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Parallelizing IPsec: switching SMP to 'On' is not even half the way

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The IPsec protocols

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- *IP - Authentication Header (AH)*
  - AH builds a cryptographic checksum over the payload and parts of the header of a network packet.
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- *IP - Authentication Header (AH)*
  - AH builds a cryptographic checksum over the payload and parts of the header of a network packet.
  - This checksum is appended to the network packet and is used to ensure authenticity of this network packet.
- *IP - Encapsulated Security Payload (ESP)*
  - ESP is primary used to encrypt the payload of network packets.
  - A cryptographic checksum can be used to ensure authenticity of the payload, similar to AH.

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ESP modes

The ESP protocol can be used in several modes.

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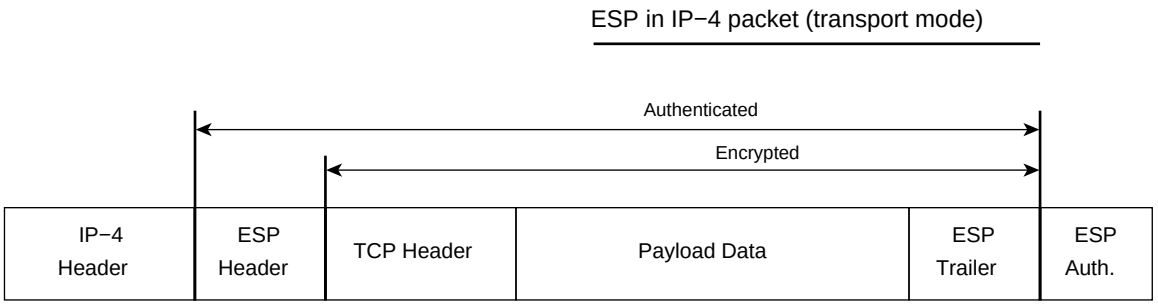
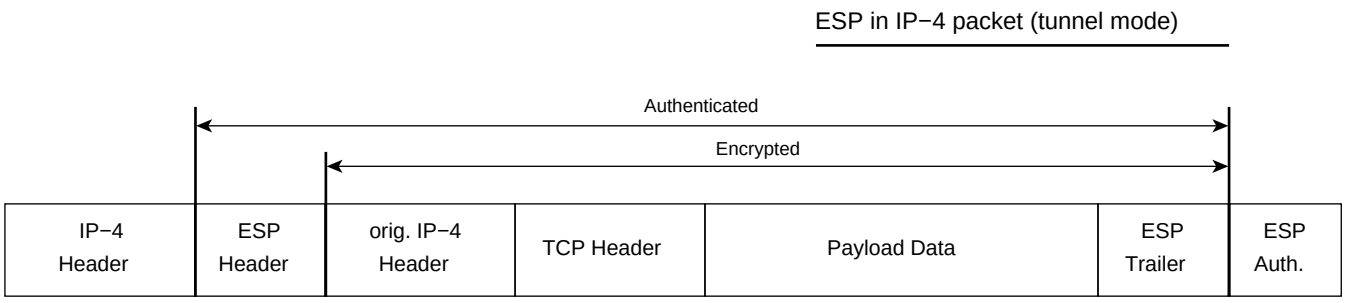
ESP modes

The ESP protocol can be used in several modes.

- *Transport mode* - Pure layer 4 payload encryption.
- *Tunnel mode* - Encryption for the whole IP packet (payload + IP header).





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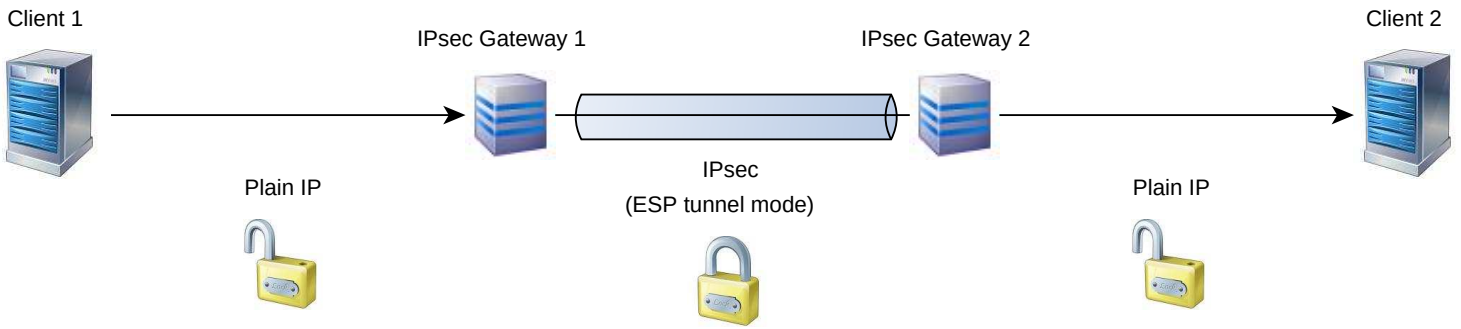
The Hardware setup and IPsec scenario

The hardware setup is the simplest possible IPsec VPN scenario, consisting of two IPsec gateways and two clients.



Packet forwarding from client 1 to client 2, unidirectional traffic, one packet flow.

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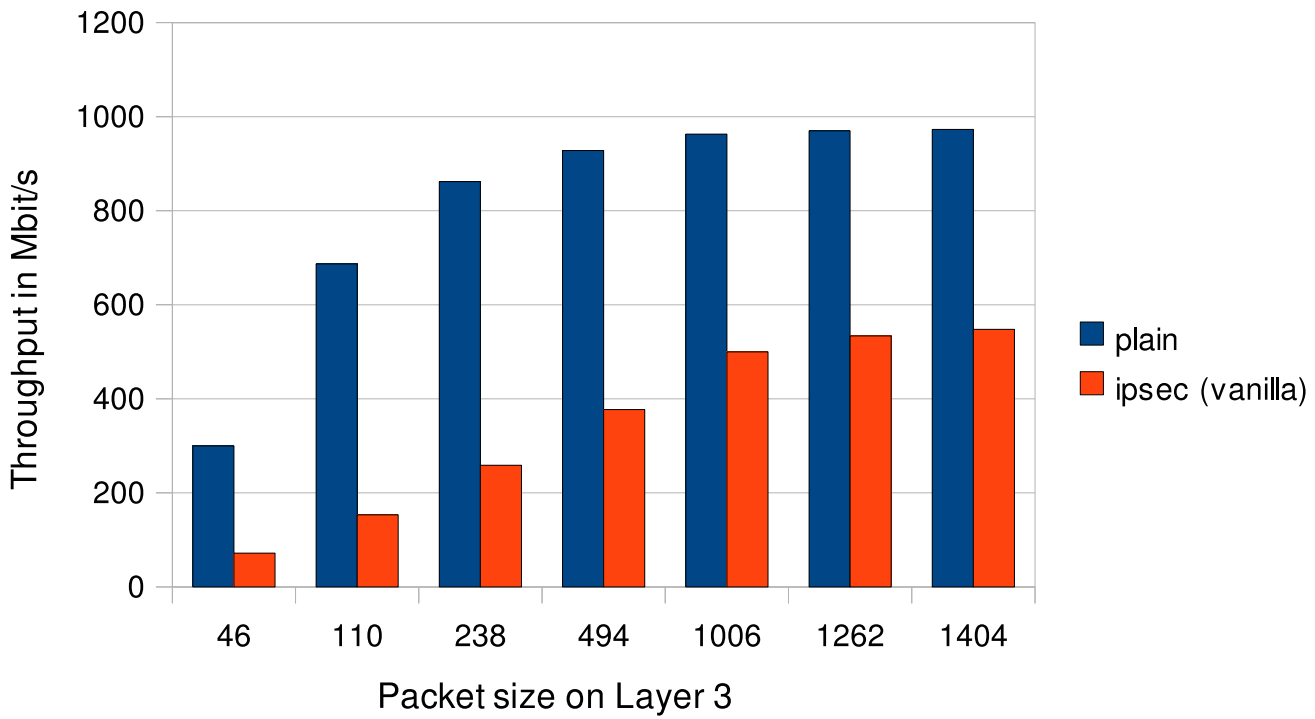
Plain packet forwarding vs. tunnel mode ESP with cbc-aes192 / hmac-sha1 on a Gbit network.



