RIPE #81
2020-10-27

ungleich

HIGH SPEED NAT64 WITH P4

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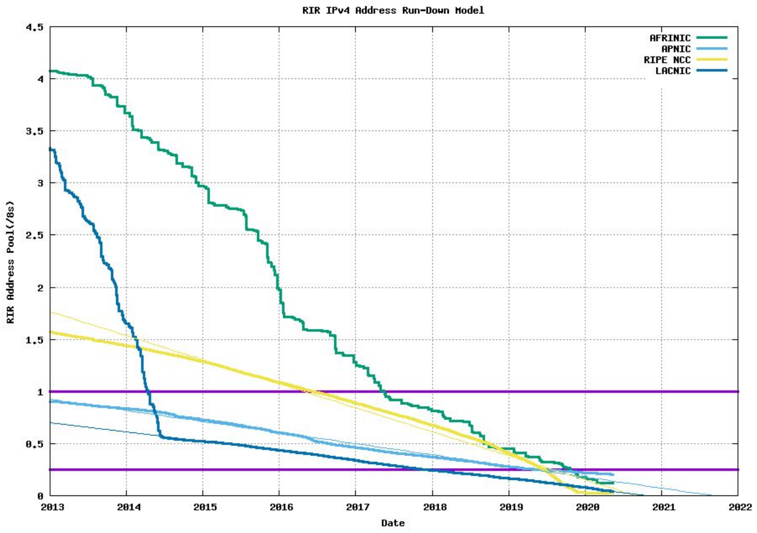
IPv6 only HOSTING

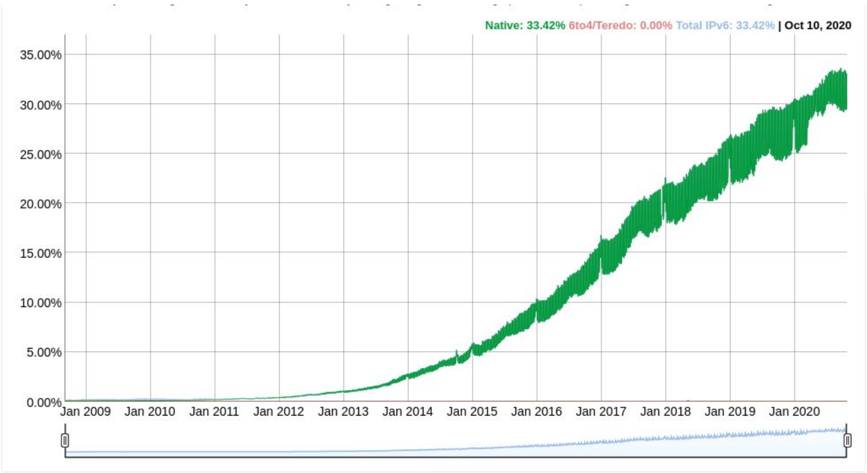
Motivation

Motivation: IPv4 depletion & IPv6 rise

- Only 0.39 /8s (or ca. 6.5 million IPv4 addresses) available **world wide**
- More than ⅓ IPv6 traffic at Google
- Need to bridge the gap



