Network Monitoring in Practice

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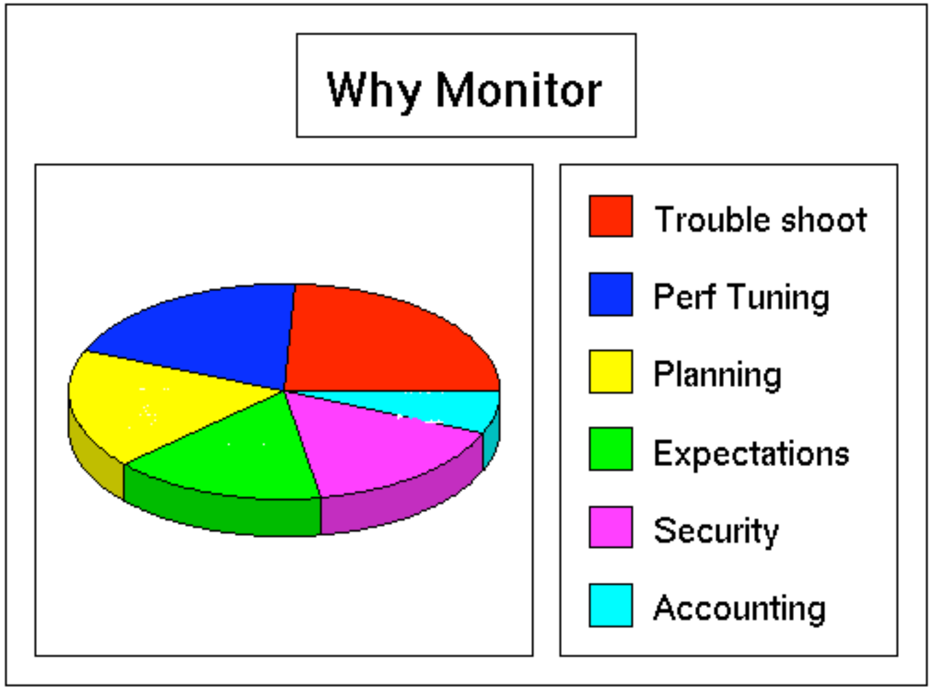
1. Introduction

Motivation: Why Do We Need Traffic Analysis and Monitoring ? [1/2]

- Current situation:
  - increasing meaning of strategic resources "information”.
  - a computer network is no longer only a supporting item in an enterprise, but takes even more frequently a key position.
  - the number of interconnected computers rose dramatically in the past few years. This process will probably continue to persist.
  - Complexity and functionality of the components grows in correspondence with the performance of the available hardware.
- Demand:
  - Permanent availability of network services with optimal quality.
  - Cost reduction for the network infrastructure of the company.
- Necessity:
  - computer-aided management of heterogeneous networks.

Motivation: Why Do We Need Traffic Analysis and Monitoring ? [2/2]



In a nutshell:

traffic analysis is the foundation upon which proactive management is possible.

Monitoring Requirements [1/4]

- Guarantee the availability of the function on the net.
  - Service maintenance (availability, response time) need to face with technological changes and big quota increase.
    - Security of the services through the control of security components.
    - (Human) Mistake prevention and bottleneck identification/recovery.
  - Automatic or semiautomatic reaction on operation anomalies:
    - Real-time configuration modification in case of error.
    - Activation of redundant components in case of error.

Monitoring Requirements [2/4]

- Dynamic reactions to changes on the network and environment:
  - Changes regarding applications, users, components, services or fees.
  - Dynamic adaptation of the available transmission bandwidth according to requests originated by the management system.

Monitoring Requirements [3/4]

- Network Control:
  - Collection and (compressed) representation of relevant network information.
  - Definition and maintenance of a database of network configurations.
  - When applicable, centralisation of the control over peripherals and implemented functions (central management console).
  - Integration of management procedures on heterogeneous environments

Monitoring Requirements [4/4]

- Improvement of system/network administrators work conditions :
  - Improvement and standardisation of the available tools.
  - Identify and implement gradual automation of management functions.
  - Good integration of tools into the existing operational sequences.
- Progress through standardisation :
  - Transition of existing, often proprietary, solutions in a standardised environment.

Various Actors, Various Metrics

- End-Users vs. (Internet) Service Provider
  - Remote user (Dial-up or xDSL) vs. AOL
    - Internet User (no services provided)
    - Mostly P2P, Email, WWW traffic
  - ntop.org vs. Telecom Italia
    - Provided Services (e.g. DNS, Mail, WWW)
    - Connected to a Regional ISP (no worldwide branches)
  - Interroute/Level3 vs. Telecom Italia
    - Need to buy bandwidth for national customers
    - Need to sign SLA with customers influenced by the SLA signed with the global carrier.

End-Users Requirements

- Monitoring of Application performance:
  - Why this web page takes so long to load?
  - Why does the multicast video isn't smooth?
- Check that the expected SLA can be provided by the available network infrastructure
  - Do I have enough bandwidth and network resources for my needs and expectations?
- Is poor performance "normal" or there's an ongoing attack or suspicious activity?
  - Is there a virus that takes over most of the available resources?
  - Is anybody downloading large files at high priority (i.e. bandwidth monopolization)?

Service Provider Requirements

- Monitor SLA (Service Level Agreements) and current network activities.
- Enforce committed SLA and monitor their violation (if any).
- Detection of network problems and faults.
- Redesign the network and its services based on the user feedback and monitoring outcome.
- Produce forecasts for planning future network usage hence implement extensions before it's too late (digging out ground for laying cables/fibers takes a lot of time).

Problem Statement

- End-users and ISPs speak a different language
  - End-users understand network services
    - Outlook can't open my mailbox.
    - Mozilla isn't able to connect to Google.
  - ISPs talk about networks
    - BGP announces contain wrong data.
    - The main Internet connection is 90% full.
    - We need to sign a peering contract with AS XYZ for cheaper bandwidth.

Traffic Analysis Applications: Some Requirements [1/2]

- What: Volume and rate measurements by application host and conversation.
  Why: Identify growth and abnormal occurrences in the network.
- What: Customizable grouping of traffic by logic groups (e.g. company, class of users), geography (e.g. region), subnet.
  Why: Associate traffic with business entities and trend growth per grouping (aggregate data isn't very meaningful here: we need to drill-down the analysis at user level).

Traffic Analysis Applications: Some Requirements [2/2]

- What: Customizable filters and exceptions based on network traffic.
  Why: Filters can be associated with alarm notifications in the event of abnormal occurrences on the network.
- What: Customizable time-periods to support workday reporting.
  Why: Analyzing data based on the calendar helps identifying problems (e.g. the DHCP is running out of addresses every Monday morning between 9-10 AM, but the problem disappears for the rest of the week.)

Further Measurement Issues [1/2]

- Network appliances have very limited measurement capabilities (a router must switch packets first!).
  - Limited to few selected protocols
  - Aggregated measurements (e.g. per interface)
  - Only a few selected boxes can be used for network measurements (e.g. a router is too loaded for new tasks, this L2 switch isn't SNMP manageable)
  - High-speed networks introduce new problems: measurement tools can't cope with high speeds.

Further Measurement Issues [2/2]

- Need to constantly develop new services and applications (e.g. mobile video on 3G phones).
- Most of the services have not been designed to be monitored.
- Most of the internet traffic is consumed by applications (P2P) that are designed to make them difficult to detect and account.
- Modern internet services are:
  - Mobile hence not tight to a location and IP address
  - Encrypted and based on dynamic TCP/UDP ports (no fingerprinting, i.e. 1:1 port to service mapping)

Monitoring Capabilities in Network Equipment

- End-systems (e.g. Windows PC)
  – Completely under user control.
  – Simple instrumentation (just install new apps)

- Standard Network boxes (e.g. ADSL Router)
  – Access limited to network operators
  – Poor set of measurement capabilities
  – Only aggregated data (e.g. per interface)

- Custom Boxes (Measurement Gears)
  – Instrumentable for collecting specific data.
  – Issues in physical deployment so that they can analyze the traffic where it really flows

Problem Statement

- Users demand <u>services</u> measurements.
- Network boxes provide simple, aggregated <u>network</u> measurements.
- You cannot always install the measurement box wherever you want (cabling problems, privacy issues).
- New protocols appear every month, measurement protocols are very static and slow to evolve.

Common Measurement Metrics

- Performance measurement
  - Availability
  - Response time
  - Accuracy
  - Throughput
  - Utilization
  - Latency and Jitter

Measurement Metrics: Availability [1/2]

- Availability can be expressed as the percentage of time that a network system, component or application is available for a user.
- It is based on the reliability of the individual component of a network.

Measurement Metrics: Availability [2/2]

$$\% \text{ Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

MTBF = mean time between failures

MTTR = mean time to repair following a failure.

Measurement Metrics: Response Time

- Response time is the time it takes a system to react to a given input.
  - Example: In an interactive transaction, it may be defined as the time between the last keystroke by user and the beginning of the resulting display by the computer.
- Short response time is desirable.
- Necessary for interactive applications (e.g. telnet/ssh) not very important for batch applications (e.g. file transfer).

Measurement Metrics: Throughput

- Metric for measuring the quantity of data that can be sent over a link in a specified amount of time.
- Often it is used for giving an estimation of an available link bandwidth.
- Note that bandwidth and throughput are very different metrics.
- Throughput is an application-oriented measure
- Examples:
  - The number of transactions of a given type for a certain period of time
  - The number of customer sessions for a given application during a certain period of time

Measurement Metrics: Utilization

- Utilization is a more fine-grained measure than throughput. It refers to determining the percentage of time that a resource is in use over a given period of time.
- Often very little utilization means that something isn't working as expected (e.g. little traffic because the file server crashed).

Measurement Metrics: Latency and Jitter

- Latency: amount of time it takes a packet from source to destination. It is very important for interactive applications (e.g. online games).
- Jitter: variance of intra-packet delay on a mono-directional link. It is very important for multimedia applications (e.g. internet telephony or video broadcast)
- Both are expressed in ms (milliseconds).

Per-Link Measurements

- Metrics available on a link
  - # packets, # bytes, # packets discarded on a specific interface over the last minute
  - # flows, # of packets per flow
- It does not provide global network statistics.
- Useful to ISPs for traffic measurements.
- Examples:
  - SNMP MIBs
  - RTFM (Real-Time Flow Measurement)
  - Cisco NetFlow

End-to-End Measurements

- Network performance != Application performance
  - Wire-time vs. web-server performance
- Most of network measurements are by nature end-to-end.
- Per path statistics
    - Are paths symmetric? Usually they are not. (Routing issue?)
    - How does the network behave with long/short probe packets?
- It is necessary for deducting per-link performance measurements.

Monitoring Approaches [1/2]

- Active Measurement
  - To inject network traffic and study how the network reacts to the traffic (e.g. ping).

- Passive Measurement
  - To monitor network traffic for the purpose of measurement (e.g. use the TCP three way handshake to measure network round-trip time).

Monitoring Approaches [2/2]

- Active measurements are often end-to-end, whereas passive measurements are limited to the link where the traffic is captured.
- There is no good and bad. Both approaches are good, depending on the case:
  - Passive monitoring on a switched network can be an issue.
  - Injecting traffic on a satellite link is often doable only by the satellite provider.
- Usually the best is to combine both approaches and compare results.

Inline vs. Offline Measurement

- Inline Measurements
  Measurement methods based on a protocol that flows over the same network where measurements are taken (e.g. SNMP).