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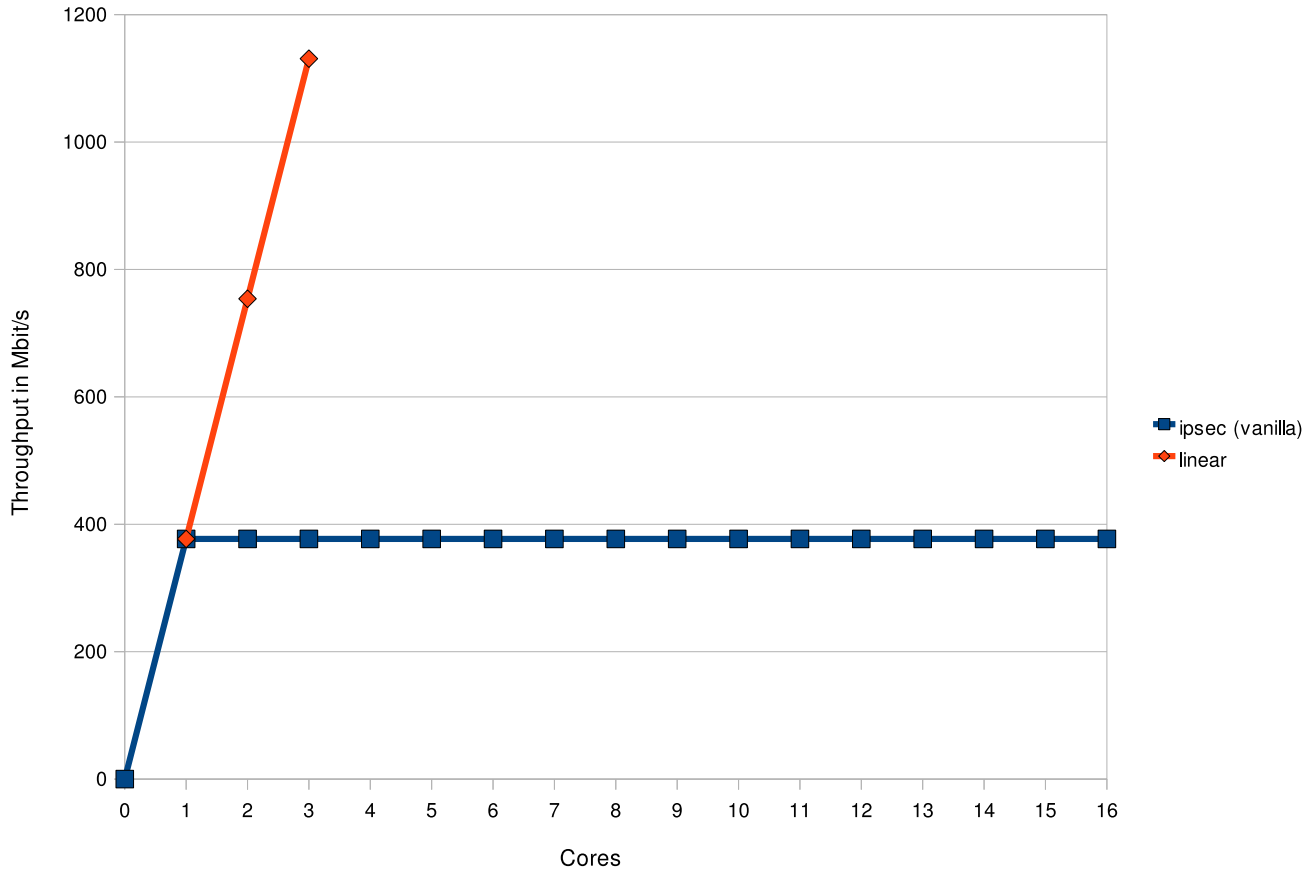
IPsec throughput: scaling with the number of cpus



494 byte packets (L3) cbc-aes-192 / hmac-sha1

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IPsec throughput: scaling with the number of cpus

The forward packet path is strictly serialized. I.e. the cpu that drives the interrupt of the receiving NIC does all the work!

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Why?

- The upper layer (L4) protocols rely on a certain packet order. The packets must be received in the same order they where sent.
- IPsec adds a sequence number to each packet to notify packet replay attacks.

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Why?

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Distributing the received network packets to multiple cpus leads to packet reordering!

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Network parallelization approaches

Due to packet reorder problems, parallelization of the network stack is a highly nontrivial task. Several software, as well as hardware based approaches came up during the last years.

- Multiqueue network devices.
- Receive packet steering.

These techniques do flow based parallelization, i.e. distributing packet flows across the cpus.

No parallelization within the flows to preserve the packet order!

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Flow based parallelization on IPsec

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Flow based parallelization on IPsec

Flow based parallelization is only limited useful for tunnel mode ESP.

