Security Level:

Building Dual Stack IPv4 / IPv6 Router On Linux

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This Session Will Talk about -

- Current IPv4 Residential/SOHO Router Capabilities
  - Key Features ISPs require
- Well known IPv4 Limitations
- Brief IPv6 Background – relevant topics
- Linux Connection tracking, NAT, ALGs in IPv4 and IPv6
- IPv6 Integration of Connection tracking
- CPU Network Offload Linux Integration
- Brief 6rd overview
- Cable eRouter Dual-Stack Implementation

IPv4 Residential/SOHO Router Basic Features

- **Gateway – ISPs view as focal hub for**
  - Cable/IPTV streaming to consumer devices
  - Media Server, NAS/Print server, Home Automation, Guest Access
  - ISP – eventually IPv6 Support required
- **Provisioning - DHCPv4/DNS Client, Server (PPPoE, PPTP, L2TP going away) – Impacts IPv6**
  - IPv6 Provisioning - WAN dhclient6 – IP address; LAN Prefix delegation + host OUI Unique IP and DHCP info request
  - DNS – proxy server/or direct recursive – can handle resolving/caching 'AAAA' records
- **Performance**
  - Lowest 116Mbps/DS – 104Mbps/US – both DOCSIS/GPON will push up to 1Gbps
  - Packet routing Zero impact to application Processor – ISPs require Offload engine for predictable growth
- **Network Features**
  - NAT – IPv6 N/A - Whole purpose of IPv6 – global IP space
  - Bridging (i.e. Wireless/LAN, others) – IPv6 no impact
    - Bridged LAN+SSID and/or VLANs – only L2 header matters
  - WDS – depending on topology - at L2 no impact at L3 extra configuration – rare configuration.
  - VLANs (port based/Tagged) – Some IPv6 Impact
    - For routed vlan interfaces – Typical IPv6 Provisioning – LL, Prefix+OUI, DAD, IPv6 Routing

IPv4 Residential/SOHO Basic Router Features

- Basic Wireless Networking (user/guest) SSID – Some IPv6 Impact
  - Similar to VLANs – SSID an interface – guest SSIDs, hot-spots – IPv6 FW rules
- Advanced Wireless Networking (WPA/WPA2 Enterprise) – IPv6 Impact - Maybe
  - For EAP-TLS, EAP-PEAP, EAP-TTLS - Authenticator – maybe use IPv4 Radius – depends on ISP reqs.
- Routing – Heavy IPv6 impact
  - Different L2 → L3 hooks, routing table, cache, policy based routing, configuration differs
- Port Forwarding, DMZ – IPv6 N/A
  - Not needed in IPv6 private network dests can be reached directly, in IPv4 Dest is always GW Public IP
- Multicast routing
  - In IPv4 Gateway manages hosts queries/reports and forwards them on WAN and sets up multi-cast routes
  - Same is needed in IPv6

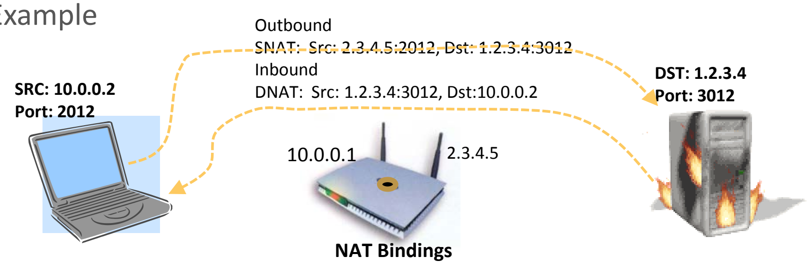
IPv4 Residential/SOHO Router Features

- **Security**
  - IP/Port/Protocol Filtering - Same considerations as IPv4, require IPv6 FW rules
  - ALGs
    - Same considerations as IPv4 (with exception of packet rewrite), require IPv6 equivalent ALGs for port opening
  - SPI
    - Same considerations as IPv4 (tracking original/reply directions), require IPv6 equivalent FW rules
  - Port Triggering - impacts IPv6
    - Same considerations as IPv4 (open in-bound port based on configured out-bound port), require IPv6 equivalent impl.
  - UPnP IGD – IPv6 impact

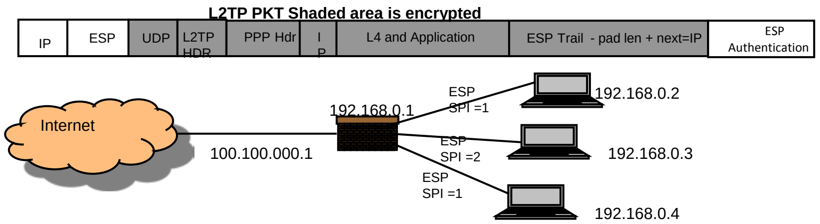
- **Management/Accessibility**
  - SSH, TFTP
    - For management require both protocol types to work
  - Web (HTTP/HTTPS)
    - For UI require access from both protocols
  - SNMP
    - Manage SNMP MIBs for IPv6 as well
  - NTP – may not require IPv6
- **Many other features** - **Gateways today do lot more work! -** NAT Bypass, VPN Pass-Through , Routed Subnets, Parental Control, TR-69, Wireless Roaming,….

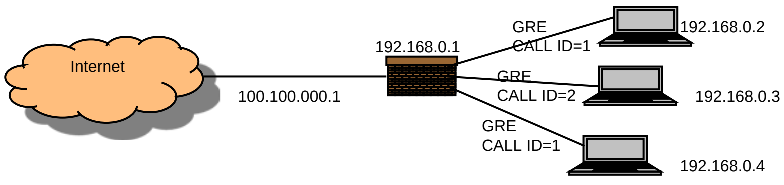
Well known IPv4 Limitations

- **Well known Issues with IPv4 –**
  - Small IP Range – NAT implemented to reuse (private address range 10.xx…, 192.168….., 172.16. …) – Basic NAT operation Example



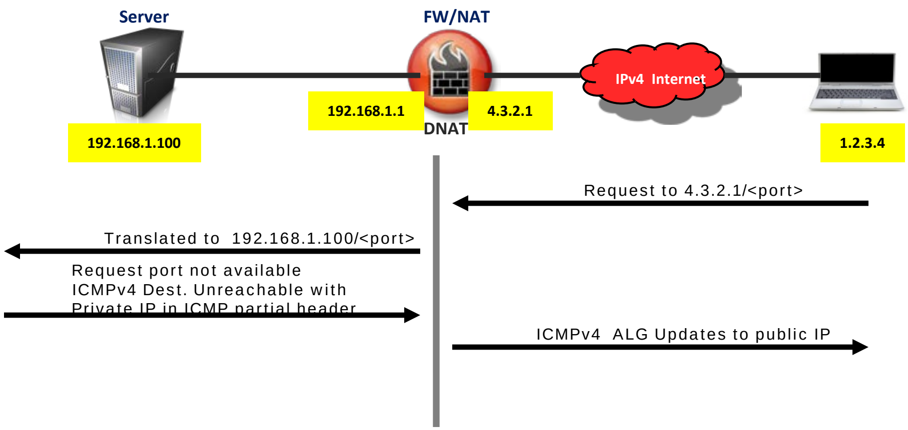
- **NAT introduces many issues –** Performance – SNAT on way out, DNAT on way in – packet rewrite, IP, TCP checksum update
  - NATs come in different flavors –
    - Symmetric (original dst ip/port only) – most restrictive
    - Full Cone (any ip/port) – least restrictive – can handover connection to other server
    - Restricted Cone NAT (original dst, any port) – handover within server
    - Restricted Port NAT (any dst, orig dst port) – handover across server with same port
    - NAT traversal discovery protocols STUN, TURN, ICE
    - IPv6 – Can connect from any IP/port to private device behind FW (TCP/UDP)
  - Packet Rewrite (aka ALGs) – few protocols affected – complicates processing, affects CPU offload engines – few examples
    - PPTP (uses GRE) – several clients behind FW with same Call ID connecting to Server – must rewrite Call ID (on way out and in)





Well known IPv4 Limitations

- **ICMP – Public or Private IP can't be revealed to client**
  - Other important protocols – TFTP, FTP, RTSP, SIP, Kerberos, DNS – used under all sorts of circumstances by ISPs



