Kernel TLS and hardware TLS offload in FreeBSD 13

by

Mellanox, Chelsio and Netflix

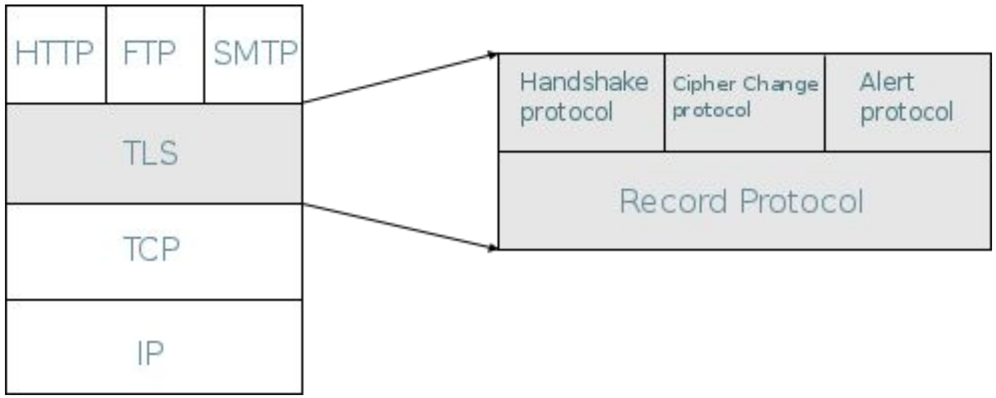
Why crypto?

- Bob and Alice and the secret message
- Mathematical dependance on a relatively small pre-shared key
- When used right:
  - Prevents eavesdropping
  - Prevents data tampering
- When used wrong:
  - Makes denial of service easier

What is TLS ?

- Transport Layer Security, TLS
- Used behind https:// (TCP port 443)
- Supports multiple crypto codecs among others
  - AES 128B / 256B
- Supports multiple key exchange protocols
  - DiffieHellman, DH
  - Ron Rivest, Adi Shamir, Leonard Adleman, RSA
- Most recent version is v1.3

What is TLS ?


HTTP
FTP
SMTP
TLS
TCP
IP
Handshake protocol
Cipher Change protocol
Alert protocol
Record Protocol

TLS v1.2

- Layout of a TLS record
- More detailed information at: https://tls.ulfheim.net/

TLS REC(s)
TCP HDR
IPv4/IPv6 HDR
ETH HDR

uint8_t	tls_type (data, handshake,alert)
uint8_t	tls_vmajor (3)
uint8_t	tls_vminor (3)
uint16_t	tls_length (0..16K)
uint8_t	tls_nonce[ ]
uint8_t	tls_data[ ]

TLS v1.3

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TLS REC(s)
TCP HDR
IPv4/IPv6 HDR
ETH HDR

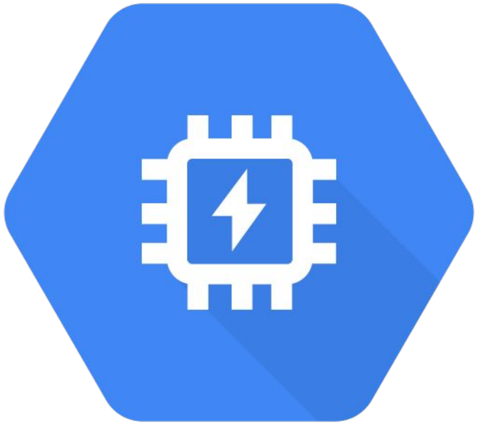
uint8_t	tls_type (data=23)
uint8_t	tls_vmajor (3)
uint8_t	tls_vminor (3)
uint16_t	tls_length (0..16K)
uint8_t	tls_data[ ]

AES 128B / 256B

- Advanced Encryption Standard, AES
  - See: https://en.wikipedia.org/wiki/Advanced_Encryption_Standard
- A 16-byte block cipher
- The stream version can stop and resume encryption at any arbitrary point in the TLS record
  - Supports the concept of a crypto cursor
- FreeBSD also supports CBC

TLS implementations

- Current FreeBSD alternatives (OpenSSL based)
  - Generic user-space, AES-NI
  - SW kernel TLS, AES-NI
  - Open Crypto Framework kernel backend
  - TCP Offload Engine for TLS
  - NIC kernel TLS



... vs ...

