Multipath TCP Upstreaming

Mat Martineau (Intel) and Matthieu Baerts (Tessares)

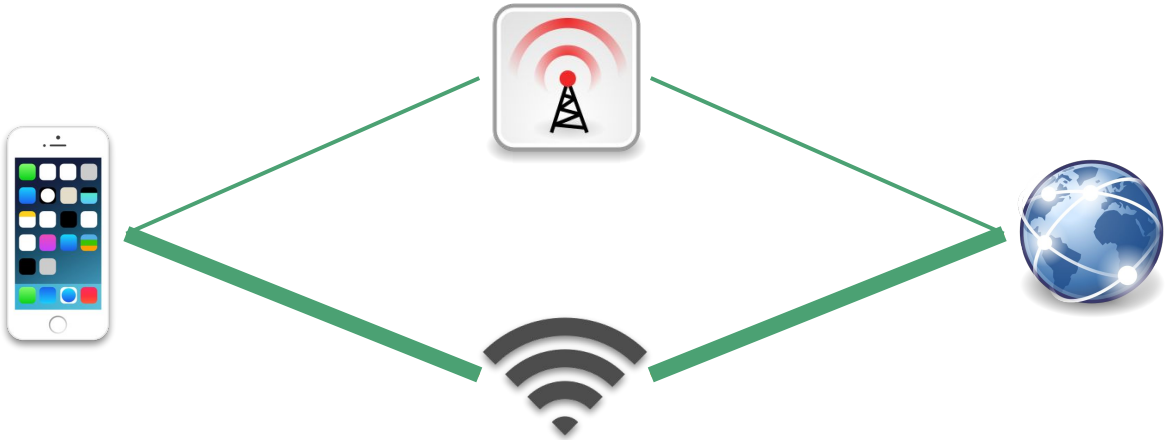
Plan

- Multipath TCP Overview
- First Patch Set Upstreaming Roadmap
- Advanced Features Roadmap
- Conclusion and links

What is MPTCP?

Multipath TCP (MPTCP)

- Exchange data for a single connection over different paths, simultaneously
- RFC-6824 and supported by IETF Multipath TCP (MPTCP) working group



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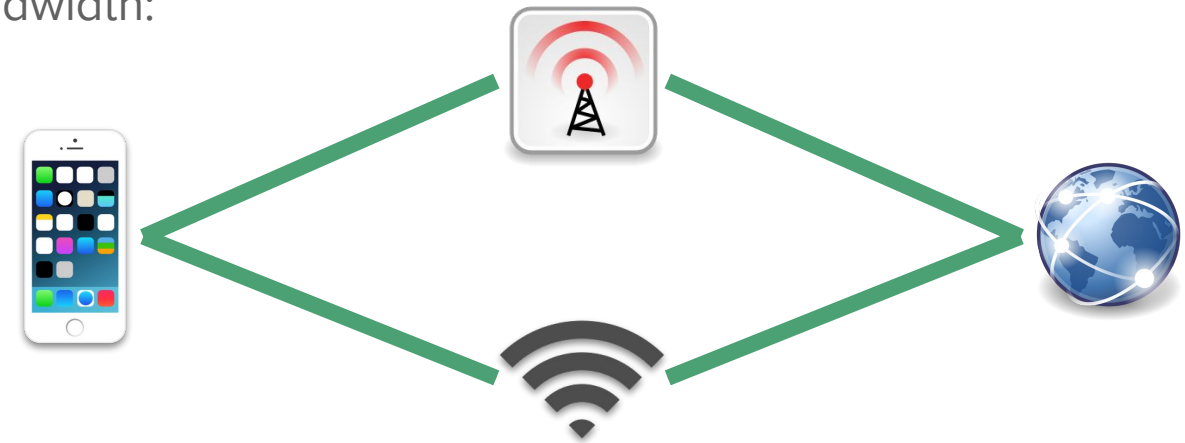

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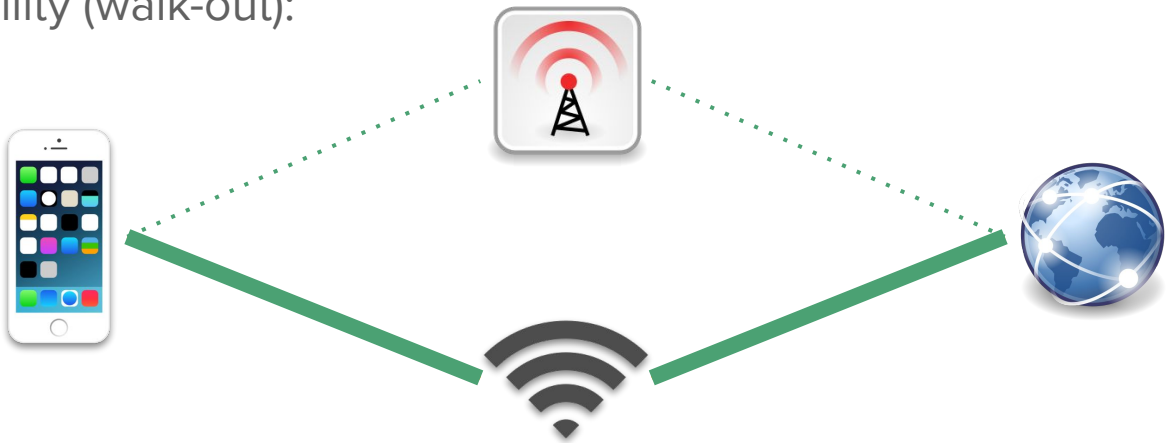

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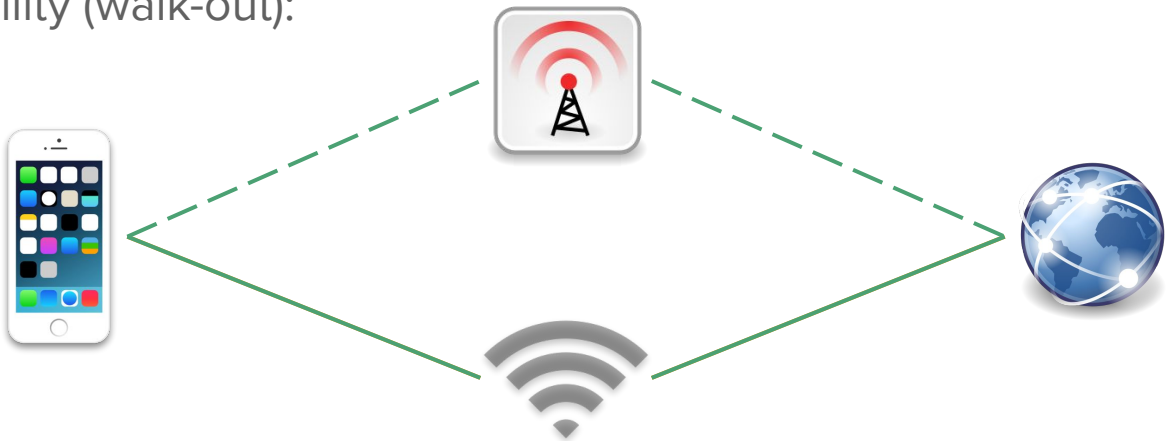