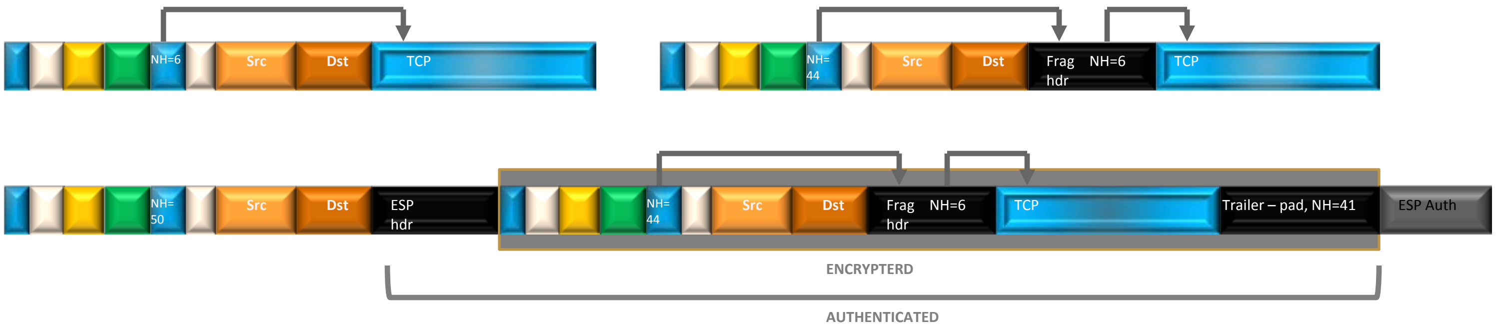
Related IPv6 Background

- **Primarily based on Cable eRouter standard for IPv6 delivery to premises**
- **IPv6 Addressing**
  - In theory IPv6 has 340,282,366,920,938,463,463,374,607,431,768,211,456 address and IPv4 4,294,967,296 in practice 64 bits are used for subnet mask and 64 bits for host, probable to further subdivide the subnet without OUI usage
  - IPv6 addresses can be huge - f.e. *1**28.91.45.157**.220.40.0.0.**0.0.252.87**.212.200.31.20 - this would be an IPv6 address*
  - *New Notation – compact hex with 16 bits → 805B:2D9D:DC28:0000:0000:FC57:D4C8:1F14 and multiple 0's can be collapsed so address becomes 805B:2D9D:DC28**::**FC57:D4C8:1FFF*
  - *Subnet notation CIDR like → 805B:2D9D:DC28**::***/48 – routing prefix match is on first 48 bits
  - Address Space Allocation dictated by bit prefixes
    - Loopback → ::1/128 – the 0's collapse to ::
    - Global Unicast → 2000::/3
    - Link-Local unicast → FE80::/10 – address in range can't make it outside of subnet
    - Multicast → FF00::/8
      - 4-byte defines scope 2 – link local, …, 8 site local – MC can go beyond local subnet: FF02::1 all nodes MC, …
    - Unspecified address → ::/128 – f.e. in DHCP messages when host does not know its IP address
  - *The elegant notation for 'loopback' interface comes from here - 0:0:0:0:0:0:0:1* is reduced to ***::1***
  - IPv6 address Network/Host; Host is OUI constructed - for MAC = 39-A7-94-07-CB-D0 Host is: 3BA7:94**FF:FE**07:CBD0
  - IPv6 Header is 40 bytes – twice IPv4 size

4b	8b	20b	16b	8b	8b	128b	128b
Version	TC	Flow Label	Payload Length	Next Header	Hop Limit	Source IP	Destination IP

Relevant IPv6 Background

- **IPv6 Packet Structure – combination of main header and extension header and option fields**
  - It does not have a header checksum
  - Next Header → TCP, UDP, Hop by Hop Header, ESP, AH, ICMPv6
  - Couple Examples – of IPv6 Payload construction



Relevant IPv6 Background

- Additional Extension Headers
  - Hop by Hop – options that can be inspected by each node
  - Destination Options – options targeted for destination
  - Routing Option – similar to LSR in IPv4, also used in conjunction with destination option
  - Fragment Header – illustrated above
  - ICMPv6 – Neighbor & Router Discovery
  - AH, ESP – headers – transport/tunneled mode
- Routers don't fragment, only hosts – minimum Fragment size changes from 576 to 1280
- Key Changes since IPv4
  - Renamed - Traffic class (IPv4 TOS), hop limit (IPv4 TTL)
  - Payload Length, Next Header, IPv4
  - Added - Flow Label; Removed - Internet Header Length, Identification, Flags (MF, ...), Fragment Offset, header checksum.

Link Configuration - Both Stateful and Stateless

- difference is for stateful address assignment has state associated with it
- Both built upon: Link Local Address , multicasting, ND (ICMPv6), OUI address generation and DHCPv6 (even in stateless)
- Key ICMPv6 Neighbor Discovery Protocol Messages– RS actively solicits for Routers to send RAs – sent to MC address 0xFF02::2 All routers MC address

ICMPv6 Router Solicitation (RS)

Type=133	Code 0	Checksum	....

ICMPv6 Router Advertisement (RA)

Type=134	Code 0	....	Hop Limit	AutoConf Flags M=manages,O=other	Default Router Lifetime in Sec.	Neighbor Reach. Time
NS Transmit Time		OPTIONS: Router Source Layer Address		MTU	Network Prefix(es)	

Related IPv6 Background

- **Neighbor Solicitation Messages, for Neighbor disc, DAD, IP addr change – msg types NS, NA**
- **Target address - 'Unsolicited Node MC Address' - FF02::1:FF<XX:YYYY> - followed by lower 24 bits of target IP address (33:33:FF:XX:YY:YY)**
- **Only Hosts subscribed to MC address receive – helpful to mobile devices in PM mode.**

ICMPv6 Neighbor Solicitation (NS)

Type=135	Code 0	Checksum	Target Address

ICMPv6 Neighbor Solicitation (NA)

Type=136	Code 0	Checksum	Router Flag R	Solicited Flag S	Override Flag O	L2 Target Address

- **Brief Overview Stateless Operation**
  - Link Local Address is generated - prefix '0xFE80::OUI L2 MAC' when interface is up f.e. fe80::20c:29ff:fece:6446/64
  - Address uniqueness test – NS issued, check for DAD
  - Issue RS or listen for RA – check M flag for stateless or stateful, O flag for other (typically with stateless)
  - Get and install advertised parameters: Network Prefix, Router L2 address for default GW, Router Lifetime, MTU & few ND params
- **Stateful Configuration**
  - RA from router sets the stateful flag host runs DHCP
- **Stateless + Managed**
  - Stateless configuration with DHCP to get various network config. params like DNS Server f.e. – common scenario

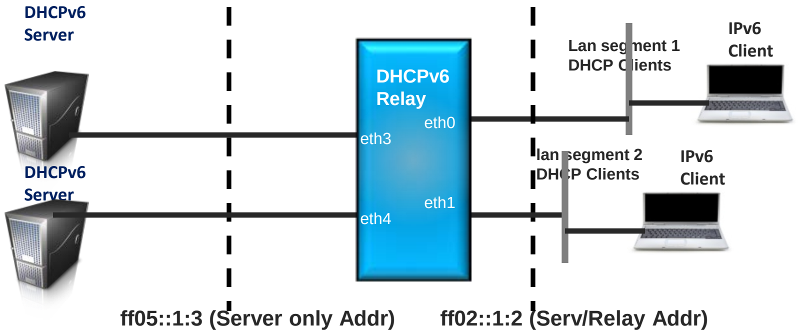
Related IPv6 Background

- **Primary Attributes of ICMPv6 ND**
  - Ethernet broadcasting eliminated
  - All hosts, All Routers, ND use Multi-Casting – host must be member of at least 3 MC groups – lower 24 bits of IP in solicitation
    messages used in MAC MC dest – f.e. for LL target Link Local: fe80::20f:3dff:fe7d:cbf MAC message: 0x33.33.FF.7D.0C.BF
    Target host subscribes to this MC address – it's the only one that will match
  - Only affected hosts are affected, good Mobile Devices in PM Mode

- **Security is built in – AH, ESP are another options that encapsulate the payload**
  - Allows even securing NS, NA functions – in IPv4 ARP can't be secured, MIM attacks eliminated
  - Eliminates NAT issues - with several clients behind the FW (when same SPI is used)
  - Related to security – scanning IPv6 address space much harder – larger address space

Related IPv6 Background

- **More on Stateful Configuration – More in Linux Dual-Stack GW**
- **DHCPv6 three primary goals**
  - Address Configuration
  - Non-Address Configurable Parameters (like DNS Server, Domain Name, NTP server …..)
  - Prefix delegation – provide several prefixes (eRouter implementation)
- **Client known as "Request Router", Server as "Delegating Router"**
- **DHCP Server and Relay agent MC address: FF02::1:2 – this MC Link scope**
  - Used by IPv6 DHCP clients, LL addresses are acceptable in source field for clients, although client may use the unspecified address ::0/128
  - The recipient(s) may be a Server or Relay agent
- **All DHCP servers MC address: FF05::1:3 – this site scope**
  - Used by relay agents to contact a DHCP server, in this case the relay agent must have non-LL address
- **UDP over IPv6, Client uses port 546 and server uses port 547, that is client sends to port 547, server replies to port 546.**



Related IPv6 Background

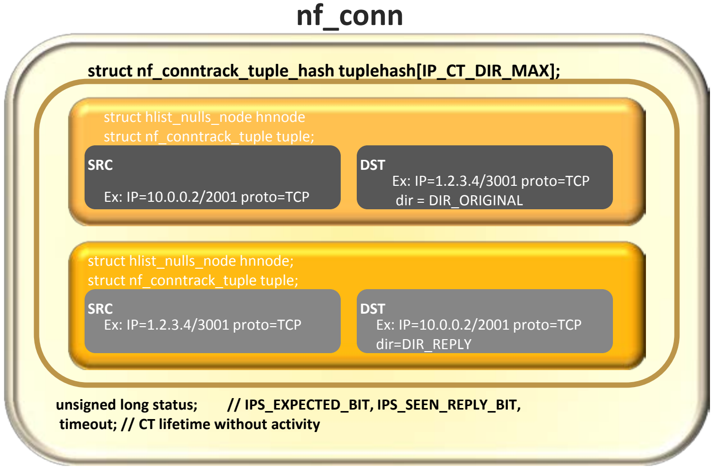
- **Architecture Principles**
  - Each subnet should not require a DHCP server, but at least a Relay agent
  - DHCP server in the cloud accessed through the FF02::1:2 relay agent. The relay agent then uses a site local address DHCP server.
  - There can be several DHCPv6 Relay agents in route.
  - Default DHCP client behavior is to send requests to local MC address
  - Clients in IPv6 are known by a DUID (as opposed to IPv4 *MAC* or *client user identifier option)*
    - Combination of MAC and some other string
  - *For relay – interface identifier used to route back responses (in above figure DHCP Relay disambiguates between LAN Segment 1 or 2).*
- **Messaging – many similarities to IPv4**
  - *SOLICIT, ADEVERTISE – client locate DHCP server, Server Advertises*
  - *REQUEST, REPLY – client request parameters including addresses, Server replies*
- **INFORMATION-REQUEST – client sends to server - reqst config params without an IP address assignment (F.e. Stateless + Managed)**
- **Two and Four Message Exchanges**
  - Two Message – 'Rapid Commit' - both client and server need to be configured for 'rapid commit'
    - The client sends a SOLICIT and internally sets the 'rapid commit' option,
    - server responds with REPLY IP and config info
  - Few other scenarios for 2-message exchange – like info request
- **Four Message Exchange – SOLICIT, ADVERTISE, REQUEST, REPLY**
- **DNS in IPv6**
  - New Resource Record 'AAAA' added for Forward Lookup – 'A' for IPv4
  - Reverse lookup – new reverse tree 'ip6.arpa' – 'in-addr.arpa' for IPv4