A look inside OpenSSL

- Datapath is oriented around:
  - typedef struct bio_st BIO;
  - BIO_read()
  - BIO_write()
- All data must have a pointer in user-space in order to be encrypted
- Based on the source and sink methodology
- Refer to the bio(3) manual page

OpenSSL and kTLS

- 16 patches have been submitted by:
  Boris Pismenny <borisp@mellanox.com>
- FreeBSD userspace APIs:
  - #include <sys/ktls.h>
  - setsockopt(TCP_TXTLS_ENABLE)
  - setsockopt(TCP_TXTLS_MODE)
- FreeBSD kernel support added in r351522:
  - https://svnweb.freebsd.org/changeset/base/351522

Netflix kTLS

- Kernel TLS Motivation
  - Handle 100Gb/s of TLS with nginx
  - Retain performance advantages of async sendfile(9) (fewer context switches, no nginx thread pool, no extra memory copy)
  - Eliminate any possible inefficiency

New mbuf technologies

- Not ready flag
- Unmapped mbufs
- Send Tags

not ready mbuf flag

- mbuf flag M_NOTREADY tell socket buffers if mbufs are ready for transmission or not.
- Added to support async sendfile in r275329
- Sendfile(9) adds mbuf to socket buffer marked M_NOTREADY
    - Until M_NOTREADY is cleared, tcp cannot send it
- disk reads are issued into those mbufs
- M_NOTREADY cleared and tcp_usr_ready() routine called after disk read is complete
- Allows a simple mbuf filter routine, like TLS encryption, to process the mbufs before they are submitted to the network driver via the TCP stack.

Netflix “unmapped” mbufs

- Called “unmapped” because they carry an array of pointers to unmapped physical addresses.
- Initially envisioned for sendfile, not TLS
- Dramatically reduces the length of socket buffer mbuf chains, thus reducing cache misses. For a 16K TLS record, it compresses chains by about 6:1 (TLS hdr, trailer and 4 buffers). For unencrypted sendfile, it can compress mbuf chains up to 19:1
  - 5-20% CPU reduction in Netflix unencrypted workloads
- Describes a TLS record entirely, including TLS header, trailer, message data, and pointers to kernel TLS session state in a single mbuf
- A single reference counted entity per TLS record is key for NIC TLS offload to be able to easily handle TCP retransmissions.

Netflix Software kTLS

Software Kernel TLS Implementation, TLS 1.0 -> TLS 1.3

- Plaintext data passed to kernel via sendfile() or sosend().
- The kernel frames TLS records into M_NOMAP mbufs at sendfile() or sosend() time and places them into socket buffers.
- Mbuf chains are marked with M_NOTREADY
- Framed records are queued for encryption when they would previously be marked “ready”
- Encryption is done by a pool of kernel threads (1 per core)
- Once encrypted, mbufs are marked “ready” & sent to TCP

mbuf send tags

- A property of mbufs which tell the underlying network interface about dedicated packet processing and queues.
- A quick and efficient way to demultiplex data traffic.
- Allows for traversal through VLAN and LAGG (Link Aggregation).
- Safe against route changes.

mbuf send tag APIs

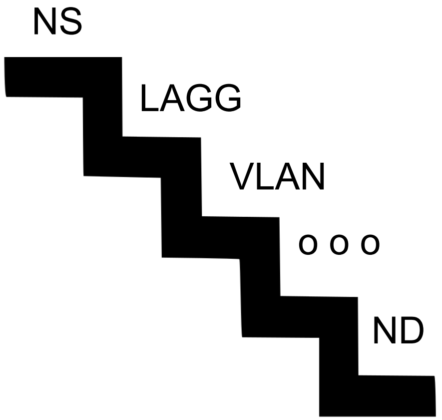
- Control path methods:
  - struct mbuf_snd_tag *mst;
  - struct ifnet *ifp;
  - Allocate(ifp, &mst)
  - Modify(mst, arg)
  - Query(mst, arg)
  - Free(ifp, mst)