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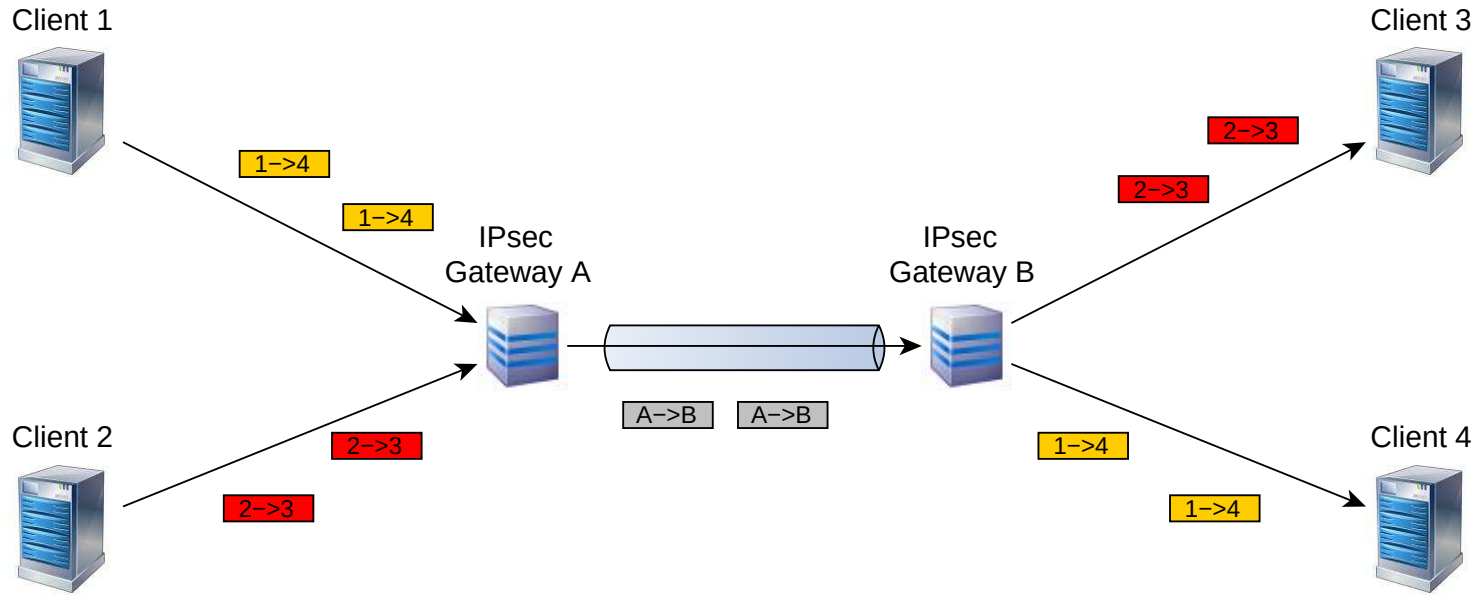
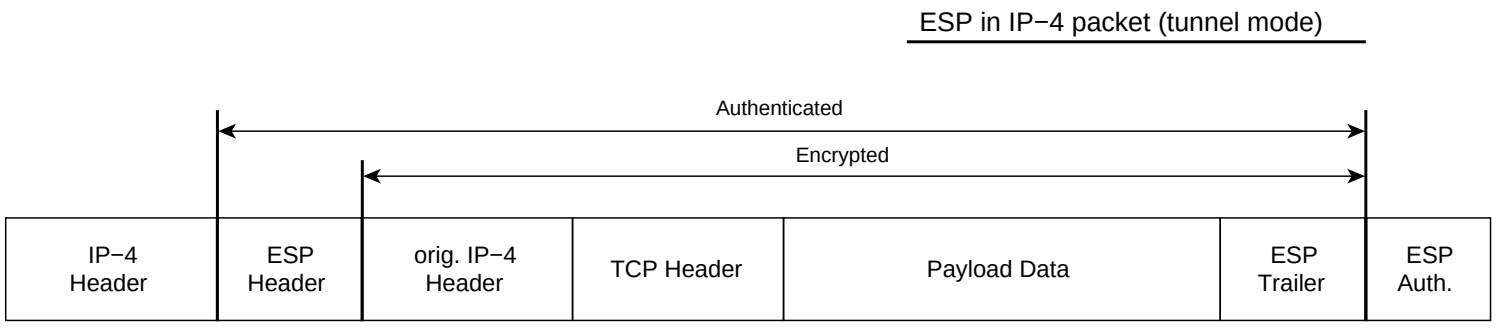
Flow based parallelization on IPsec (tunnel mode ESP)





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Requirements of an IPsec parallelization

- **R1:** *It should be possible to distribute cpu intensive codepaths to a given set of cpus.*
- **R2:** *It should be possible to parallelize even within a flow.*
- **R3:** *The parallelization framework must preserve the order of the parallelized network packets. E.g. the packets must leave the parallel codepath in the same order as they entered.*

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A parallel crypto layer

Advantages of a parallel crypto layer:

- The crypto operations are by far the most cpu intensive codepath (R1).
- The crypto layer does not know about the crypto user (ESP), no need to care about the order of the requests within the crypto layer (R2).
  We just have to ensure that the crypto requests leave the crypto layer in the same order as they entered (R3).

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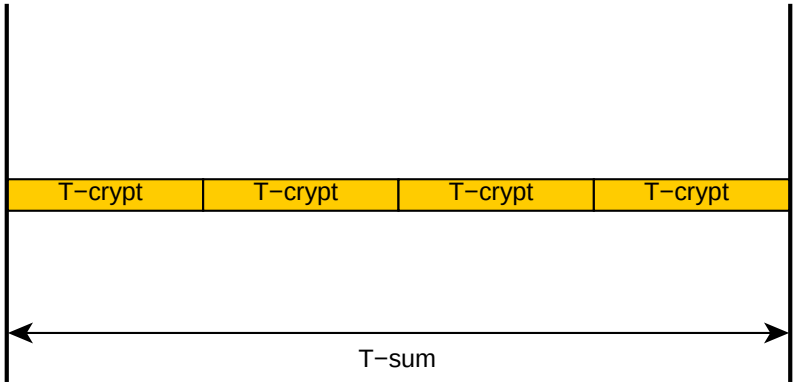
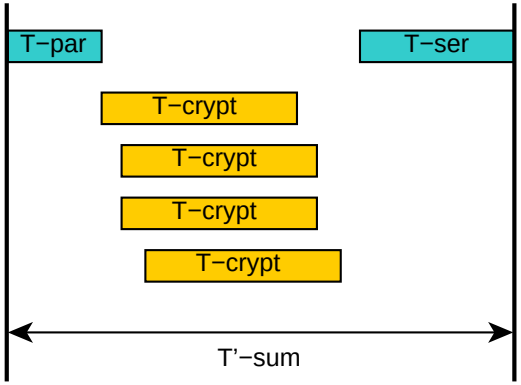
The gain of a crypto layer parallelization





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The gain of a crypto layer parallelization

- Large crypto requests (e.g. big network packets) benefit well.
- Very cpu intensive crypto algorithms benefit well.