Background on Conn Tracking, NAT, FW for IPv4

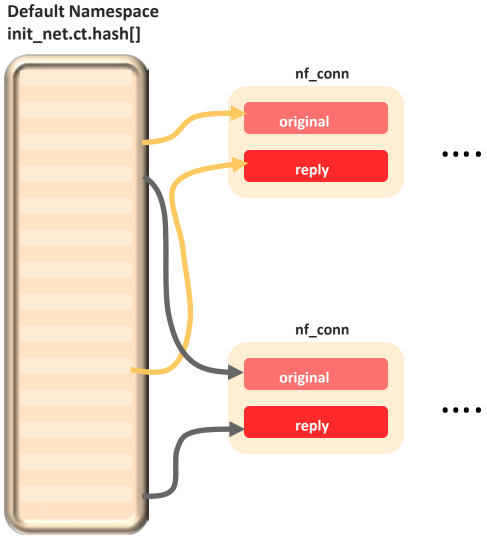
- Connection tracking – key concepts – few practical examples will follow
  - Key to understanding stateful, FW, NAT and CPU Offload Engine
  - Clear up confusion on ALGs in IPv6
  - Foundation of Stateful Packet Inspection
  - Conn tracking few key concepts
    - concept of ORIGINAL, REPLY direction
      - Monitor REPLY packet on receive – if FW rules – Filter/FORWARD – ESTABLISHED let through
    - conntrack structure with a hash – associated with each flow/session
    - FW rules integrated with conntracking – facilitates generic stateful packet inspection (i.e. FW rules)
  - NAT – requires conntracking – to manage mapping for SNAT (MASQUERADE SNAT variant), DNAT
  - Basis of ALGs – two parts – although coined as one –
    - Inbound Port opening (for example FTP)
    - Packet rewriting - (also FTP another good example)
  - ALGs build on conntracking
    - Basis of ALGs – helper to monitor packet flow of ALG control stream
    - On match create an expectation, on hit mark as RELATED, - Filter/FORWARD – RELATED let through
  - Network Offload Engine – Several reasons for it
    - New Technologies DOCSIS, GPON – high DL/UL data rates (128,256Mbps)
    - BOM – must be low
    - Preferable CPUs/SMP – built for high data rates into future – CPU(s) dedicated to Apps - QAM tuning/Stream MPEG over IP, D LNA/UPnP, NAS
    - Offload Engine – tightly integrated to contracking, ALGs
      - ALG Control stream let OS handle
      - Mansge TLU, entry into/out of OS
      - Mange conntrack states like – conntrack timeout
      - Many other – routing table updates, interfaces up/down, ….,

IPv4 Connection Tracking – SPI

- **Key Connection Tracking Structures**
  - tuplehash – has the original and reply tuples and links for hash table
  - status – and other fields pointers, important later

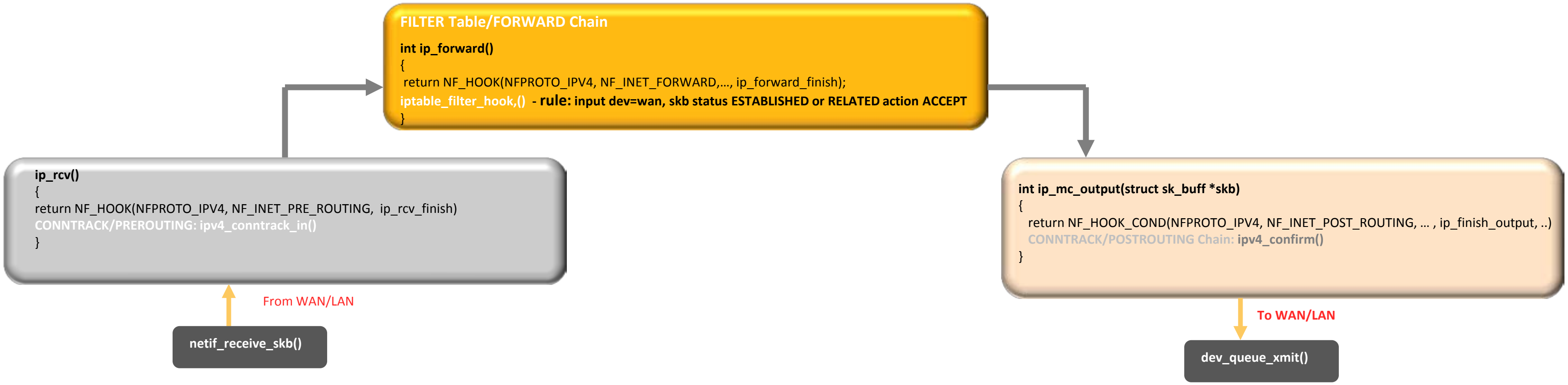


- **Conntrack hash table – can hit in original or reply direction**

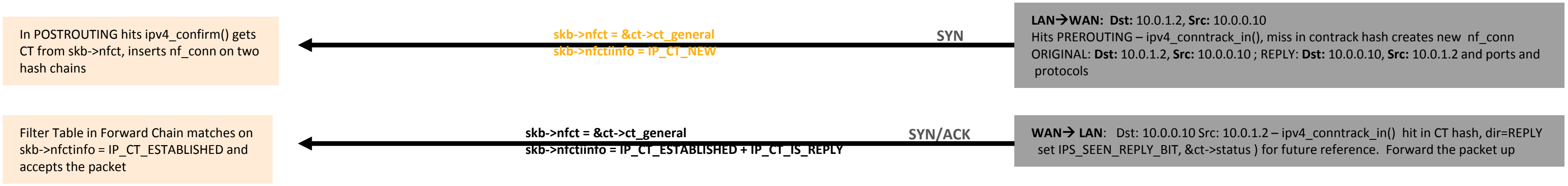


IPv4 Connection Tracking – SPI

- Example of stateful firewall, with no NAT -- subset of Network stack Tables and Chains illustrated



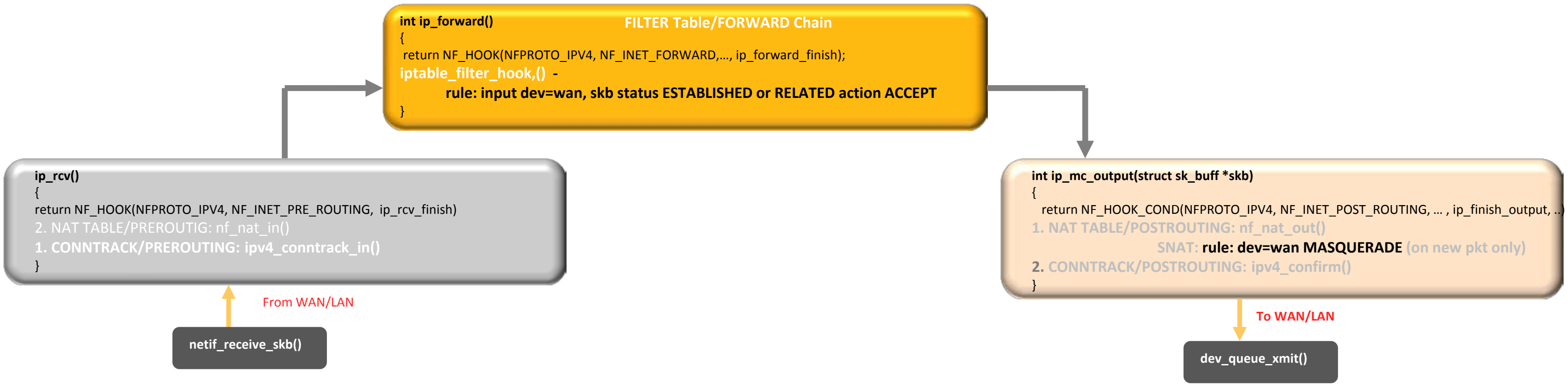
- Following Rule in Forward Chain: iptables –A FORWARD –i $WAN-IFACE –m state –state ESTABLISHED,RELATED –j ACCEPT



- After DIR_REPLY statefulness established – means private host opened the FW
- The skb carries status – used by Filter Rules
- In summary generic statefullness means – hit in Conntrack hash on DIR_REPLY packet
- Protocol Statefullness – more extra work i.e. matching packets against TCP state machine
  - F.E TCP – state transitions, seq# ordering, …. – done in PREROUTING Connection tracking

IPv4 Connection Tracking – SPI+NAT

- Extend to NAT with Conntracking – typical scenario client using private IP



- For Clarity L4 and protocol are not shown
- Following rule installed to NAT table (in addition to Filter): iptables -t nat -A POSTROUTING -o $WAN-IF -j MASQUERADE

LAN→WAN: Dst: 1.2.3.4, Dst: 10.0.0.10; GW Public=2.2..2.2

1. Hits PREROUTING – ipv4_conntrack_in(), miss in contrack hash creates new nf_conn ORIGINAL: Dst: 1.2.3.4, Src: 10.0.0.10 ; REPLY: Dst: 10.0.0.10, Src: 1.2.3.4 and ports and protocols
2. nf_nat_in() – ctstats not updated

SYN ←

skb->nfct = &ct->ct_general
skb->nfctiinfo = IP_CT_NEW

1. In POSTROUTING hits nf_nat_out() –
   a) IP_CT_NEW – hits MASQUERADE rule, updates CT DIR_REPLY tuple: Src: 1.2.3.4, Dst: 2.2.2.2 Replies can now hit in conntrack hash
   b) Marks ct->status with IPS_SRC_NAT
   c) Invert reply tuple – Src: 2.2.2.2; Dst: 1.2.3.4 (and L4 proto) update IP hdr and checksums
2. In POSTROUTING hits ipv4_confirm() gets CT from skb->nfct, inserts nf_conn on two hash chains, oblivious to NAT updates.

