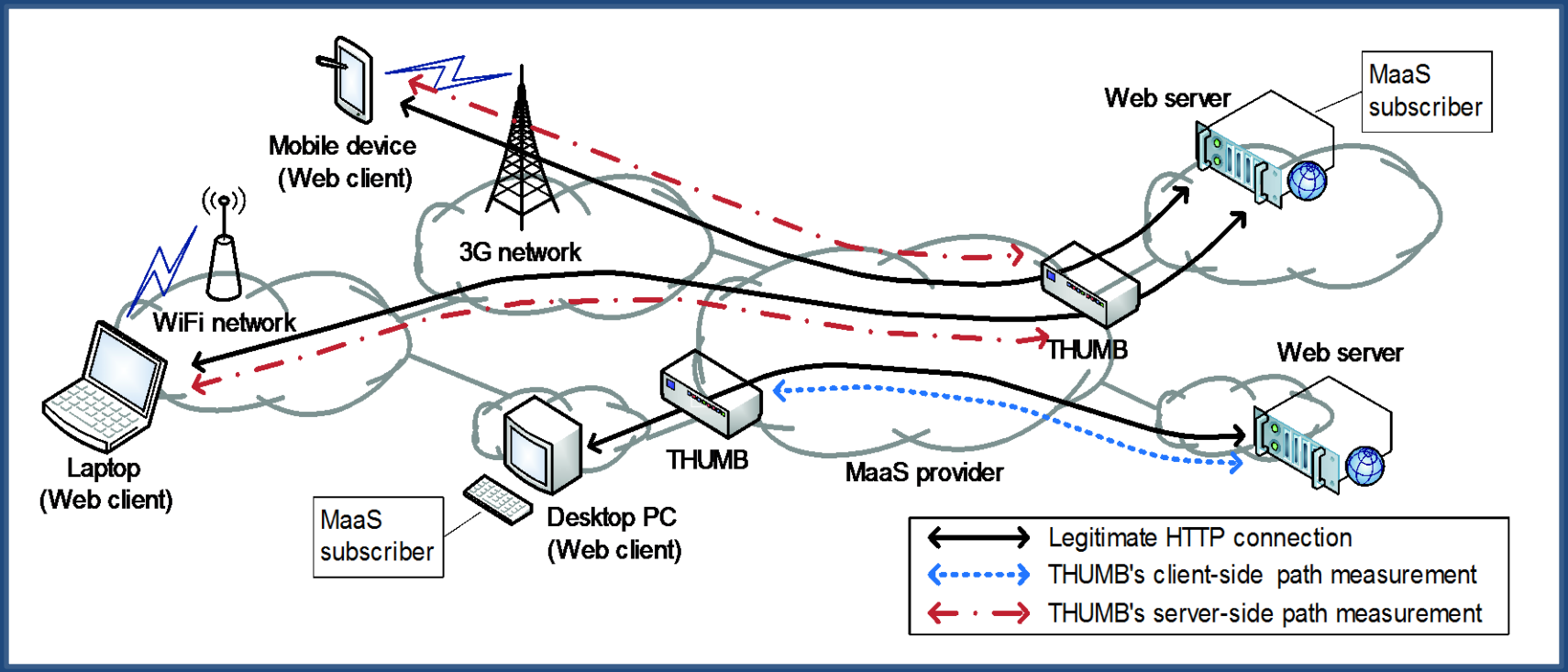
(2) High-performance measurement box

- Implementing measurement functions in kernel and NetMagic
- Supporting client-side and server-side measurement
- Unified APIs for POSIX raw socket, OpenWrt and NetMagic