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The padata/pcrypt framework

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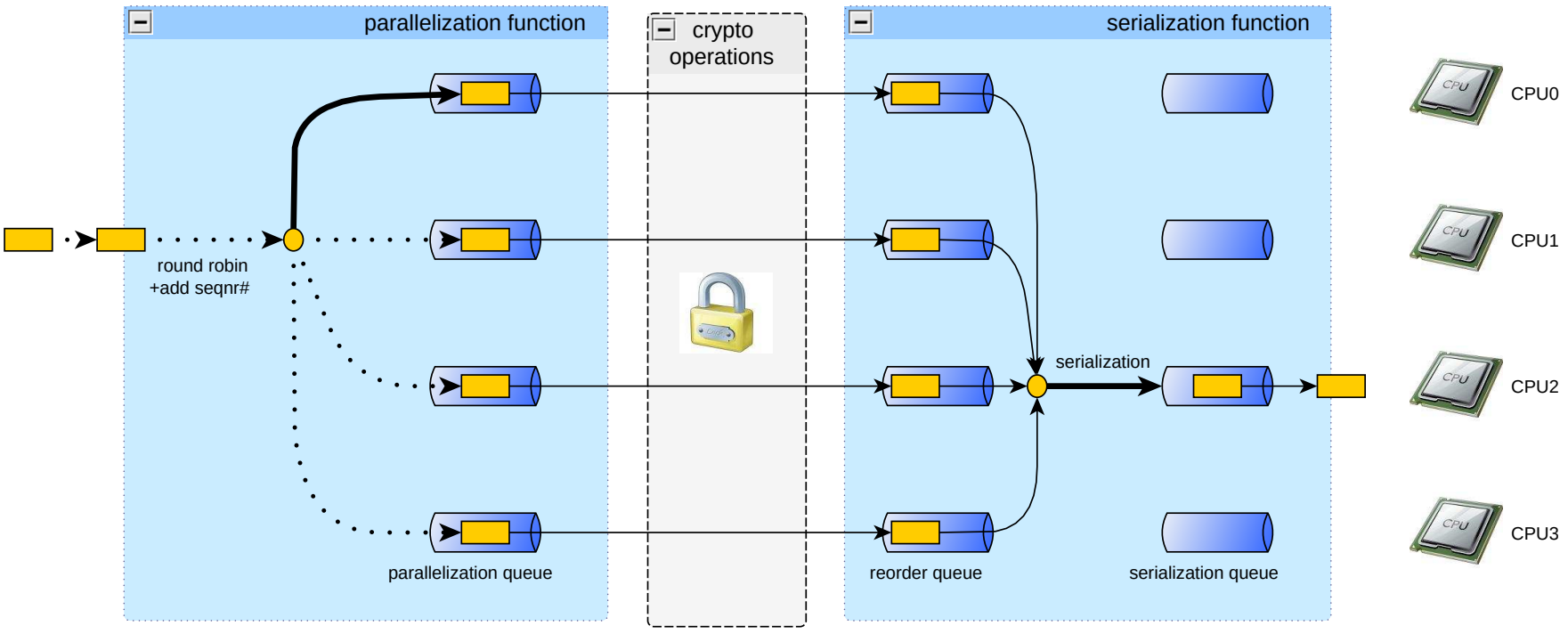

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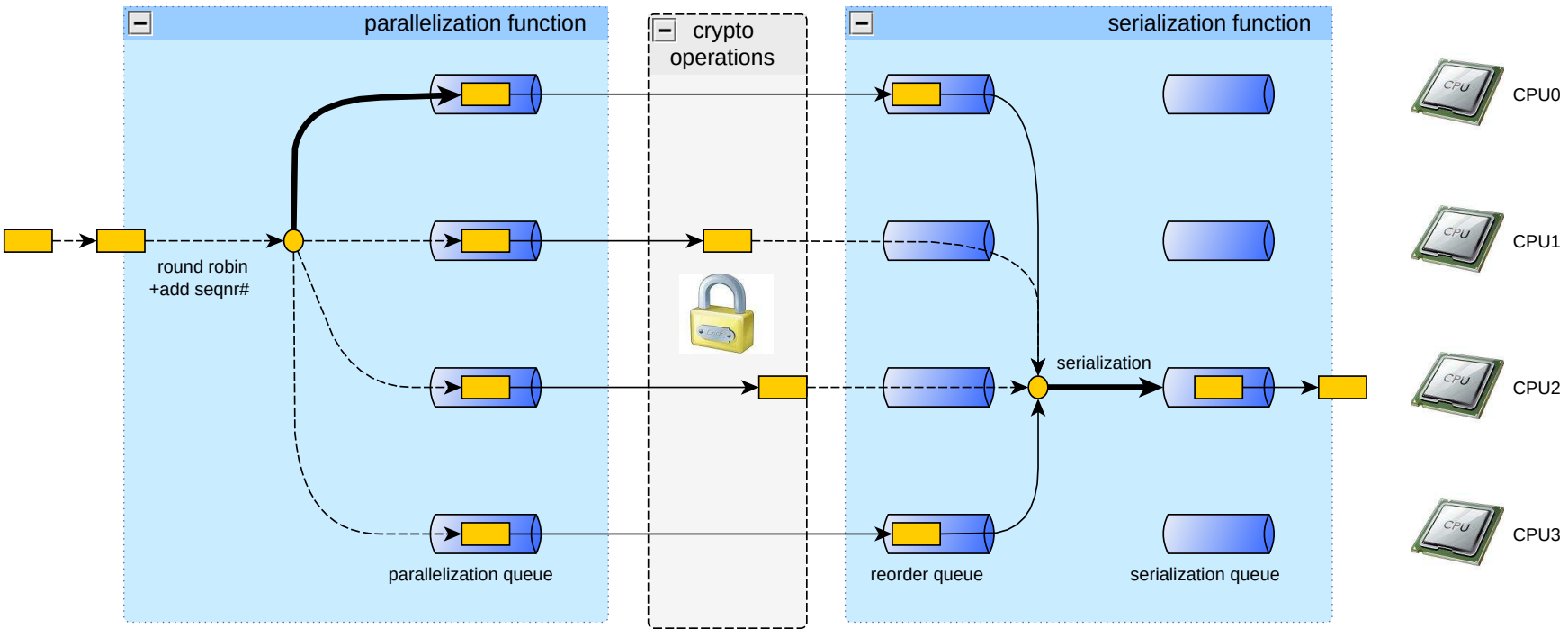
The padata/pcrypt framework



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The software test setup

- Kernel: linux-2.6.33-rc7 with two additional patches (padata/pcrypt) picked from the cryptodev-2.6 tree.
- IPsec: Tunnel mode ESP on IPv4.
- Encryption/Decryption: cbc-aes-192 (x86_64 optimized version of AES).
- Authentication: hmac-sha1 (generic C version).