WAN→ LAN: Dst: 2.2.2.2 Src: 1.2.3.4

1. Hits PREROTING - ipv4_conntrack_in() hit in CT hash, dir=REPLY set IPS_SEEN_REPLY_BIT, &ct->status for future reference. Forward the packet up
2. For DIR_REPLY reverse original direction tuple update ip hdr (L4) with reversed destination in this case 10.0.0.10 – update checksums

SYN/ACK ←

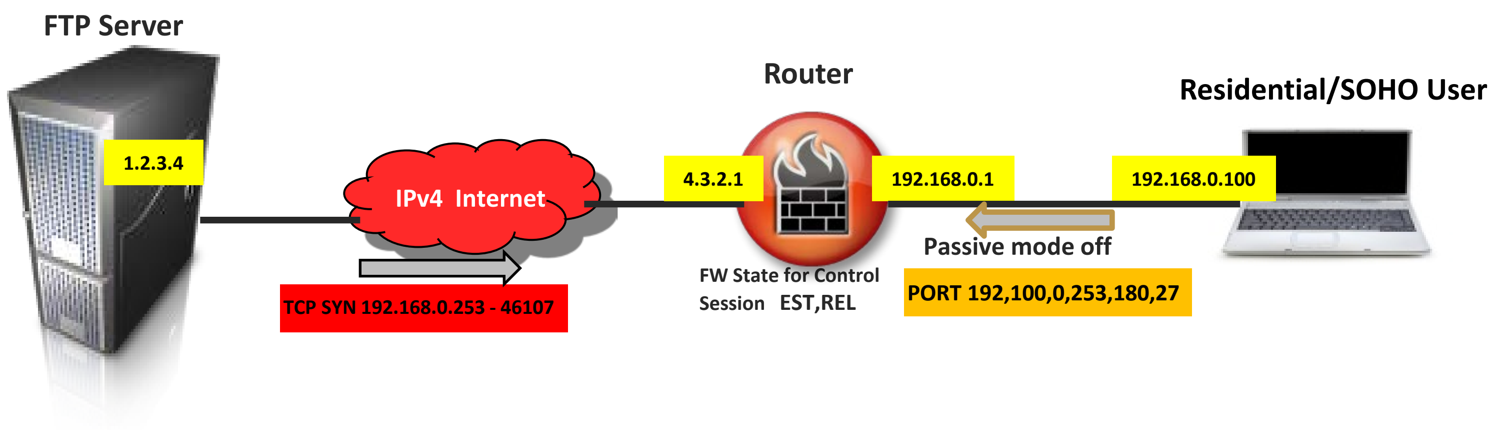
skb->nfct = &ct->ct_general
skb->nfctiinfo = IP_CT_ESTABLISHED + IP_CT_IS_REPLY

1. Filter Table in Forward Chain matches on skb->nfctinfo IP_CT_ESTABLISHED and accepts the packet
2. nf_nat_out() – does nothing due to IPS_SRC_NAT flag
3. ipv4_confirm() – does nothing

- For this NAT setup – general rule:
  - original dir – invert reply and use Source – update packet/recalc checksums
  - reply dir – invert original use Dst – update packet/reclac checksums

IPv4 Connection Tracking – SPI+NAT+ALG

- Add ALG to NAT with Conntracking – typical scenario client using private IP
- ALG Example – FTP – the problem



- FTP client in Passive Mode – passes private IP in Payload
- Server will attempt – private IP
- Several Extra ALG Layers Added – to handle
  a. ALG helper scans for header sig. i.e. port 21
  b. Monitors commands and rewrites to Public IP
  c. Adds an expectation – incoming data connection
  d. For this scenario Creates DNAT mapping

IPv4 Connection Tracking – SPI+NAT+ALG

- **IPv4 FTP ALG example – covers both general ALG work with FTP specifics**
- **Register FTP ALG Helper manually**
  - **Register “FTP helper” – ‘nf_conntrack_ftp’ registers ‘helper’ in ‘nf_ct_helper_hash[]’ – monitor FTP pkts**
  - **Later “NAT helper” – ‘nf_nat_ftp’ referenced (can be dynamically loaded)**

int ip_forward() **FILTER Table/FORWARD Chain**
{
return NF_HOOK(NFPROTO_IPV4, NF_INET_FORWARD,…, ip_forward_finish);
iptable_filter_hook,() -
rule: input dev=wan, skb status ESTABLISHED or RELATED action ACCEPT
}

ip_rcv()
{
return NF_HOOK(NFPROTO_IPV4, NF_INET_PRE_ROUTING, ip_rcv_finish)
2. NAT TABLE/PREROUTIG: nf_nat_in()
1. CONNTRACK/PREROUTING: ipv4_conntrack_in() – **process expect, execute DNAT helper**
}

From WAN/LAN

netif_receive_skb()

int ip_mc_output(struct sk_buff *skb)
{
return NF_HOOK_COND(NFPROTO_IPV4, NF_INET_POST_ROUTING, … , ip_finish_output, ..)
1. NAT TABLE/POSTROUTING: nf_nat_out()
SNAT: **rule: dev=wan MASQUERADE** (on new pkt only)
2. CONNTRACK/POSTROUTING: ipv4_confirm() – **ftp helper**
}

To WAN/LAN

dev_queue_xmit()

LAN→ WAN: Client (w/Private IP) issues SYN to FTP server with port 21
-PREROUTING ipv4_conntrack_in() - misses , helper hash searched “ftp_helper” associate with ‘CT’
- Do standard NAT work

skb->nfct = &ct->ct_general (with associated helper)
skb->nfctiinfo = IP_CT_NEW

POST ROUTING ipv4_confirm() executes helper to parse packet – f.e. PORT commaidn with Private IP (i.e. PORT 192,168,0,253,180,27)

Several Packets go by before ALG command executed
…….

LAN → WAN: PREROUTING: Client issues PASSIVE mode PORT command

skb->nfct = &ct->ct_general (with associated helper)
skb->nfctiinfo = IP_CT_ESTABLISHED + IP_CT_IS_REPLY

POSTROUTING: helper finds PORT command
- modifiesl packet PORT IP with Public IP
- Creates a “nf_contrack_expect” – programs DNAT
- Associates a NAT helper with expectation (nf_nat_ftp)
- enqueues ‘nf_contrack_expect” on - init_net->ct. expect_hash[]

WAN → LAN: PREROUTING: FTP data connection from server will mis conntrack hash table.
-will hit the expect hash table, execute the NAT helper to create DNAT entry
-Set IPS_EXPECTED_BIT in ct->status, causes skb to be marked RELATED

skb->nfct = &ct->ct_general (with associated helper)
skb->nfctiinfo = IP_CT_RELATED

FILTER TABLE/ FORWARD CHAIN accepts packet it’s marked RELATED

….. Data Connection Statefully established by Connection Tracking and FW Rules ….

CPU Offload integrated with IPv4 Connection Tracking – SPI+NAT+ALG

General Principles of CPU Network Offload Integration

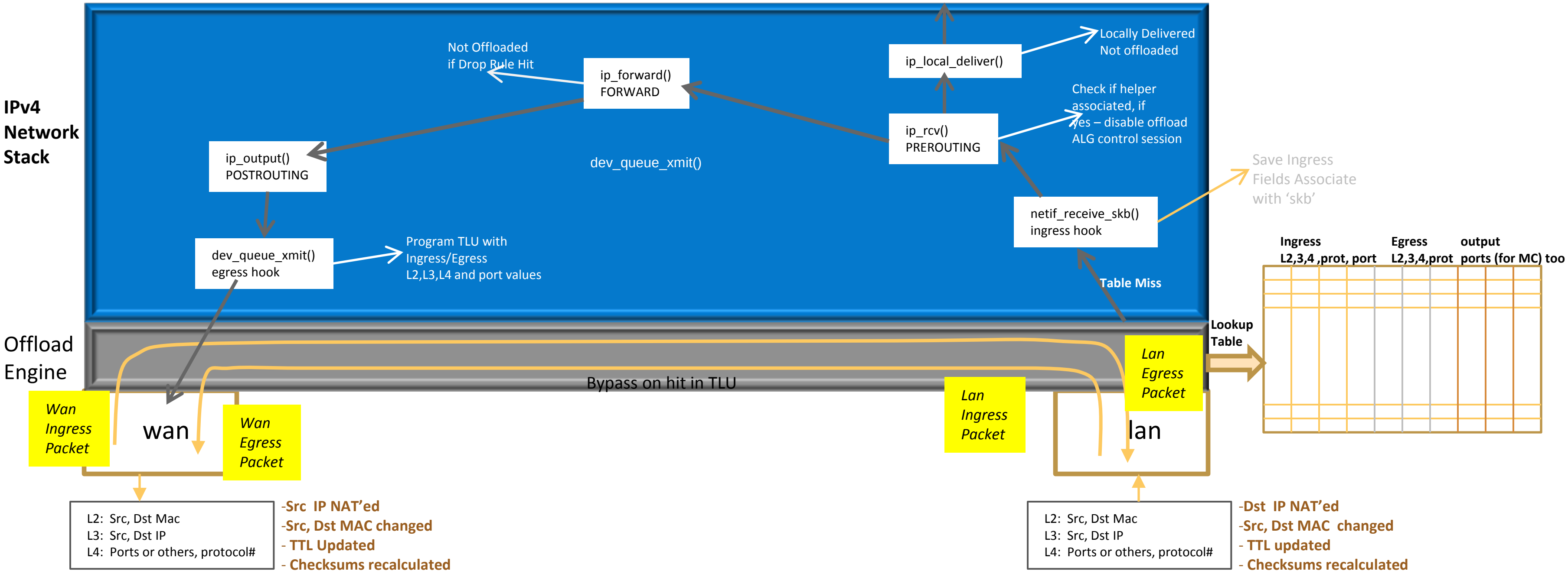
- ISPs want CPU heavy Apps on application processor – thus need to offload traffic
  - More predictable & cost effective – then adding CPUs i.e. as UL/DL rates go up
- CPU should be IDLE with Max packet bandwidth – GPON, DOCSIS 8-Ch Bonding 240 Mbps/DL 104 Mbps UL – higher in future
- Initial Packets – go up to kernel – to program offload engine – primarily L2/L3/L4 used
  - For DPI apps – Parental control – transparent proxy, content filtering more – kernel determines
- Must be fully integrated into: IP stack – connection tracking, NAT, ALGs, Routing, …..,
- Sessions Limited resource – must prioritize TLU – like streaming over casual browsing
  - Light DPI (f.e. HTTP persistent connection, Content-Type, …, fields)