- Offline Measurements
  Measurement methods that use different networks for reading network measurements (e.g. to read traffic counters from CLI using a serial port or a management network/VLAN).

2. SNMP Monitoring

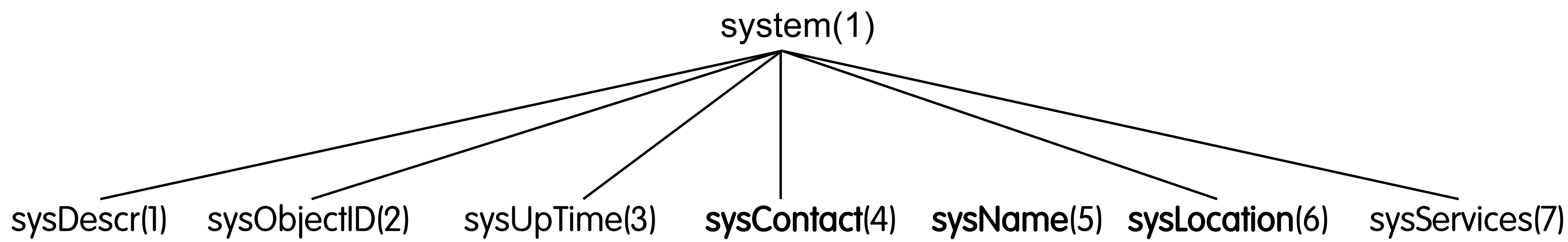
SNMP MIB II: Introduction

- MIB-II (RFC 1213) defines object types for the Internet Protocols IP, ICMP, UDP, TCP, SNMP (and other definitions not relevant here). Basically it models the management of the TCP/IP protocol stack.
- Altogether 170 object types.
- Some MIB definitions turned out to be too simple and minimal (Routing table, Interface table).
- Some MIB definitions presuppose a 4-Byte address format, hence these tables must be redefined for IP version 6 (IPv6).

SNMP MIB II: Goals

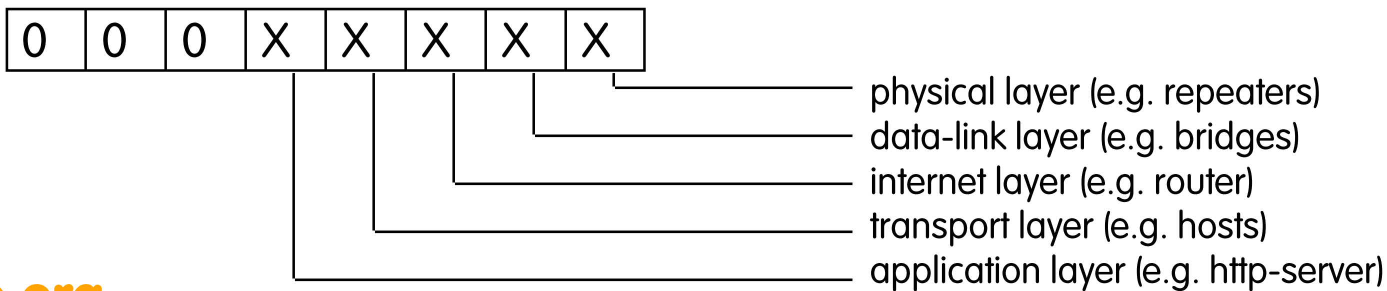
- Goals of the MIB-II definition:
  - Define basic error and configuration management for Internet protocols.
  - Very few and weak control objects.
  - Avoidance of redundant information in the MIB.
  - MIB implementation should not interfere with the normal network activities.
  - No implementation-dependent object types.

"system" Group [1/2]



- sysUpTime.0 is a very important variable as it is used for determining service discontinuities:
  - If $sysUpTime.0_{t1} > sysUpTime.0_{t2}$ where $t_2 > t_1$ then the agent has been reinitialised and management application rely on previous values.

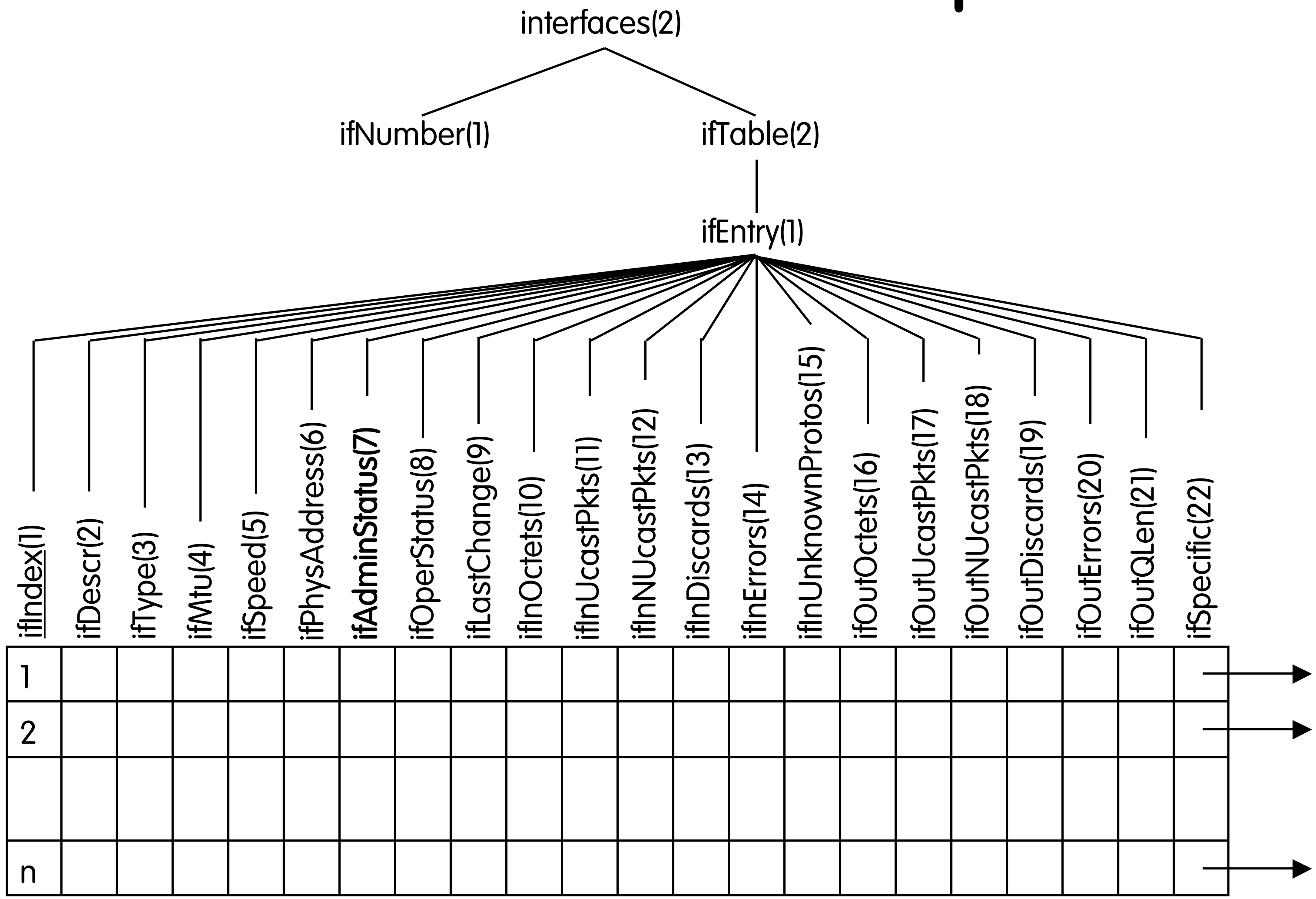
- sysServices roughly reports the services supplied by the system:



"system" Group [2/2]

- sysObjectId.0 has the format enterprises.<manufacturer>.<id>$^{+}$ and it is used to identify manufacturer and model. For instance enterprises.9.1.208 identifies a Cisco (.9) 2600 router (.1.208).
- sysDescr.0 provides a precise description of the device (e.g. "Cisco Internetwork Operating System Software IOS (tm) C2600 Software (C2600-I-M), Version 12.2(23), RELEASE SOFTWARE (fc2) Copyright (c) 1986-2004 by cisco Systems, Inc.")
- In a nutshell the system group is important for:
  – Device mapping (via sysObjectId.0, sysDescr.0, and sysLocation.0)
  – Counter wrapping check (sysUpTime.0)
  – Reporting problems about the device to the administrator (sysContact.0)

"interface" Group



"interface" Group Variables

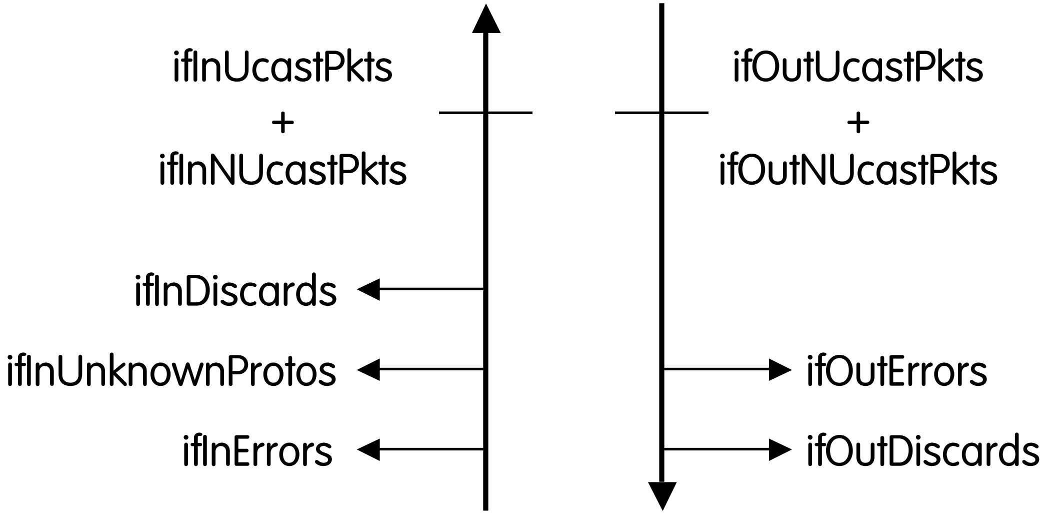
- ifAdminStatus: the current administrative state of the interface. Values: up(1), down(2), testing(3). A value different from up means that the interface is not physically present on the system or that it's present but unavailable to the operating system (e.g. the driver has not been loaded).
  Caveat: SNMP MIB index holes

- ifOperStatus: the current operational state of the interface. Values: up(1), down(2), testing(3). It is similar to ifconfig <device> up/down.

- ifOutQLen: the length of the output packet queue (in packets). It is useful for knowing more about transmission speeds and throughput (buffer full means that the receiver is not as fast as the sender).

- ifLastChange contains the value of sysUpTime at the time the interface entered its current operational state. Useful for detecting when an interface changed state (e.g. cable connected).