From https://ipv4.potaroo.net/, 2020-10-27

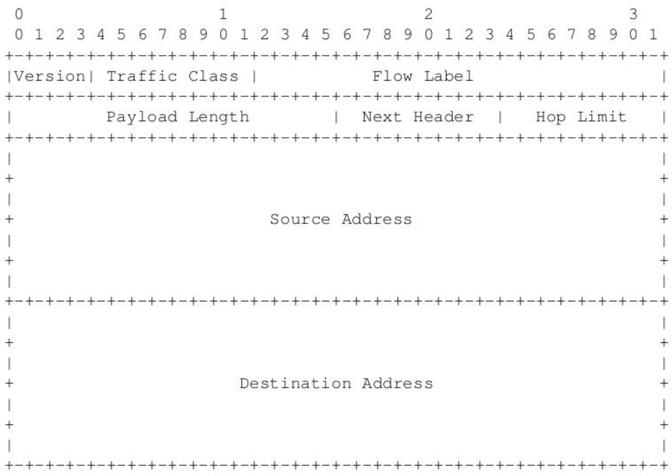


From https://www.google.com/intl/en/ipv6/statistics.html, 2020-10-27

Key Technologies

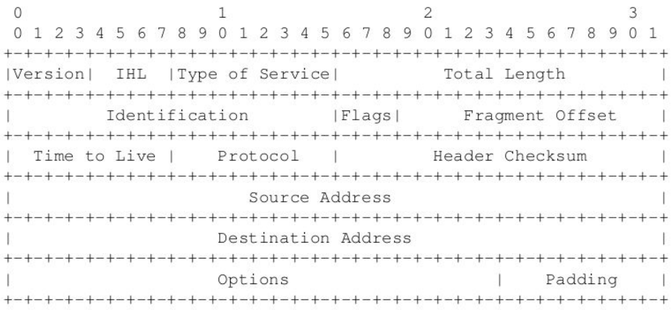
IPv6 and IPv4

- IPv6 and IPv4 are incompatible
  - Ethernet type: 0x86dd vs. 0x0800
  - Address sizes: 128 Bit vs. 32 Bit
  - Header format
  - Checksum
- Translation methods
  - Higher level, protocol dependent (“proxying”)
  - NAT64



```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version| Traffic Class |           Flow Label                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Payload Length        |  Next Header  |   Hop Limit   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                         Source Address                        +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                      Destination Address                      +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2.4: IPv6 Header [17]



```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version|  IHL  |Type of Service|          Total Length         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Identification        |Flags|      Fragment Offset    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Time to Live |    Protocol   |         Header Checksum       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Source Address                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Destination Address                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Options                    |    Padding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2.5: IPv4 Header [43]

NAT64: Overview

- Translation on IP level
- Steps
  - Adjust lower level (Ethernet) protocol
  - Change IPv4 <-> IPv6 headers
  - Adjust higher level (TCP/UDP/ICMP/ICMP6) protocol checksum

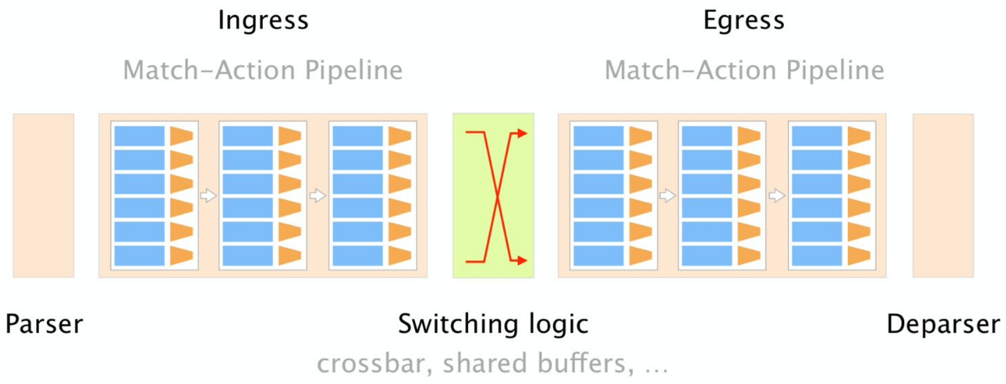
P4

P4 Targets

- BMV2
  - Software emulation
  - Fast prototyping
  - Checksum over payload support
- NetFPGA
  - P4->PX->HDL->Bitstream
  - Near line speed processing
  - No payload checksum support

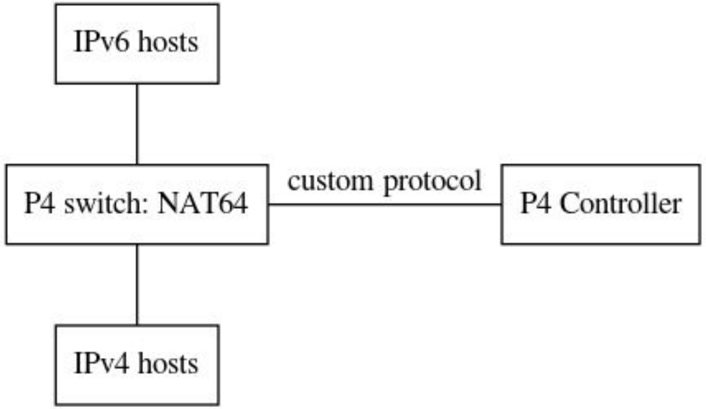
P4 Language

- Protocol independent
- Target independent: same code, different line speed
  - BMW2 and NetFPGA
- Parsing of well defined fields