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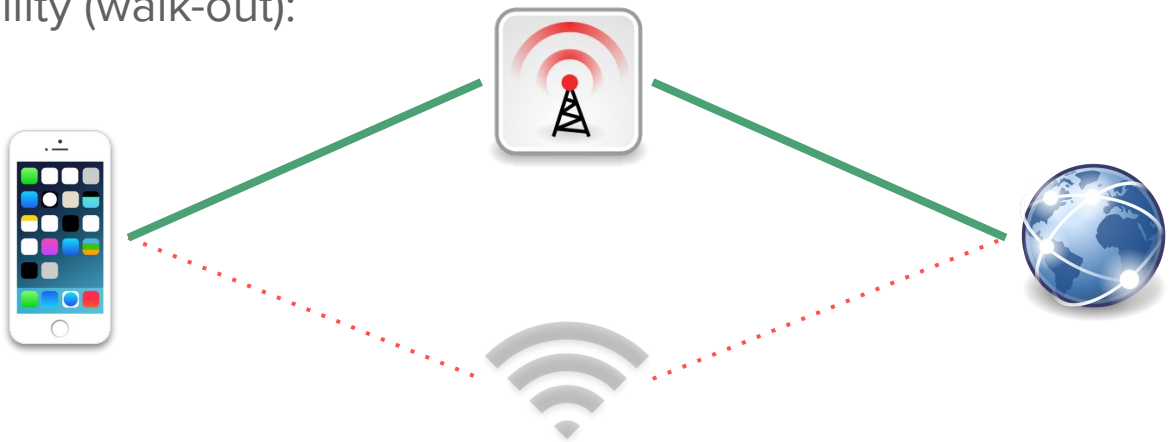

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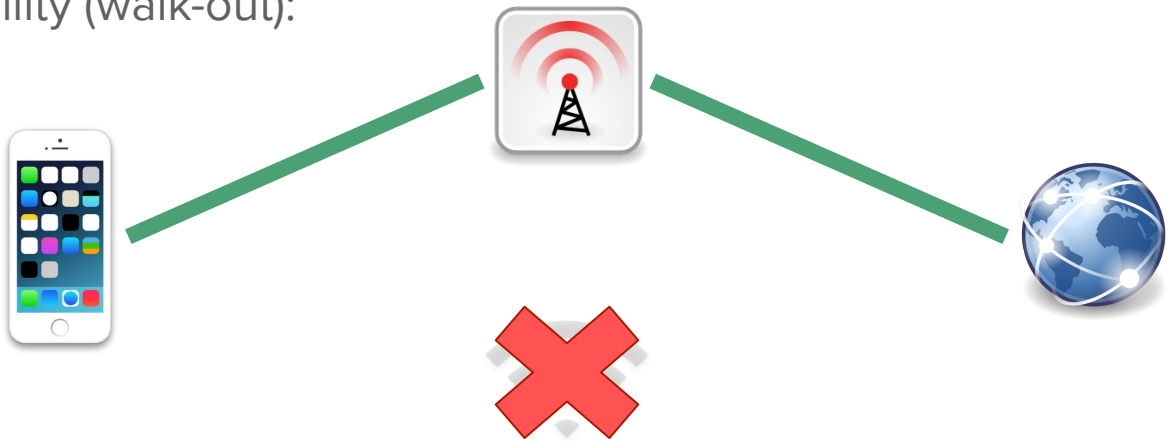
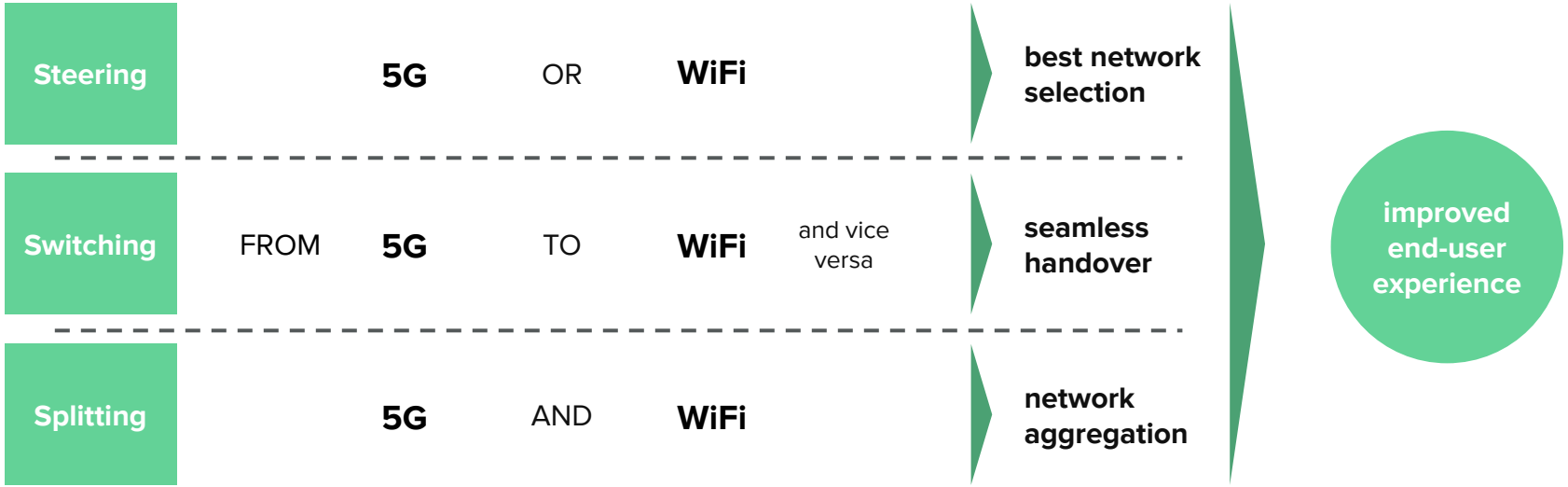


Multipath TCP Use Cases

- Smartphones (Apple, Samsung, LG, others)
  - Support failover / “walk-out” scenario.
  - More Bandwidth
- Residential Gateways (LTE + DSL, for example)
  - More Bandwidth
- Multipath TCP is part of 5G standardisation:
  - Access Traffic Steering, Switching and Splitting: ATSSS

Multipath TCP Use Cases: ATSSS



Defined in 3GPP Release 16, ATSSS is a core network function in 5G networks,
playing a key role in managing data traffic between 3GPP (5G, 4G) networks and non-3GPP (Wi-Fi) networks