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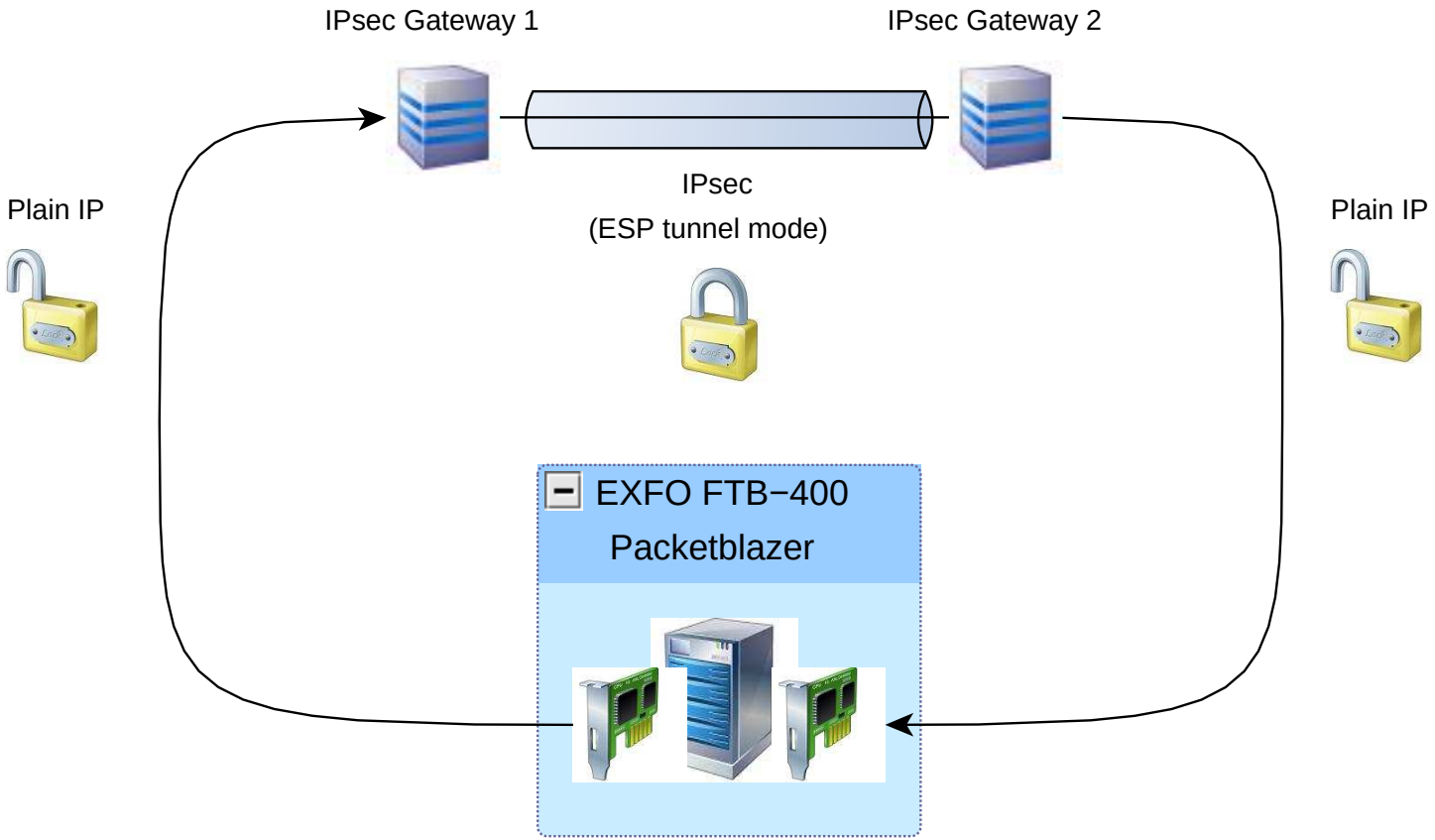
The hardware test setup



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The hardware test setup

IPsec gateway 1 (Apligo Nexom NSA7110):

- 2 x XEON DP E5540 2.53GHz (2 x quad-core)
- 2 x 1024 DDR3 ECC
- 8 x Intel Corporation 82575EB Gbit NIC
- Intel 5520 and ICH10R Chipset

IPsec gateway 2 (SIE XL-1.0):

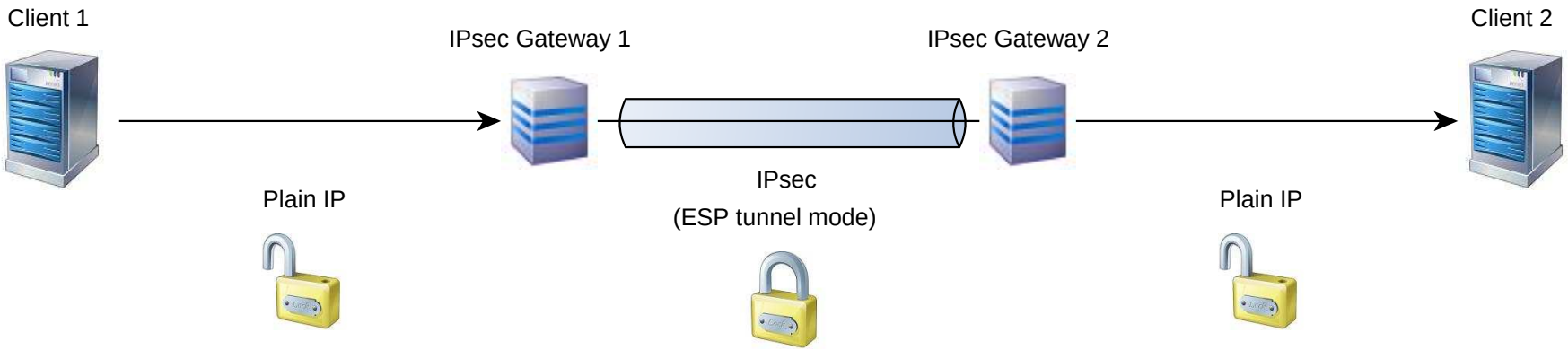
- 2 x Intel Xeon X5550 2,66GHz (2 x quad-core)
- 4 x 1024 DDR3 ECC
- Intel 4Port Gbit NIC EXPI9404PTL
- Intel 5520 and ICH10R Chipset

Hyperthreading was enabled on both IPsec gateways on all tests, so we had 16 logical cores (8 on each socket) for parallel processing.

RFC 2544 Benchmarking Methodology

- Test duration: 60 sec.
- Throughput test results: Maximal throughput rate without packet loss (60 sec.).
- latency test results: Latency at Maximal throughput rate without packet loss.
- Packet sizes RFC 2544 (Layer 2): 64, 128, 256, 512, 1024, 1280, 1518 byte.
- Used packet sizes (Layer 2): 64, 128, 256, 512, 1024, 1280, 1420 byte.
- Used packet sizes (Layer 3): 46, 110, 238, 494, 1006, 1262, 1402 byte.

Maximum theoretical throughput on Layer 3



Wire speed at layer 1: 1000 Mbit/s.

IP−4 Header	TCP Header	Payload Data

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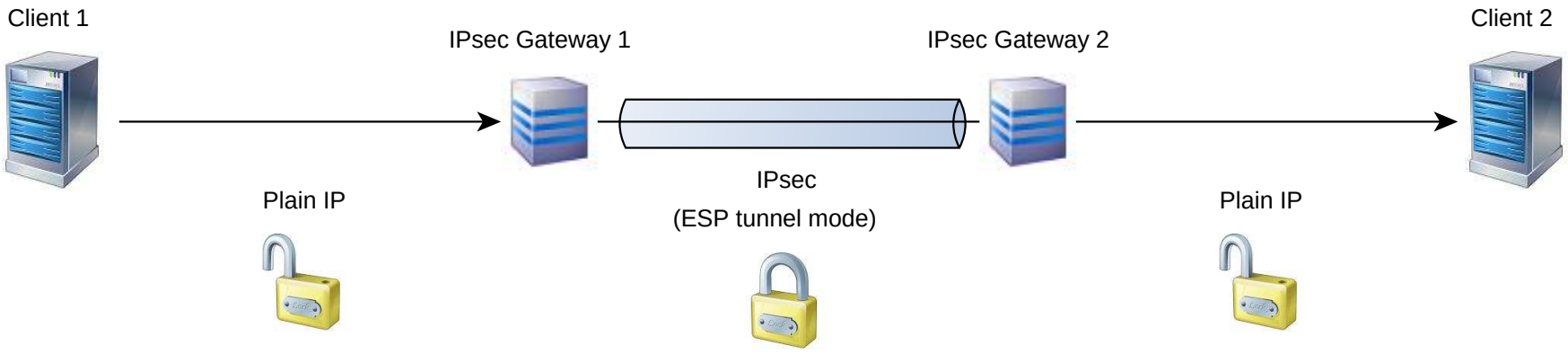
Maximum theoretical throughput on Layer 3



IP−4 Header	TCP Header	Payload Data

IP−4 Header (Tunnel)	ESP Header	IP−4 Header	TCP Header	Payload Data	ESP Trailer	ESP Auth.