mbuf send tags

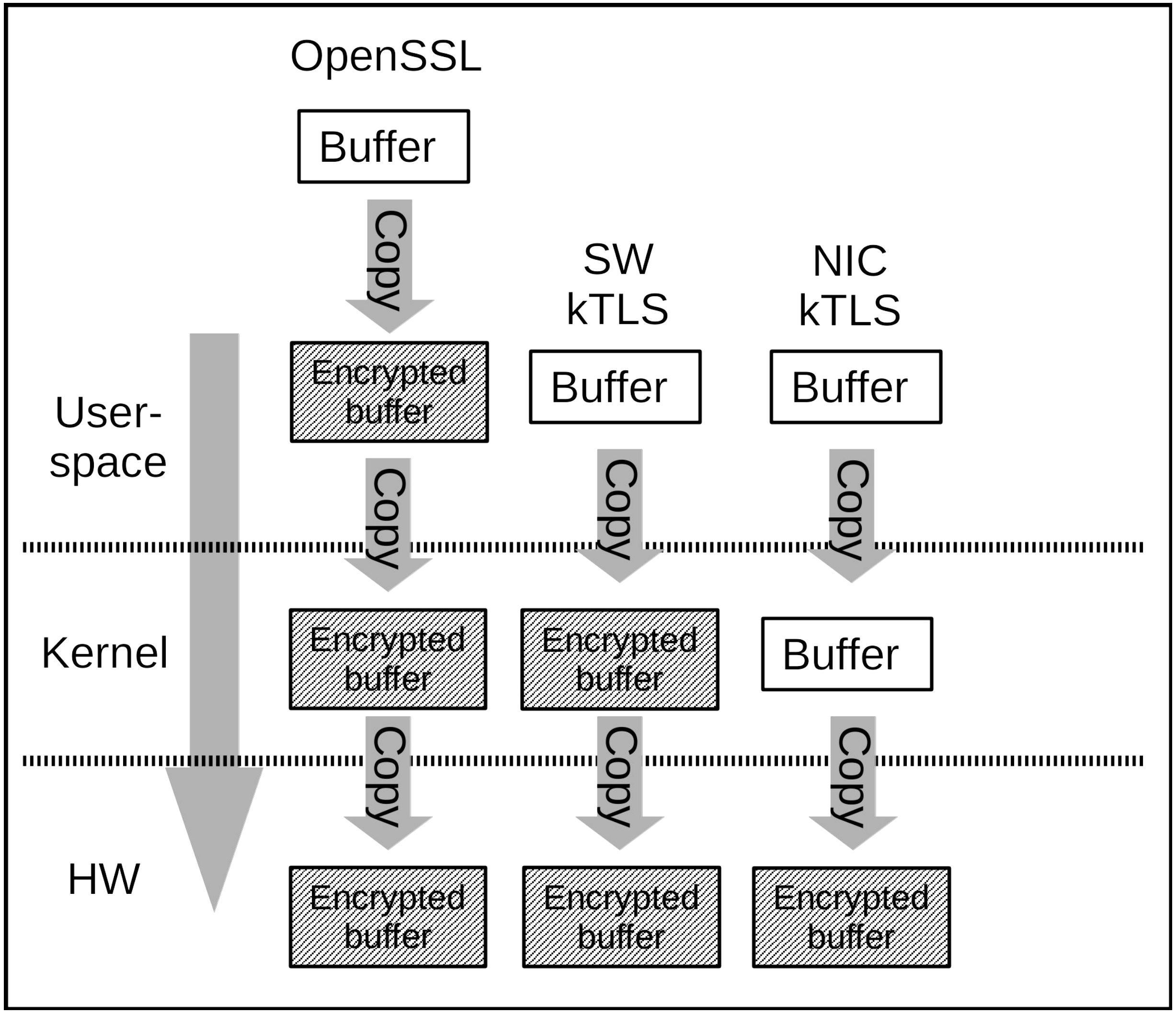
- From Network Stack, NS, perspective:
  - struct mbuf *mb;
  - struct ifnet *ifp;
  - m_pkthdr.snd_tag = mst;
  - m_pkthdr.csum_flag |= CSUM_SND_TAG;
  - ifp->if_output(mb);

mbuf send tags

- From Network Driver, ND, perspective:
  - struct mbuf *mb;
  - struct xxx_send_tag *st;
  - st = container_of(m_pkthdr.snd_tag, …)
  - select queue by st->queue;