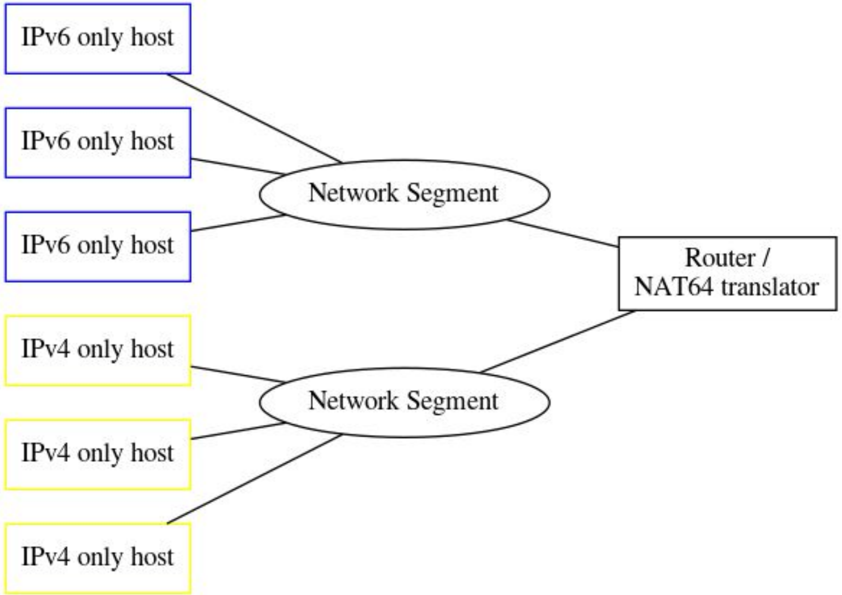


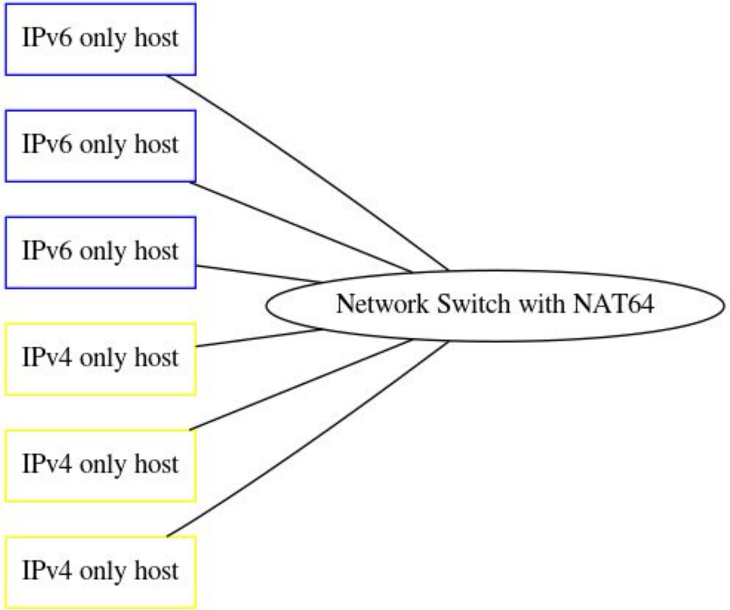
P4 NAT64 Design

- Same P4 design for both targets
  - Same checksum code
- No functions on NetFPGA
  - Using #defines



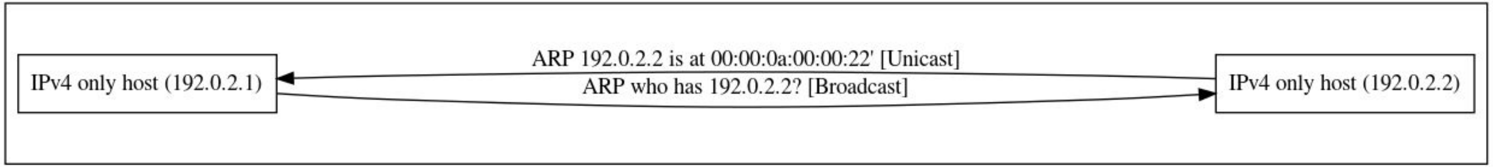
P4 Network design: In-network translation

