OAM Functions: Error Reporting, Configuration, Management (ICMP, DHCP, NAT, SNMP)

Shivkumar Kalyanaraman
Rensselaer Polytechnic Institute
shivkuma@ecse.rpi.edu
http://www.ecse.rpi.edu/Homepages/shivkuma

Based in part upon slides of Prof. Raj Jain (OSU), S.Deering (Cisco), C. Huitema (Microsoft)
Overview

- Operations and Management (OAM)
- Error Reporting (ICMP); Tools: ping, traceroute
- Configuration: RARP, BOOTP, DHCP
- Address Management: DHCP, Private Addresses, NAT, RSIP
- Network Management: SNMP, RMON

- Ref: Chap 5,6,9,20,23,30: Doug Comer textbook, Interconnections by Perlman
- Reference Site: IETF NAT Working Group
- Reference: RFC 2663: IP Network Address Translator (NAT) Terminology and Considerations: In HTML
- Reading: RFC 3022: Traditional IP Network Address Translator (Traditional NAT):
ICMP Features

- Used by IP to send error and control messages
- Uses IP to send its messages
- Does not report errors on ICMP messages.
- ICMP message are not required on datagram checksum errors.
- ICMP reports error only on the first fragment
### ICMP Message Format

<table>
<thead>
<tr>
<th>Field</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP Header</td>
<td>8b</td>
</tr>
<tr>
<td>Type of Message</td>
<td>8b</td>
</tr>
<tr>
<td>Error Code</td>
<td>8b</td>
</tr>
<tr>
<td>Checksum</td>
<td>16b</td>
</tr>
<tr>
<td>Parameters, if any</td>
<td>Var</td>
</tr>
<tr>
<td>Information</td>
<td>Var</td>
</tr>
</tbody>
</table>

- ICMP error messages normally include the IP header of the datagram that generated the error, plus at least 8 bytes following the IP header =>
- **Typical ICMP message sizes = 70 bytes**
Sample ICMP Messages

- **Echo Request/Reply:** *Used in ping*
- **Source Quench:** Please slow down! I just dropped one of your datagrams.
  - Congestion control function: *deprecated…*
- **Time Exceeded:** Time to live field in one of your packets became zero.” or “Reassembly timer expired at the destination.
- **Fragmentation Required:** Datagram was longer than MTU and “No Fragment bit” was set.
  - Used in *fragmentation/reassembly and path MTU detection*
Sample ICMP Messages (Continued)

- **Address Mask Request/Reply**: What is the subnet mask on this net? Replied by “Address mask agent”
- **Redirect**: Send to router X instead of me.
  - *Configuration functions… Redirect used. Mask config handled by BOOTP/DHCP.*
- **Time Stamp Request/Reply**: used to find current time or RTT.
  - *Deprecated…*
### ICMP: Message Types Summary

<table>
<thead>
<tr>
<th>Type</th>
<th>Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Echo reply</td>
</tr>
<tr>
<td>3</td>
<td>Destination unreachable</td>
</tr>
<tr>
<td>4</td>
<td>Source quench</td>
</tr>
<tr>
<td>5</td>
<td>Redirect</td>
</tr>
<tr>
<td>8</td>
<td>Echo request</td>
</tr>
<tr>
<td>11</td>
<td>Time exceeded</td>
</tr>
<tr>
<td>12</td>
<td>Parameter unintelligible</td>
</tr>
<tr>
<td>13</td>
<td>Time-stamp request</td>
</tr>
<tr>
<td>14</td>
<td>Time-stamp reply</td>
</tr>
<tr>
<td>15</td>
<td>Information request</td>
</tr>
<tr>
<td>16</td>
<td>Information reply</td>
</tr>
<tr>
<td>17</td>
<td>Address mask request</td>
</tr>
<tr>
<td>18</td>
<td>Address mask reply</td>
</tr>
</tbody>
</table>
ICMP-based tools: *Ping*

- **Ping**: Used to test
  - destination reachability,
  - compute round trip time
  - count the # of hops to destination
  - may provide record route option.