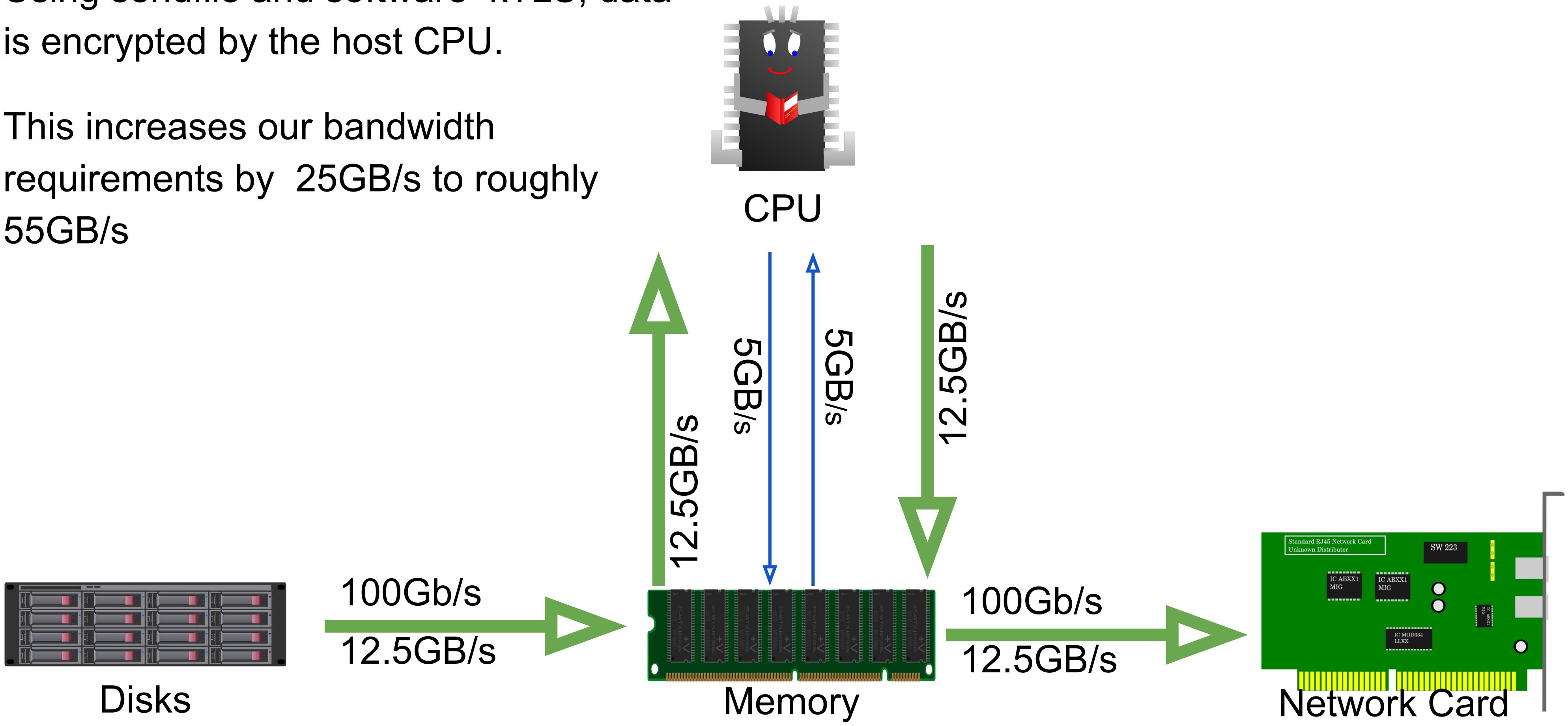
Dataflow overview



Sendfile dataflow overview

Using sendfile and software kTLS, data is encrypted by the host CPU.