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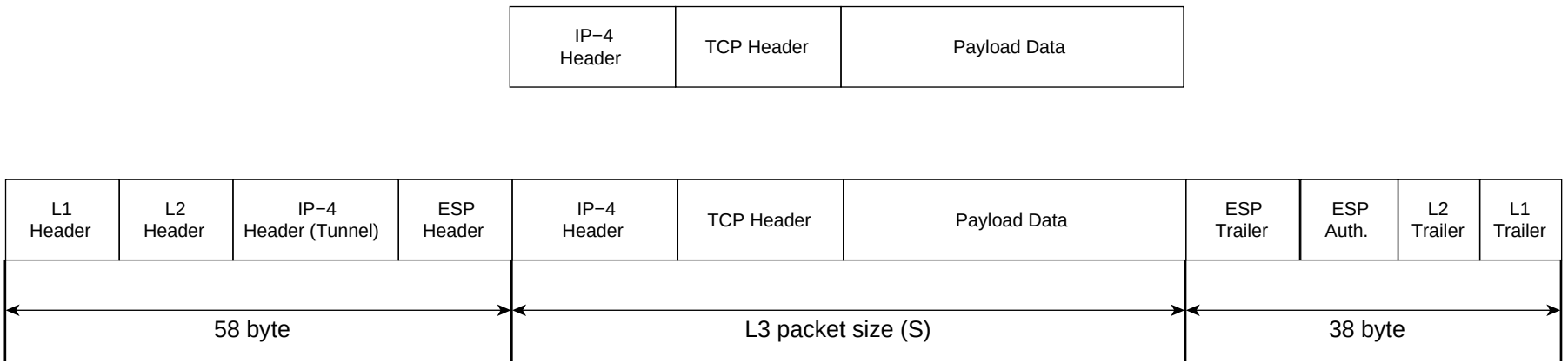
Maximum theoretical throughput on Layer 3



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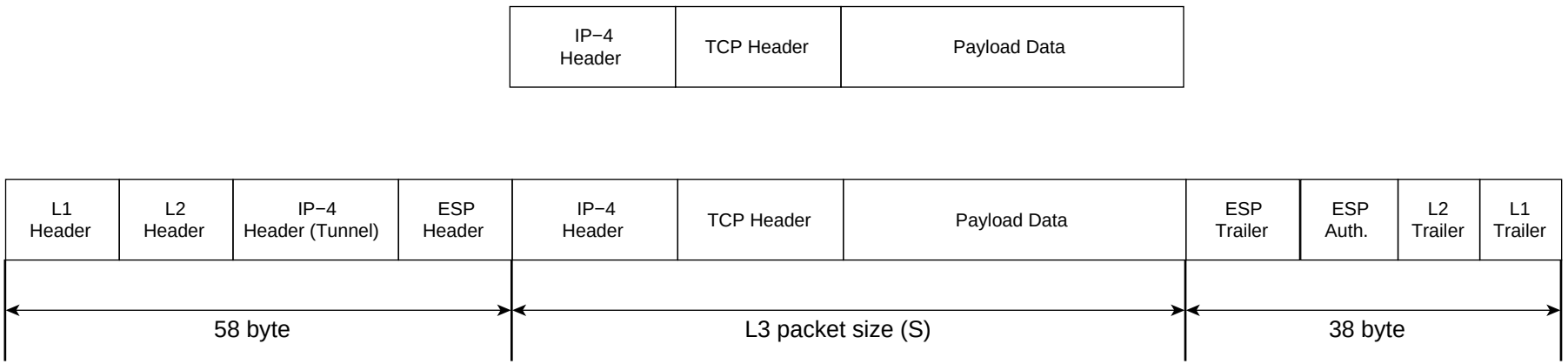

Maximum theoretical throughput on Layer 3:

$$MTT(S) = \frac{S}{S + 96} \times 1000\ \mathrm{Mbit/s}$$

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Maximum theoretical throughput on Layer 3

$$MTT(46) = 324\ \text{Mbit/s} \quad (1)$$
$$MTT(110) = 534\ \text{Mbit/s} \quad (2)$$
$$MTT(238) = 712\ \text{Mbit/s} \quad (3)$$
$$MTT(494) = 837\ \text{Mbit/s} \quad (4)$$
$$MTT(1006) = 913\ \text{Mbit/s} \quad (5)$$
$$MTT(1262) = 929\ \text{Mbit/s} \quad (6)$$
$$MTT(1402) = 932\ \text{Mbit/s} \quad (7)$$

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Effective throughput on Layer 3