- Ping failure does not guarantee unreachability. Firewalls may filter pings.
ICMP-based tools: *Traceroute*

- **Traceroute:** Exploit TTL and ICMP
  - Send the packet with time-to-live = 1 (hop)
  - The first router discards the packet and sends an ICMP “time-to-live exceeded message”
  - Send the packet with time-to-live = 2 (hops) etc…
- Does not use optional features like record route
ICMP-based tools: Path MTU Discovery

- Send a large IP datagram with “Don’t fragment” bit set.
  - Failure to fragment at a link will result in ICMP message.
  - Later version of ICMP specifies MTU size in such ICMP messages.
- Reduce MSS until success (No ICMP message received)
Configuration: Issues

- Configuration: give protocols the parameters they need to operate
- Several things to configure... Eg scenario:
7 Things to configure…

- 1. End systems need Layer 3 address, names, masks
- 2. Router finds Layer 3 addresses of end systems
- 3. Router finds Layer 2 addresses of end systems
- 4. End systems find a (default) router, name server
- 5. End nodes on the same LAN discover that they can send directly to each other
- 6. End systems find the best router for exit traffic
- 7. End systems communicate on a router-less LAN

- Typically end systems only know their hardware (IEEE 802) address…
Method 1: Reverse ARP (RARP)

- H/w (MAC) address -> IP address mapping
  - End system broadcasts RARP request…
  - RARP server responds.
- Once IP address is obtained, use “tftp” to get a boot image. Extra transaction!

RARP design complex:

- RARP server is a user process and maintains table for multiple hosts (/etc/ethers). Contrast: no ARP server
- RARP needs a unique Ethernet frame type (0x8035) & works through a special kernel-level filter
- Multiple RARP servers needed for reliability
  - RARP servers cannot be consolidated since RARP requests are broadcast => router cannot forward
- After all this, you get only the L3 (IP) address
Method 2: BOOTP

- Runs over UDP/IP as a user process
  - IP software can broadcast (to 255.255.255.255) even if local IP address unknown => client broadcasts BOOTP request
  - Port number 67 for server and 68 for client (not an ephemeral port)
  - Delivers BOOTP reply to BOOTP client and not other UDP apps when reply is broadcast
  - Does not wake up other servers during broadcast reply
BOOTP (Continued)

- BOOTP requests/replies sent w/ DF bit set.
- Server can send reply via broadcast or unicast:
  - For unicast reply, BOOTP server knows the IP address, but the link layer address is not in the ARP cache.
  - Note that the server cannot send an ARP message because client does not know its IP address.
- Server can use ioctl(8) {or arp -s } to set the value of the cache based upon BOOTP request => can do this only if it has permission.
BOOTP Features (Continued)

- Else send broadcast reply
- Reply: IP Address, Boot Server IP address, Default Router, Boot file name, subnet mask
- More information, but still only a single packet exchange
- Client gets boot image using TFTP => booting still a 2-step process
Advantages of using UDP/IP:
- Bootstrapping can occur across a router via a relaying mechanism
- BOOTP uses checksum provided by UDP

Multiple requests/replies
- Process the first one
- Client uses a transaction ID field to sort out replies

Clients responsible for reliability
- Uses timeout, retransmission & exponential backoff
- Random initial timeout (between 0 & 4s): simultaneous reboot after power restoration.
<table>
<thead>
<tr>
<th>Field</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>1</td>
</tr>
<tr>
<td>H/W Type</td>
<td>1</td>
</tr>
<tr>
<td>H/W Length</td>
<td>1</td>
</tr>
<tr>
<td>Hops</td>
<td>1</td>
</tr>
<tr>
<td>Transaction Identifier</td>
<td>16</td>
</tr>
<tr>
<td>Seconds elapsed</td>
<td>64</td>
</tr>
<tr>
<td>Unused</td>
<td>64</td>
</tr>
<tr>
<td>Client IP Address</td>
<td>16</td>
</tr>
<tr>
<td>Your IP Address</td>
<td>64</td>
</tr>
<tr>
<td>Server IP Address</td>
<td>128</td>
</tr>
<tr>
<td>Router IP Address</td>
<td>64</td>
</tr>
<tr>
<td>Client H/W address</td>
<td></td>
</tr>
<tr>
<td>Server Host Name</td>
<td></td>
</tr>
<tr>
<td>Bootfile Name</td>
<td></td>
</tr>
<tr>
<td>Vendor Specific Area</td>
<td></td>
</tr>
</tbody>
</table>
BOOTP Message (Continued)

- Operation: 1 = Request, 2 = Reply
- H/w type: 1 = Ethernet
- H/w Address Length
- Hops: Initialized to zero. Incremented by BOOTP relays (routers)
BOOTS Message

- **Boot File name**: Generic name like "unix" in the request. Full name in response.
- **Vendor specific area**: Misnomer. Also used for general purpose info.
- **Magic cookie**: First 4 octets = 99.130.83.99
- **Type-length-value**: describes the option

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Padding</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Subnet mask</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Time of Day</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>End</td>
<td>255</td>
<td>-</td>
</tr>
</tbody>
</table>
Method 2a: DHCP