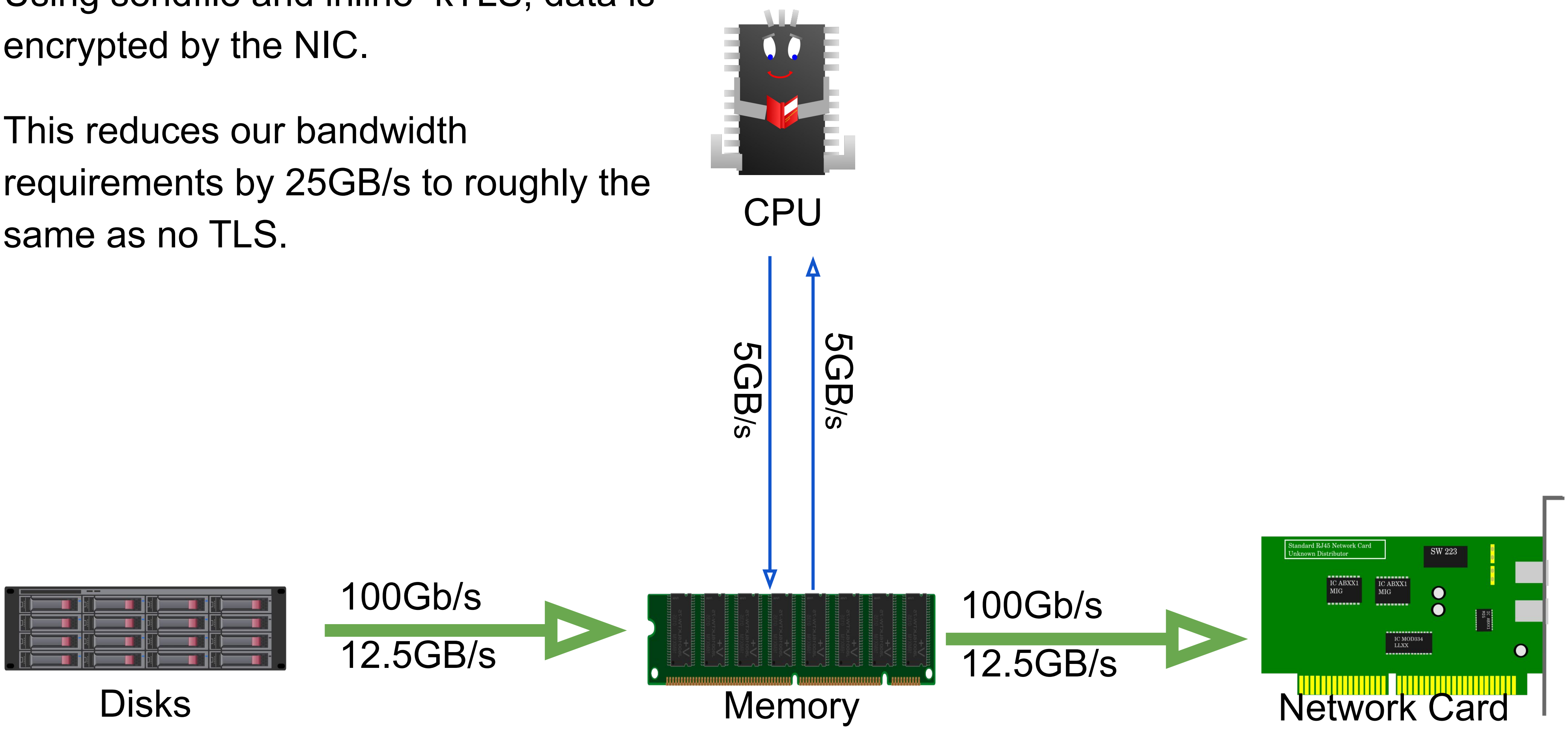
This increases our bandwidth requirements by 25GB/s to roughly 55GB/s



