In-kernel TLS Framing and Encryption for FreeBSD

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Overview

- What is KTLS?
- TLS Transmit
- TLS Receive
- Current Status

What is TLS?

- Transport Layer Security (TLS) is an application layer protocol
- Provides authentication and privacy
- Structured as a stream of records, or frames, sent and received over a transport protocol
- Includes handshake messages to negotiate session keys and application data messages to tunnel application data

What is KTLS?

- In-kernel TLS (KTLS) handles TLS framing and encryption/decryption in the kernel
- KTLS does not handle session key negotiation
  - Userland library such as OpenSSL supplies session keys to kernel after handshake

Why KTLS?

Two reasons to handle TLS in the kernel

1. Enable zero-copy send over TLS via `sendfile()`
2. Support TLS offload in NICs

TLS Sessions

- TLS Sessions describe session keys
  - Ciphersuite (AES-GCM, AES-CBC with HMAC)
  - Cipher and MAC keys
- SSL library provides session keys via `setsockopt()`
- TLS Sessions are associated with socket buffers
  - Separate sessions for transmit and receive

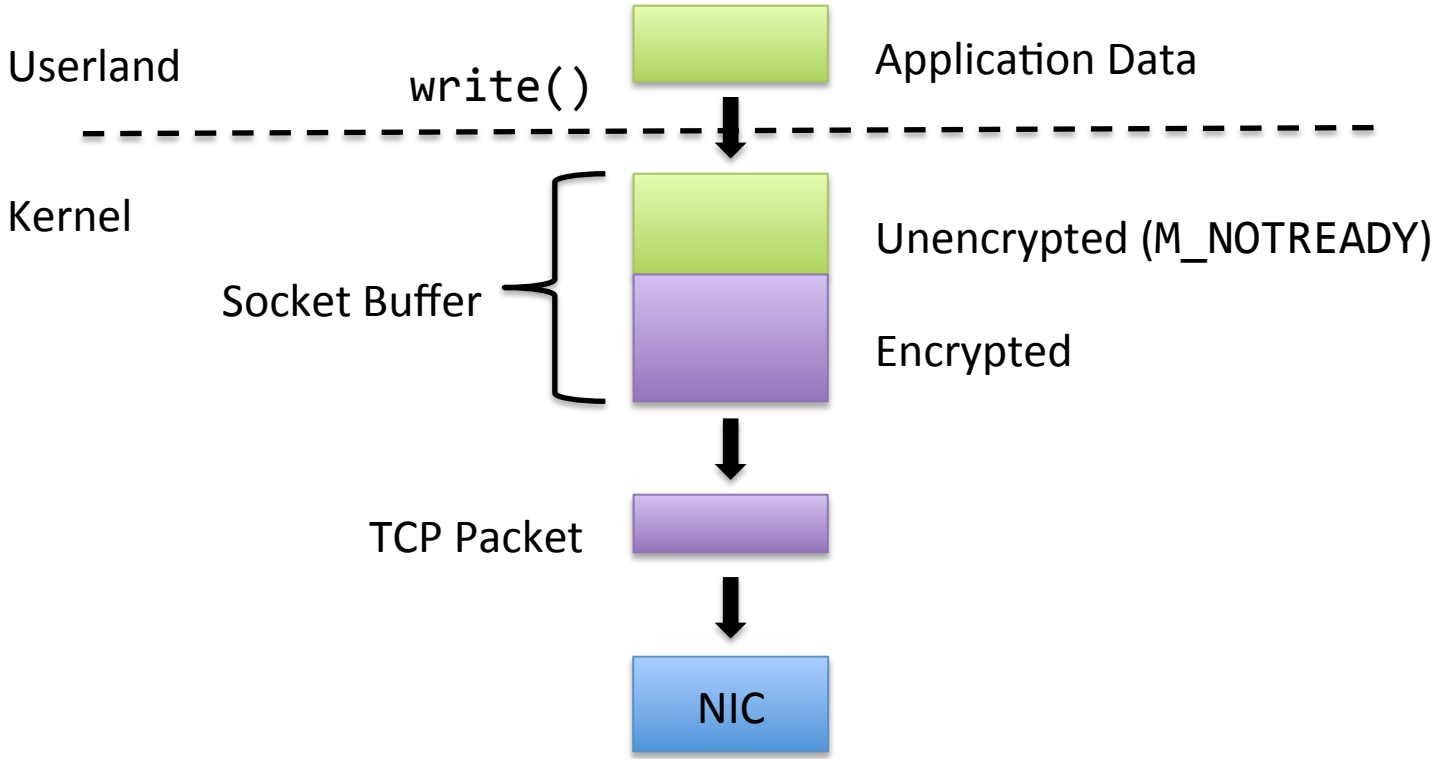
TLS Transmit

- All data written on a socket using KTLS transmit is encrypted by the kernel
- Userland can send individual TLS records with a specific record type and length via `sendmsg()`
  - `TLS_SET_RECORD_TYPE` control message
- Kernel chooses framing and uses “application data” record type for all other data