Case Diagram for the "interface" Group



- Case diagrams illustrate dependencies between Variables:
  - the number of packets delivered by a network interface to the next higher protocol layer: ifInUcastPkts + ifInNUcastPkts.
  - the number of packets received by the network: (ifInUcastPkts + ifInNUcastPkts) + ifInDiscards + ifInUnknownProtos + ifInErrors
  - he number of actually transmitted packets: (ifOutUcastPkts + ifOutNUcastPkts) - ifOutErrors - ifOutDiscards

Using the "interface" Group [1/2]

- It is the base of SNMP-based monitoring.
- Many tools periodically poll values from interfaces (mostly ifInOctets and ifOutOctets).
- Values are aggregated and not divided per protocol, destination, AS. This is a major limitation if fine grained monitoring is required. The reason is that SNMP counters are basically the kernel counters 'exposed' via SNMP.
- Interface errors can be used for detecting communication problems, especially on WAN links.

Using the "interface" Group [2/2]

- Packet size statistics are not reported however simple Octets/Packets statistics can be computed.
- Many manufacturers (e.g. Cisco, Juniper) report information about both physical and logical interfaces (also known as sub-interfaces). Others (e.g. Extreme) have the entry in the table but counters are always zero.
- Using the interface counters it is possible to produce reports about:
  - VLAN (Virtual LAN)
  - PVC (Private Virtual Circuit) on Frame Relay Links

Using the "arp" Group

- Useful for accessing the arp (Address Resolution Protocol) table of a remote device.
- It can be used for identifying arp-poisoning attacks or misconfigured hosts (e.g. duplicated IP addresses).
- Example:

```
RFC1213-MIB::atIfIndex.4.1.172.22.6.168 = INTEGER: 4
RFC1213-MIB::atIfIndex.4.1.172.22.7.255 = INTEGER: 4
RFC1213-MIB::atPhysAddress.4.1.172.22.6.168 = Hex-STRING: 00 40 F4 67 49 08
RFC1213-MIB::atPhysAddress.4.1.172.22.7.255 = Hex-STRING: FF FF FF FF FF FF
RFC1213-MIB::atNetAddress.4.1.172.22.6.168 = Network Address: AC:16:06:A8
RFC1213-MIB::atNetAddress.4.1.172.22.7.255 = Network Address: AC:16:07:FF
```

Bridge MIB (RFC 1493)

- Useful for controlling the status of L2/L3 switches. Do not make the common mistake to believe that it is is used only on bridges.
- It somehow complementary to the MIB II as it provides information the hosts connected to the switch ports.
- Common uses of the bridge MIB:
  - To know the MAC address of a host connected to the port X/unit Y of the switch (NOTE: the MIB II has the MAC address of the switch port).
  - The MAC/port association is the base for detecting the physical location of a host. In fact as switch ports are usually connected to wall sockets, this is a good method for know who's where (user -> computer -> switch port -> room/desk)
  - It keeps track of the "previous" MAC address (and the time) connected to a port so it is possible to track users as they move from a room to another (JLocator product).
  - It can be used for detecting ports with associated multiple MAC addresses (trunk) hence to detect users with multiple MACs (e.g. a user runs VMware on his PC, or a user has been infected by a virus/worm) or ports with a switch connected to it that the network policy could be violated.

Relations Between MIBs [1/2]

	MIB-II	Host	Repeater	Bridge	RMON
Interface Statistics	X				
IP, TCP & UDP Statistics	X				
SNMP Statistics	X				
Host Job Counts		X			
Host File System Information		X			
Link Testing			X	X	
Network Traffic Statistics			X	X	X
Address Tables			X		X
Host Statistics			X		X

Relations Between MIBs [2/2]

	MIB-II	Host	Repeater	Bridge	RMON
Historical Statistics					X
Spanning Tree Performance				X	
Wide Area Link Performance				X	
Thresholds for any variable					X
Configurable Statistics					X
Traffic Matrix with all Nodes				X	
'Host Top N' Information					X
Packet/Protocol Analysis					X
Distributed Logging					X

Side note: SNMP vs. CLI Counters [1/4]

- It a common belief among the network administrator community that SNMP and CLI counters are basically a different view of same thing.
- Many administrators do like CLI counters more, as:
  - Are formatted for direct human consumption
    - 0 packets input, 0 packets output
  - Many implementations provide command to clear/reset counter
    - clear interface ethernet 3
- Note: the definition of what a given counter counts is dependent on vendor documentation

Side note: SNMP vs. CLI Counters [2/4]

```
c4500#sh int e1
Ethernet1 is up, line protocol is down
Last clearing of "show interface" counters never
Output queue 0/40, 0 drops; input queue 0/75, 0 drops
0 packets input, 0 bytes, 0 no buffer
     Received 0 broadcasts, 0 runts, 0 giants
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored, 0 abort
     0 input packets with dribble condition detected
     187352 packets output, 11347294 bytes, 0 underruns
     187352 output errors, 0 collisions, 3 interface resets
```

- Notes:
  - CLI counters remain the basic way of life in element management.
  - Counters format/appearance change vendor to vendor (often even within the same manufacturer, e.g. Cisco IOS vs. CatOS vs. PIX)

Side note: SNMP vs. CLI Counters [3/4]

- SNMP counters instead:
  - Allow you to compare apples to apples
    - Counters have standard definitions
      - as defined by IETF, IEEE, some vendors…
      - regardless of network element type or vendor
    - and globally unique, hard to pronounce names
      - 1.3.6.1.2.1.17.2.4 dot1dStpTopChanges
  - Have a well specified size
    - 32 or 64 bits wide (64 bit available in SNMP v2c or v3).
  - Counters do not necessarily start at zero
    - Vendor implementation friendly.
  - Are not designed for directing human consumption
    - require a delta function to compute rate.

Side note: SNMP vs. CLI Counters [4/4]

```
dot1dTpPortInFrames OBJECT-TYPE
             SYNTAX  Counter
             ACCESS  read-only
             STATUS  mandatory
             DESCRIPTION
                   "The number of frames that have been received by
                   this port from its segment. Note that a frame
                   received on the interface corresponding to this
                   port is only counted by this object if and only if
                   it is for a protocol being processed by the local
                   bridging function, including bridge management
                   frames."
             REFERENCE
                   "IEEE 802.1D-1990: Section 6.6.1.1.3"
```

- Note: good counters are generally derived from underlying protocol specification.

3. Remote Monitoring

Networks are Changing… [1/2]

Force 1: the Internet

- network security will become even more critical in the future.
- the enterprise network will become a public network.

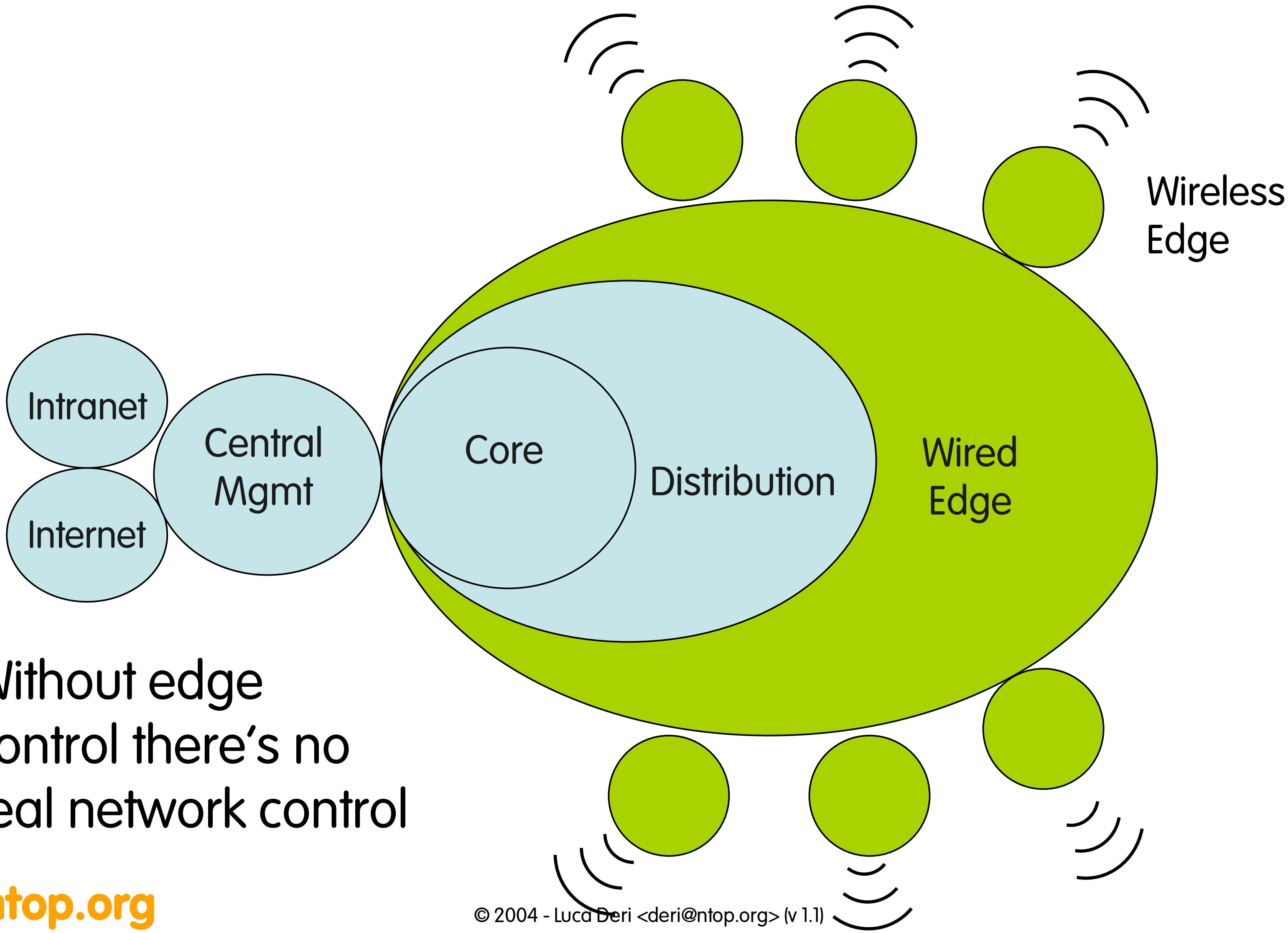
Force 2: Mobility

- supporting mobility across wired and wireless will be a key element of the network future.
- the network will become an anytime, anywhere resource.

Force 3: Dynamic Communications

- supporting a broad range of applications will be a key element in the future: convergence.
- the data network will become the only network.

Networks are Changing… [2/2]



Without edge control there's no real network control

Towards Remote Monitoring [1/4]

- Modern networks are distributed across various buildings, managed by different people with different skills (security, traffic engineer, DB administrator).
- It is necessary to collect traffic statistics on each network trunk, send them to a (limited number of) collector, in order to produce an aggregate network view.
- Some distributed analysis capabilities are necessary because a centralized network is not fault tolerant and scalable.

Towards Remote Monitoring [2/4]

- Deploying remote traffic analyzers (e.g. pcap-based probes) are not always feasible because:
  - Server manufacturers do not always permit generic, untested software (e.g. the licence enforces that on a Oracle server you install only Oracle-certified apps) to be installed.
  - Modern servers often have several network interfaces (1Gb main+failover for data and 100 Mbit for server access), so a multi-interface probe is required.
  - Monitoring a 1 GE using a network tap requires 2 x GE (one RX for each direction of the original GE).

Towards Remote Monitoring [3/4]

- Solution: use traffic analysis capabilities provided by network appliances.
- Drawbacks:
  - Not all the appliances provide traffic analysis capabilities (e.g. most ADSL routers do not)
  - Even if supported, not always such capabilities can be enabled (strong impact on CPU and memory).
  - Basic monitoring capabilities provided by the default OS are rather limited so a custom card is necessary.
  - Custom cards for traffic analysis are not so cheap.

