Hashing on broken assumptions

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Fastly
Problem:
Spreading traffic across multiple links, paths, hosts

Solutions:
• Link Aggregation
• Equal Cost Multipath (ECMP)
Link aggregation

Combine multiple physical links between network devices into one logical link
Equal Cost Multipath (ECMP)

Balance traffic across paths

Balance traffic across hosts

switch

switch

switch

switch

host

host

host
Requirements

Load balance
Traffic must be uniformly spread across next-hops

Stateless-but-sticky path pinning
All packets of a flow must take the same path
Load imbalance

Load imbalance reduces system capacity
Load imbalance reduces system capacity

Perfect load balance
Load imbalance

Load imbalance reduces system capacity

All resources fully utilized
Load imbalance reduces system capacity
Load imbalance

Load imbalance reduces system capacity

Unused capacity

Cannot take any additional load
Quantifying impact of load imbalance

Load imbalance:
\[ \frac{L_{\text{max}}}{L_{\text{avg}}} = [1, +\infty) \]

Max attainable utilization:
\[ U_{\text{max}} = \left( \frac{L_{\text{max}}}{L_{\text{avg}}} \right)^{-1} = \frac{L_{\text{avg}}}{L_{\text{max}}} \]
Quantifying impact of load imbalance

$\Delta_{0}$ $\Delta_{1}$ $\Delta_{5}$

$L_{\text{max}}$ $\ll L_{\text{avg}}$

$U_{\text{max}}$

$L_{\text{max}} / L_{\text{avg}}$

$\Delta_{0}$ $\Delta_{2}$ $\Delta_{4}$ $\Delta_{6}$ $\Delta_{8}$
Quantifying impact of load imbalance

- Perfect balance
- Full utilization
Quantifying impact of load imbalance

- Most loaded resource 1.5x average
- 33.3% reduction of capacity
What happens without path pinning?

Same endpoints, different paths:
- Out-of-order packets
- Frequent drops of TCP congestion window (CWND)
- Poor throughput performance

Different endpoints:
- TCP resets
TCP resets
Requirements:
• Load balance
• Path pinning

Solution:
Flow-level hashing
Flow-level hashing

- src IP addr
- dst IP addr
- protocol
- src port
- dst port

packet → read five tuple → hash function → next-hop
Assumptions

**Load balance**
Hashing uniformly spread traffic across next-hops

**Path pinning**
Hashing pins packets of a flow to the same path
Do these assumptions hold?
Assumptions

**Load balance**
Hashing uniformly spread traffic across next-hops

**Path pinning**
Hashing pins packets of a flow to the same path
Hashing quality

Two switch models:
- Switch A
- Switch B

$2^{16}$ five-tuple combinations

256 nexthops
Switch A

Perfect hashing

Measured
Switch B

Perfect hashing

Measured

$\frac{L}{L_{avg}}$

Nexthop index
Switch B

Vendor claims supporting an arbitrary number of next-hops [1, 256]

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Switch B

Only a subset of next-hops are actually supported

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Switch B
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6 next-hops don’t get any traffic
Assumptions

Load balance
Hashing uniformly spread traffic across next-hops

Path pinning
Hashing pins packets of a flow to the same path
Hashing on IPv4 TOS field

+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version|  IHL  |Type of Service|          Total Length         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Identification        |Flags|      Fragment Offset    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Time to Live |   Protocol   |       Header Checksum      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Source Address        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Destination Address   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Options                    |    Padding    |
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Hashing on IPv4 TOS field
RFC 1812 - Requirements for IP Version 4 Routers
explicitly permits to involve the second-to-last bit of the TOS/DS octet
in routing decisions

RFC 2474 - Definition of the Differentiated Services Field
deprecates the IPv4 Type of Service field redefines it as the
Differentiated Services field

RFC 3168 - The Addition of Explicit Congestion Notification (ECN) to IP
reserves the last two bits of the DS octet for ECN
Hashing on IPv4 TOS field

Scenario
- Hosts are ECN capable
- Router uses IPv4 TOS for hash computation (RFC 1812)

TCP handshake:
- Hosts negotiate ECN support
- ECN-capable bits unset

Flow data:
- ECN-capable bits set
IPv6 flow label rewrite

if flow_label != 0:
    flow_label = rand()

uses IPv6 flow label for hash computation

forbidden by RFC 6437

allowed by RFC 6437
Switches:
- use ingress interface for hash computation, or
- use different hash function seeds
Conclusions

**Load balancing**
There are devices that do not hash traffic uniformly

**Path pinning**
Hashing on fields other than five tuples breaks ECMP
- Ingress port
- IPv4 TOS
- IPv6 flow label
Recommendations

Operators:
• Ensure that your network devices hash flows uniformly or that could cost you money
• Disable additional inputs if you do not need extra entropy

Vendors:
• Disable hashing inputs other than five-tuple by default
• Make hash input fields configurable
• Make hash seed configurable
FIN