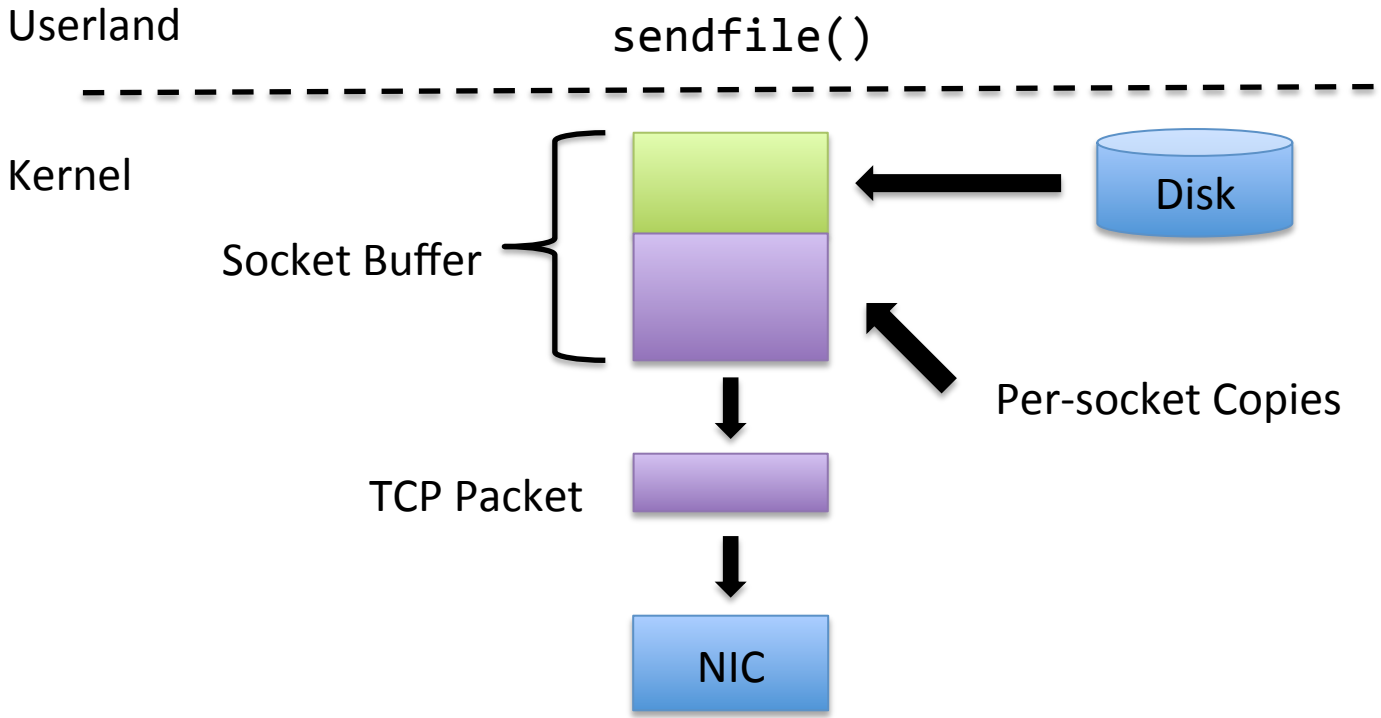
TLS Transmit

- TLS records stored in a special type of mbuf
  - TLS header and trailer stored inline in mbuf
  - Payload data referenced via physical address pointers
- Not-yet-encrypted TLS record mbufs hold a reference to a TLS session
  - Session reference inherited from socket buffer