Towards Remote Monitoring [4/4]

- Price of some commercial monitoring cards (monitoring software sold separately):

Product	Price (Card Only)
Cisco MSFC-2	46’000 $
Juniper PM-PIC	30’000 $

RMON: Remote Monitoring using SNMP

- Present in most mid-high end network appliances: often these are poor/limited implementations.
- Some vendors sell stand-alone probes: preferred case as
  - they are full implementations of the protocol.
  - They do not add additional load on the router.
- Not all the implementations (in particular those embedded in router/switches) support the whole standard but only selected SNMP groups.
- Together with Cisco NetFlow is the industrial, "trusted" monitoring standard.
- Two versions: RMON-1 (L2) and RMON-2 (L2/L3).

What can RMON do?

- Collect data and periodically report it to a more central management station, which potentially reduces traffic on WAN links and polling overhead on the management station.
- Report on what hosts are attached to the LAN, how much they talk, and to whom
- "see" all LAN traffic, full LAN utilization, and not just the traffic to or through the router.
- Filter and capture packets (so you don't have to visit a remote LAN and attach a LAN Analyzer) : it is basically a remote sniffer that can capture real-time traffic (until the integrated memory buffer is full).
- Automatically collect data, compare to thresholds, and send traps to your management station -- which offloads much of the work that might bog down the management station.

RMON vs. SNMP [1/2]

- The SNMP protocol is used to control and configure a probe. Usually GUI managers mask the complexity of SNMP-based configuration.
- Statistics and saved traffic are retrieved using SNMP by management applications to record statistics on a network and, possibly selected portions of the network traffic.

RMON vs. SNMP [2/2]

SNMP and RMON differ in the way they gather traffic statistics:

- SNMP is a periodic poll-request process: it requires a query of the SNMP device to get network statistics (the network status is kept by the manager).
- RMON, on the other hand, reduces the stress of the manager by gathering and storing the statistics in counters or buckets for retrieval by a management station.

RMON Monitoring Groups [1/3]

Groups	Function	Elements
Statistics	Contains statistics measured by the probe for each monitored interface on this device.	Packets dropped, packets sent, bytes sent (octets), broadcast packets, multicast packets.
History	Records periodic statistical samples from a network and stores them for later retrieval.	Sample period, number of samples, items sampled.
Alarm	Periodically takes statistical samples from variables in the probe and compares them with previously configured thresholds. If the monitored variable crosses a threshold, an event is generated.	Alarm type, interval, starting threshold, stop threshold.

RMON Monitoring Groups [2/3]

Groups	Function	Elements
Host	Contains statistics associated with each host discovered on the network.	Host address, packets, and bytes received and transmitted, as well as broadcast, multicast, and error packets.
HostTopN	Prepares tables that describe the hosts that top a list ordered by one of their base statistics over an interval specified by the management station. Thus, these statistics are rate-based.	Statistics, host(s), sample start and stop periods, rate base, duration.
Matrix	Stores statistics for conversations between sets of two addresses. As the device detects a new conversation, it creates a new entry in its table.	Bit-filter type (mask or not mask), filter expression (bit level), conditional expression (and, or not) to other filters.

RMON Monitoring Groups [3/3]

Groups	Function	Elements
Filters	Enables packets to be matched by a filter equation. These matched packets form a data stream that might be captured or that might generate events. Bit-filter type (mask or not mask), filter expression (bit level), conditional expression (and, or not) to other filters	Bit-filter type (mask or not mask), filter expression (bit level), conditional expression (and, or not) to other filters
Packet Capture	Enables packets to be captured after they flow through a channel.	Size of buffer for captured packets, full status (alarm), number of captured packets.
Events	Controls the generation and notification of events from this device.	Event type, description, last time event sent

RMON Ethernet Statistics

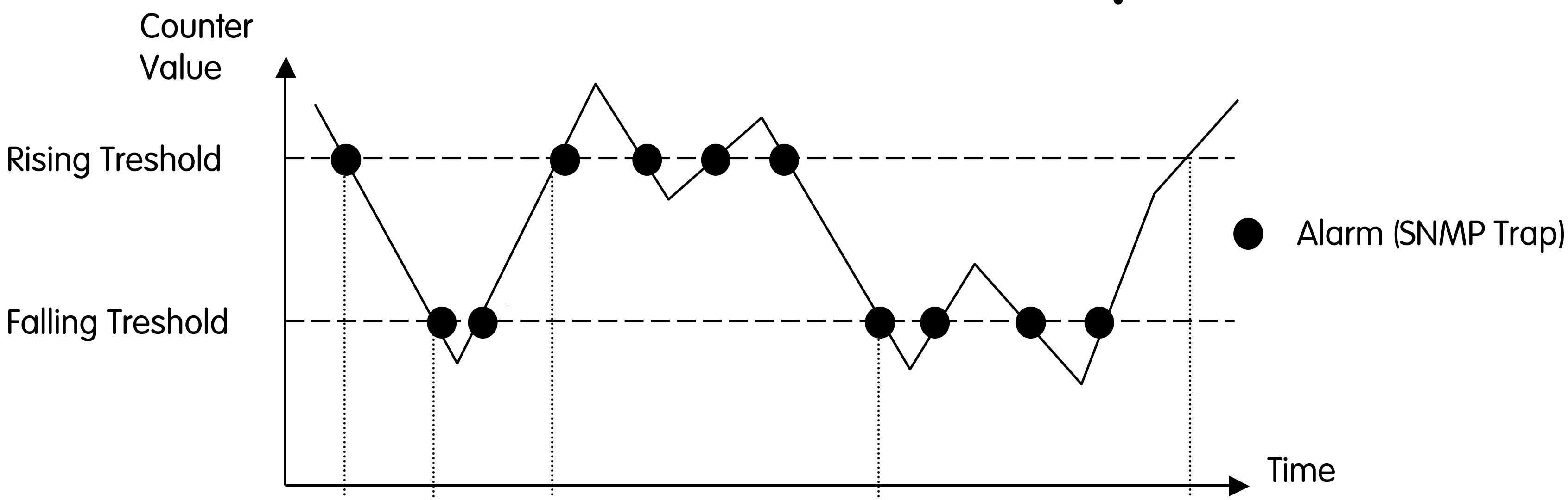
- Packets: A unit of data formatted for transmission on a network.
- Multicast Packet: communication between a single sender and multiple receivers on a network.
- Broadcast Packet: a packet that is transmitted to all hosts on an Ethernet.
- Drop Events: An overrun at a port. The port logic could not receive the traffic at full line rate and had to drop some packets.
- Fragments: A piece of a packet. Sometimes a communications packet being sent over a network has to be temporarily broken into fragments; the packet should be reassembled when it reaches its destination.
- Jabbers: Packets received that were longer than 1518 octets and also contained alignment errors.
- Oversize Packets: Packets received that were longer than 1518 octets and were otherwise well formed.

Network Utilization with RMON

- Most RMON managers use RMON counters to compute network utilization.
- Network Utilization can be calculated for all the ports of a given switch at regular intervals. This information can be gathered over the course of a day and be used to generate a network utilization profile of a switch or hub.

$$\%\ \text{Network Utilization} = \frac{100 \times ((\#\ \text{packets} \times 160) + (\#\ \text{octets} \times 8))}{\text{port speed} \times \text{time (secs)}}$$

RMON Alarm Group



- In case of exceeding a upper limit value, an event is produced each time the threshold is exceeded or when a value that used to be above a threshold returns inside the specified range. Similar considerations can be applied to lower threshold value.
- Thresholds can either be on to the measured value (absolute absolute) or on the difference of the current value to the last measured value (delta value).

Case Study: Counter Sampling Interval [1/2]

Example 1: (10 seconds sampling interval, threshold value 20, 10 seconds test interval)

Time:	0	**10**	**20**
Value:	0	19	32
Delta:		19	13
Actual Threshold To Check:		19	13

Example 2: (5 seconds sampling interval, threshold value 20, 10 seconds test interval)

Time:	0	5	**10**	15	**20**
Value:		10	19	30	32
Delta:		10	9	11	2
Actual Threshold To Check :			19	<u>20</u>	13

Case Study: Counter Sampling Interval [2/2]

- MIB instance value sampling must be done twice per sampling interval, otherwise exceeded thresholds may be undetected for overlapping intervals.
- Fast polling has some drawbacks:
  - Much more data is collected.
  - Increased load on SNMP agents.
  - More data changes are detected (this can lead to false positives).
- Slow polling has some drawbacks too:
  - Some alarms can be missed (inaccuracy)

RMON-Like Home-grown Network Probes [1/4]

- Every router/switch (ranging from Cisco boxes to Linux-based router) has the ability to define ACL (Access Control Lists) for preventing selected traffic to flow.
- ACLs with an 'accept' policy can very well be used to account traffic.
- Drawbacks:
  - ACLs are limited to IP whereas RMON is not (e.g. IPX, NeBEUI)
  - On many systems ACLs have impact on CPU.
  - The number or total/per-port ACLs is limited.
  - Often ACLs are limited to packet header (no payload).

RMON-Like Home-grown Network Probes [2/4]

ACL definition examples:

- Cisco

```
access-list 102 permit icmp any any
```

- Juniper

```
filter  HTTPcounter {
  from {
        destination-address {
                10.10.20/24;
                10.40.30/25;
                11.11/8;
        }
        destination-port [http https];
  }
  then {
        count Count-Http;
        accept
  }
}
```

RMON-Like Home-grown Network Probes [3/4]

- Linux (iptables)

```
[root@mail deri]# /sbin/iptables -xnvL
Chain INPUT (policy ACCEPT 0 packets, 0 bytes)
   pkts      bytes target     prot opt in     out     source               destination
 236675 169960206 RH-Firewall-1-INPUT  all  --  *      *       0.0.0.0/0            0.0.0.0/0
Chain FORWARD (policy ACCEPT 0 packets, 0 bytes)
   pkts     bytes target     prot opt in     out     source               destination
      0         0 RH-Firewall-1-INPUT  all  --  *      *       0.0.0.0/0            0.0.0.0/0
Chain OUTPUT (policy ACCEPT 262868 packets, 233122676 bytes)
   pkts       bytes target     prot opt in     out     source               destination
Chain RH-Firewall-1-INPUT (2 references)
   pkts     bytes target     prot opt in     out     source               destination
  68169  81214627 ACCEPT     all  --  lo     *       0.0.0.0/0            0.0.0.0/0
    677     53751 ACCEPT     icmp --  *      *       0.0.0.0/0            0.0.0.0/0
      0         0 ACCEPT     esp  --  *      *       0.0.0.0/0            0.0.0.0/0
      0         0 ACCEPT     ah   --  *      *       0.0.0.0/0            0.0.0.0/0
 155984  87891801 ACCEPT     all  --  *      *       0.0.0.0/0            0.0.0.0/0
```

RMON-Like Home-grown Network Probes [4/4]

- Counters are usually accessed from SNMP in addition to CLI (Command Line Interface).
- Proprietary MIBs allow values to be read from remote.
- Cisco has recently introduced a new technology named "Static NetFlow" that allows routers to emit flows for each defined ACL.
- Extreme Network's "ClearFlow" is also a similar technology. In addition it also has the ability to send alarms by setting thresholds on counter values.