3GPP A GLOBAL INITIATIVE

Existing Linux implementation

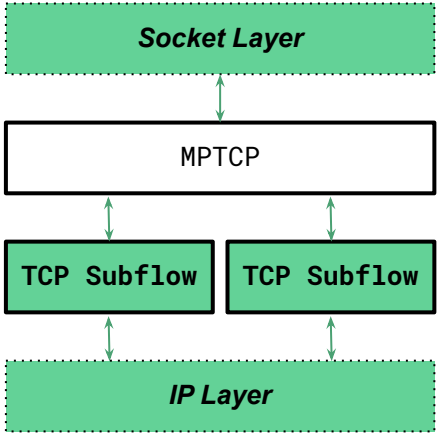
- First implementation for Linux kernel in March 2009
  - Latest MPTCP out-of-tree Linux kernel version is v0.95
  - Generally used as a client / server in current deployments, for millions of users
- But not upstreamable
  - Built to support experiments and rapid changes but not generic enough
  - Special purpose implementation of MPTCP

Guidelines for upstream

- New implementation cannot affect existing TCP stack:
  - Without performance regressions. No code size change if `CONFIG_MPTCP=n`
  - Maintainable and configurable
  - Can be used in a variety of deployments
- Multipath TCP will be "opt-in"
- Proceed in steps:
  - Minimal features set
  - Optimisations and advanced features for later

Protocol Overview: RFC 6824

- **Looks like TCP on the wire, similar usage for apps**



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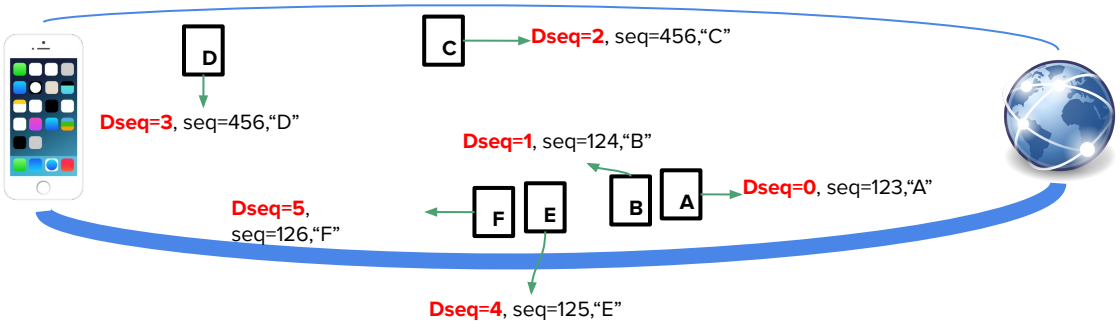

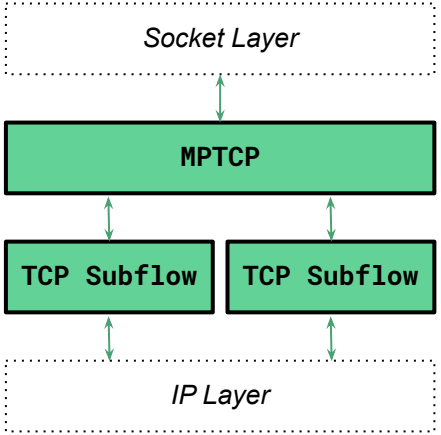

Smartphone icon by Blurred203 under CC-by-sa, others from Tango project, public domain

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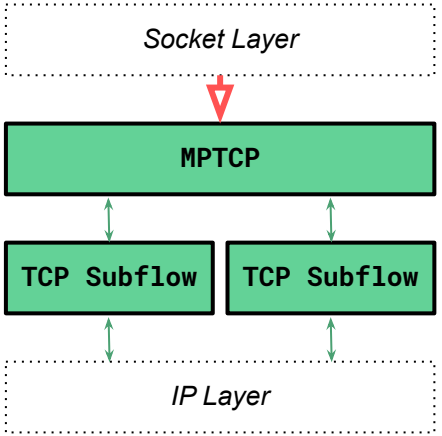

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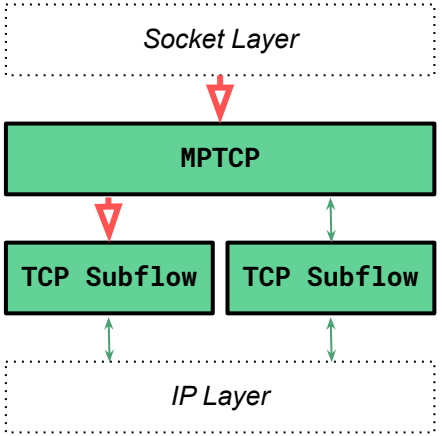

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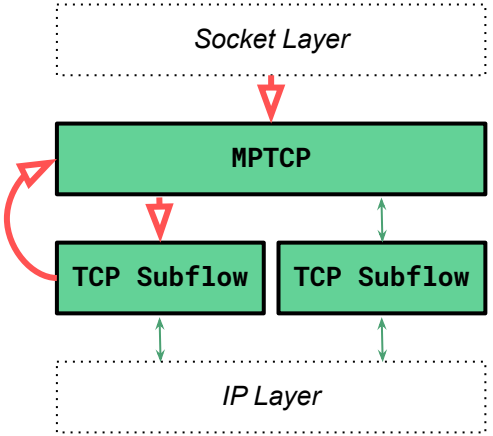

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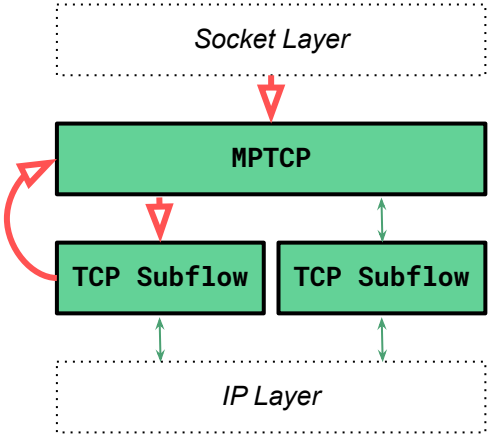

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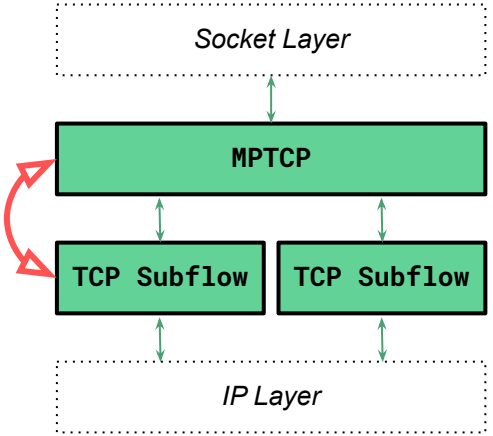