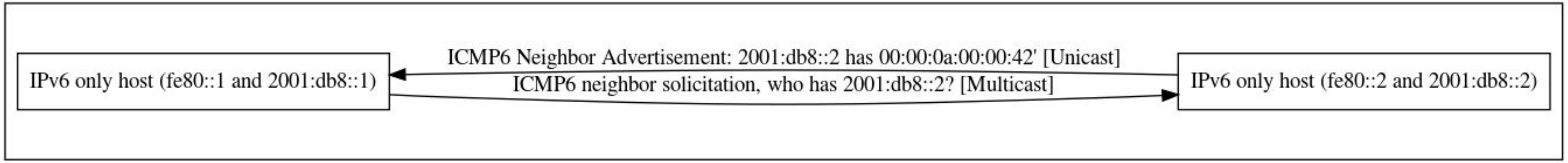


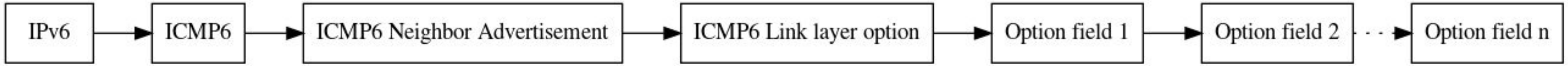


Address resolution: ARP/NDP

- IPv4: ARP: separate protocol; no checksum; Broadcast
- IPv6: NDP: IPv6 only; checksum; Multicast
- ICMP6 option **list of 64 bit blocks**


IPv4 only host (192.0.2.1)
ARP 192.0.2.2 is at 00:00:0a:00:00:22' [Unicast]
ARP who has 192.0.2.2? [Broadcast]
IPv4 only host (192.0.2.2)


IPv6 only host (fe80::1 and 2001:db8::1)
ICMP6 Neighbor Advertisement: 2001:db8::2 has 00:00:0a:00:00:42' [Unicast]
ICMP6 neighbor solicitation, who has 2001:db8::2? [Multicast]
IPv6 only host (fe80::2 and 2001:db8::2)

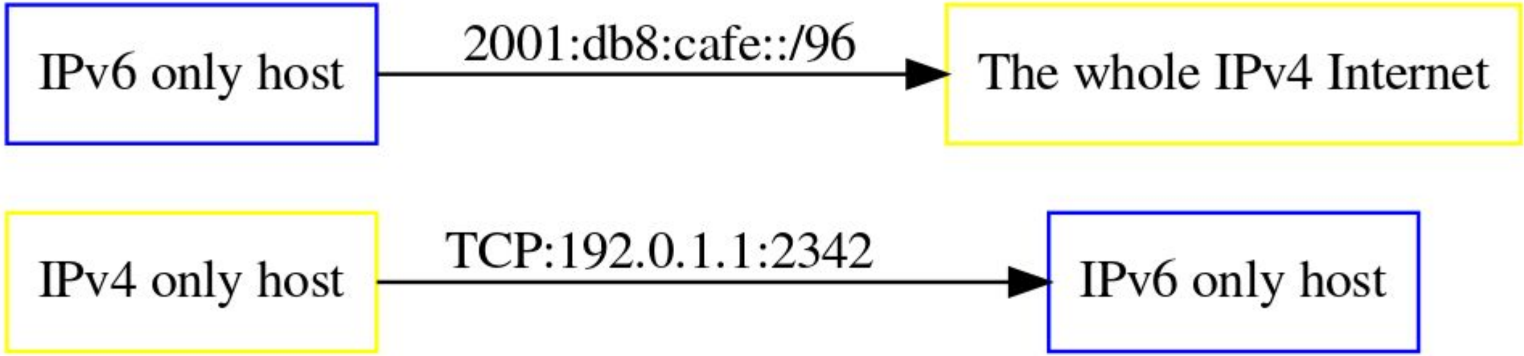


NAT64 Translation: From IPv6 to IPv4

- IPv6 host sends packet to 2001:db8:cafe::192.0.2.2
- P4 switch table matches on 2001:db8:cafe::/96 (nat64 prefix)
- P4 switch calls nat64 action
  - nat64 action adds IPv4 header, maps IPv6 source and destination address
  - nat64 action removes IPv6 header
- NAT64 P4 switch deparsers/sets egress port