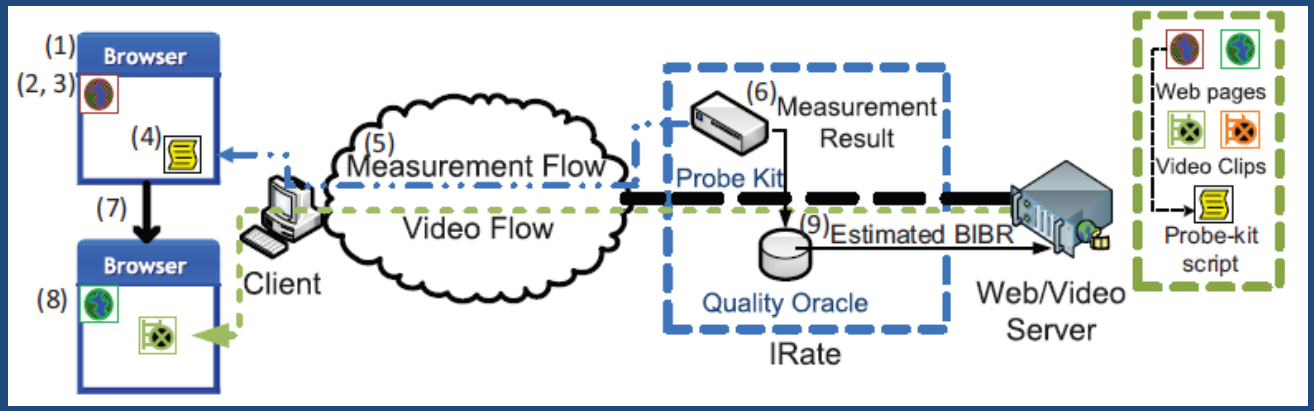
(3) Network measurement as a service

- Providing measurement service to a content service provider
- Providing measurement service to clients

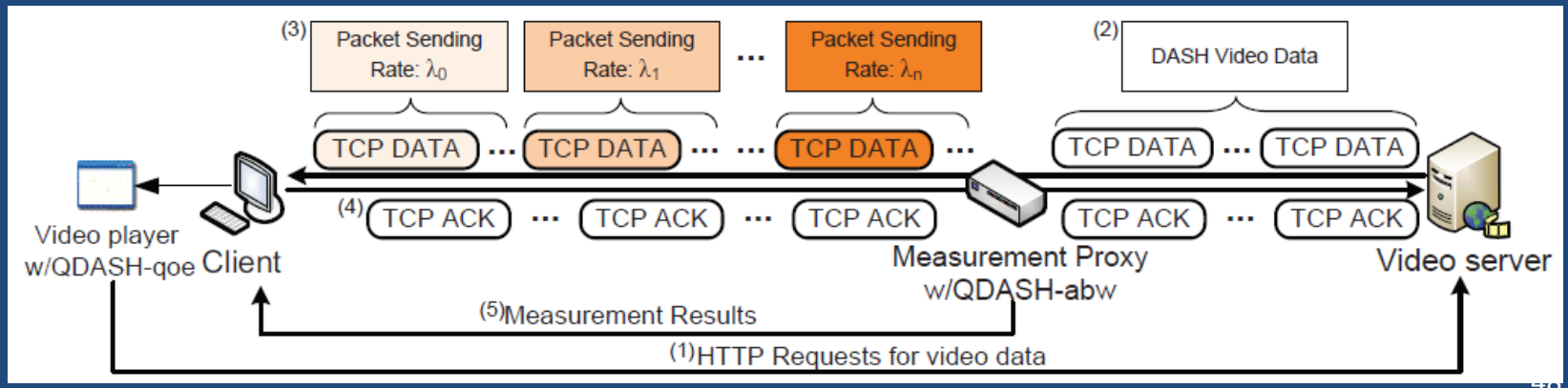


(4) HTTP streaming

- IRate: determining the the best initial bit rate



- QDASH: adjust bit rate during the playback



(5) Appraising the accuracy of browser-based measurement

- Inaccuracy introduced by browsers
- Inaccuracy introduced by the measurement methods