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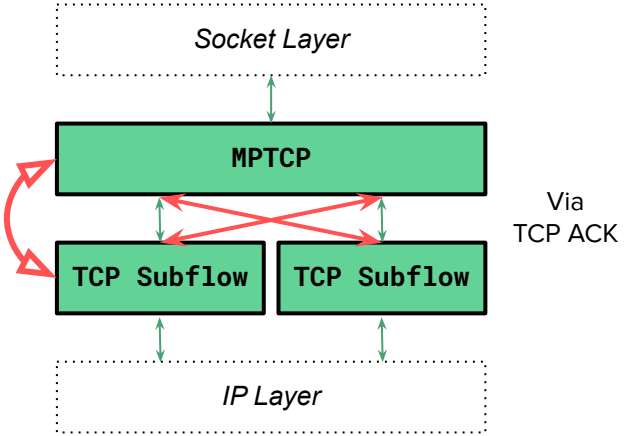

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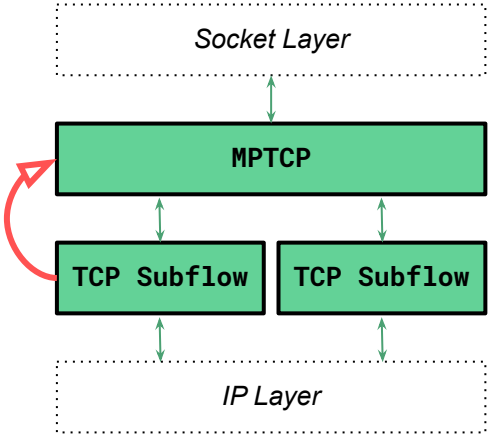
- Signaling: Add/Remove Addresses, Fast Close
- **Coupled receive windows across TCP subflows**

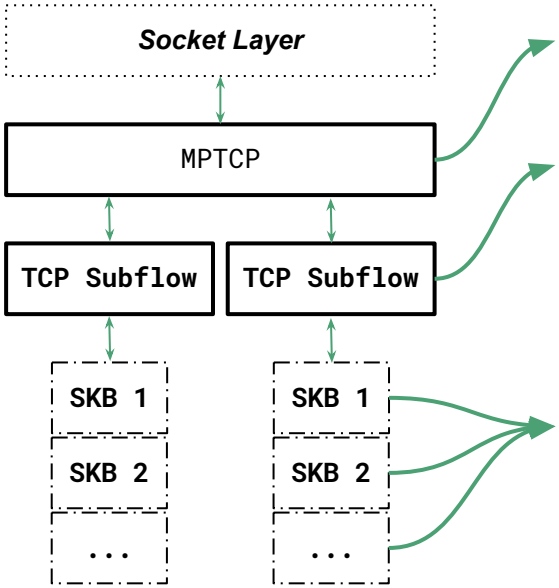


Multiple versions of MPTCP

- RFC 6824: *Experimental*
  - All known implementations support it, only this version
- RFC 6824 bis: *Standard*
  - Submitted to IESG for publication
  - Behavioral changes: MPTCP v0 ➡ MPTCP v1
  - Some parts easier to implement
  - Selected by 3GPP for 5G

First Patch Set Roadmap

MPTCP Socket architecture



IP Proto: `struct proto`

TCP ULP: `struct tcp_ulp_ops`
We start from: `tcp_request_sock_ops`

SKB extension: `struct mptcp_ext`
To store Data Sequence Signal (25 bytes)

Userspace API

- MPTCP selected when creating the socket:

```
socket(AF_INET(6), SOCK_STREAM, IPPROTO_MPTCP);
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- `getsockopt()` / `setsockopt()` with MPTCP socket or its TCP subflows?

Userspace API

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  - `IPPROTO_MPTCP = IPPROTO_TCP | 0x100; /* = 262 */`

- `getsockopt()` / `setsockopt()` with MPTCP socket or its TCP subflows?

- Security: who can create MPTCP sockets?

  - Initial implementation will not be hardened by broad use yet (syzkaller, etc.)

  - `sysctl` per network namespace, MPTCP disabled by default: is it enough?

Diagnostics

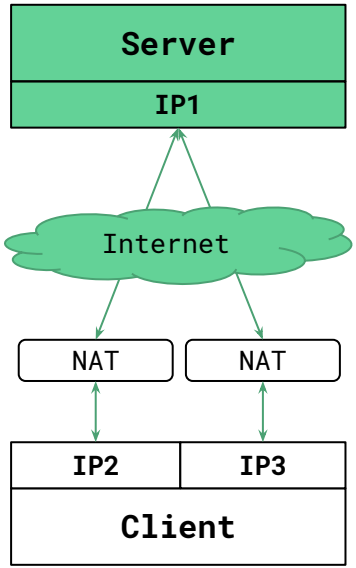
- MPTCP will have a collection of counters for diagnostic and debug purposes
- Per-socket data will be shared with userspace via `sock_diag(7)`
  - TCP ULP framework has been extended to enable diag
- Some TCP counters are also found in `/proc`
  - Should MPTCP add to these as well?

Tests

- Kernel Self Tests
  - Between multiple namespaces (`veth`)
  - MPTCP ⇔ MPTCP, MPTCP ⇔ TCP, TCP ⇔ MPTCP
  - Various conditions including packet loss, reordering, and variations in routing
- Packetdrill
  - Background project ongoing to add MPTCP support
  - Out-of-tree Packetdrill with MPTCP support but old and limited

Initial use case

- Server role is a good place to start
- Simpler path management
  - Client side handles multiple interfaces (like cellular + Wi-Fi)
- Common server configuration uses one public interface for clients
  - Advertising additional interfaces not required
- Client features all build on what's needed for servers



Code already merged upstream

- SKB extensions
  - Needed to carry MPTCP options that are tied to the data payload
  - Also used to remove `sp` (`sec_path`) and `nf_bridge` pointers from `struct sk_buff`
  - Suitable for data that can't fit in `sk_buff` and justifies memory overhead
- Add `inet_diag_ulp_info` to socket diag format and ULP `get_info` hook

Change in TCP Code

Git Stat:

```
include/linux/skbuff.h             |   11 ++
include/linux/tcp.h                |   51 ++++++++++
include/net/sock.h                 |    6 +-
include/net/tcp.h                  |   20 ++++
include/trace/events/sock.h        |    5 +-
include/uapi/linux/in.h            |    2 +
net/Kconfig                        |    1 +
net/Makefile                       |    1 +
net/ax25/af_ax25.c                 |    2 +-
net/core/skbuff.c                  |    7 ++
net/decnet/af_decnet.c             |    2 +-
net/ipv4/inet_connection_sock.c    |    2 +
net/ipv4/tcp.c                     |    8 +-
net/ipv4/tcp_input.c               |   29 +++++-
net/ipv4/tcp_ipv4.c                |    4 +-
net/ipv4/tcp_minisocks.c           |    6 ++
net/ipv4/tcp_output.c              |   62 ++++++++++++-
net/ipv4/tcp_ulp.c                 |   12 +++
```

Changes to TCP code

- `tcp_ulp_clone()`
- Export two low-level TCP functions and one struct
- SKBs with MPTCP extensions can’t be coalesced or collapsed
- MPTCP option parsing and writing
- `is_mptcp` flag in `tcp_sock` and `tcp_request_sock`

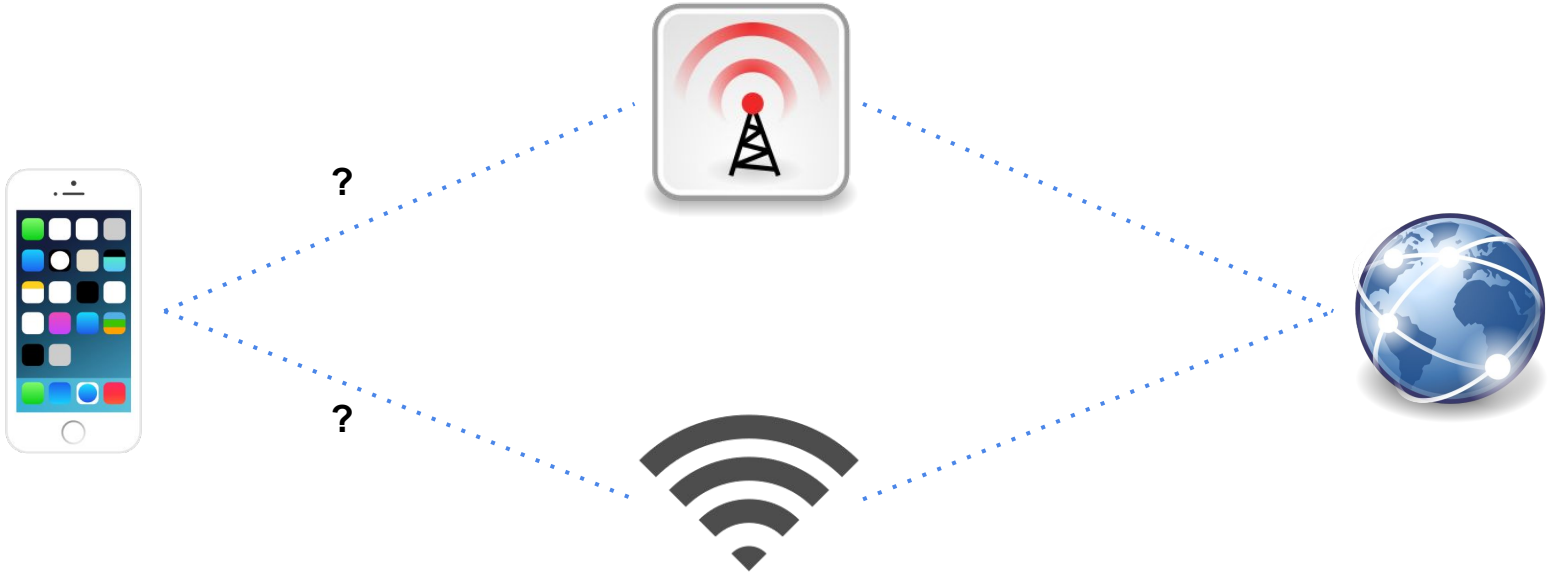
Changes to TCP code, continued

- One MPTCP-specific branch in TCP minisocks
- Call out to MPTCP from `tcp_data_queue` to add SKB extension and process ACKs
- Additional members in `struct tcp_options_received`