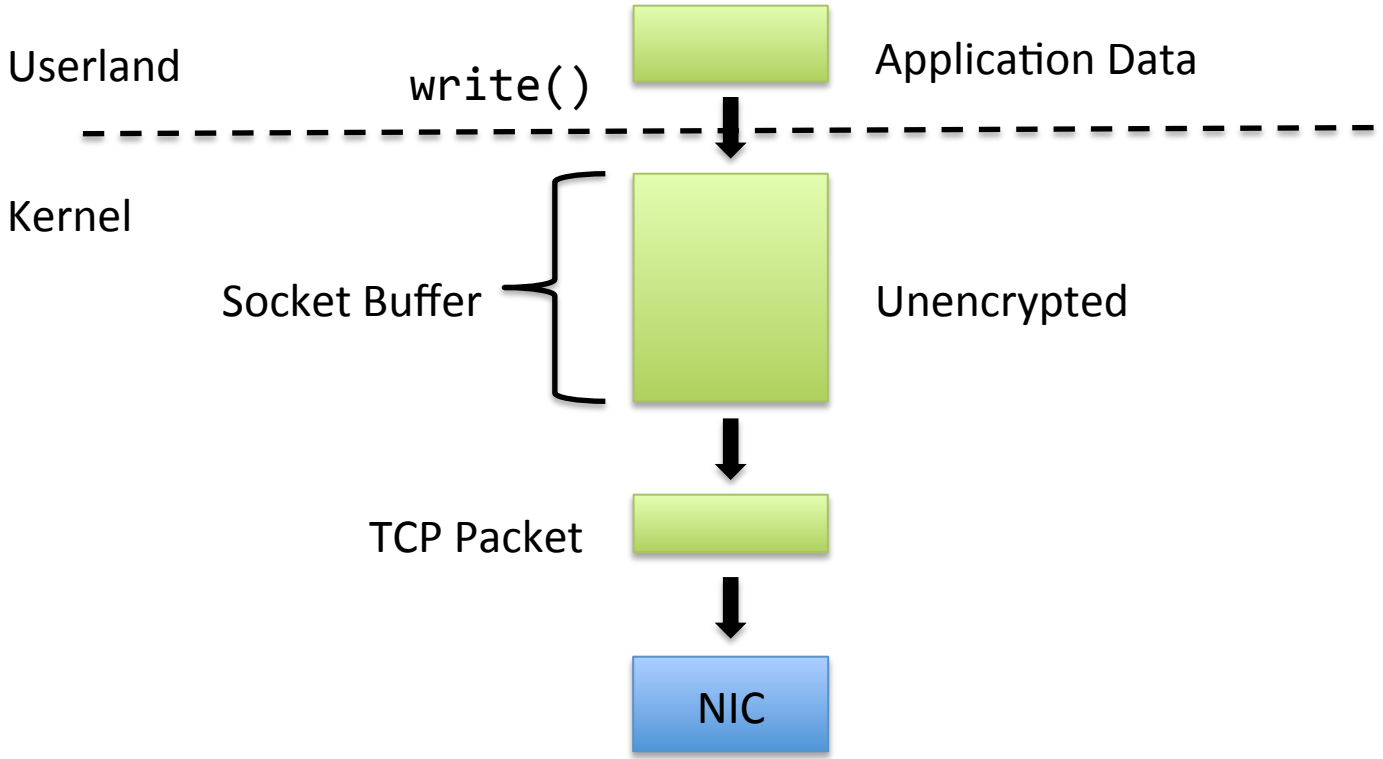
TLS Transmit: SW KTLS



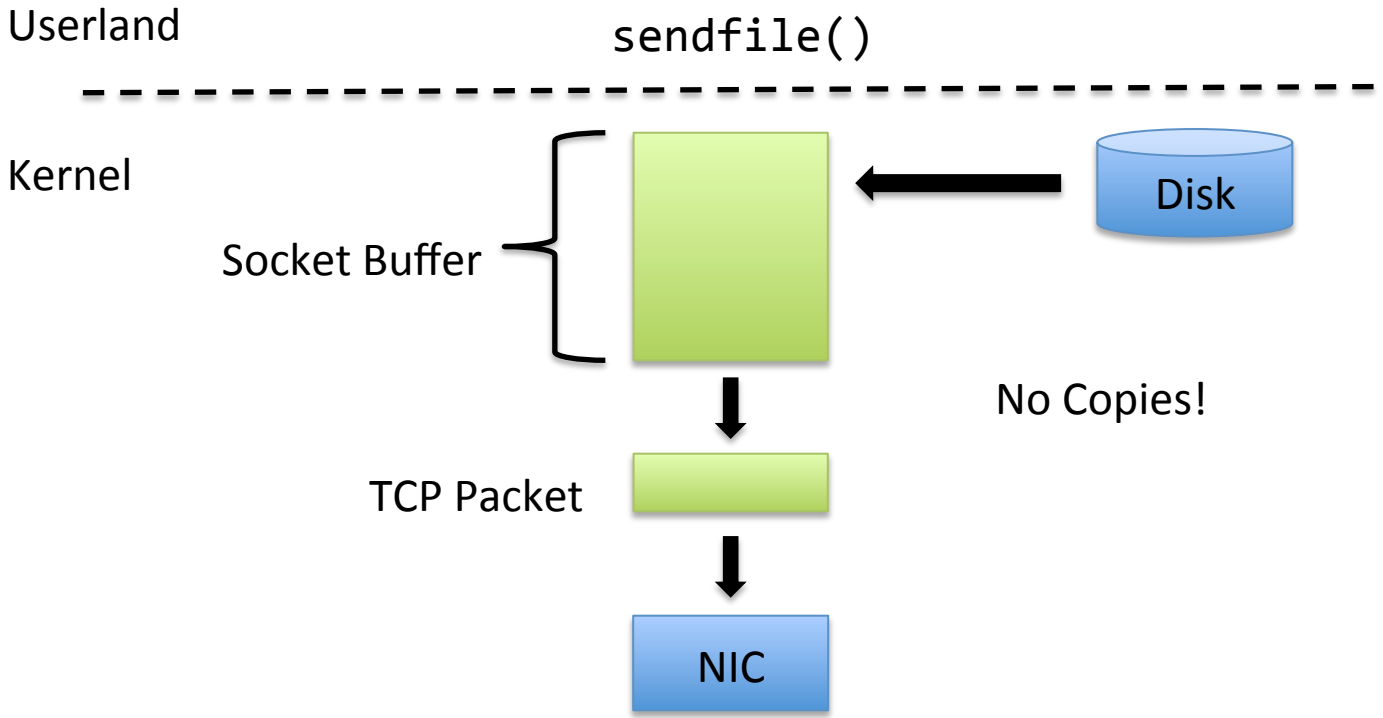
TLS Transmit: SW KTLS



TLS Transmit: NIC/TOE KTLS



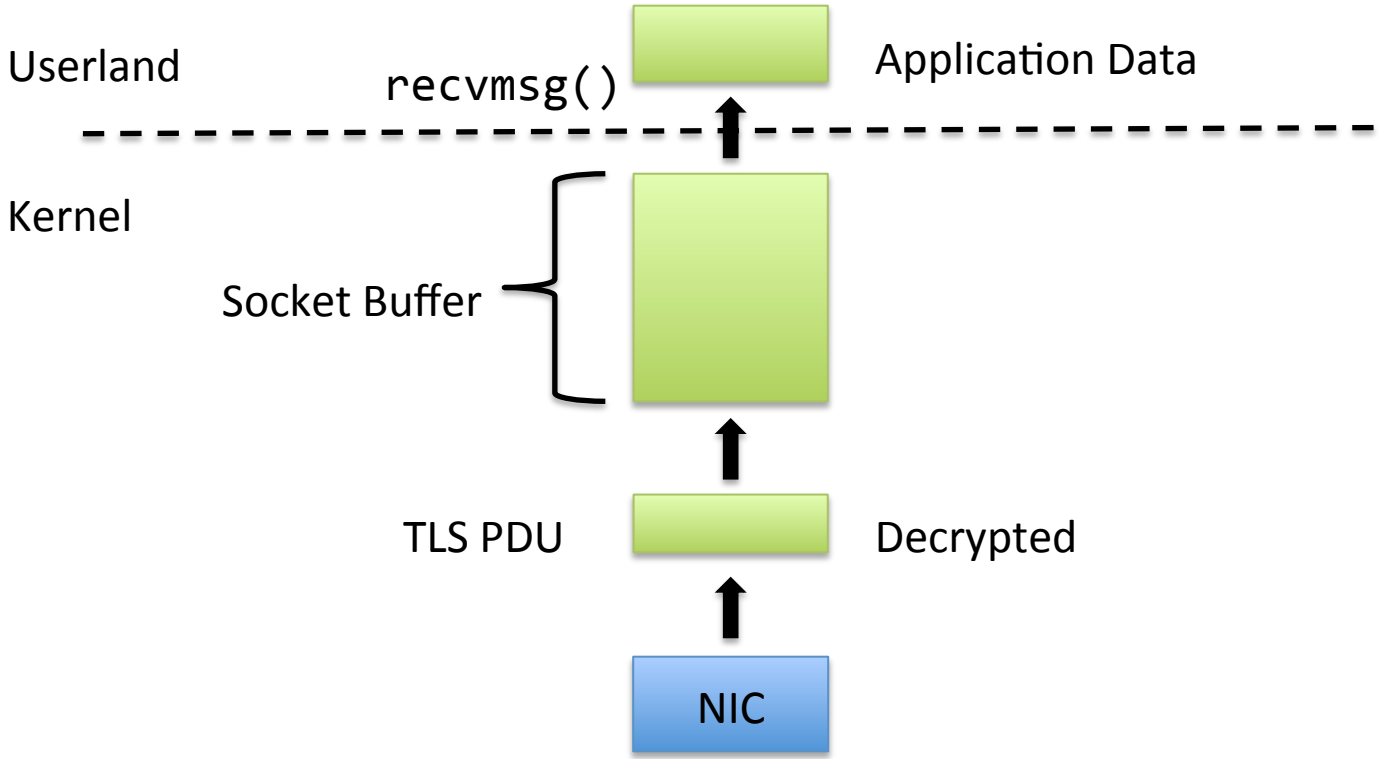
TLS Transmit: NIC/TOE KTLS



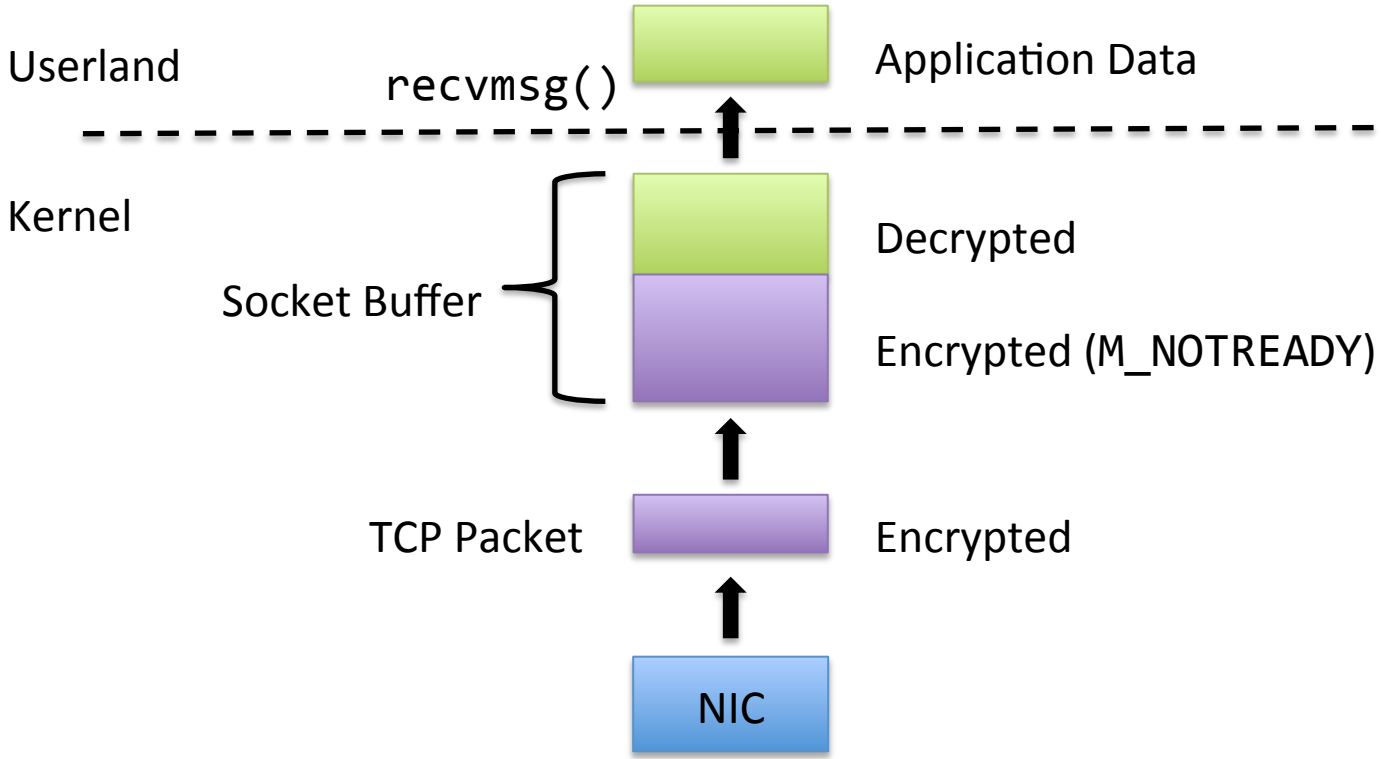
TLS Receive

- All data received on a socket using KTLS receive is decrypted by the kernel