General Operation

- LAN -> WAN
  - ingress hook: saves pre-SNAT'ed SRC L3/L4 (i.e. private IP), local MACs attaches info to skb
    - PREROUTING drops packet if ALG, offloading stops here;
  - egress hook: saves SNAT'ed L3/L4 (i.e. Public IP) , WAN, GW MACs – programs Offload Engine
- WAN-> LAN (Path not shown)
  - ingress hook: saves pre DNAT'ed L3/L4 (i.e. public IP), GW, WAN MAC attaches to skb
    - PREROUTING drops packet if ALG, offloading stops here;
  - egress hook: saves DNAT'ed L3/L4 (i.e. Private IP), local MACs – Programs Offload Engine
- Two Offload Entries programmed – on match packet headers update, switched to egress port
- Must see at least 2 packets – ORIGINAL/REPLY
- Must have: src/dst macs, src/dst IPs, src/dst ports (if applicable), protocol type, ingress, and egress port(s)
- Local packets to/from GW – obviously not accelerated

CPU Offload integrated with IPv4 Connection Tracking – SPI+NAT+ALG

- General integration of Offload Engine into Linux Network Stack

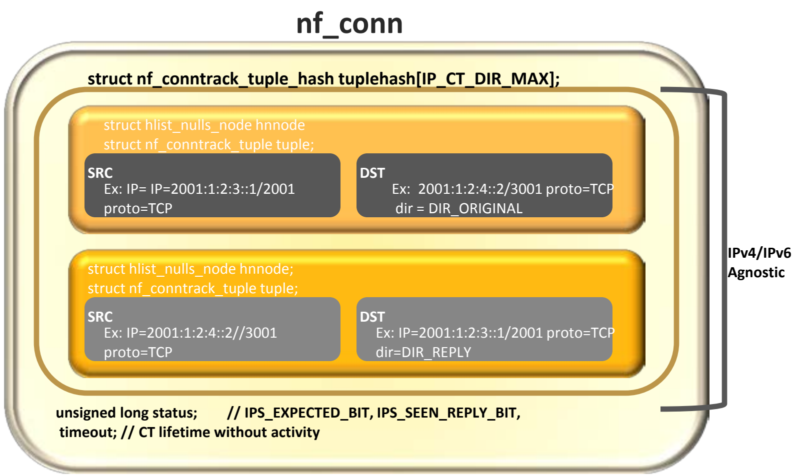


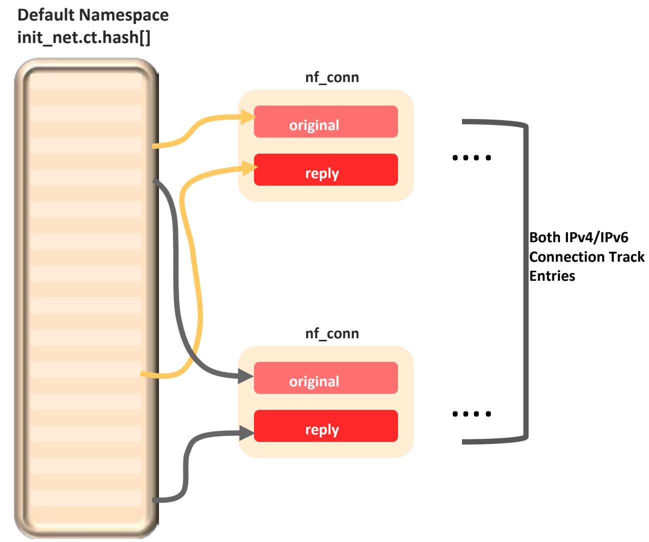
CPU Offload integrated with IPv4 Connection Tracking – SPI+NAT+ALG

- **Additional kernel hooks for Offload Engine**
  - NETDEV_UP/DOWN (netdev_chain) – must flush TLU – prevent forwarding
  - Address change (inetaddr_chain) – lan, wan – flush TLU – prevent wrong addr use - for offloaded sessions
  - Routes added/deleted – static/dynamic – flush TLU – sessions out of sync
  - Conntrack timeout – extend timeout – if session offloaded
    - offloaded session invisible to OS
  - NAT – changes – flush TLU – sessions out of sync
  - MC routing – when added insert one entry – several egress ports
  - Few problems
    - GRE (PPTP) – may need to drop out – if call id's collide – must let ALG handle (previous slide)
    - Similar issue with IPsec Tunneled Mode – ESP
    - Once offloaded – not secure
  - Handle session re-entrancy – OS ←→ Offload engine – disable Protocol Connection tracking
  - Parental Control/DPI – requires more logic – inspect packets longer – before offload

IPv6 Connection Tracking – SPI

- **Same conntrack structure – used for IPv6, same hash table**

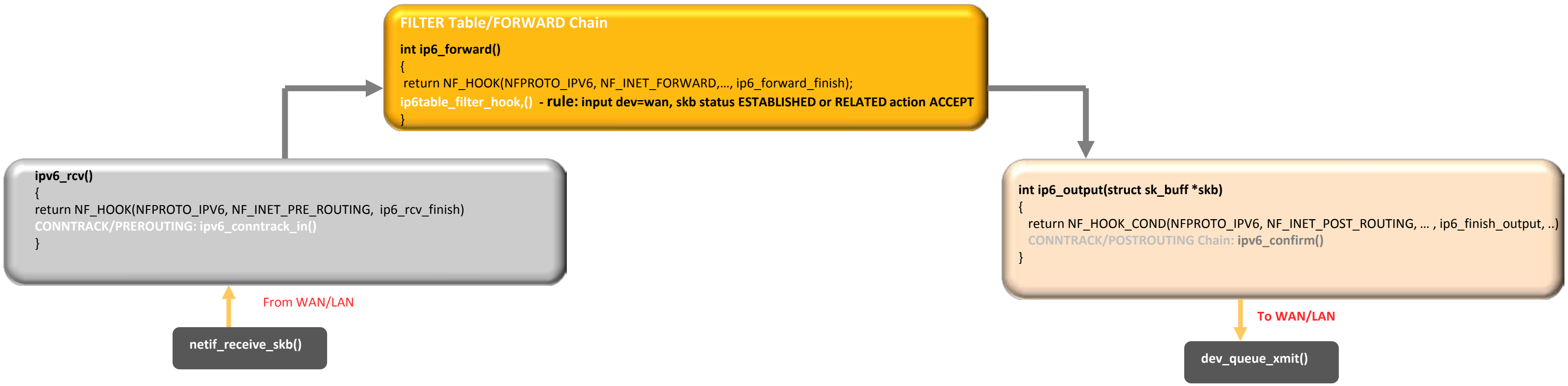




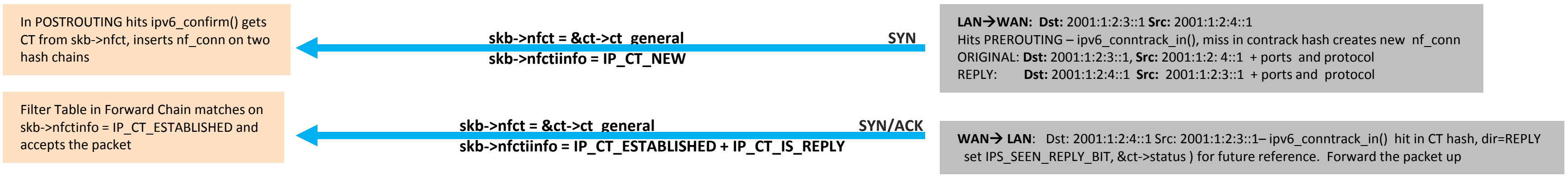
- **IPv6 & IPv4 SPI fully integrated**
  - common nf_conn, conntrack table – key structure ‘nf_conntrack_tuble’ - common