- **BOOTP limitation:** cannot dynamically assign IP address
- Dynamic Host Configuration Protocol (DHCP)
  - **BOOTP + Dynamic allocation** of IP addresses
    => compatible with BOOTP.
  - No new fields in header.
  - Addresses can be **leased** for a period. Reallocated to the same or other nodes after lease expiry.
# DHCP Message Format

<table>
<thead>
<tr>
<th>Field</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>1 B</td>
</tr>
<tr>
<td>H/W Type</td>
<td>1 B</td>
</tr>
<tr>
<td>H/W Length</td>
<td>2 B</td>
</tr>
<tr>
<td>Hops</td>
<td>1 B</td>
</tr>
<tr>
<td>Transaction Identifier</td>
<td>6 B</td>
</tr>
<tr>
<td>Seconds elapsed</td>
<td>4 B</td>
</tr>
<tr>
<td>Flags</td>
<td>1 B</td>
</tr>
<tr>
<td>Client IP Address</td>
<td>4 B</td>
</tr>
<tr>
<td>Your IP Address</td>
<td>4 B</td>
</tr>
<tr>
<td>Server IP Address</td>
<td>4 B</td>
</tr>
<tr>
<td>Router IP Address</td>
<td>4 B</td>
</tr>
<tr>
<td>Client H/W address</td>
<td>4 B</td>
</tr>
<tr>
<td>Server Host Name</td>
<td>16 B</td>
</tr>
<tr>
<td>Bootfile Name</td>
<td>64 B</td>
</tr>
<tr>
<td>Options (Variable)</td>
<td>128 B</td>
</tr>
</tbody>
</table>
DHCP States

- Boots => INITIALIZE state
- DHCPDISCOVER: broadcast request to servers => SELECT state
- DHCPOFFER (from server) => remain in SELECT
- DHCPREQUEST => select one of the offers and notify server (goto REQUEST state) about the lease
DHCP States (Continued)

- **DHCPACK** => server Oks request to lease => go to the **BOUND** state
- **Renewal**: after 50% of lease go to **RENEW** state
- **Rebind**: after 87.5% of time, if server has not responded, try again and go to **REBIND**.
- If server NACKs or lease expires, or client sends **DCHPRELEASE**, go to **INITIALIZE**, else come back to **BOUND** state
Answer to 7 config problems…

- 1. End systems: Layer 3 address, names, masks: DHCP
- 2. Router finds Layer 3 addresses of end systems: Same network ID (i.e. IP prefix)
- 3. Router finds Layer 2 addresses of end systems: ARP
- 4. End systems find a default router, name server: DHCP
- 5. End nodes on the same LAN discover that they can send directly to each other: Same network ID + ARP
- 6. End systems find the best router for exit traffic: ICMP Router Redirect
- 7. End systems communicate on a router-less LAN: need a DHCP server at least. Same prefix => same LAN; ARP

- Zeroconf IETF WG: networking without server-based configuration in certain scenarios…

Shivkumar Kalyanaraman
NAT: translate addresses, without changing the application

10.0.1.2 192.1.2.3

A  NAT  B

Private addresses  Global Internet

128.96.41.1
Address Management: Private Addresses

- Since IPv4 addresses are scarce, enterprises may use private addresses within their “realms”

<table>
<thead>
<tr>
<th>Class</th>
<th>Private Address Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10.0.0.0 ... 10.255.255.255</td>
</tr>
<tr>
<td>B</td>
<td>172.16.0.0 ... 172.16.255.255</td>
</tr>
<tr>
<td>C</td>
<td>192.168.0.0 ... 192.168.255.255</td>
</tr>
</tbody>
</table>

- Need to get “globally unique” public addresses for external use.
- Mapping between public & private addresses done by NAT (Network Address Translator)
Simple NAT operation
Dynamic NAT = NAT + DHCP
Network Address Port Translation (NAPT)
NAPT (contd)

- Also known as IP masquerading. Allows many hosts to share a single IP address differentiated by port numbers.

- Eg: Suppose private hosts 192.168.0.2 and 192.168.0.3 send packets from source port 1108.

- NAPT translates these to a single public IP address 206.245.160.1 and two different source ports, say 61001 and 61002.