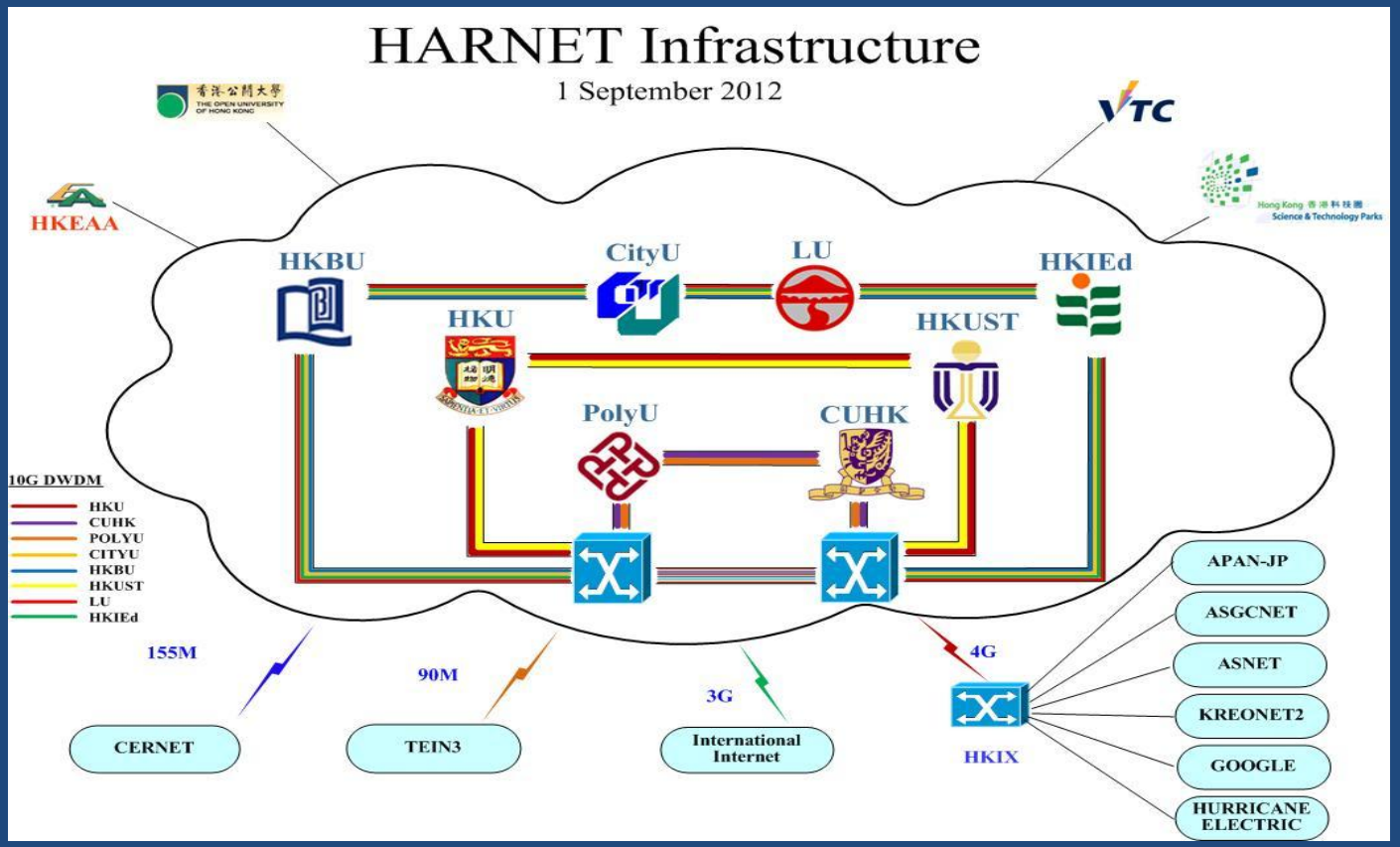
Table 1: A summary of the browser-based network measurement methods and tools.

Approaches	Technology	Availability	Methods	Subject to the same-origin policy by default?	Measured path quality	Tools / Services
HTTP-based	XHR	Native	GET	Yes	RTT, Tput	Speedof.me [2], BandwidthPlace [14] Janc's methods [9]
			POST	Yes	RTT, Tput	
	DOM	Native	GET	No	RTT, Tput	[9], [14], Wang's method [22]
	Flash	Plug-in	GET	Yes*	RTT, Tput	Speedtest [17], AuditMyPC [3], Speedchecker [20] Bandwidth Meter [5], InternetFrog [8]
			POST	Yes*	RTT, Tput	
	Java applet	Plug-in	GET	Yes*	RTT, Tput	
			POST	Yes*	RTT, Tput	
Socket-based	WebSocket	Native	TCP	No	RTT, Tput	
	Java applet	Plug-in	TCP	No	RTT, Tput	Netalyzr [12], HMN [18], JavaNws [13], Pingtest [16], NDT [15], AuditMyPC [4]
			UDP	No	RTT, Tput, Loss	
	Flash	Plug-in	TCP	Yes*	RTT, Tput	[17]

Note: * The same-origin policy can be bypassed.