- Userland receives individual TLS records via `recvmsg()`
  - `TLS_GET_RECORD` control message
- Socket buffer holds a list of TLS records like a datagram socket even though TCP is a stream socket

TLS Receive: TOE KTLS



TLS Receive: SW KTLS



TLS & Socket Send Buffers

- TLS uses send socket buffer in the “usual” way. It is a single “record” holding a stream of TLS mbufs.
  - Each mbuf describes a single TLS record
  - Unencrypted records are marked as `M_NOTREADY`
  - Both unencrypted and encrypted TLS records live in the same stream
  - To mark a record as encrypted, clear `M_NOTREADY`

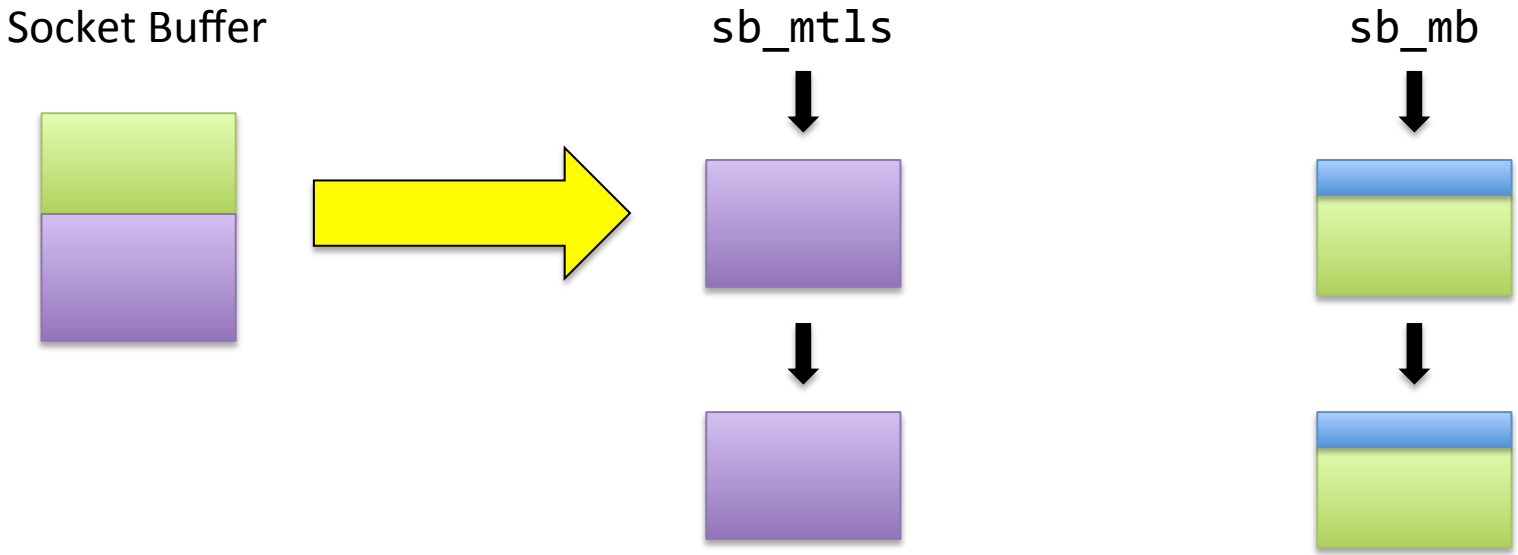
TLS & Socket Receive Buffers

- TLS uses receive socket buffer differently
  - Decrypted TLS records are stored as “records” in socket buffer consisting of control message mbuf holding TLS header followed by decrypted data in “normal” mbufs. No trailer.
  - Encrypted TLS records received from TCP are just “normal” mbufs with TLS header and trailer data in the mbuf payload
  - Can’t simply flip `M_NOTREADY` bit to convert from encrypted to decrypted