  - Response traffic received for port 61001 is routed back to 192.168.0.2:1108,
  - Traffic for port 61002 traffic is routed back to 192.168.0.3:1108.
Realm-Specific IP (RSIP)

- NAT (and NAPT) have to mess with several transport/application level fields.
- NAT breaks IPSec…. Solution: RSIP
- RSIP leases public IP addresses and ports to RSIP hosts => not transparent like NAT.
  - RSIP does not operate in stealth mode and does not translate addresses on the fly.
- RSIP allows hosts to directly participate concurrently in several addressing realms.
- Avoids violating the end-to-end nature of the Internet => allows IPSec
RSIP “external address server”, eliminating side effects of NATs

But the applications must be upgraded…

A

B

RSIP

10.0.1.2

192.1.2.3

Global Internet

Private addresses

128.96.41.1

Rensselaer Polytechnic Institute

Shivkumar Kalyanaraman
RSIP with “net 10” is a limited solution

- Not as easy to deploy as NAT
  - need to agree on a standard RSIP protocol,
  - need to upgrade the applications.
- Not as future-proof as IPv6
  - extensions by sharing address + ports between stations
  - one station may well use 256 ports,
  - hence RSIP = IPv4 + 8 bits = 40 bit addresses,
  - at most 4 billion networks.
- Limited interest in RSIP at this point…
network address translators and app-layer gateways
- inevitable loss of some semantics
- hard to diagnose and remedy end-to-end problems
- stateful gateways inhibit dynamic routing around failures
- no global addressability => brokered with NATs
- new Internet devices more numerous, and may not be adequately handled by NATs (e.g., mobile nodes)
Argument against NATs

- End-to-end vs Optimizations
- Short term problem
  - Connect many computers,
  - IP address are expensive
- Short term optimization
  - Use a NAT box,
    - Hide many computers behind one address
    - Works well for web clients...
- Addresses are the key...
  - Scarcity: the user is a “client”
  - Plethora: the user is a “peer”

Qn: Today’s optimizations, tomorrow’s roadblocks?
Argument against NATs…

- they won’t work for large numbers of “peers”, i.e., devices that are “called” by others (e.g., IP phones)
- they break most current IP multicast, IP mobility, IP Security protocols
- they break many existing and emerging applications
- they limit the market for new applications and services
- they compromise the performance, robustness, security, and manageability of the Internet
Can’t We Make NATs Better?

- we could keep adding more protocols and features to try to alleviate some of their shortcomings
  - might improve their functionality, but will increase their complexity, fragility, obscurity, unmanageability,…
  - new problems will arise when we start needing inter-ISP NAT

- **Anti-NAT suggestion:** moving to IPv6 will avoid the need to continue doing many other things to keep the Internet working and growing
  - IPv6 is not the only possible solution, but the most mature, feasible, and widely agreed-upon one
Network Management

- Management = Initialization, Monitoring, Control
  - Today: automated, reliable diagnosis, and automatic control are still in a primitive stage

- **Architecture:** Manager, Agents & Management Information Base (MIB)

- Observe that management-plane has a new interface to the network distinct from data-, and control-plane
SNMP History

- Early: based upon ICMP messages (eg: ping, source routing, record routing)
- A lot of informal network debugging is done using tcpdump, netstat, ifconfig etc
- When the internet grew, Simple Gateway Management Protocol (SGMP) was developed (1987)
- Build single protocol to manage OSI and IP
  - CMIP (an OSI protocol) over TCP/IP {called CMOT}
  - Goal: Keep object level same for both OSI and IP
  - CMOT progressed very sluggishly
- SNMP: parallel effort. Very simple => grabbed the market.
SNMP

- Based on SGMP
- Simple: only five commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>get-request</td>
<td>Fetch a value</td>
</tr>
<tr>
<td>get-next-request</td>
<td>Fetch the next value</td>
</tr>
<tr>
<td>get-response</td>
<td>Reply to a fetch operation</td>
</tr>
<tr>
<td>set-request</td>
<td>Set (store) a value</td>
</tr>
<tr>
<td>trap</td>
<td>Agent notifies manager</td>
</tr>
</tbody>
</table>

- Simple: handles only scalars. “get-next-request” used successively to get array values etc
- SNMP is bare-bones protocol to support monitoring & management
SNMP (Continued)

- Stateless => one management station can handle hundreds of agents
- Simple: Works as an application protocol running over UDP
- Agent and manager apps work on top of SNMP
- Proxy-SNMP can be used to manage a variety of devices (serial lines, bridges, modems etc).
  - Proxy (similar to bridge) is needed because these devices may not run UDP/IP
  - For each new device define a new MIB.
Management Information Base (MIB)

- Specifies *what variables the agents maintain*
- Only a *limited number of data types* are used to define these variables
- MIBs follow a fixed naming and structuring convention called “Structure of Management Information” (SMI). See next slide.
Management Information Base (MIB) (Continued)