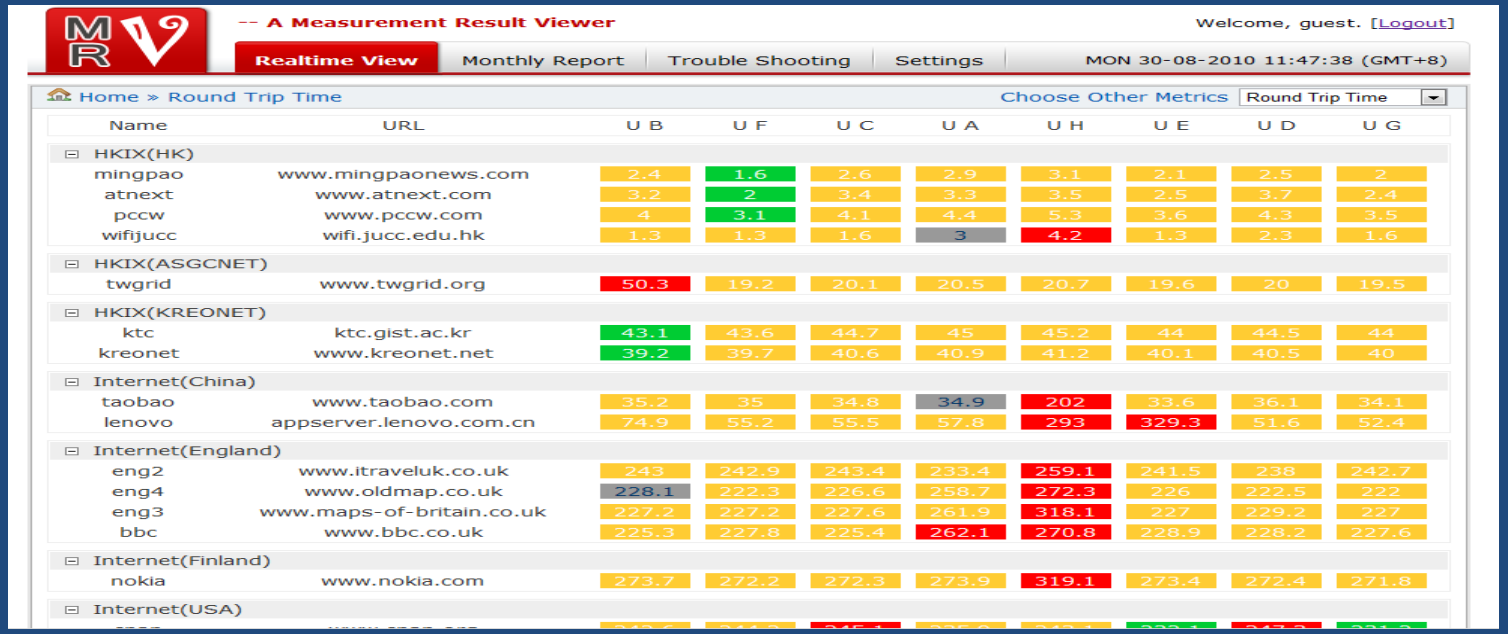
(6) Open measurement platform

- HARNET measurement (since 1 Jan 2009)



(5) Open measurement platform

- OMP for CERNET-2: Tsinghua U., Xiamen U., …
- OMP for residential broadband
- OMP for IPv4 networks



Name	URL	U B	U F	U C	U A	U H	U E	U D	U G
HKIX(HK)									
mingpao	www.mingpaonews.com	2.4	1.6	2.6	2.9	3.1	2.1	2.5	2
atnext	www.atnext.com	3.2	2	3.4	3.3	3.5	2.5	3.7	2.4
pccw	www.pccw.com	4	3.1	4.1	4.4	5.3	3.6	4.3	3.5
wifijucc	wifi.jucc.edu.hk	1.3	1.3	1.6	3	4.2	1.3	2.3	1.6
HKIX(ASGCNET)									
twgrid	www.twgrid.org	50.3	19.2	20.1	20.5	20.7	19.6	20	19.5
HKIX(KREONET)									
ktc	ktc.gist.ac.kr	43.1	43.6	44.7	45	45.2	44	44.5	44
kreonet	www.kreonet.net	39.2	39.7	40.6	40.9	41.2	40.1	40.5	40
Internet(China)									
taobao	www.taobao.com	35.2	35	34.8	34.9	202	33.6	36.1	34.1
lenovo	appserver.lenovo.com.cn	74.9	55.2	55.5	57.8	293	329.3	51.6	52.4
Internet(England)									
eng2	www.itraveluk.co.uk	243	242.9	243.4	233.4	259.1	241.5	238	242.7
eng4	www.oldmap.co.uk	228.1	222.3	226.6	258.7	272.3	226	222.5	222
eng3	www.maps-of-britain.co.uk	227.2	227.2	227.6	261.9	318.1	227	229.2	227
bbc	www.bbc.co.uk	225.3	227.8	225.4	262.1	270.8	228.9	228.2	227.6
Internet(Finland)									
nokia	www.nokia.com	273.7	272.2	272.3	273.9	319.1	273.4	272.4	271.8
Internet(USA)									

E. Conclusions

Conclusions

- “IP networks are hard to measure by design.” (Grossglauser and Rexford)
  - Best-effort network measurement
  - The deployed e2e methods much less than best effort.
- The role of network measurement in the increasingly network-dependent and usage-based applications
  - A lack of science in the network measurement practices
  - Not enough skepticism on the measurement accuracy
- Operational experience informs research; research underpins network operations
  - Unearthing important problems and questions from operations
  - Putting research output into practice.

Thanks