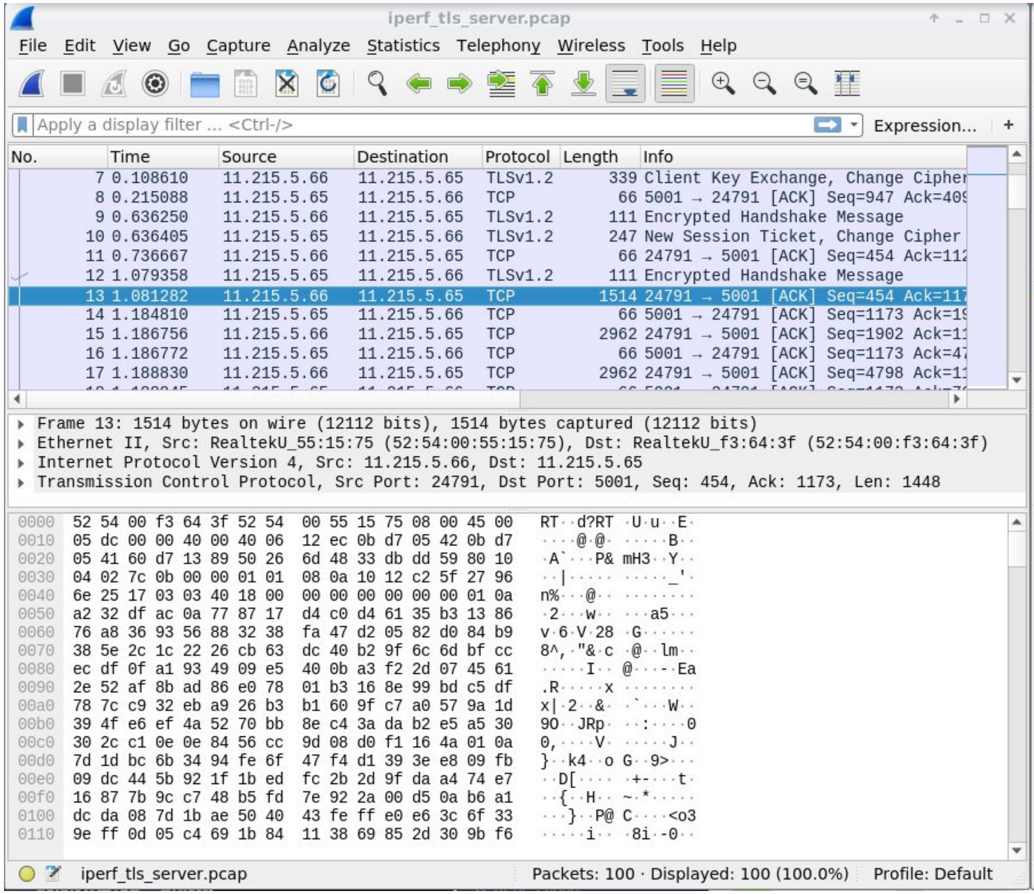
Sendfile dataflow overview

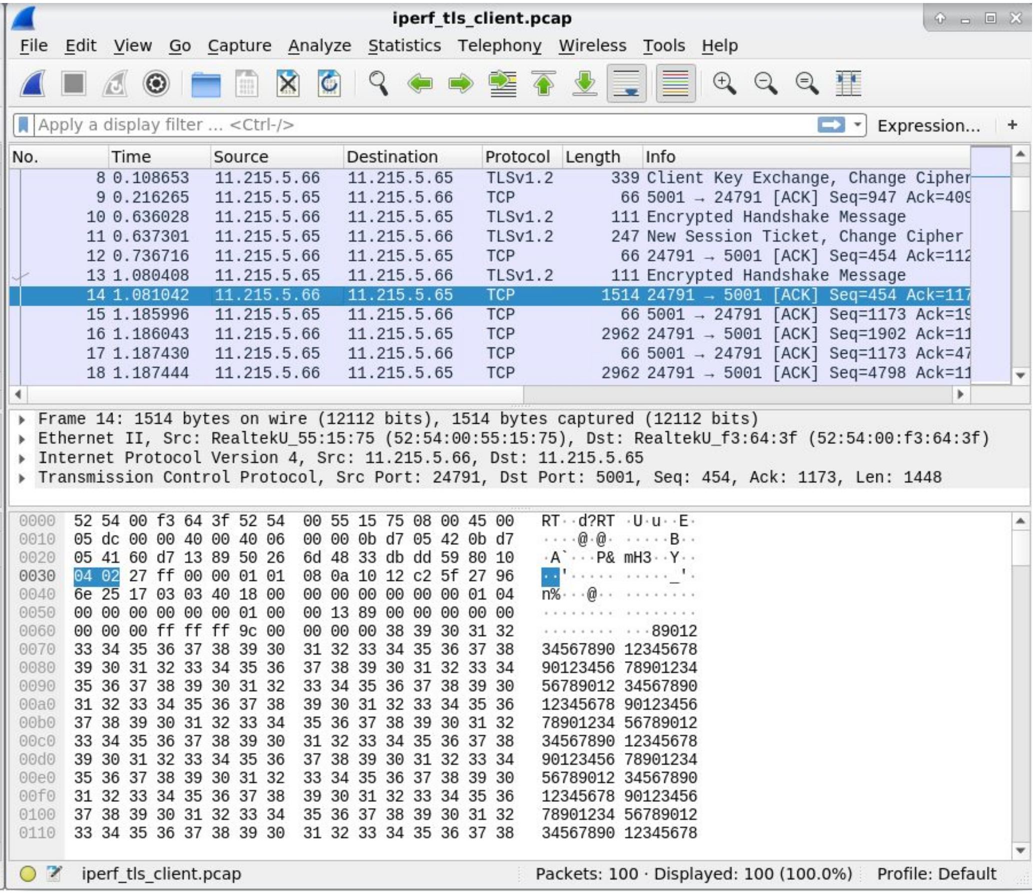
Using sendfile and inline kTLS, data is encrypted by the NIC.