- Subflow receive window sharing will introduce changes too

Advanced Features Roadmap

Path Manager

Which path to create/remove? Which address to announce?

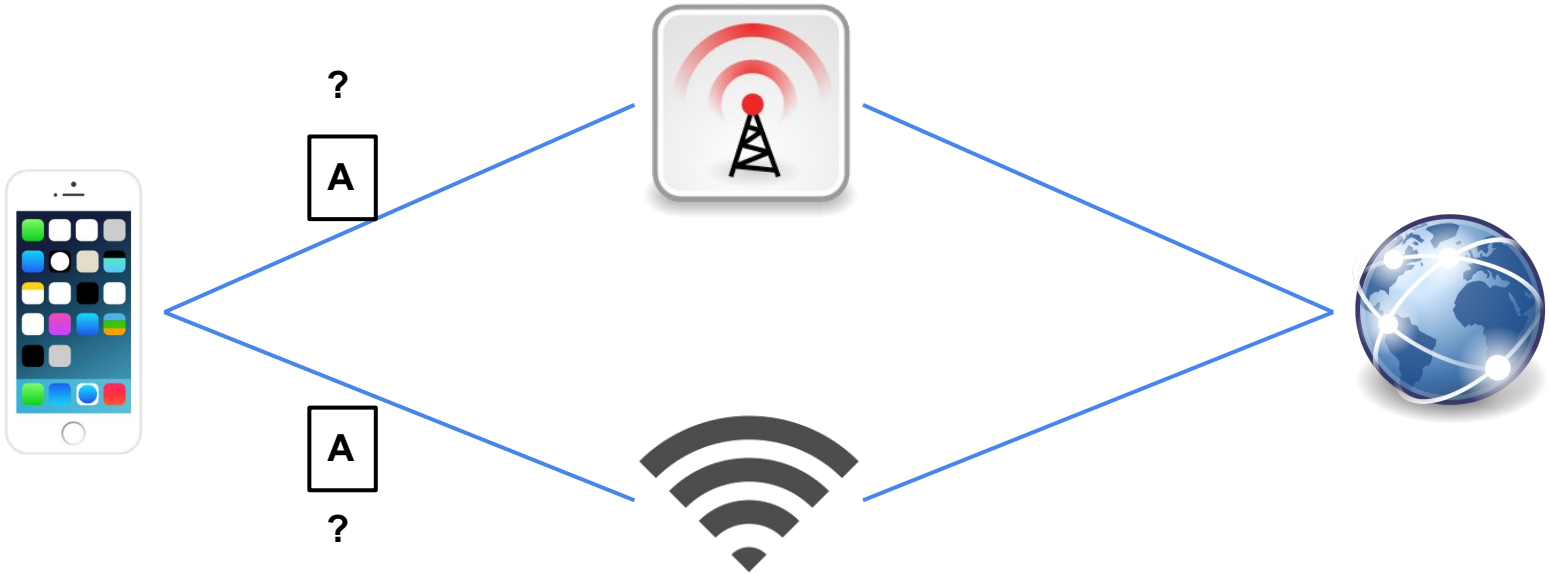


Userspace Path Manager

- Peers share `ADD_ADDR` and `REMOVE_ADDR` signals to advertise available addresses for each MPTCP connection
- Path manager runs in userspace and uses generic netlink to track address and local interface updates and request subflow changes
- Can be customized with different policies.
- Multipath TCP Daemon alpha release is available at github.com/intel/mptcpd

Packet Scheduler

On which available path packets will be sent? Reinject packets in another path?



Packet scheduling

- Different connections may optimize for throughput, latency, or redundancy.
- Peers can set a ‘backup’ flag on each subflow to limit transmission on that flow
- Include basic scheduler options in the kernel
- Consider eBPF to define custom schedulers, instead of kernel modules

Using MPTCP with unmodified binaries

- Some organizations want to take advantage of MPTCP without recompiling their userspace
- Can add BPF_CGROUP_SOCKET to attach an eBPF program that rewrites the protocol number passed to socket()
- Similar attachment points exist for bind() and connect()

MPTCP Performance optimizations

- Initial emphasis is on correctness and reasonable MPTCP performance