IPv6 Connection Tracking – SPI

- Example of IPv6 stateful firewall



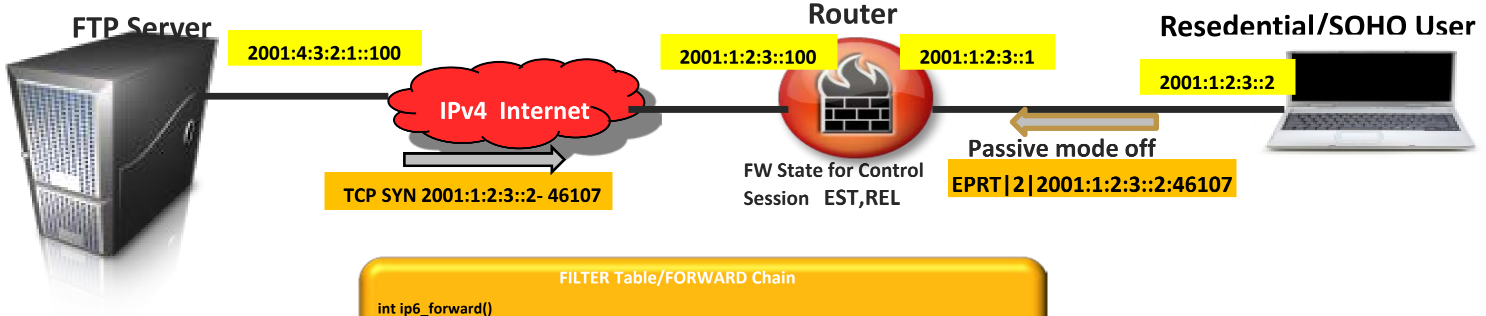
- Following Rule in Forward Chain: ip6tables –A FORWARD –i $WAN-IFACE –m state –state ESTABLISHED,RELATED –j ACCEPT



- After DIR_REPLY statefulness established – means private host opened the FW
- The skb carries status – used by Filter Rules

IPv6 Connection Tracking – SPI+ALG

- **Same ALG Example as for IPv4, NAT not applicable**



FILTER Table/FORWARD Chain

```
int ip6_forward()
{
 return NF_HOOK(NFPROTO_IPV6, NF_INET_FORWARD,..., ip6_forward_finish);
ip6table_filter_hook,() - rule: input dev=wan, skb status ESTABLISHED or RELATED action ACCEPT
}
```

```
ipv6_rcv()
{
return NF_HOOK(NFPROTO_IPV6, NF_INET_PRE_ROUTING, ip6_rcv_finish)
CONNTRACK/PREROUTING: ipv6_conntrack_in() - process expect
}
```

From WAN/LAN

netif_receive_skb()

```
int ip6_output(struct sk_buff *skb)
{
  return NF_HOOK_COND(NFPROTO_IPV6, NF_INET_POST_ROUTING, ... , ip6_finish_output, ..)
  CONNTRACK/POSTROUTING Chain: ipv6_confirm() – execute helper
}
```

To WAN/LAN

dev_queue_xmit()

- **Register an ALG helper – 'nf_contrack_ftp' – registers FTP helper - on "nf_ct_helper_hash[]" - monitor for port 21**

Client issues SYN to FTP server with port 21
-PREROUTING ipv6_conntrack_in() - misses , helper hash searched "ftp_helper" associate with 'CT'

skb->nfct = &ct->ct_general (with associated helper)
skb->nfctiinfo = IP_CT_NEW

POST ROUTING ipv6_confirm() executes helper to parse packet – (f.e. command with EPRT |2|2001:1:2:3::2|46107)

-Several Packets go by before ALG command executed

- PREROUTING: Client issues PASSIVE mode EPRT command

skb->nfct = &ct->ct_general (with associated helper)
skb->nfctiinfo = IP_CT_ESTABLISHED + IP_CT_IS_REPLY

POSTROUTING: helper finds EPRT command
- Creates a "nf_conntrack_expect" –
- enqueues 'nf_contrack_expect" on - init_net->ct. expect_hash[]

- PREROUTING: FTP data connection from server will mis conntrack hash table.
- will hit the expect hash table,
- Set IPS_EXPECTED_BIT in ct->status, causes skb to be marked RELATED

skb->nfct = &ct->ct_general (with associated helper)
skb->nfctiinfo = IP_CT_RELATED

FILTER TABLE/ FORWARD CHAIN accepts packet it's marked RELATED

CPU Offload integrated with IPv6 SPI, ALGs

General Operation

- LAN -> WAN - **ingress hook**: similar to IPv4, although deals with IPv6 header structures
  - PREROUTING drops packet if ALG, offloading stops here – allow helper to follow ALG control connection – pkt modified
  - **egress hook:** similar to IPv4 – programs Offload Engine
- WAN-> LAN (Path not shown) **ingress hook:** similar to IPv4
  - PREROUTING drops packet if ALG, offloading stops here; egress hook: similar to IPv4– Programs Offload Engine
- Two Offload Entries programmed – on match packet headers update, switched to egress port
- Must see at least 2 packets – ORIGINAL/REPLY
- Must have: src/dst macs, src/dst IPs, src/dst ports (if applicable), protocol type, ingress, and egress port(s)
- Local packets to/from GW – obviously not accelerated
- Issues with protocols like IPsec/ESP go away
- Configuration and source directories

Kernel Configuration

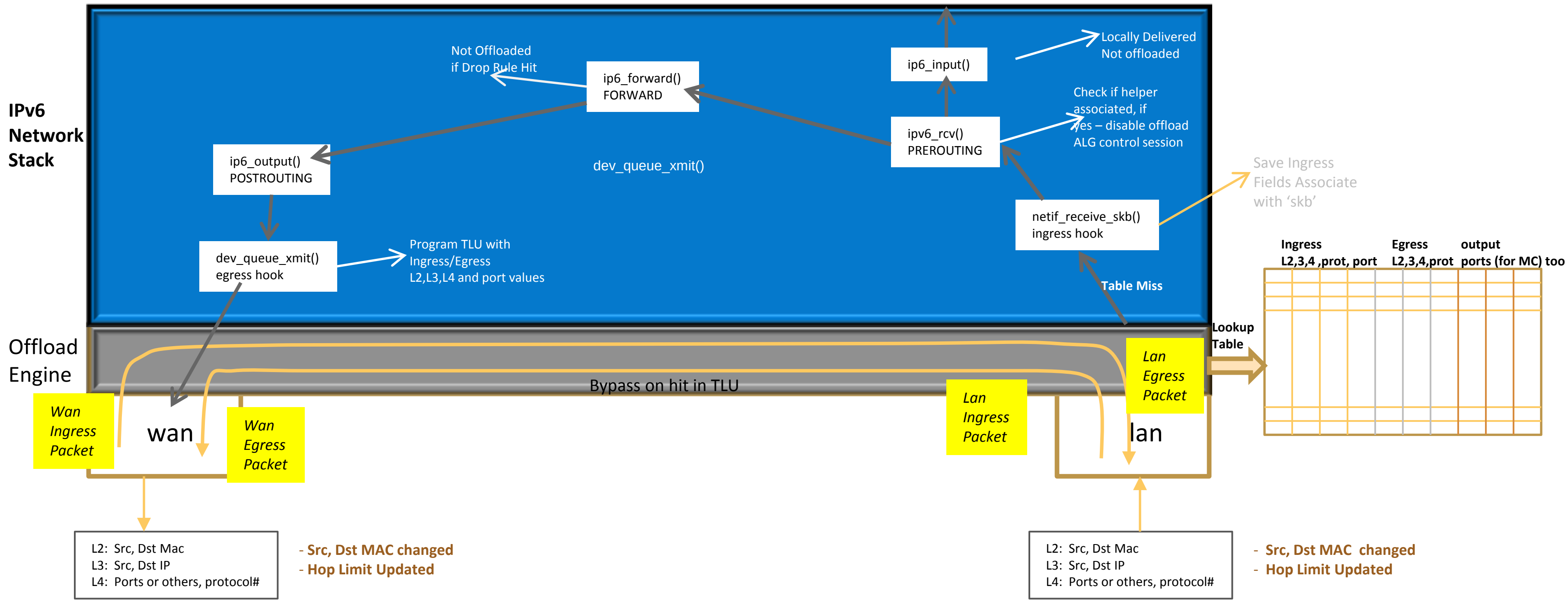
- must enable IPv6 to see IPv6 Net filter Options
<*> The IPv6 protocol --->
[*] Network packet filtering framework (Net filter) --->
Core Net filter Configuration --->
IP: Net filter Configuration --->
IPv6: Net filter Configuration --->

Source Directories

net/net filter – connection tracking, ALG helpers (port opening) – both IPv4/IPv6 supported, some generic match modules
net/ipv4/net filter - ipv4 specific – NAT, NAT helpers, IPv4 specific match modules, IPv4 table registration
net/ipv6/net filter - ipv6 match modules , IPv6 Table registration

-For FTP ALG: **net/net filter/nf_conntrack_ftp** – required for both IPv4 & IPv6
net/net filter/ipv4/nf_nat_ftp -