This reduces our bandwidth requirements by 25GB/s to roughly the same as no TLS.



TLS before and after





NIC kTLS offload challenges

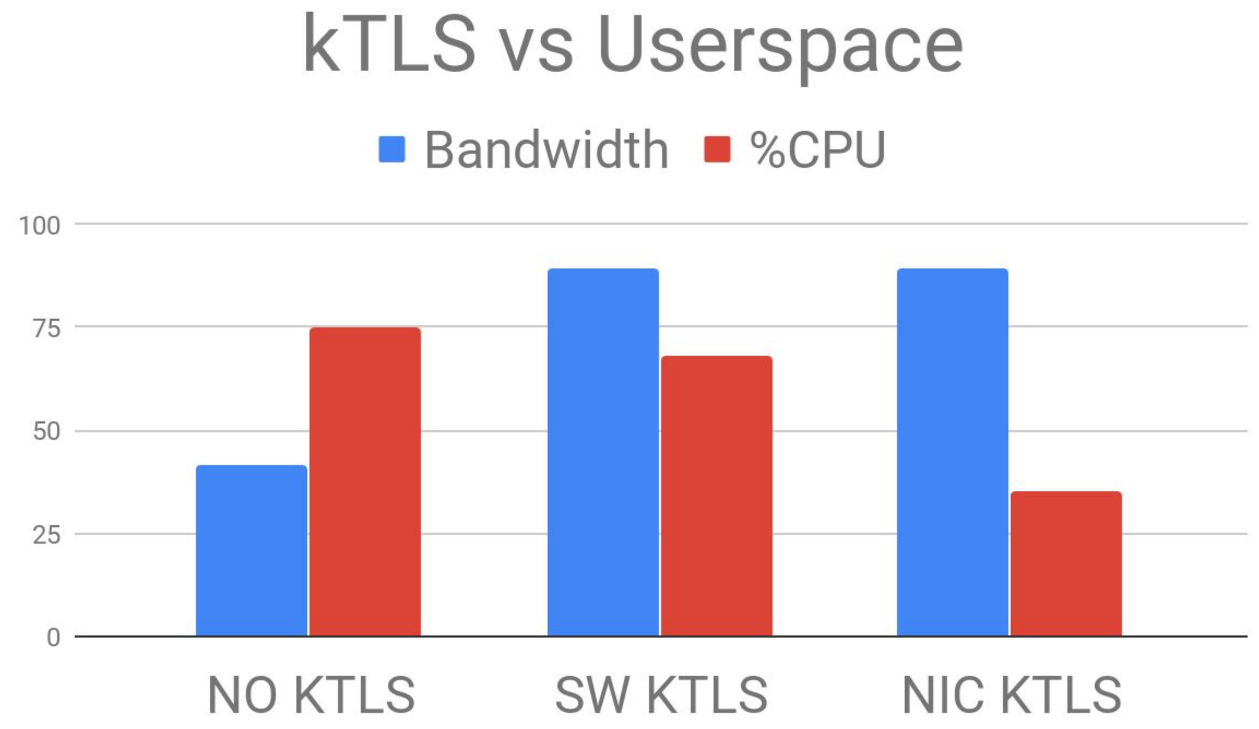
- Minor OSI model violation.
- Packets are sent containing full headers, except for un-encrypted payload.
- Prior to retransmission, crypto cursor needs update by re-transmitting off-the-wire parts of the TLS record, if any.

