P4TG: 1 Tb/s Traffic Generation for Ethernet/IP Networks

Steffen Lindner, Marco Häberle, Michael Menth

http://kn.inf.uni-tuebingen.de
New protocols & network equipment needs to be tested with realistic traffic rates

Traffic generators (TGs) used for this purpose

The top 10 used TGs in the literature are all software-based!
- iperf2
- Netperf
- Moongen
- ...

100+ Gbit/s difficult to generate with software
- Need hardware acceleration
- Hardware based TGs very expensive ($$$$$)

Multi-Port (several 100 Gbit/s) testing for business-grade switches/routers not feasible with software TGs
► Traffic generation with P4 and Intel Tofino™ ASIC (< 8.000€)
► Intel Tofino™ offers built-in capabilities for traffic generation

► We implement measuring functions and configuration in P4 + GUI
► Constant bit-rate & poisson traffic
Intel Tofino™ ASIC

- 3.2 Tbit/s or 6.2 Tbit/s P4 programmable switching ASIC (Gen. 1)
  - Our Edgecore Wedge supports 32x 100 Gbit/s ports
- 12.8 Tbit/s P4 programmable switching ASIC with 32x 400 Gbit/s ports (Gen. 2)
- 25.6 Tbit/s P4 programmable switching ASIC with 64x 400 Gbit/s ports (Gen. 3)

Intel Tofino™ ASIC allows for internal traffic generation

- Up to 8 different packet (byte) descriptions with periodic timer for packet generation

https://www.edgecore.com/productsInfo.php?id=335
P4: Programming protocol-independent packet processors

- High-level programming language to describe data planes
- Target-specific compiler maps P4 program to hardware

```cpp
control MyPipeline(inout headers hdr, inout metadata meta, inout standard_metadata_t std_meta) {
    /* Declarations region */
    table ipv4_lpm { … }
    action ipv4_forward(...) { … }
    …
    apply {
        /* Control Flow */
        if(hdr.ipv4.isValid()){
            ipv4_lpm.apply();
        }
    }
}
```

- P4 defines low level (packet processing) operations
  ⇒ Fully programmable data plane
    - Limited only by expressiveness and features of P4 (and not by vendor)
P4-programmable
- Ingress/Egress Parser
- Ingress/Egress Control
- Ingress/Egress Deparser

Match+action table used in ingress/egress control
P4TG: Overview

- Leverage internal traffic generator for packet generation
- Packet header rewrite for traffic randomization
- VLAN & Q-in-Q encapsulation support
- Up to 10x 100 Gbit/s traffic generation

- Measure several metrics directly in the data plane (P4) for highest precision
  - L1/L2 TX & RX rates
  - Per stream TX & RX rates
  - TX & RX frame sizes and types (unicast, multicast, broadcast, IPv4, IPv6, VLAN, Q-in-Q)
  - Packet loss, out of order
  - TX & RX inter-arrival times (mean and mean-absolute-error)
  - Round-trip-time (RTT; sampled)
► Each of the 10x P4TG ports is associated with two recirculation ports
  ▪ $P_{out}^R$ and $P_{in}^R$

► Packets received on port $P_{in}$ are recirculated to port $P_{in}^R$
► Packets sent on port $P_{out}$ are initially sent to port $P_{out}^R$

► Statistics are collected during recirculation
Measurements

- 64-bit registers to store total TX & RX bytes per port
  - Hardware timestamps with nanosecond precision for rate calculation
  - Tcpdump timestamp accuracy ~ 100us
- 64-bit registers to store # of lost and out-of-order packets
- 32-bit register to store running sum of IATs
- 32-bit register to store running sum of absolute error

Collected statistics are regularly sent to the control plane

- Monitoring packets retrieve stored measurements
  - Follows path of generated packets
- Monitoring packets are tagged with a hardware timestamp for accurate measurements
Generated packets contain Ethernet, (VLAN / QinQ), IPv4, UDP, P4TG header

- 32-bit sequence number for packet loss & out-of-order detection
- 48-bit timestamp for RTT calculation
- 8-bit stream identification
REST-API may be used to automate tests
Traffic Generation

\[ f_{\text{size}} = 64 \text{ byte} \]

![Graph showing configured and achieved packet rates for different packet rates (Mpps), with expected, P4TG, and TRex configurations.]
Demo
P4TG offers traffic generation at high data rates (up to 100 Gbit/s per port)
- (Possibly) Up to 400 Gbit/s with 2. Gen. Tofino

Low-cost hardware TG

Customizable for individual needs
- Both data and control plane

https://github.com/uni-tue-kn/P4TG

Any Questions?

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🔗 https://github.com/uni-tue-kn/P4TG

Steffen Lindner
University of Tübingen
steffen.lindner@uni-tuebingen.de