NBAR: RMON-Like Traffic Stats [1/6]

- Cisco NBAR (Network Based Application Recognition) is a traffic classification engine with QoS support (i.e. you can shape traffic based on traffic stats).
- Real-time traffic pattern analysis (with payload analysis) and protocol discovery.
- NBAR Example: stop KaZaA traffic and give priority to the video conference traffic.

NBAR: RMON-Like Traffic Stats [2/6]

- Capable of classifying applications that have:
  - Statically assigned TCP and UDP port numbers.
  - Non-TCP and non-UDP IP protocols.
  - Dynamically assigned TCP and UDP port numbers during connection establishment.
  - Classification based on deep packet inspection: NBAR can look deeper into the packet to identify applications.
  - HTTP traffic by URL, host name or MIME type using regular expressions (*, ?, [ ]), Citrix ICA traffic, RTP Payload type classification.
  - Currently supports 88 protocols/applications.
- NBAR statistics can be read using SNMP (Cisco NBAR Protocol Discovery MIB).

NBAR: RMON-Like Traffic Stats [3/6]

Caveats:

- Proprietary technology: available only on Cisco boxes with a recent IOS version.
- Strong router CPU overhead (more than NetFlow).
- It does not recognize all protocols.
- Difficult to configure in particular if associated with QoS/Bandwidth Management.

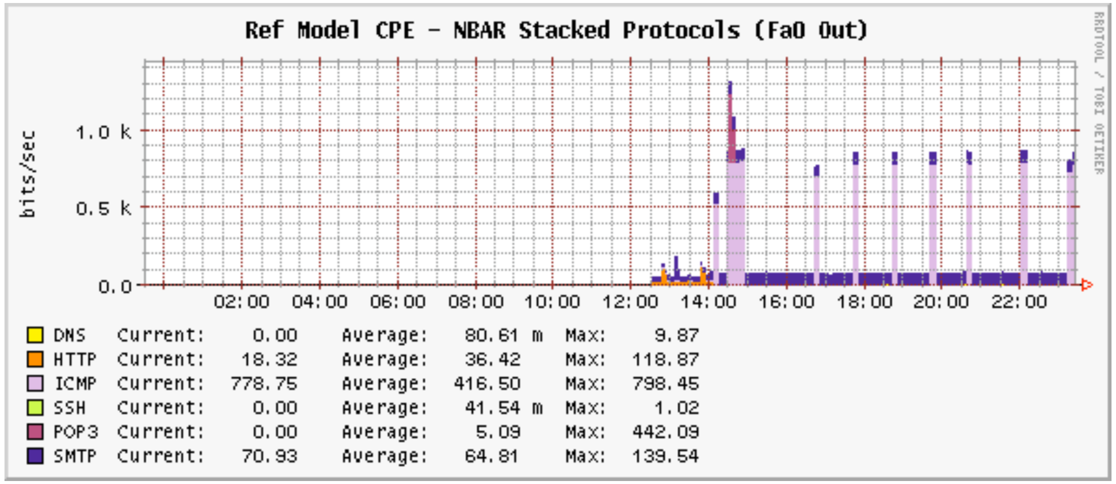
NBAR: RMON-Like Traffic Stats [4/6]

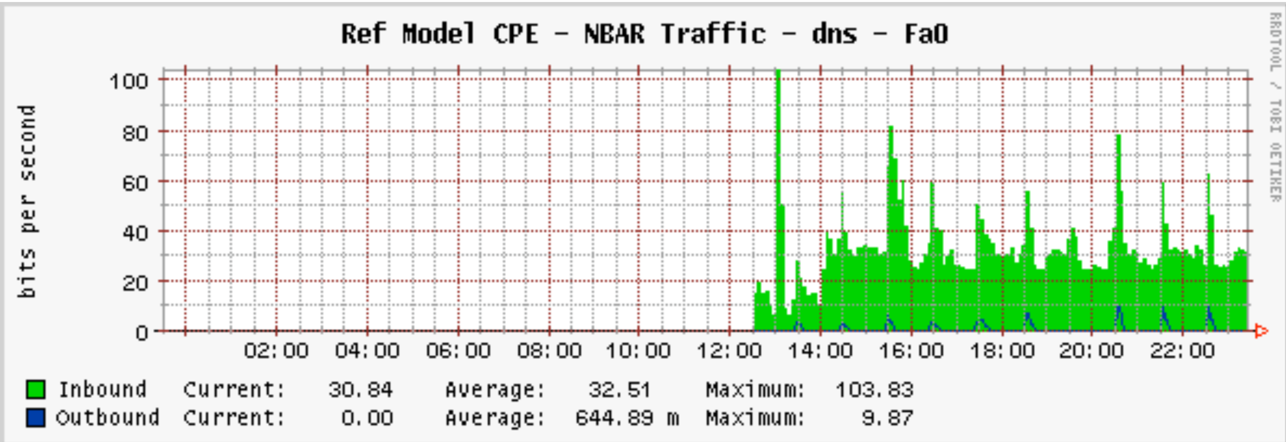
```
Router# conf t
Router(config)# ip cef
Router(config)# int eth0/0
Router(config-if)# ip nbar protocol-discovery
Router(config-if)# exit
Router(config)# int se0/0
Router(config-if)# ip nbar protocol-discovery

Router# show ip nbar protocol discovery int eth0/0 top 3

 FastEthernet0/0
                           Input                    Output
   Protocol                Packet Count             Packet Count
                           Byte Count               Byte Count
                           5 minute bit rate (bps)  5 minute bit rate (bps)
   ------------------------ ------------------------ ------------------------
   ftp                     64175242                 45153848
                           89351513113              2484576000
                           1073000                  28000
   http                    58194017                 32519125
                           82356099996              1958417833
                           924000                   22000
   netshow                161827                   76694
                           211785210                4328663
                           0                        0
   unknown                 151860                   24174
                           103546921                1594651
                           0                        0
   Total                   123055877                77838212
                           172435146582             4477038399
                           1997000                  50000
```

NBAR: RMON-Like Traffic Stats [5/6]

```
Router# show policy-map int eth0/0

 Ethernet0/0
  Service-policy input: dscp_mark

    Class-map: stream (match-any)
      130521 packets, 97066868 bytes
      5 minute offered rate 0 bps, drop rate 0 bps
      Match: protocol rtp
        0 packets, 0 bytes
        5 minute rate 0 bps
      Match: protocol rtspplayer
        117857 packets, 79344153 bytes
        5 minute rate 0 bps
      Match: protocol netshow
        12664 packets, 17722715 bytes
        5 minute rate 0 bps
      Match: ip dscp ef
        0 packets, 0 bytes
        5 minute rate 0 bps
      QoS Set
        dscp ef
          Packets marked 130521

    Class-map: class-default (match-any)
      175792 packets, 231418813 bytes
      5 minute offered rate 0 bps, drop rate 0 bps
      Match: any
```

NBAR: RMON-Like Traffic Stats [6/6]





4. Flow Monitoring

SNMP vs. Network Flows [1/2]

- SNMP is based on the manager agent paradigm
  - The agent monitors the network and informs the manager (via traps) when something important happened (i.e. and interface changed state).
  - The manager keeps the whole system status by periodically reading (polling) variables (e.g. via SNMP Get) form the agent.
  - SNMP variables can be used for both element/device/system management (e.g. info about disk space and partitions) and traffic monitoring.

SNMP vs. Network Flows [2/2]

- Network flows are emitted by a probe towards one or more collectors according to traffic conditions.
  - Flows contain information about the analysed traffic (i.e. they do not contain device/probe information such as the MIB II variables).
  - Emitted flows have a well defined format (e.g. Cisco NetFlow v5) and often use UDP as transport (no specialized protocol like SNMP).
  - No concept of 'alarm' flows nor ability for the probe to perform actions based on flows: all the intelligence is in the collector.
  - Probe instrumentation is performed offline.
  - Probes are activated where the network traffic flows (e.g. inside routers and switches).

So What Do You Expect To Measure with Flows? [1/2]

- Where your campus exchanges traffic with by IP address, IP Prefix, or ASN.
- What type and how much traffic (SMTP, WEB, File Sharing, etc).
- What services running on campus.
- Department level traffic summaries.
- Track network based viruses back to hosts.

So What Do You Expect To Measure with Flows? [2/2]

- Track DoS attacks to the source(s), i.e. the 100 servers flooding XXX.com domain.
- Find busy hosts on campus (top host).
- How many destinations each campus host exchanges traffic with.
- Campus host counts by service, i.e. how many active web servers.

What You Can't Measure with Flows?

- Non-IP traffic (e.g. NetBIOS, AppleTalk).
- L2 information (e.g. interface up/down state changes).
- Filtered traffic (e.g. firewall policy counters).
- Per-link statistics (e.g. link usage, congestion, delay, packet loss).

Network Flows: What Are They?

- "A flow is a set of packets with a set of common packet properties".
- A flow is (queued to be) emitted only when expired.
- Creation and expiration policy
  - What conditions start and stop a flow?
  - Maximum flow duration timeout regardless of the connection status (e.g. a TCP connection ends when both peers agreed on FIN/RST).
  - Emit a flow when there's no flow traffic for a specified amount of time.

Network Flows Content

- Flow contain:
  - Peers: flow source and destination.
  - Counters: packets, bytes, time.
  - Routing information: AS, network mask, interfaces.
- Flows can be unidirectional (default) or bidirectional (very rare).
- Bidirectional flows can contain other information such as round trip time, TCP behavior.

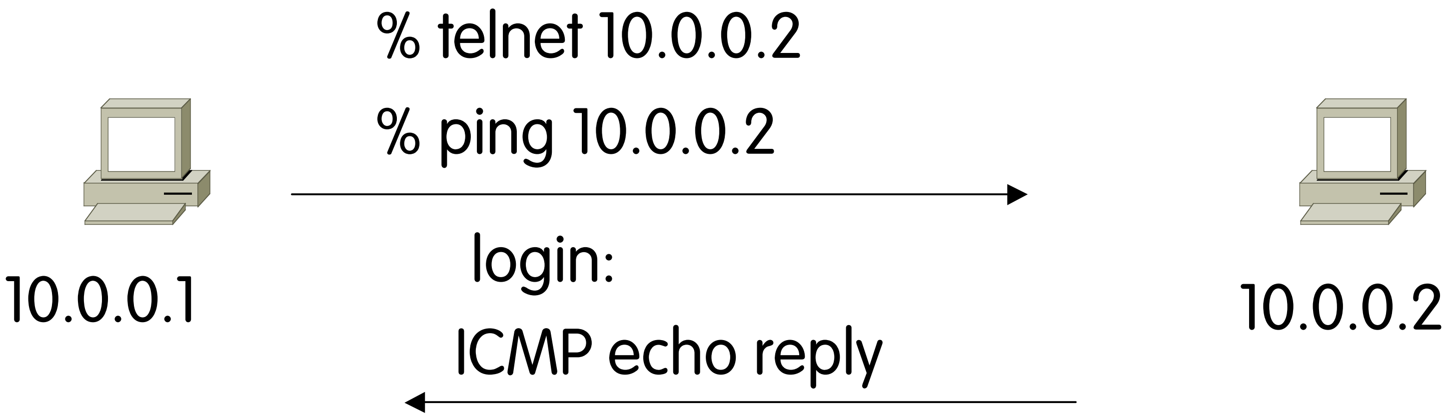
Network Flows Aggregation

- Flows can be aggregated according to:
  - TCP/UDP Port, ToS (Type of Service), Protocol (e.g. ICMP, UDP), AS (Autonomous System)
  - Source/Destination IP Address
  - Subnet, time of the day.
- Aggregation can be performed by the probe, the collector or both.
- Probe aggregation is very effective in terms of resource usage and network flow traffic.
- Collector aggregation is more powerful (e.g. aggregate flows produced by different probes) but rather costly (receive all the aggregate).