- Variables are identified by “object identifiers”
  - Hierarchical naming scheme (a long string of numbers like 1.3.6.1.2.1.4.3 which is assigned by a standards authority)
  - Eg:
    - iso.org.dod.internet.mgmt.mib.ip.ipInReceives
    - 1.3.6.1.2.1.4.3
Global Naming Hierarchy

ccitt(0)

iso (1)

joint-iso-ccitt (2)

standard (0)

iso9314 (9314)

fddiMIB (1)

org (3)

dod (6)

internet (1)

directory (1)

mgmt(2)

experimental (3)

private (4)

mib (1)

system (1)

interfaces (2)

transmission (10)

fddi (15)

fddimib (73)

fddi (8)

Internet SMI is this subtree

Shivkumar Kalyanaraman
MIB (Continued)

- All names are specified using a subset of Abstract Syntax Notation (ASN.1)
- **Types**: INTEGER, OCTET STRING, OBJECT IDENTIFIER, NULL
- **Constructors**: SEQUENCE (like struct in C), SEQUENCE OF (table i.e. vector of structs), CHOICE (one of many choices)
- ASN.1 provides more types and constructors, but they are not used to define MIBs.
Standard MIBs

- For every new device, write MIB for it and include it as a branch of MIB-II.
- MIB-II (RFC 1213) a superset of MIB-I (RFC 1156).
- Only “weak” objects. Tampering => limited damage.
- No limit on number of objects (unlike MIB-I).
- Contains only essential objects. Avoid redundant objects, and implementation-specific objects.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Category</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>sysUpTime</td>
<td>system</td>
<td>Time since last reboot</td>
</tr>
<tr>
<td>ifNumber</td>
<td>interfaces</td>
<td># of Interfaces</td>
</tr>
<tr>
<td>ifMTU</td>
<td>interfaces</td>
<td>MTU</td>
</tr>
<tr>
<td>ipDefaultTTL</td>
<td>ip</td>
<td>Default TTL</td>
</tr>
<tr>
<td>ipInReceives</td>
<td>ip</td>
<td># of datagrams received</td>
</tr>
<tr>
<td>ipForwDatagrams</td>
<td>ip</td>
<td># of datagrams forwarded</td>
</tr>
<tr>
<td>icmpInEchos</td>
<td>icmp</td>
<td># of Echo requests received</td>
</tr>
<tr>
<td>tcpRtoMin</td>
<td>tcp</td>
<td>Min retrans time</td>
</tr>
<tr>
<td>tcpMaxConn</td>
<td>tcp</td>
<td>Max connections allowed</td>
</tr>
</tbody>
</table>
Instance Identification

- How does the manager refer to a variable?
  - **Simple variables**: append ".0" to variable’s object identifier
    - Eg: `udpInDatagrams.0 = 1.3.6.1.2.1.7.1.0`
    - Only leaf nodes can be referred (since SNMP can only transfer scalars)
Instance Identification (Continued)

- *Table elements:*
  - Each element in a table needs to be fetched separately.
  - Traverse MIB based upon *lexicographic ordering* of object identifiers using get-next
  - *Column-by-column:* Elements of each column first.
RMON

- Remote Network Monitoring
- Defines remote monitoring MIB that supplements MIB-II and is a step towards internetwork management
- It extends SNMP functionality though it is simply a specification of a MIB
- Problem w/ MIB-II
  - Can obtain info that is purely local to individual devices
  - Cannot easily learn about LAN traffic as a whole (eg like LAN analyzers or “remote monitors”)
RMON (Continued)

- Functionality added: Promiscuously count, filter and store packets
- System that implements RMON MIB is called an RMON probe (or less frequently, an RMON agent).
  - No changes to SNMP protocol.
  - Enhance the manager and agents only.
- RMON MIB organization:
  - Control table: read-write. Configures what parameters should be logged and how often.
  - Data table: read-only (statistics etc logged)
- Other issues: shared probes, ownership of tables, concurrent table access ...
Summary

- Error reporting is a separate protocol in IP: ICMP
  - Features help build neat tools: ping, traceroute etc
- Configuration:
  - 7 basic configuration problems
  - Internet solution: ARP, DHCP (server-based)
  - Earlier attempts: RARP, BOOTP
- Address Mgmt: Private addresses, NAT, NAPT, RSIP
- Management = Initialization, Monitoring, and Control
  - SNMP = Only 5 commands (simple polled transfer of management information)
  - MIB: labeling of mgmt info using ASN.1 encoding
  - Standard MIBs defined for each object
  - RMON extends management functionality through definition of a new MIB (no protocol changes)