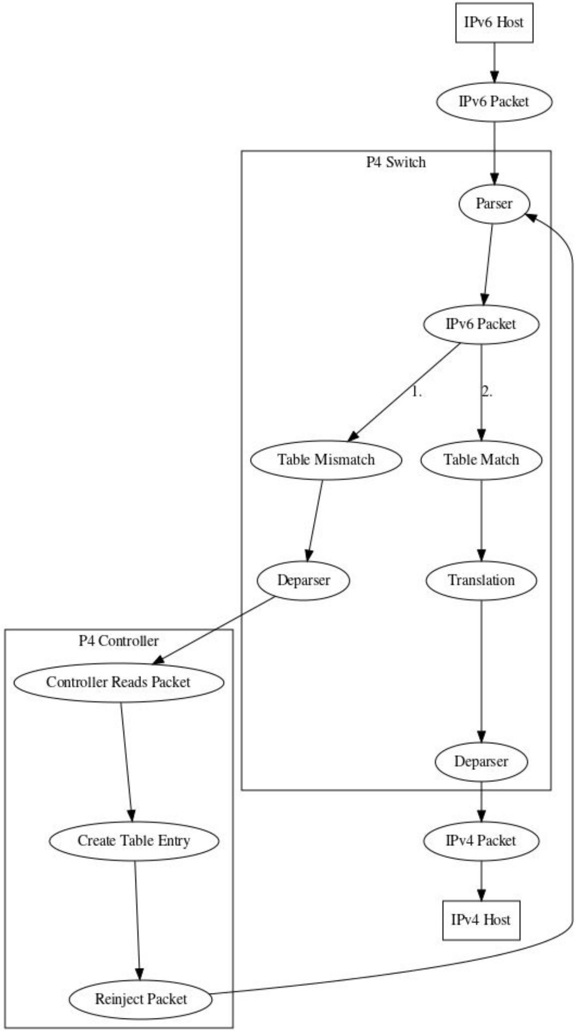
2001:db8:cafe::192.0.2.2 == 2001:db8:cafe::c000:202

NAT64 Translation: Directions matter



Stateless vs. Stateful NAT64

- Stateless
  - Usually 1:1 mappings
  - Static mappings
- Stateful
  - Usually 1:n mappings
  - Session table
  - Active controller required

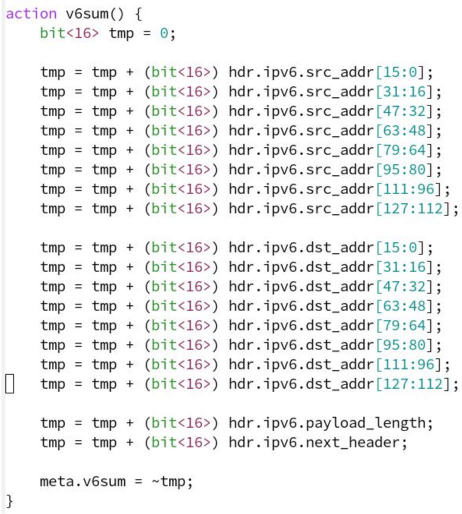


NAT64: Checksum changes

- Used in TCP, UDP, ICMP, ICMP6
  - Includes payload
- P4/NetFPGA
  - No support for checksum over payload
- Internet checksum: “Sum of 1’s complements”
  - Solution: Calculate differences

Delta Checksum in P4

- Example: UDP: IPv6 to IPv4
  - v4sum = v4_src_addr + v4_dst_addr + (totalen-20) + protocol
  - v6sum = v6_src_addr + v6_dst_addr + payloadlen + next_header
  - udpchecksum = udpchecksum + v4sum - v6sum