Network Flows Issues

- Overhead vs. Accuracy
  - More measurement results in more collected data.
  - More flow aggregation, less granularity.
  - Overhead (e.g. CPU load) on routers, switches, end-hosts.
- Security vs. Data Sharing
  - Emitted flows must reach collectors on protected paths (e.g. using a different network/VLAN).
  - User privacy must be respected.
  - Traffic measurements must be kept protected in order not to disclosure important network information to third parties.

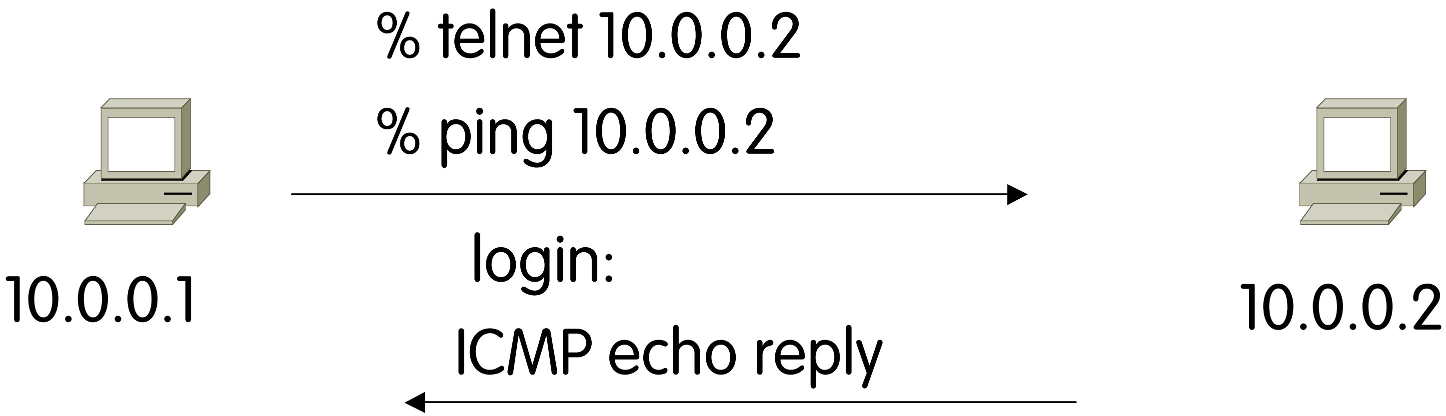
Unidirectional Flow with Source/Destination IP Key



Active Flows

Flow	Source IP	Destination IP
1	10.0.0.1	10.0.0.2
2	10.0.0.2	10.0.0.1

Unidirectional Flow with IP, Port, Protocol Key



Active Flows

Flow	Source IP	Destination IP	Proto	srcPort	dstPort
1	10.0.0.1	10.0.0.2	TCP	32000	23
2	10.0.0.2	10.0.0.1	TCP	23	32000
3	10.0.0.1	10.0.0.2	ICMP	0	0
4	10.0.0.2	10.0.0.1	ICMP	0	0

Aggregated Flows

Main Active Flow Table

Flow	Source IP	Destination IP	Proto	srcPort	dstPort
1	10.0.0.1	10.0.0.2	TCP	32000	23
2	10.0.0.2	10.0.0.1	TCP	23	32000
3	10.0.0.1	10.0.0.2	ICMP	0	0
4	10.0.0.2	10.0.0.1	ICMP	0	0

Source/Destination IP Aggregation

Flow	Source IP	Destination IP
1	10.0.0.1	10.0.0.2
2	10.0.0.2	10.0.0.1

Cisco NetFlow Basics

- Unidirectional flows.
- Several versions v 1,5,6,7,8,9. The most common is v5, the latest version is v9.
- Traffic analysis only on inbound (i.e. the traffic that enters the router) IP-only traffic (not on all platforms).
- IPv4 unicast and multicast. IPv6 is supported only by v9.
- Supported on IOS and CatIOS platforms (no NetFlow support on PIX firewalls) as well as on on-Cisco platforms (e.g. Juniper, Extreme).

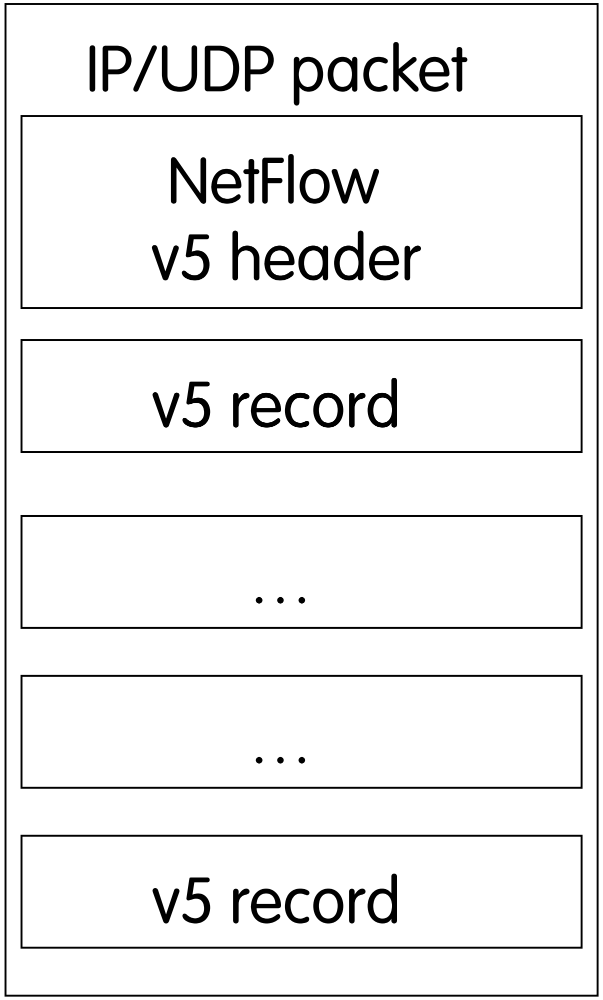
Cisco NetFlow Versions

- Each version has its own packet format
  - v1, 5,6,7,8 have a fixed/closed, specified format.
  - v9 format is dynamic and open to extensions.
- Sequence Numbers:
  - v1 does not have sequence numbers (no way to detect lost flows).
  - v5,6,7,8 have flow sequence numbers (i.e. keep track of the number of emitted flows).
  - v9 has packet (not flow) sequence number (I.e. easy to know the number of lost packets but not of lost flows).
- The “version” defines what type of data is in the flow.
- Some versions (e.g. v7) specific to Catalyst platform.

NetFlow Packet Format

- Common header among export versions.
- Version specific data field where N records of data type are exported.
- N is determined by the size of the flow definition (e.g. N=30 for v5). Packet size is kept under ~1480 bytes. No fragmentation on Ethernet.

Cisco NetFlow v5 [1/3]



Cisco NetFlow v5 [2/3]

```
struct netflow5_record {
  struct flow_ver5_hdr flowHeader;
  struct flow_ver5_rec flowRecord[30];
} NetFlow5Record;

struct flow_ver5_hdr {
  u_int16_t version;          /* Current version=5*/
  u_int16_t count;            /* The number of records in PDU. */
  u_int32_t sysUptime;        /* Current time in msecs since router booted */
  u_int32_t unix_secs;        /* Current seconds since 0000 UTC 1970 */
  u_int32_t unix_nsecs;       /* Residual nanoseconds since 0000 UTC 1970 */
  u_int32_t flow_sequence;    /* Sequence number of total flows seen */
  u_int8_t  engine_type;      /* Type of flow switching engine (RP,VIP,etc.)*/
  u_int8_t  engine_id;        /* Slot number of the flow switching engine */
};
```

Cisco NetFlow v5 [3/3]

```
struct flow_ver5_rec {
  u_int32_t srcaddr;          /* Source IP Address */
  u_int32_t dstaddr;          /* Destination IP Address */
  u_int32_t nexthop;          /* Next hop router's IP Address */
  u_int16_t input;            /* Input interface index */
  u_int16_t output;           /* Output interface index */
  u_int32_t dPkts;            /* Packets sent */
  u_int32_t dOctets;          /* Octets sent */
  u_int32_t First;            /* SysUptime at start of flow */
  u_int32_t Last;             /* and of last packet of the flow */
  u_int16_t srcport;          /* TCP/UDP source port number (.e.g, FTP, Telnet, etc.,or equivalent) */
  u_int16_t dstport;          /* TCP/UDP destination port number (.e.g, FTP, Telnet, etc.,or equivalent) */
  u_int8_t pad1;              /* pad to word boundary */
  u_int8_t tcp_flags;         /* Cumulative OR of tcp flags */
  u_int8_t prot;              /* IP protocol, e.g., 6=TCP, 17=UDP, etc... */
  u_int8_t tos;               /* IP Type-of-Service */
  u_int16_t dst_as;           /* dst peer/origin Autonomous System */
  u_int16_t src_as;           /* source peer/origin Autonomous System */
  u_int8_t dst_mask;          /* destination route's mask bits */
  u_int8_t src_mask;          /* source route's mask bits */
  u_int16_t pad2;             /* pad to word boundary */
};
```

NetFlow v5 Flow Example [1/2]

```
Cisco NetFlow
    Version: 5
    Count: 30
    SysUptime: 1518422100
    Timestamp: May  7, 1993 08:49:48.995294598
        CurrentSecs: 736757388
        CurrentNSecs: 995294598
    FlowSequence: 9751
    EngineType: 0
    EngineId: 0
    SampleRate: 0
pdu 1/30
    [ ...... ]
```

NetFlow v5 Flow Example [2/2]

```
pdu 1/30
        SrcAddr: 10.16.237.114 (10.16.237.114)
        DstAddr: 213.92.16.87 (213.92.16.87)
        NextHop: 10.158.100.1 (10.158.100.1)
        InputInt: 4
        OutputInt: 1
        Packets: 5
        Octets: 627
        StartTime: 1518415.920000000 seconds
        EndTime: 1518416.352000000 seconds
        SrcPort: 3919
        DstPort: 80
        padding
        TCP Flags: 0x1b
        Protocol: 6
        IP ToS: 0x00
        SrcAS: 0
        DstAS: 0
        SrcMask: 16 (prefix: 10.16.0.0/16)
        DstMask: 0 (prefix: 0.0.0.0/32)
        padding
pdu 2/30
  [ ........................... ]
```

Why Do We Need NetFlow v9?

- Fixed formats (v1-v8) for export are:
  - Easy to implement.
  - Consume little bandwidth.
  - Easy to decipher at the collector.
  - Not flexible (many proprietary hacks such as using TCP/UDP ports for transporting ICMP type/code).
  - Not extensible (no way to extend the flow unless a new version is defined).

NetFlow v9 Principles [1/2]

- Flow Template + flow record
  - Template composed of type and length.
  - Flow record composed of template ID and value.
  - Templates are sent periodically and they are a prerequisite for decoding flow records.
  - Flow records contain the 'flow meat'.
- Options templates + option records contain probe configuration (e.g. sampling rate, interface packet counters).