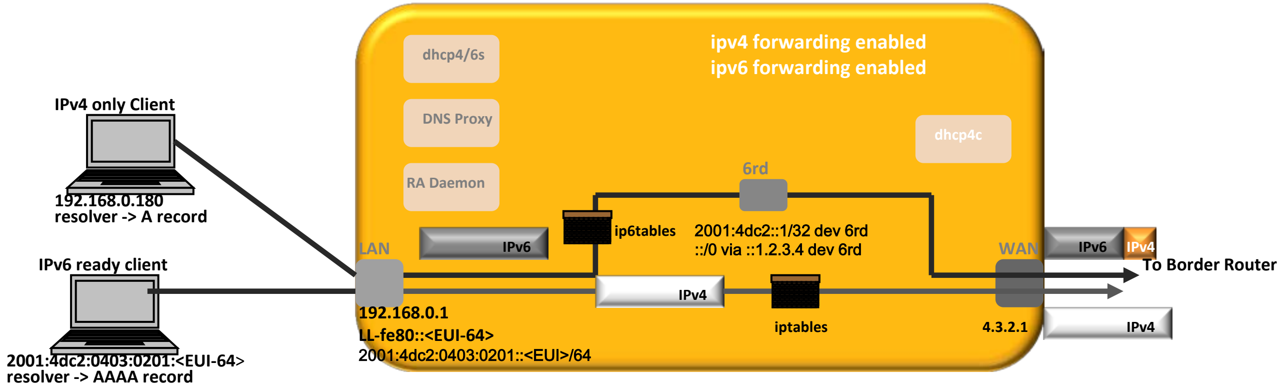
CPU Offload integrated with IPv6 SPI, ALGs



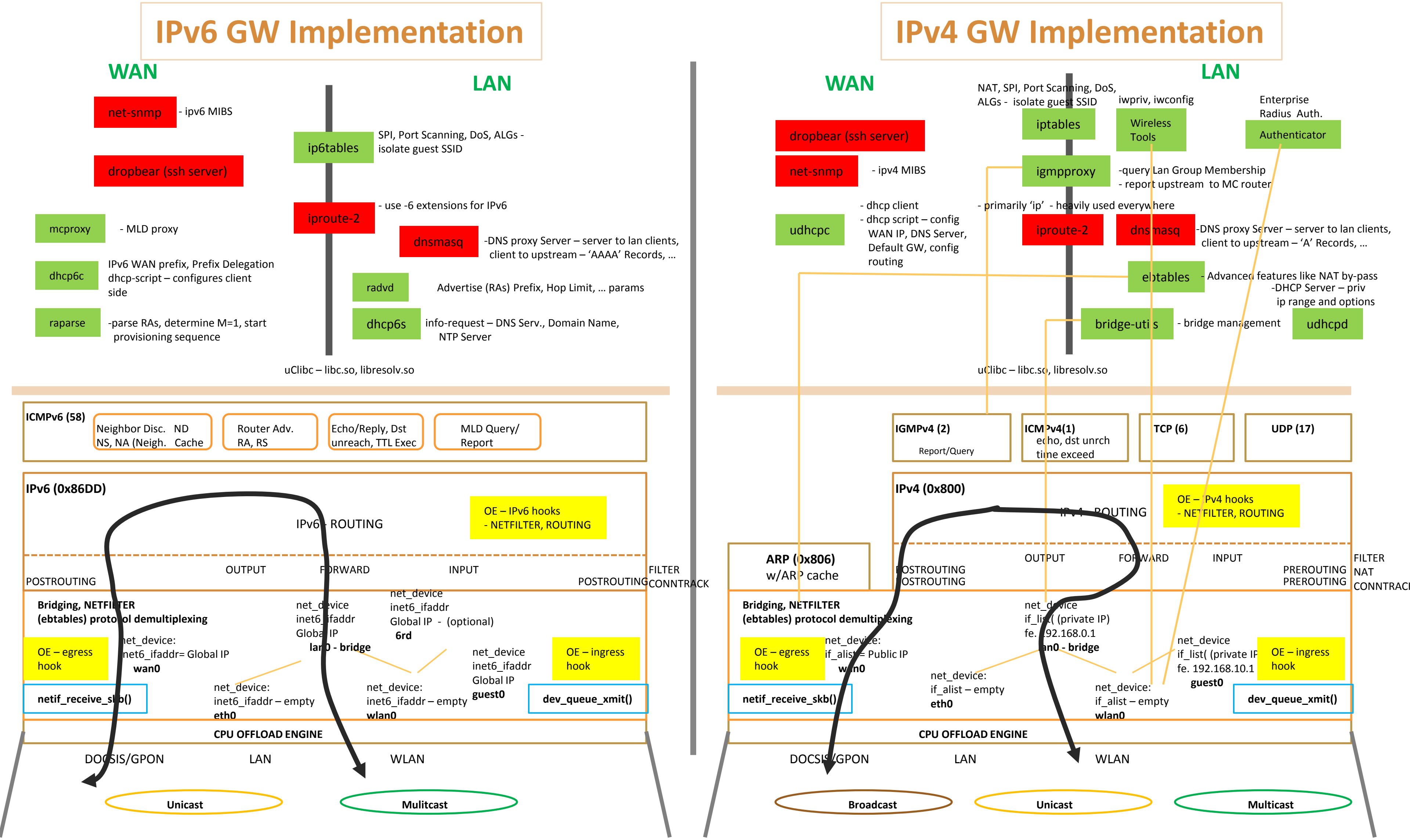
6RD

- **Dual-Stack long term Preferable option for ISPs (example spec DOCSIS eRouter)**
- **Expected both protocols will co-exist for years to come – few reasons - applications not migrated to IPv6, embedded devices**
- **DS-Lite another option – tunneling IPv4 in IPv6 – breaks IPv4 features – UPnP IGD, DDNS, DMZ, …**
- **6RD – Rapid Deployment another option**
  - Tunneling IPv6 over IPv4 similar to 6to4
  - tun6to4 device – used predefined IPv4 Anycast router to reach IPv6 internet
  - 6RD allows ISP specific prefix (instead of 2002::/16) used w/IPv4 addr – i.e. 2001:4dc2::/32, 192.0.2.100 → 2001:4dc2:c000:264::/64
    - New DHCPv4 option with prefix, border router IPv4 address
  - 6RD supported– 'ip' tool supports 6rd tunnel mode
    - [ ] IPv6: IPv6 Rapid Deployment (6RD) (EXPERIMENTAL) under "IPv6 protocols" enables 6RD
  - Offload Engines – no support IPv6 ← → IPv4

- 6rd delegated Prefix: 2002:4dc2; 6rd IPv4



Dual Stack IPv4/IPv6



IPv6 Provisioning Cablelabs eRouter Spec

- **eRouter is a dual stack spec – strong reference for IPv6 implementation**
- **Can be configured for IPv4 only, IPv4+IPv6 or IPv6 only**
  - There are TLVs in TFTP config which determine mode – mode assumed here is Dual-Stack
- **IPv4 not covered – standard dhcp client /handler script - proxy DNS server, private IP DHCP server …**
- **Procedure for ISP Facing Interface – most likely flow – other variants not practical**

1. Construct link local address (LL) – ipv6/conf/wan/autoconf=1 – 0xfe80::<OUI host> - join ND and all Hosts MC group

   Router → **DHCPv6 Server and/or Gateway**

   DAD NS – Self (Solicited Node MC) →

2. Get RAs – <u>confirm managed mode</u> (M flag set), get default router other params like Hop Limit, MTU

   Router / **DHCPv6 Server and/or Gateway**

   Construct RS – Message →

   socket(PF_INET6, SOCK_RAW, IPPROTO_ICMPV6)
   sendto() - use: struct nd_router_solicit w/ND_ROUTER_SOLICIT

   ← Expect RA – Message

   struct nd_router_advert
   inspect - ra->nd_ra_flags_reserved for ND_RA_FLAG_MANAGED

3. The M bit must be set – issue DHCPv6 request – get IA_NA, IA_PD – perm. IPv6 address, prefixes and DNS server
   - Router may use Rapid Commit option in future – discussed earlier

   Router / **DHCPv6 Server and/or Gateway**

   Solicit (FF02::1:2 UDP 547) →

   ← Advertise(IA_NA, IA_PD , DUID for router, Rapid Commit support option , DNS recursive server IP - use UDP 546)

   Request (unicast) →

   Reply (unicast) →

4. Run DAD NS, join ND and all hosts MC group
5. DHCPv6 handler script (dibbler or dhcp6c KAME) – retrieves values later used to configure LAN side

IPv6 Provisioning & Routing Cablelabs eRouter Spec

- **Procedure for Customer Facing Interface(s)**
  - ➢ The Customer Facing Interface configuration – follows ISP server configuration

1. Create LL address w/DAD, subscribe to ND & All hosts MC Groups
2. Construct IPv6 address for each interface
   - ➢ Use IA_PD + interface OUI, run DAD, subscribe to ND & All hosts MC Groups
3. Generate RAs – with O=1 and provide Prefix option
   - ➢ IA_PD – from DHCP on ISP facing interface
   - ➢ Client use SLAAC

For example RADVD configuration:

```
interface eth0.3
{
  AdvSendAdvert on;
  MinRtrAdvInterval 30;
  MaxRtrAdvInterval 100;
  AdvOtherConfigFlag on;
  prefix 2001:1:2:3::/64
  ....
};
```