$$ET(S) = \frac{\text{Measured throughput for packetsize } S}{MTT(S)}$$

$$0 \leq ET(S) \leq 1$$

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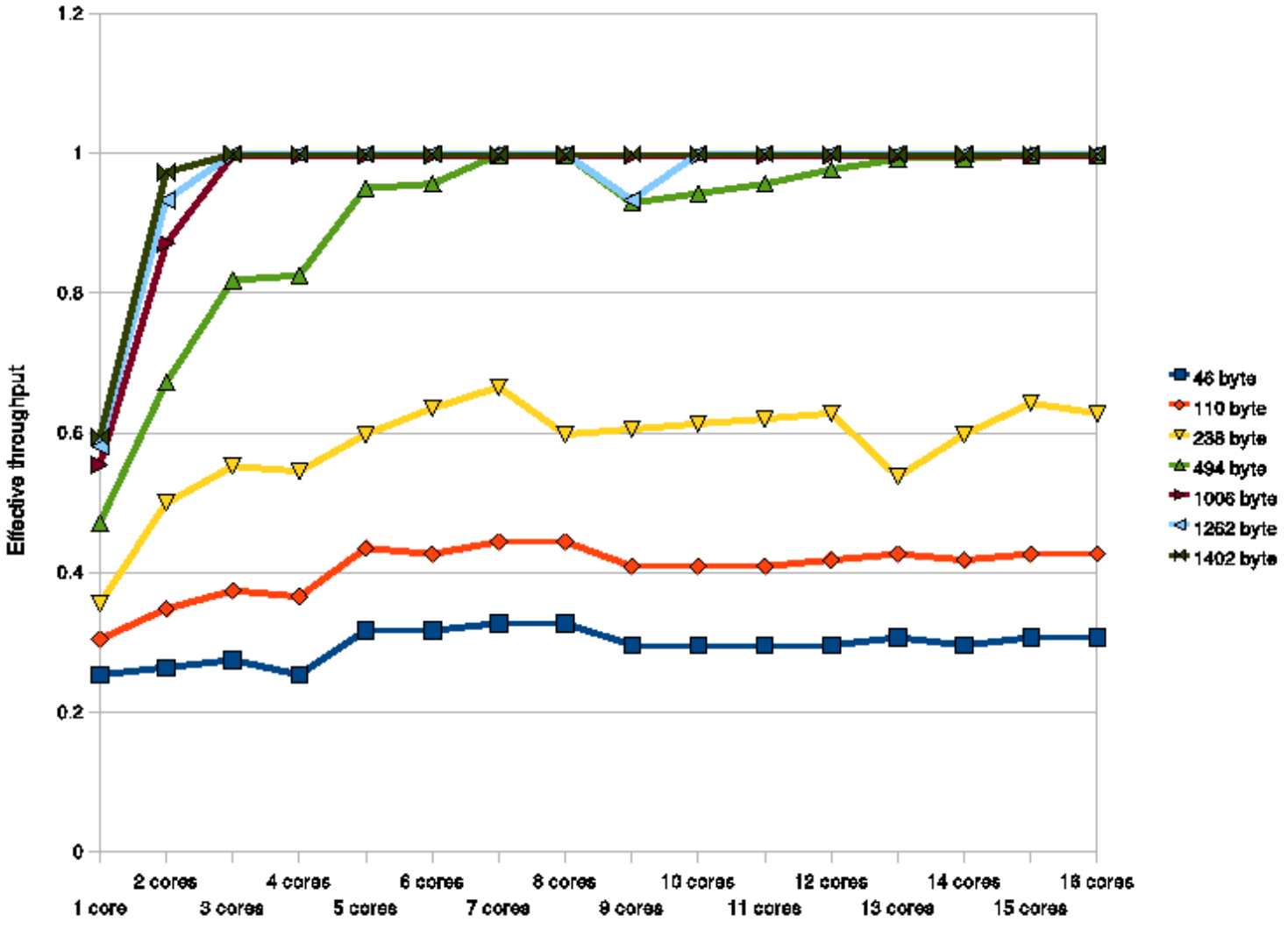
Unidirectional effective throughput benchmarks



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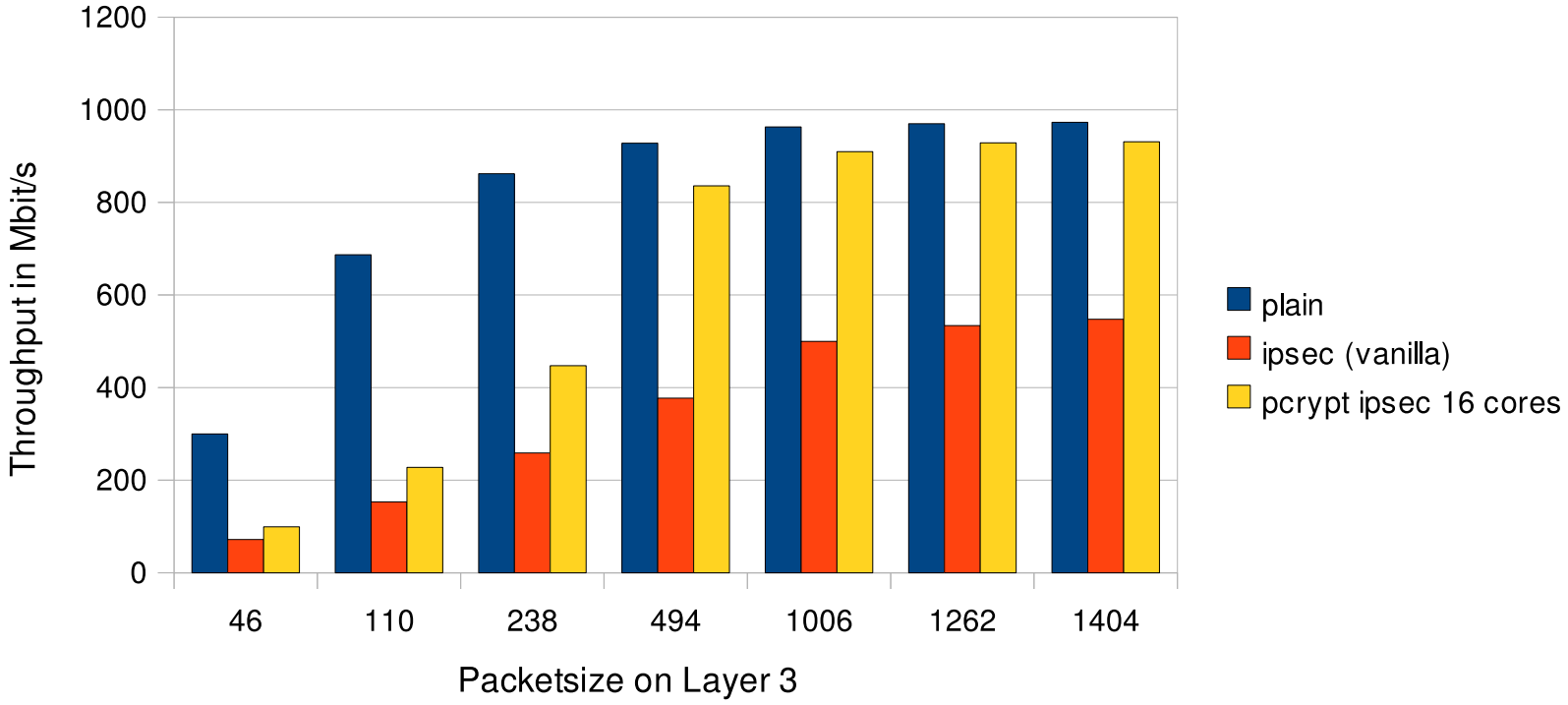
Unidirectional throughput: plain, IPsec vanilla, IPsec pcrypt