Benchmarks

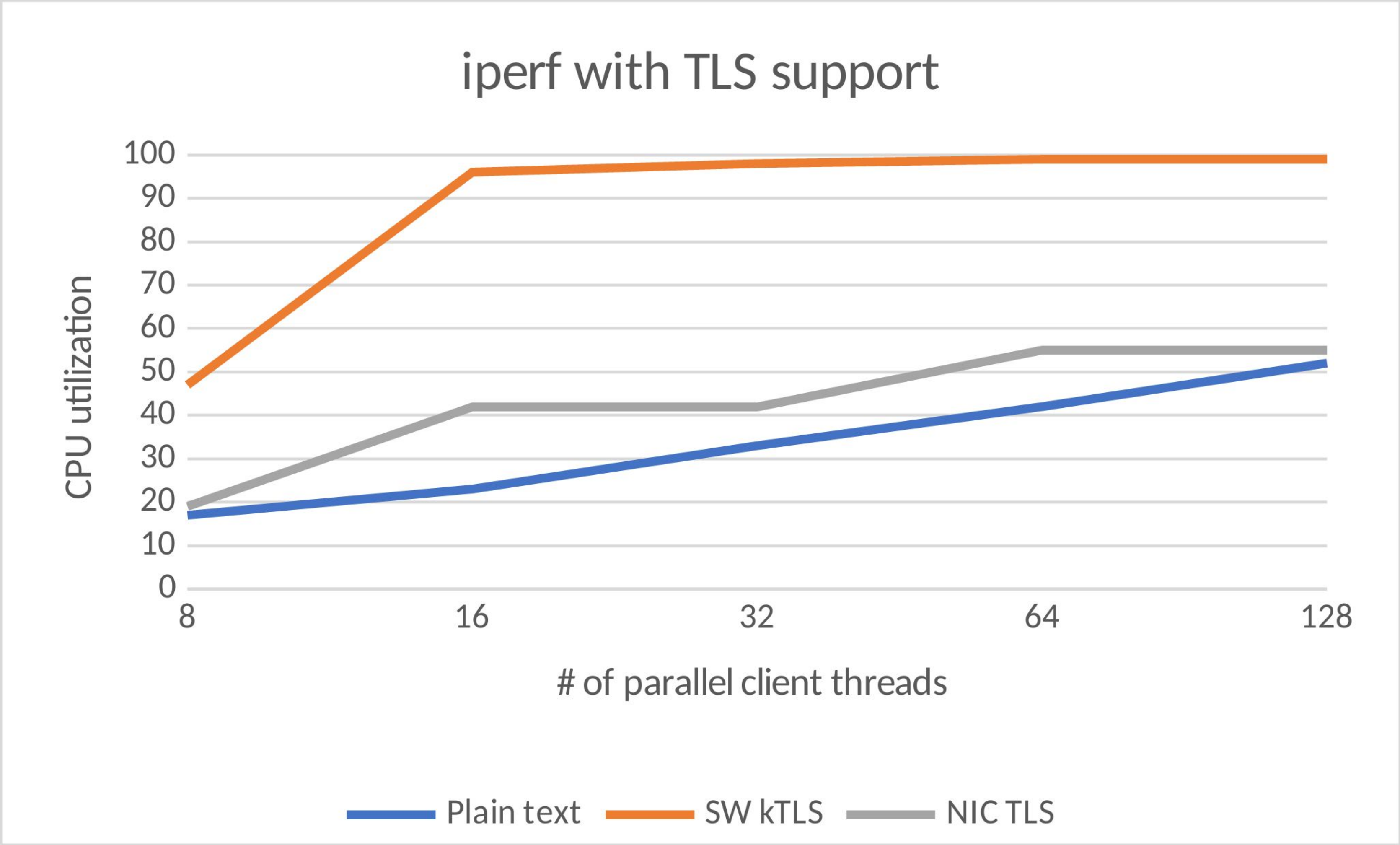
Netflix Video Serving with TLS

Kernel TLS Performance: 90Gb/s, 68% CPU (SW), 35% CPU (T6 NIC kTLS)

- Original (~2016) Netflix 100G NVME flash appliance
  - E5-2697A v4 @ 2.60GHz (16 core / 32 HTT), 128GB DDR4 2400MT/s, 1x100GbE, 4xNVME



Mellanox NIC TLS



Mellanox NIC TLS support

- ConnectX-6 DX (coming October 2019)
    - http://www.mellanox.com/page/ethernet_cards_overview
    - 16 000 000 simultaneous TLS connections (25, 50, 100 and 200 Gbit/s)

Mellanox®

TECHNOLOGIES

Chelsio HW TLS support

- T6 NIC TLS supports TLS v1.1 and v1.2 using both AES-CBC and AES-GCM.
- TOE TLS support for kTLS is in progress.
- ccr(4) can be used for AES-GCM via the OCF backend.

Questions and Answers

Q/A