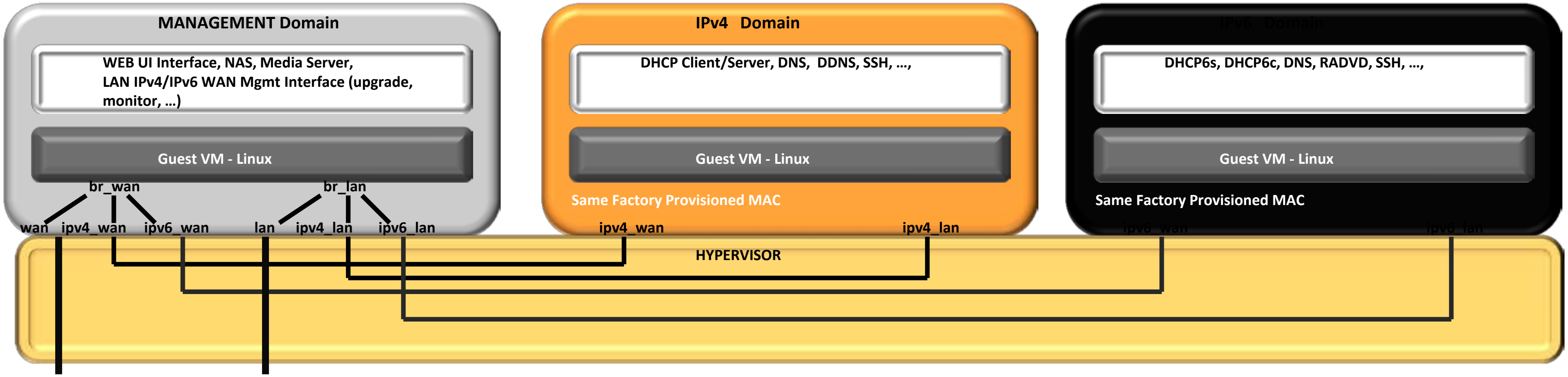
4. Start up DHCPv6 Server
   - ➢ At very least pass DNS Server – determined from ISP Interface configuration
   - ➢ Other acceptable option – run proxy DNS server – update /etc/resolv.conf - pas router as DNS server
   - ➢ Example from dhcp6s –

option domain-name-servers 2001:1:2:3::50;

- **Routing**
  - IPv6 addresses are globally routable – nothing special – of link ND for GW, on-link ND for destination
  - MLD – similar to IGMP must – manage LAN membership – provide reports to queries – on ISP facing interface

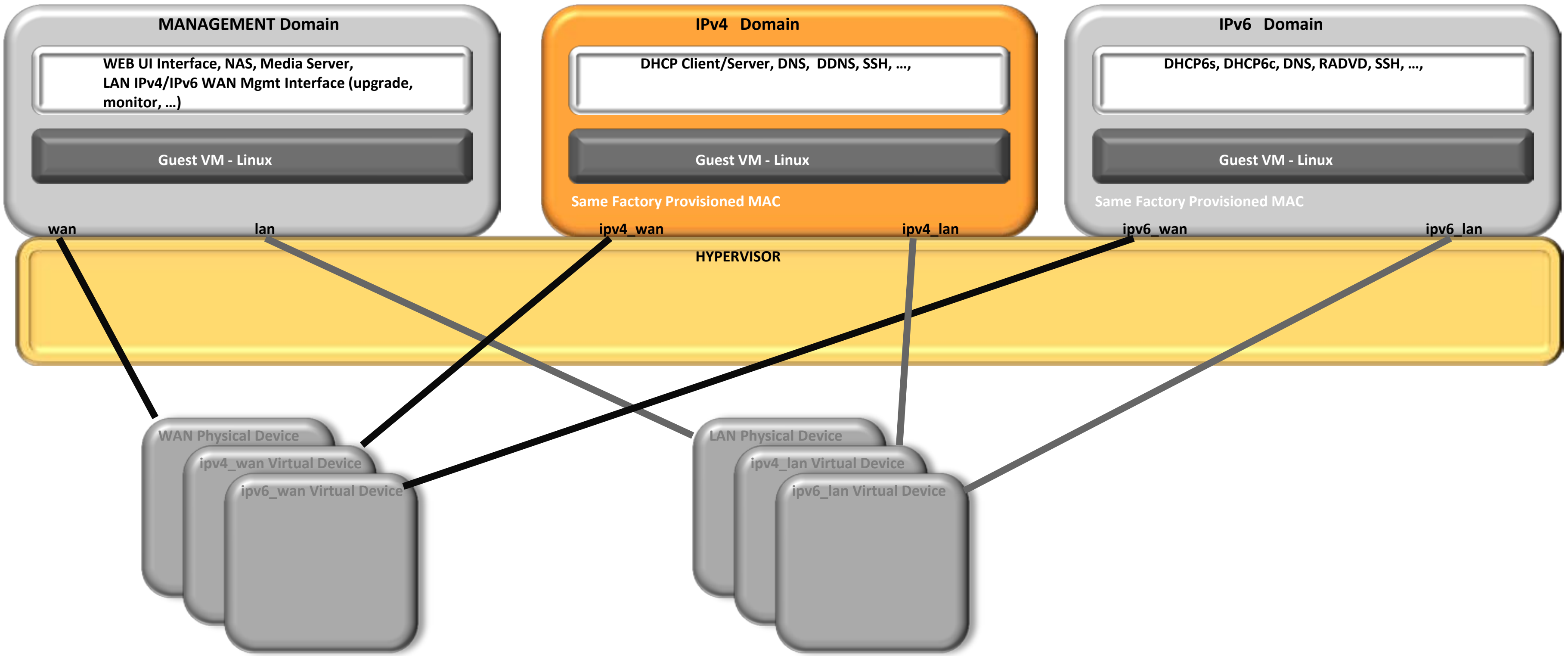
Managing Dual Stack Gateway – SW solution

- ISPs concerned Dual-Stack will require more upgrades
  - Limit Service Calls, sending out technicians
- Prefer to isolate both stacks
- Parameter changes – require total reboot – safest approach
- With Dual-Stack – shared components (DNS, SNMP, TR-69, SSH, …) – updates impact both stacks
- Upgrade Flexibility – update kernel, apps keep other stack running
- Intelligent upgrade – constant interface
- Virtualization one solution
  - introduces new challenges



- BR_FILTER in/out – Forward Filter ‘-p <ipv4,arp>’ drop on ipv6 interface; ‘-p<ipv6>’ drop on ipv4 interfaces
- BR_FILTER local in – BROUTER drop
- Same WAN MAC on both VMs
- Allows independent management of stacks
- CPU offload need backend/frontend driver

Managing Dual Stack Gateway – HW Support

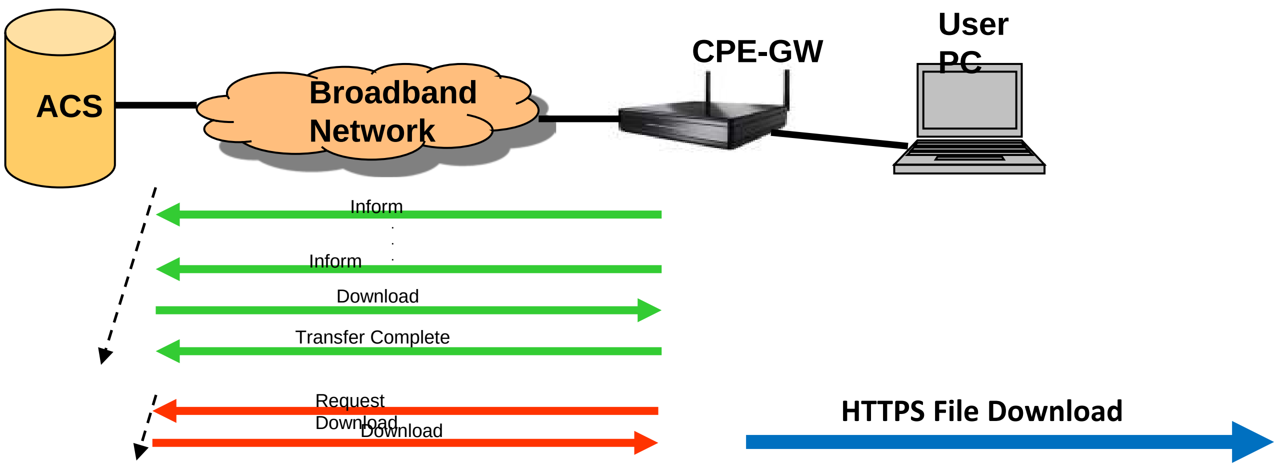


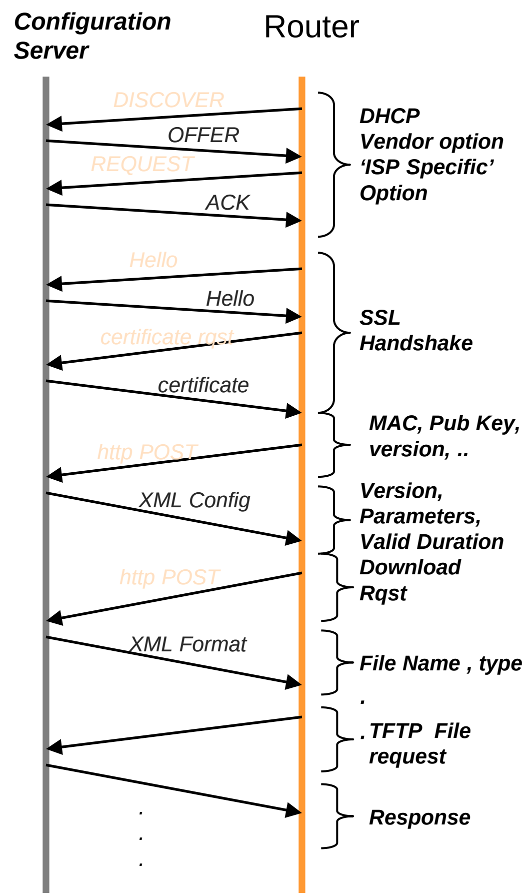
- Virtual devices with own memory mapped I/O – programmable MAC
- IPv4/IPv6 – routed at hardware level
- Physical Devices used for LAN/WAN Management interface

Managing Dual Stack Gateway – Upgrade

- Typical Image Format without virtualization

- Common upgrade Method – TR-69 – SOAP RPC Specification





- Typical Upgrade of CPE – complex procedure
- TR-69 RPC used – communicate image download
- HTTPS – used to download image
- CPE typically upgraded at image level
- After download – image burned to 'other' side, boot side switched
- During reboot blackout period - On Fault recovery involved
- Virtualization Management VM – reboot has not blackout, under constant surveillance

Thank you

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