NetFlow v9 Principles [2/2]

- Push model probe -> collector (as with past versions).
- Send the templates regularly: each X flows, each X seconds.
- Independent of the underlying protocol, ready for any reliable protocol.
- Can send both template and flow record in one export.
- Can interleave different flow records in one export packet.

NetFlow v9 Flow Example [1/2]

```
Cisco NetFlow
    Version: 9
    Count: 4
    SysUptime: 1132427188
    Timestamp: Aug 18, 2000 23:49:25.000012271
        CurrentSecs: 966635365
    FlowSequence: 12271
    SourceId: 0
    FlowSet 1/4
 FlowSet 1/4
        Template FlowSet: 0
        FlowSet Length: 164
        Template Id: 257
        Field Count: 18
        Field (1/18)
            Type: LAST_SWITCHED (21)
            Length: 4
        Field (2/18)
            Type: FIRST_SWITCHED (22)
            Length: 4
        Field (3/18)
            [ ...... ]
```

NetFlow v9 Flow Example [2/2]

```
Cisco NetFlow
    Version: 9
    Count: 1
    SysUptime: 1133350352
    Timestamp: Aug 19, 2000 00:04:48.000012307
        CurrentSecs: 966636288
    FlowSequence: 12307
    SourceId: 0
    FlowSet 1/1
        Data FlowSet (Template Id): 257
        FlowSet Length: 52
        pdu 1
            EndTime: 1133334.000000000 seconds
            StartTime: 1133334.000000000 seconds
            Octets: 84
            Packets: 1
            InputInt: 15
            OutputInt: 0
            SrcAddr: 172.18.86.77 (172.18.86.77)
            DstAddr: 11.10.65.130 (11.10.65.130)
            Protocol: 1
            IP ToS: 0x00
            [ … ]
```

NetFlow v5 vs. v9

	v5	v9
Flow Format	Fixed	User Defined
Extensible	No	Yes (Define new FlowSet Fields)
Flow Size	48 Bytes	It depends on the format
IPv6 Aware	No	IP v4/v6
MPLS/VLAN	No	Yes

Cisco IOS Configuration [1/5]

- Configured on each input interface.
- Define the version.
- Define the IP address of the collector (where to send the flows).
- Optionally enable aggregation tables.
- Optionally configure flow timeout and main (v5) flow table size.
- Optionally configure sample rate.

Cisco IOS Configuration [2/5]

```
interface FastEthernet0/0/0
 ip address 10.0.0.1 255.255.255.0
 no ip directed-broadcast
 ip route-cache flow

interface ATM1/0/0
 no ip address
 no ip directed-broadcast
 ip route-cache flow

interface Loopback0
 ip address 10.10.10.10 255.255.255.255
 no ip directed-broadcast

ip flow-export version 5 origin-as
ip flow-export destination 10.0.0.10 5004
ip flow-export source loopback 0

ip flow-aggregation cache prefix
 export destination 10.0.0.10 5555
 enabled
```

Cisco IOS Configuration [3/5]

```
krc4#sh ip flow export
Flow export is enabled
  Exporting flows to 10.0.0.10 (5004)
  Exporting using source IP address 10.10.10.10
  Version 5 flow records, origin-as
  Cache for prefix aggregation:
    Exporting flows to 10.0.0.10 (5555)
    Exporting using source IP address 10.10.10.10
  3176848179 flows exported in 105898459 udp datagrams
  0 flows failed due to lack of export packet
  45 export packets were sent up to process level
  0 export packets were punted to the RP
  5 export packets were dropped due to no fib
  31 export packets were dropped due to adjacency issues
  0 export packets were dropped due to fragmentation failures
  0 export packets were dropped due to encapsulation fixup failures
  0 export packets were dropped enqueuing for the RP
  0 export packets were dropped due to IPC rate limiting
  0 export packets were dropped due to output drops
```

Cisco IOS Configuration [4/5]

```
krc4#sho ip ca fl
IP packet size distribution (106519M total packets):
   1-32   64   96  128  160  192  224  256  288  320  352  384  416  448  480
   .002 .405 .076 .017 .011 .010 .007 .005 .004 .005 .004 .004 .003 .002 .002

    512  544  576 1024 1536 2048 2560 3072 3584 4096 4608
   .002 .006 .024 .032 .368 .000 .000 .000 .000 .000 .000

IP Flow Switching Cache, 4456704 bytes
  36418 active, 29118 inactive, 3141073565 added
  3132256745 ager polls, 0 flow alloc failures
  Active flows timeout in 30 minutes
  Inactive flows timeout in 15 seconds
  last clearing of statistics never
Protocol         Total    Flows   Packets Bytes  Packets Active(Sec) Idle(Sec)
--------         Flows     /Sec     /Flow  /Pkt     /Sec     /Flow     /Flow
TCP-Telnet     2951815      0.6        61   216     42.2      26.6      21.4
TCP-FTP       24128311      5.6        71   748    402.3      15.0      26.3
TCP-FTPD       2865416      0.6       916   843    611.6      34.7      19.8
TCP-WWW      467748914    108.9        15   566   1675.8       4.9      21.6
TCP-SMTP      46697428     10.8        14   370    159.6       4.0      20.1
TCP-X           521071      0.1       203   608     24.7      24.5      24.2
TCP-BGP        2835505      0.6         5    94      3.3      16.2      20.7
```

Cisco IOS Configuration [5/5]

```
krc4#sho ip ca fl

TCP-other    1620253066    377.2         47    631   18001.6        27.3        23.4
UDP-DNS       125622144     29.2          2     78      82.5         4.6        24.7
UDP-NTP        67332976     15.6          1     76      22.0         2.7        23.4
UDP-TFTP          37173      0.0          2     76       0.0         4.1        24.6
UDP-Frag          68421      0.0        474    900       7.5       111.7        21.6
UDP-other     493337764    114.8         17    479    1990.3         3.8        20.2
ICMP          243659509     56.7          3    166     179.7         3.3        23.3
IGMP              18601      0.0         96     35       0.4       941.4         8.1
IPINIP            12246      0.0         69     52       0.1       548.4        15.2
GRE              125763      0.0        235    156       6.9        50.3        21.1
IP-other       75976755     17.6          2     78      45.4         3.9        22.8
Total:       3176854246    739.6         33    619   24797.4        16.2        22.6

SrcIf         SrcIPaddress    DstIf          DstIPaddress    Pr SrcP DstP  Pkts
AT5/0/0.4     206.21.162.150  AT1/0/0.1      141.219.73.45   06 0E4B A029   507
AT4/0/0.10    132.235.174.9   AT1/0/0.1      137.99.166.126  06 04BE 074C     3
AT4/0/0.12    131.123.59.33   AT1/0/0.1      137.229.58.168  06 04BE 09BB   646
AT1/0/0.1     137.99.166.126  AT4/0/0.10     132.235.174.9   06 074C 04BE     3
```

JunOS Configuration [1/3]

- Sample packets with firewall filter and forward to routing engine.
- Sampling rate is limited to 7000pps (addressed with future PIC).
- Fine for traffic engineering, but restrictive for DoS and intrusion detection.
- Juniper calls NetFlow cflowd (popular collector provided by CAIDA).

JunOS Configuration [2/3]

Firewall filter

```
firewall {
    filter all {
        term all {
            then {
                sample;
                accept;
            }
        }
    }
}
```

Enable sampling / flows

```
forwarding-options {
    sampling {
        input {
            family inet {
                rate 100;
            }
        }
        output {
            cflowd 10.0.0.16{
                port 2055;
                version 5;
            }
        }
    }
}
```

JunOS Configuration [3/3]

Apply firewall filter to each interface.

```
interfaces {
    ge-0/3/0 {
        unit 0 {
            family inet {
              filter {
                    input all;
                    output all;
                }
                address 192.148.244.1/24;
            }
        }
    }
```

PC-Based NetFlow Probes

- There are some PC-based probes.
- Most of them are based on the pcap library.
- nProbe (www.ntop.org/nProbe.html)
  - Open Source (GPL2)
  - Fastest probe on the market
  - Support of v5/v9, IPFIX.
  - Flexible export format.
  - IPv4/v6 support, flexible template (not even supported by Cisco).
  - Available for both Unix and Windows

IPFIX Scope and General Requirements

- Goal: Find or develop a basic common IP Traffic Flow measurement technology to be available on (almost) all future routers.
- Fulfilling requirements of many applications.
- Low hardware/software costs.
- Simple and scalable.
- Metering to be integrated in general purpose IP routers and other devices (probes, middle boxes).
- Data processing to be integrated into various applications.
- Interoperability by openness or standardization.

IPFIX in a Nutshell

- Strongly based on NetFlow v9.
- Ability to define new flow fields using a standard format (OID).
- Transport based on SCTP (Stream Control Transport Protocol), optional UDP/TCP support.
- Current status: draft protocol specification.
- Bottom Line: IPFIX = NetFlow v9 over SCTP.

Driving Forces Towards sFlow

- **Cost**
  - Monitoring switched networks required multiple expensive probes.
  - Embedded monitoring solutions required extra hardware &/or software.
  - Traffic analysis solutions were costly.
  - Administrative costs of managing additional equipment.
- **Impact to network performance**
  - Switching performance impacted by measuring traffic flows.
  - Excessive network bandwidth used to export flow data.
- **Poor scalability of monitoring system**
  - Cannot keep up with Gigabit speeds.
  - Cannot build a network-wide traffic view for large, heavily used networks.

sFlow Principles

- Don't pretend to be as fast as the monitored network: you will loose data anyway.
- Even if you can monitor everything you'll run into trouble handling all the generated flows.
- Analyze 1 packet each X packets (sampling).
- The more packets you analyze the more precise are your traffic reports.
- If the network is too fast for you, sample more!

sFlow Specification [1/4]

- Specified in RFC 3176 (Informational RFC) proposed by InMon Inc.
- It defines:
  - sFlow packets format (UDP, no SNMP).
  - A SNMP MIB per accessing sFlow collected data.
- The sFlow architecture is similar to NetFlow: the probe sends sFlow packets to the collector.

sFlow Specification [2/4]

- The sFlow probe is basically a sniffer that captures 1 out of X packets (default ratio is 1:400).
- Such packets is sent to the collector coded in sFlow format.
- Periodically the probes sends other sFlow packets that contain network interface statistics (e.g. interface traffic counters) used to scale collected data.