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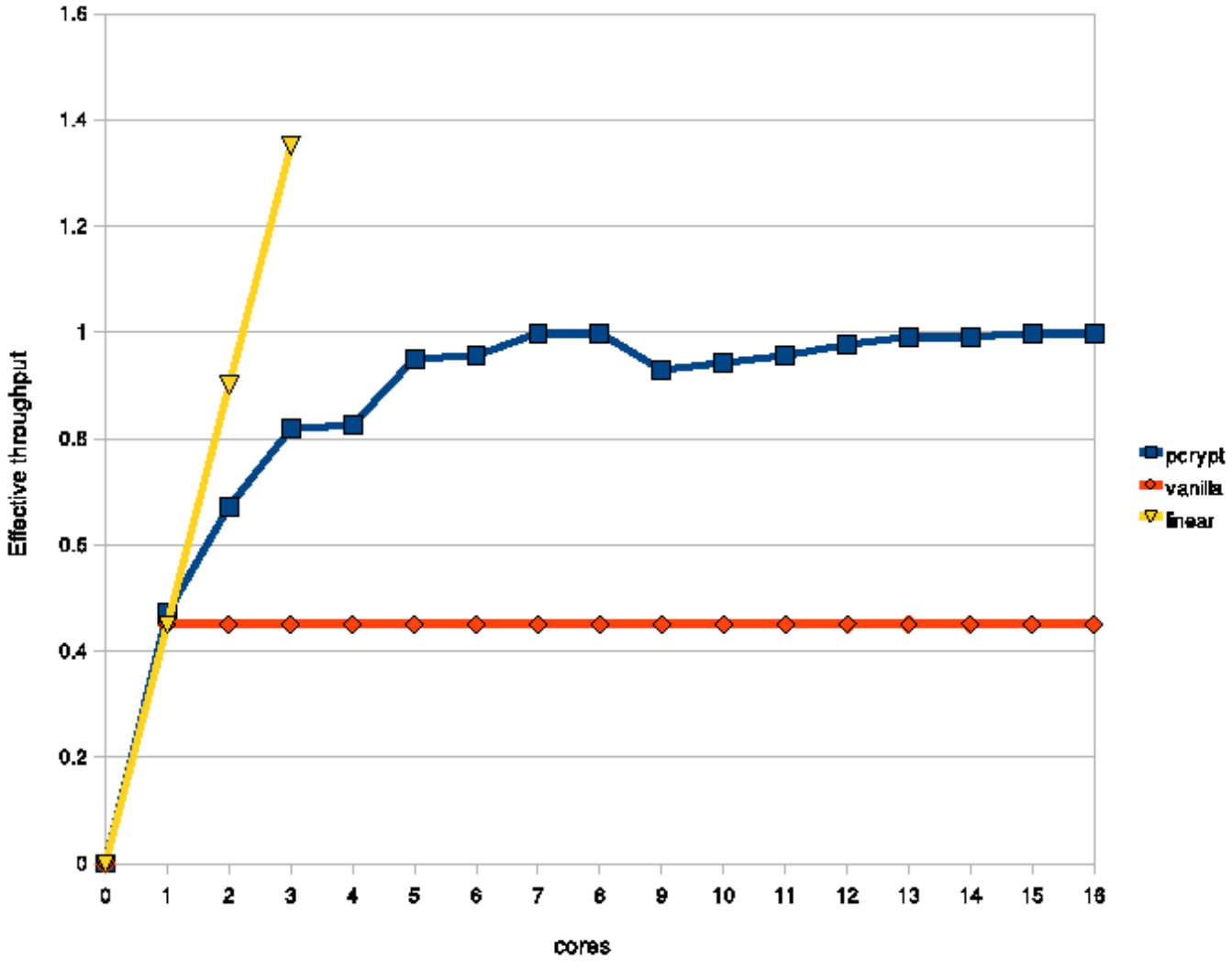
Unidirectional effective throughput 494 Byte on Layer 3



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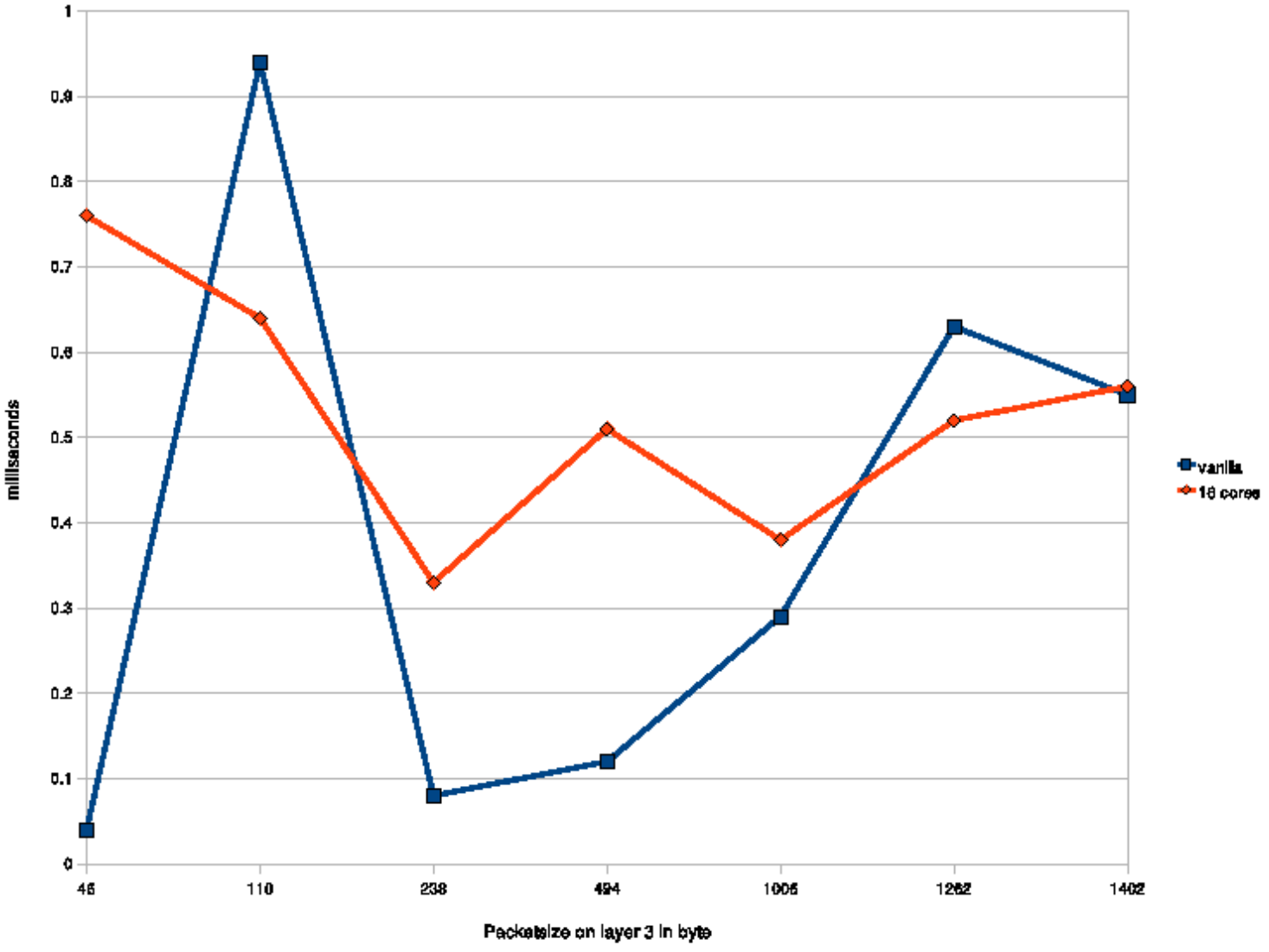
Latency with linux-2.6.33-rc7 vanilla and pcrypt 16 cores



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Thanks to Apligo for providing me with test hardware!

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Thanks for listening!