Decrypting TLS Records

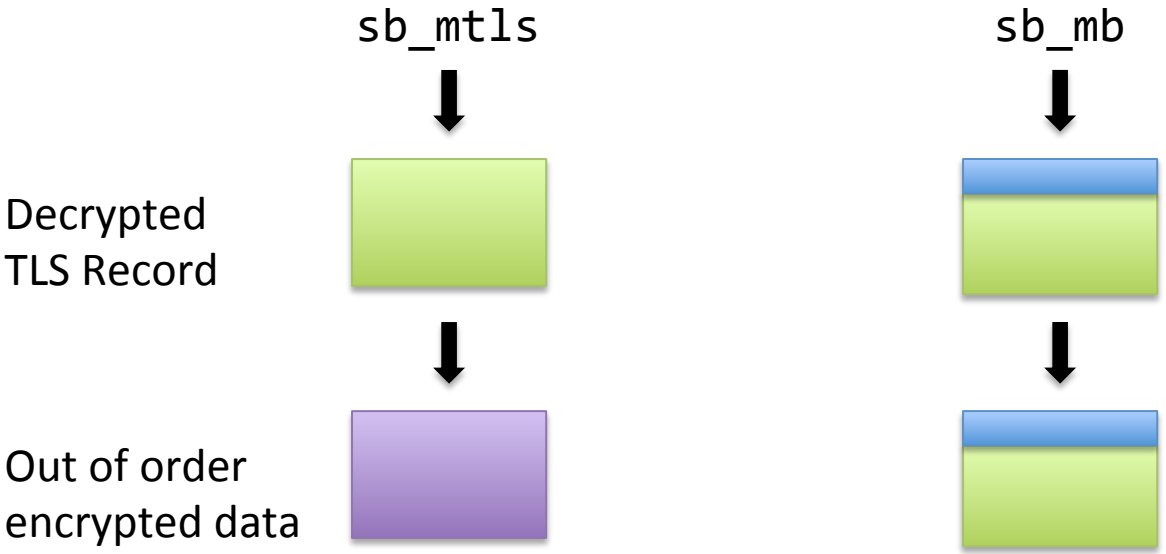
- Wait for full TLS record to be received
- Decrypt TLS record payload
- Allocate control message and copy TLS header into message
- Discard TLS header and trailer from “normal” mbufs holding TLS record
- Ensure the mbufs holding TLS record aren’t freed out from under decryption handler via sbcut(), sbdrop(), or sbflush()
- Ensure socket buffer accounting is accurate

Splitting the Receive Buffer



Decrypting a TLS Record

TLS Receive: NIC TLS (Sketch)



Current Status: Transmit

- KTLS Transmit for TLS 1.0-1.3 merged to FreeBSD 13.0-CURRENT
  - Includes SW TLS, NIC TLS, TOE TLS
  - ktls_ocf.ko and security/ktls_isa-l_crypto-kmod port/package
- KTLS Transmit for TLS 1.0-1.2 merged to OpenSSL master (will ship in 3.0)
- TLS 1.3 for OpenSSL pending review
  - https://github.com/openssl/openssl/pull/10626

Current Status: Receive

- KTLS Receive for TLS 1.1-1.2 via TOE merged to FreeBSD 13.0-CURRENT
- KTLS Receive for TLS 1.1-1.2 via SW in progress
  - https://reviews.freebsd.org/D24628
- KTLS Receive for TLS 1.1-1.2 for OpenSSL pending review
  - https://github.com/openssl/openssl/pull/11679

Current Status: nginx

- nginx patches to support `SSL_sendfile()`
  - https://github.com/nginx/nginx/compare/branches/stable-1.14...bsdjhb:ktls-1.14-openssl-master
  - https://github.com/nginx/nginx/compare/branches/stable-1.16...bsdjhb:ktls-1.16

Further WIP

- Improving KTLS performance using OCF
  - Goal is to bring aesni.ko and ktls_ocf.ko on par with security/ktls_isa-l_crypto-kmod
- Adding support for TLS 1.1 (and maybe 1.0) transmit to SW KTLS via OCF
- Adding support for TLS 1.3 receive to SW KTLS
- Making OpenSSL KTLS available via base or ports
- Adding `SSL_sendfile()` support to nginx port