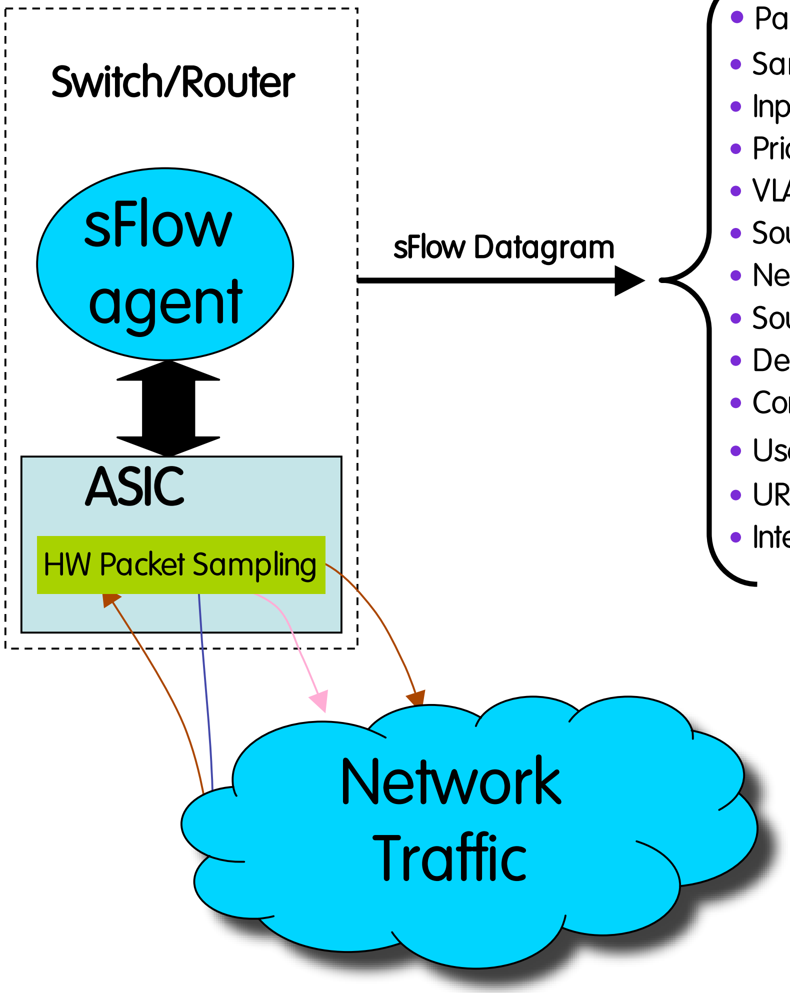
sFlow Specification [3/4]

```
typedef struct _INMFlow_sample {
  u_int32_t sequence_number;           /* Incremented with each generated flow */
  u_int32_t source_id;                 /* fsSourceId */
  u_int32_t sampling_rate;             /* fsPacketSamplingRate (e.g. 400 for 1:400) */
  u_int32_t sample_pool;               /* Total number of packets that could have been
                                            sampled (i.e. packets skipped by sampling
                                            process + total number of samples) */
  u_int32_t drops;                     /* Number of times a packet was dropped due to
                                          lack of resources */
  u_int32_t input;                     /* SNMP ifIndex of input interface.
                                          0 if interface is not known. */
  u_int32_t output;                    /* SNMP ifIndex of output interface,
                                          0 if interface is not known. */
  u_int32_t packet_data_tag;           /* enum INMPacket_information_type */
  INMPacket_data_type packet_data;     /* Sampled packet payload */
[..]
} INMFlow_sample;
```

sFlow Specification [4/4]

- Using statistical formula it is possible to produce very precise traffic reports.
- % Sampling Error <= 196 * sqrt(1 / number of samples)
- sFlow is scalable (you just need to increase the sampling ration) even on 10 Gb networks or more.
- ntop.org is part of the sFlow.org consortium.

sFlow Summary



- Packet header (eg MAC,IPv4,IPv6,IPX,AppleTalk,TCP,UDP, ICMP)
- Sample process parameters (rate, pool etc.)
- Input/output ports
- Priority (802.1p and TOS)
- VLAN (802.1Q)
- Source/destination prefix
- Next hop address
- Source AS, Source Peer AS
- Destination AS Path
- Communities, local preference
- User IDs (TACACS/RADIUS) for source/destination
- URL associated with source/destination
- Interface statistics (RFC 1573, RFC 2233, and RFC 2358)

- Low cost
- No impact to performance
- Minimal network impact
- Scalable
- Quantitative measurements

Integrated Network Monitoring

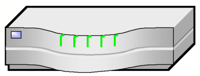
sFlow enabled switches

Core network switches

RMON enabled switches

L2/L3 Switches

NetFlow enabled routers

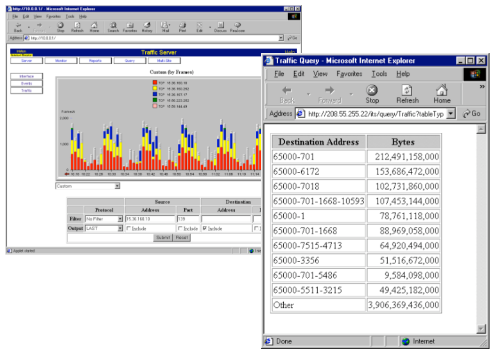


sFlow

RMON

NetFlow

Traffic Analysis & Accounting Solutions



- Network-wide, continuous surveillance
  - 20K+ ports from a single point
- Timely data and alerts
  - Real-time top talkers
  - Site-wide thresholds and alarms
- Consolidated network-wide historical usage data

5. Traffic Measurement: Some Case Studies

What Traffic Reports Do We Need? [1/2]

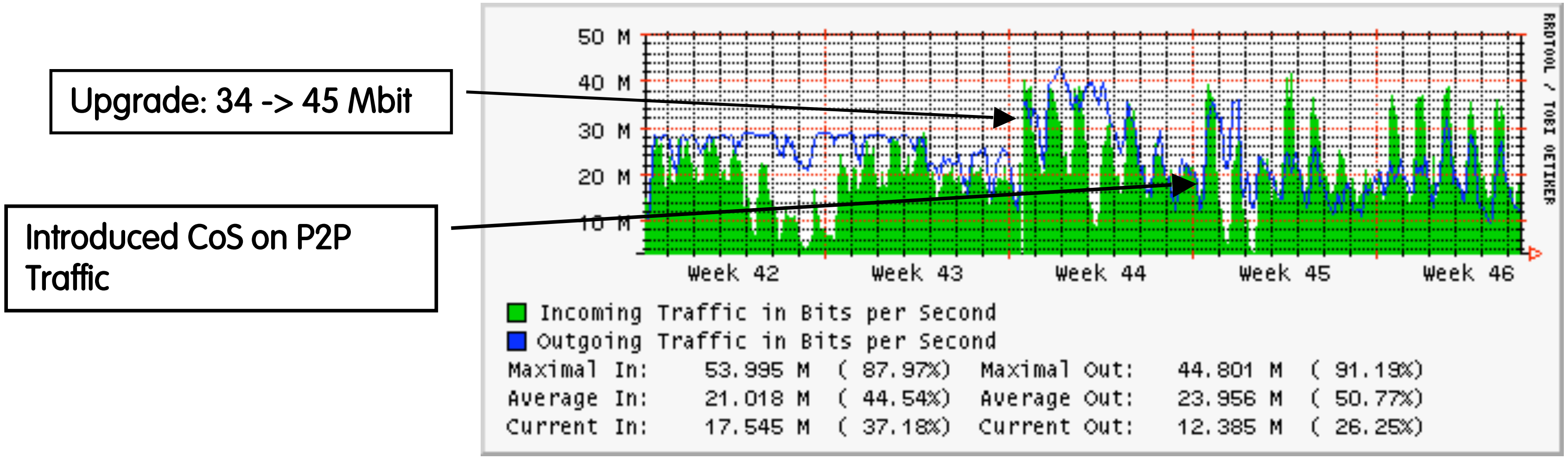
- Top N talkers (those who transmit most traffic).
- Top N conversations (the host pairs that transmit most traffic between each other).
- Top N Applications (e.g. SAP is using 70% of the available bandwidth).
- Data volume per entity basis (link, location, region, class of users).

What Traffic Reports Do We Need? [2/2]

- Data volume and rates per AS (e.g. do we need to sign a new peering contract ?).
- QoS marking per application or entity basis (e.g. does BGP reports us that we're sending the traffic on the optimal path ?).
- Reports about traffic we don't expect to see on the network (e.g. why host X is sending IPX packets although we speak pure IP ?).

Case Study: Bandwidth Management [1/3]

- Lack of bandwidth issues are not tackled purchasing additional bandwidth but managing the existing bandwidth.
  - Lesson learnt: the more bandwidth you have, the more you will use.



Case Study: Bandwidth Management [2/3]

- Solution: Monitor and Find the Answer Yourself for Your Network (there's no general solution).
  - Analyze how the available bandwidth is used (e.g. why protocol X is used ?).
  - Traffic and Flow matrix: who's talking to who and what data are they exchanging ?

Case Study: Bandwidth Management [3/3]

Lessons Learnt from Practice:

- Poor performance can be due to use of backup-links because primary ones are unavailable (do you monitor failovers -via SNMP traps- such as STP, port status ?)
- Is your routing suboptimal or very dynamic? (SNMP provides you several MIBS for this purpose).
- Are you shaping too much? CoS (Class of Services) are good but don't misuse them! (Why don't you monitor the amount of traffic that is cut by your policers ?)

Case Study: Network Security

Security is a process not a product (BS7799).

- Are you able to detect network anomalies ?
- Are you sure you know what to monitor ? Most of issues are produced by traffic we never expect to see in your network: monitor everything, filter things you expect to see, look at the rest and explain this happened.
- Do you have an automatic fault recovery ? Supposing you detect the problem (e.g. SNMP trap) is your system reacting automatically or waiting for you to come back from holidays ?

Case Study: P2P Detection

- P2P is hard to detect with standard methods:
  - It cannot be detected using fingerprints (e.g. port-2-protocol association).
- However it can be detected…
  - It can be detected in terms of deviation for a standard behaviour (e.g. a workstation cannot open more than X connections/minute nor keep more than Y connections open).
  - Analysis of initial payload bytes in order to detect the protocol.
  - High percentage of unsuccessful TCP connection establishment.
  - Packets/Bytes ratio above the average (P2P sources send many packets, mostly for talking with peers).
  - Identification of client-to-client (> 1024) communications with no FTP command channel open.

Case Study: SPAM Detection

- Large, open networks (e.g. universities, ISPs) are the best places for sending spam (unsolicited email).
- How to identify SPAM sources:
  - Problem similar to P2P but simpler (SMTP-only, 1 connection = 1 email) .
  - Select the set of top N SMTP senders.
  - Remove from the set all the known SMTP servers.
  - Studies shown that in average an host does not send more that 8-10 emails/minute.
  - Very simple problem to tackle using flow-based protocols such as NetFlow.

Case Study: Virus/Trojan Detection

- Problem similar to SPAM detection but more complex as the protocol/ports used are not fixed.
- Attacks do not have a precise target: they somehow behave as network scanners.
- Detection:
  - If the problem is known (e.g. traffic on UDP port 135) focus only on these selected traffic patterns.
  - Keep an eye on ICMP messages (e.g. port/destination unreachable) as they are the best way to detect network scanners.

6. Final Remarks

So What Can we Basically Expect from Network Monitoring ?

- Ability to automatically detect those issues that are permanently monitored (e.g. no traffic on the backbone link: network down ?).
- Receive alarms about potential (e.g. CPU utilization is too high) and real (e.g. disk is full) problems.
- Automatic notification and restore for known problems with known solutions (e.g. main link down, the backup link is used).
- Report to humans for all those problems that need attention and that cannot be restored (e.g. host X is unreachable).

Monitoring Caveats

- If a monitoring application needs human assistance for a problem that could be solved automatically, then the monitoring applications is not completely useful.
- Alarm (100% sure that there is something wrong) != Warning (maybe this is an issue): don't pretend to be precise/catastrophic if this is not the case.
- Alarms are useless if there's nobody who looks at them.
- Too many (false) alarms = no alarm: humans tend to ignore facts is some of them are proven to be false.