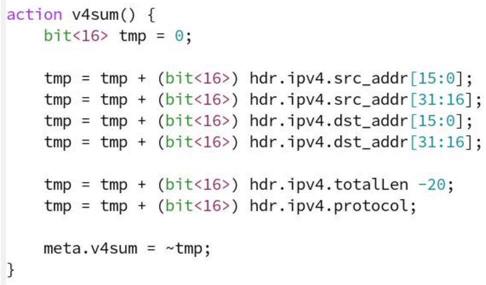
```
action v6sum() {
    bit<16> tmp = 0;

    tmp = tmp + (bit<16>) hdr.ipv6.src_addr[15:0];
    tmp = tmp + (bit<16>) hdr.ipv6.src_addr[31:16];
    tmp = tmp + (bit<16>) hdr.ipv6.src_addr[47:32];
    tmp = tmp + (bit<16>) hdr.ipv6.src_addr[63:48];
    tmp = tmp + (bit<16>) hdr.ipv6.src_addr[79:64];
    tmp = tmp + (bit<16>) hdr.ipv6.src_addr[95:80];
    tmp = tmp + (bit<16>) hdr.ipv6.src_addr[111:96];
    tmp = tmp + (bit<16>) hdr.ipv6.src_addr[127:112];

    tmp = tmp + (bit<16>) hdr.ipv6.dst_addr[15:0];
    tmp = tmp + (bit<16>) hdr.ipv6.dst_addr[31:16];
    tmp = tmp + (bit<16>) hdr.ipv6.dst_addr[47:32];
    tmp = tmp + (bit<16>) hdr.ipv6.dst_addr[63:48];
    tmp = tmp + (bit<16>) hdr.ipv6.dst_addr[79:64];
    tmp = tmp + (bit<16>) hdr.ipv6.dst_addr[95:80];
    tmp = tmp + (bit<16>) hdr.ipv6.dst_addr[111:96];
    tmp = tmp + (bit<16>) hdr.ipv6.dst_addr[127:112];

    tmp = tmp + (bit<16>) hdr.ipv6.payload_length;
    tmp = tmp + (bit<16>) hdr.ipv6.next_header;

    meta.v6sum = ~tmp;
}
```

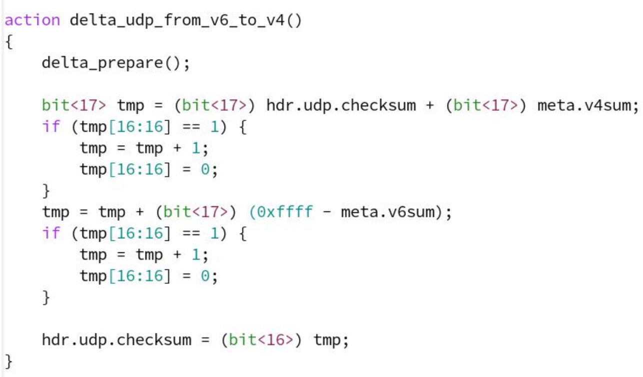


```
action v4sum() {
    bit<16> tmp = 0;

    tmp = tmp + (bit<16>) hdr.ipv4.src_addr[15:0];
    tmp = tmp + (bit<16>) hdr.ipv4.src_addr[31:16];
    tmp = tmp + (bit<16>) hdr.ipv4.dst_addr[15:0];
    tmp = tmp + (bit<16>) hdr.ipv4.dst_addr[31:16];

    tmp = tmp + (bit<16>) hdr.ipv4.totalLen -20;
    tmp = tmp + (bit<16>) hdr.ipv4.protocol;

    meta.v4sum = ~tmp;
}
```



```
action delta_udp_from_v6_to_v4()
{
    delta_prepare();

    bit<17> tmp = (bit<17>) hdr.udp.checksum + (bit<17>) meta.v4sum;
    if (tmp[16:16] == 1) {
        tmp = tmp + 1;
        tmp[16:16] = 0;
    }
    tmp = tmp + (bit<17>) (0xffff - meta.v6sum);
    if (tmp[16:16] == 1) {
        tmp = tmp + 1;
        tmp[16:16] = 0;
    }

    hdr.udp.checksum = (bit<16>) tmp;
}
```

Results

Results: NAT64 TCP Benchmark

- Measured and tested with iperf

Tayga	2.35-3.34 Gbit/s
Jool	7.18-8.25 Gbit/s
P4/NetFPGA	8.51-9.29 Gbit/s

Performance measurements with iperf, 190 seconds, 10 second warmup time, 1-50 parallel sessions, 3 repetitions; min / max values shown

Conclusion and outlook

- NAT64 successfully implemented on 2 P4 targets
- Jool surprisingly fast
- P4/NetFPGA: research only target
- Many P4 improvements possible - even a P4OS?