  - While not disrupting TCP's optimizations!
- Target performance optimizations based on data
- Protocol optimizations
  - Example: changing scheduler behavior for reinjection of data on different subflows
- TCP Fast Open support

Break-before-make

- MPTCP can keep a connection active even with zero subflows connected
    - Allows the session to continue by adding a subflow with MP_JOIN
- Can be useful to switch between access points
- Will add this capability if there’s demand for it

Subflow socket options

- One MPTCP socket manages a set of in-kernel subflow sockets
- Socket options that use TCP option space or change data flow could interfere
- The MPTCP socket can act as an intermediary for subflow options
- Will need to whitelist specific known-safe options
- Could expose file descriptors only good for getsockopt()/setsockopt()

Kernel TLS and MPTCP

- kTLS is built on top of TCP using ULP framework
- An MPTCP socket is not a TCP socket, so it doesn't have ULP
- TLS needs to operate on the MPTCP data stream, not subflow streams
  - TLS records could be split across subflows
  - MPTCP DSS mappings are specific to TCP sequence numbers
- `TLS_SW` appears feasible but would need work to integrate with an MPTCP socket type

Conclusion

Conclusion

- Build around TCP as much as we can.
- We are close to having an initial patch set ready.

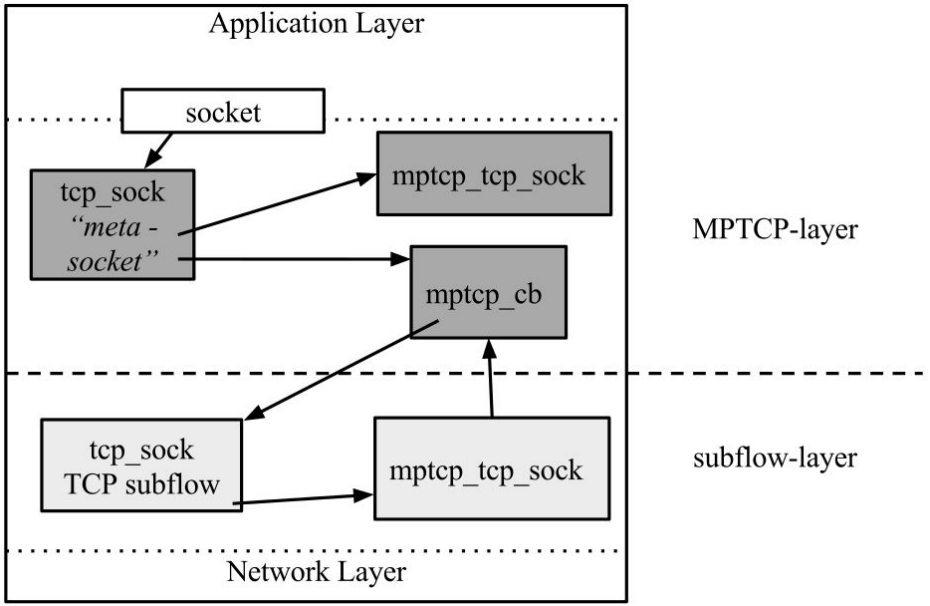
This project is open to everybody.

- Wiki: https://is.gd/mptcp_upstream
- Mailing list: https://lists.01.org/mailman/listinfo/mptcp
- Git repository: https://github.com/multipath-tcp/mptcp_net-next
- Paper: https://linuxplumbersconf.org/event/4/contributions/435/
- mathew.j.martineau@linux.intel.com
- matthieu.baerts@tessares.net

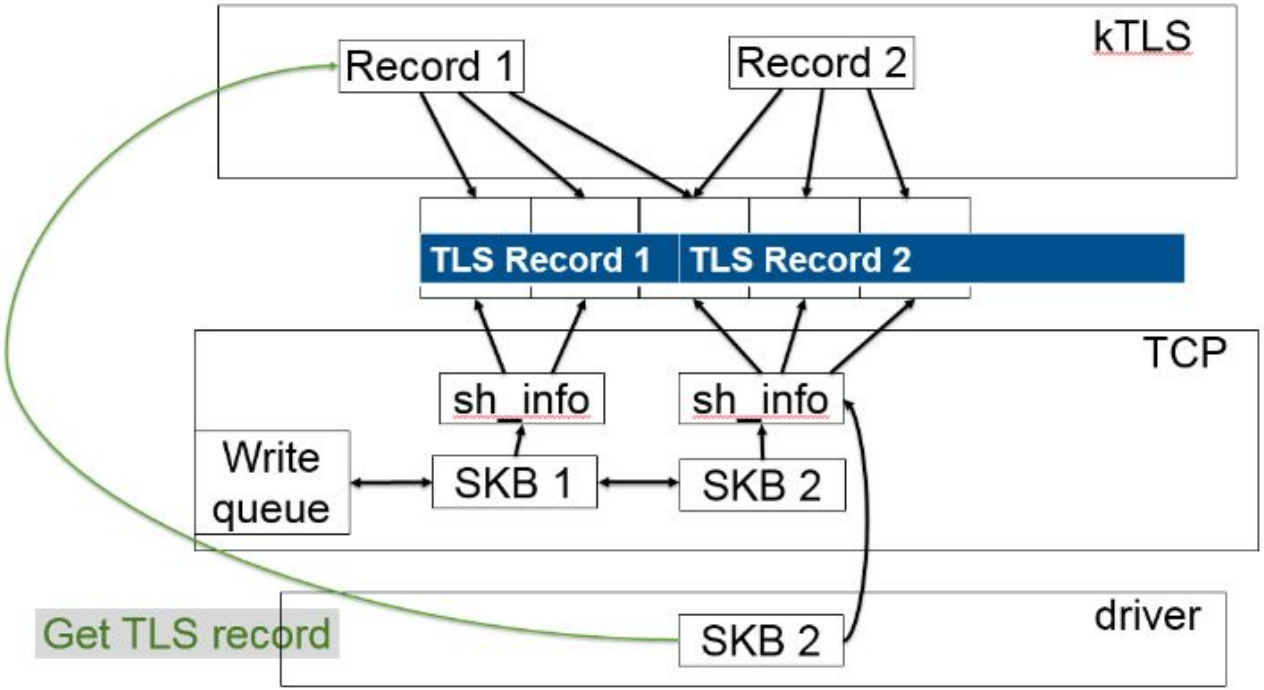
Backup slides

Protocol challenges

Relations between structures



kTLS record



From: https://netdevconf.org/1.2/papers/netdevconf-TLS.pdf

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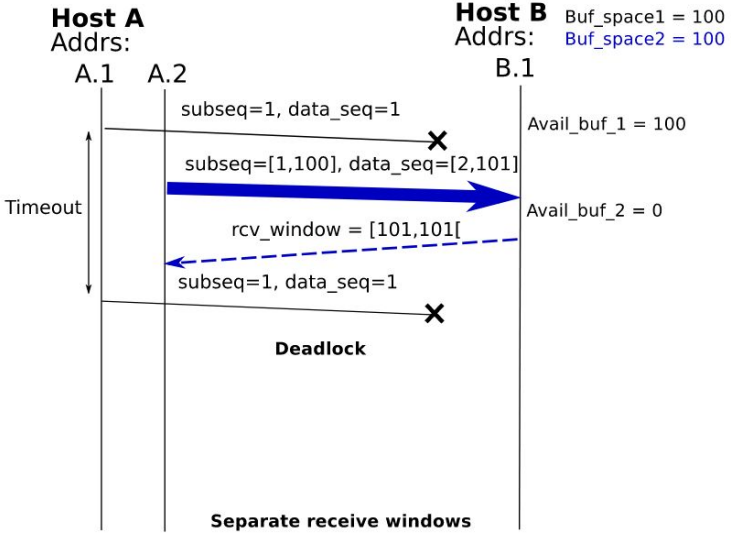
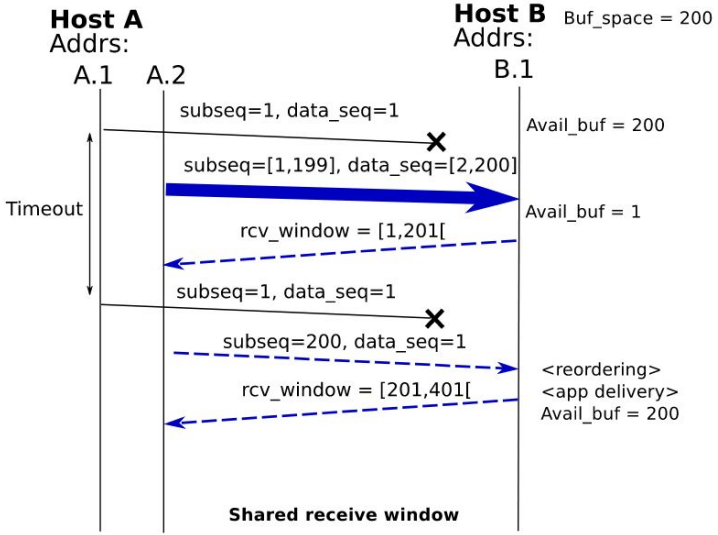
Coupled receive windows across TCP subflows

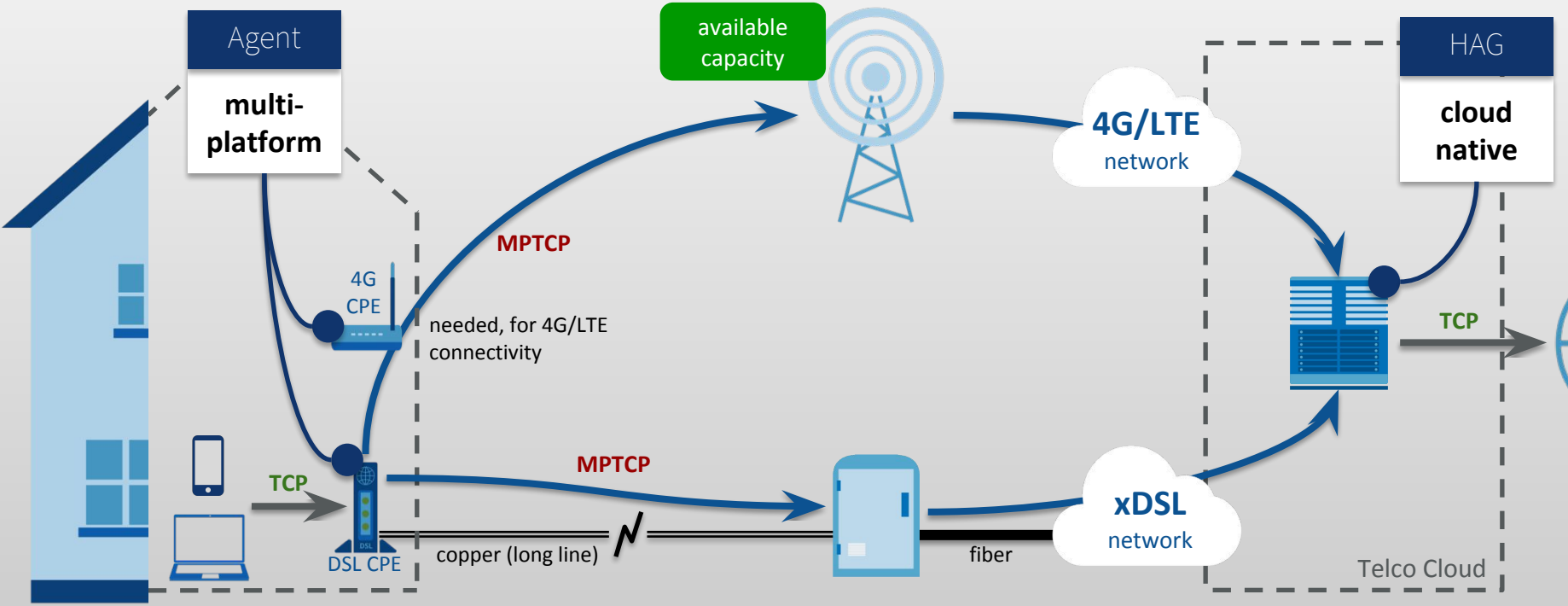




Used with Sébastien Barré's permission

Multipath TCP (MPTCP)

Hybrid access network use-case (BBF TR-348 by Tessares - SwissCom - OVH)



Images from Tessares

Protocol challenges

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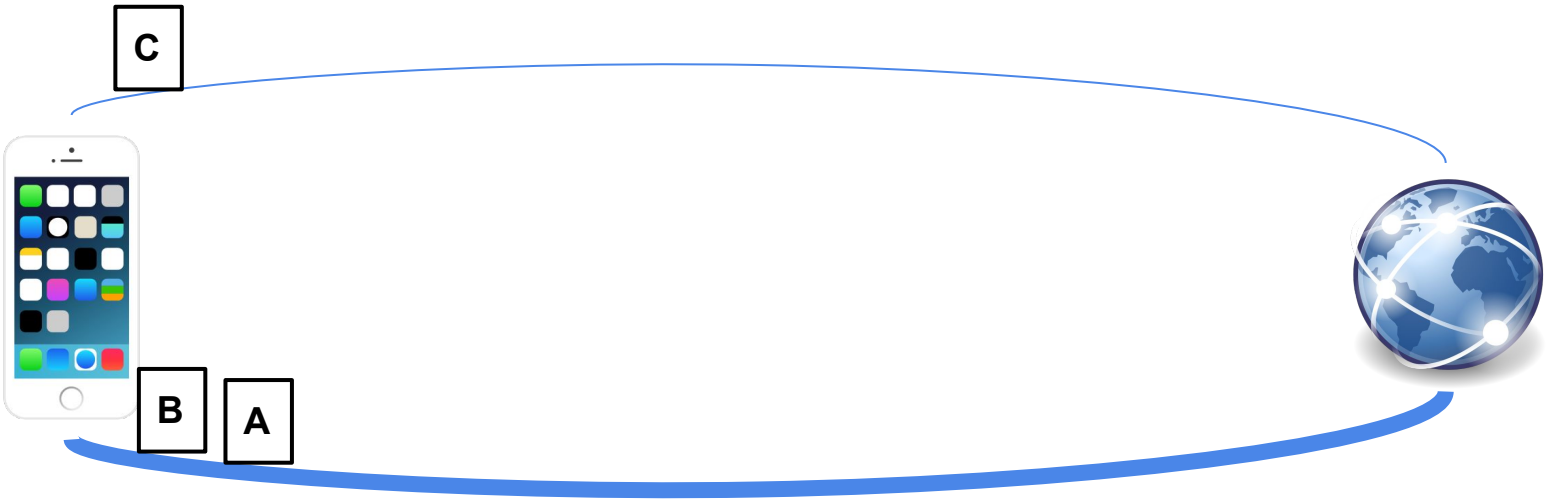
Data sequence numbers and mappings



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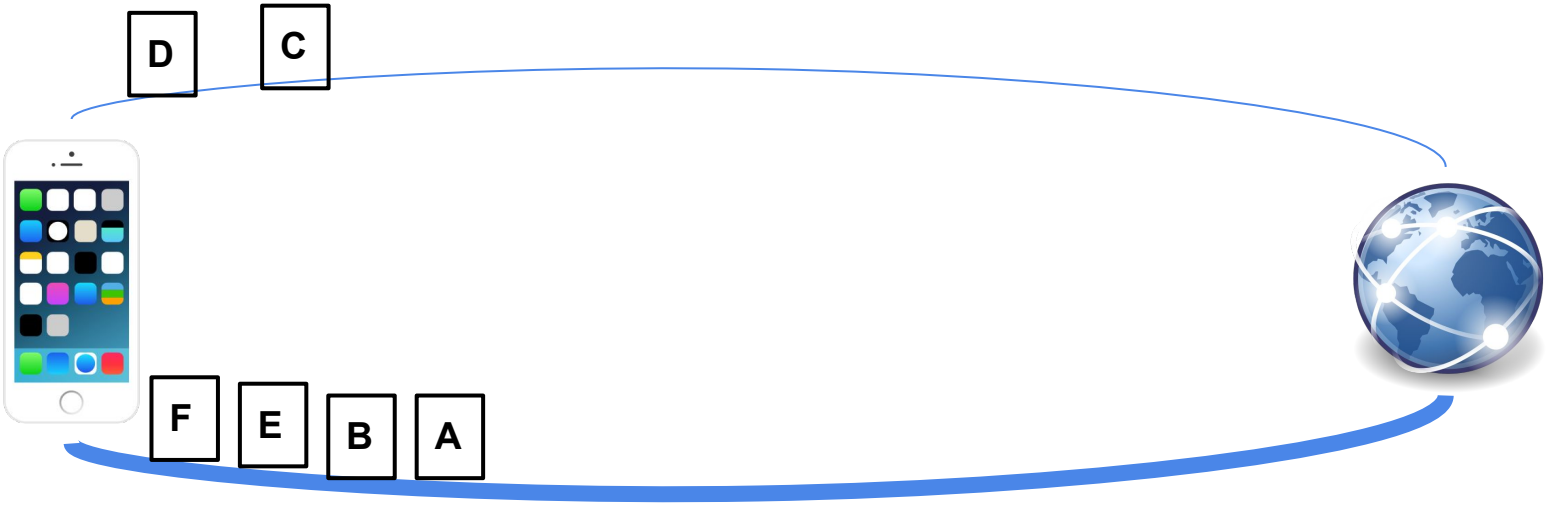

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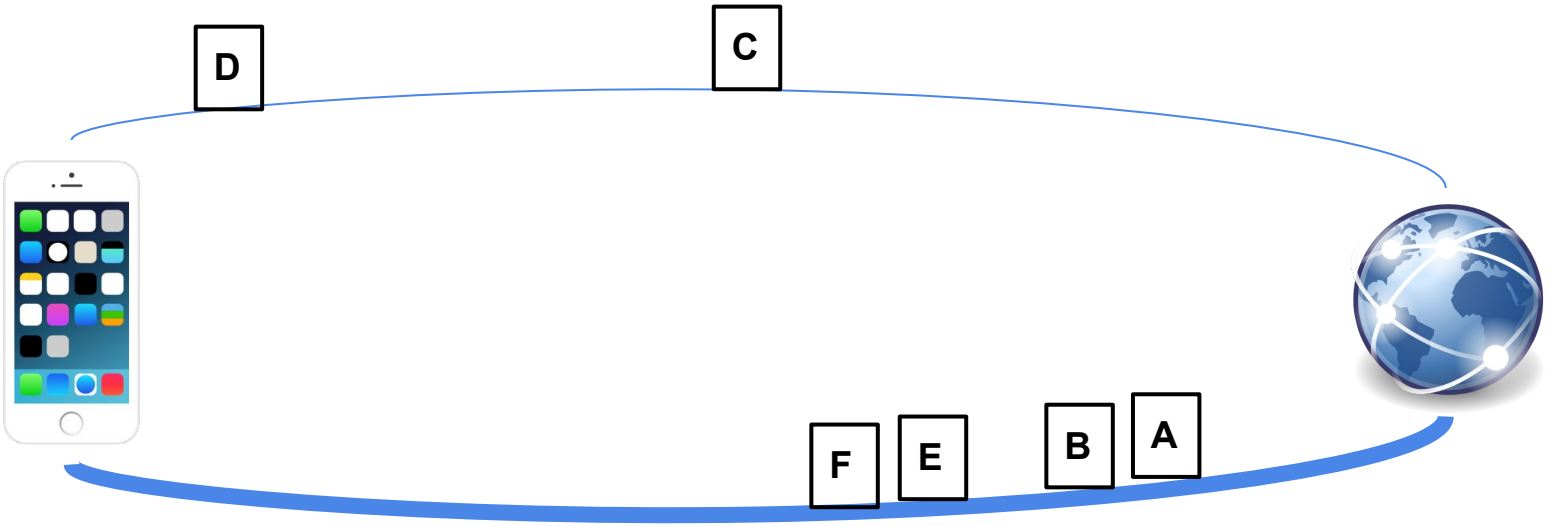

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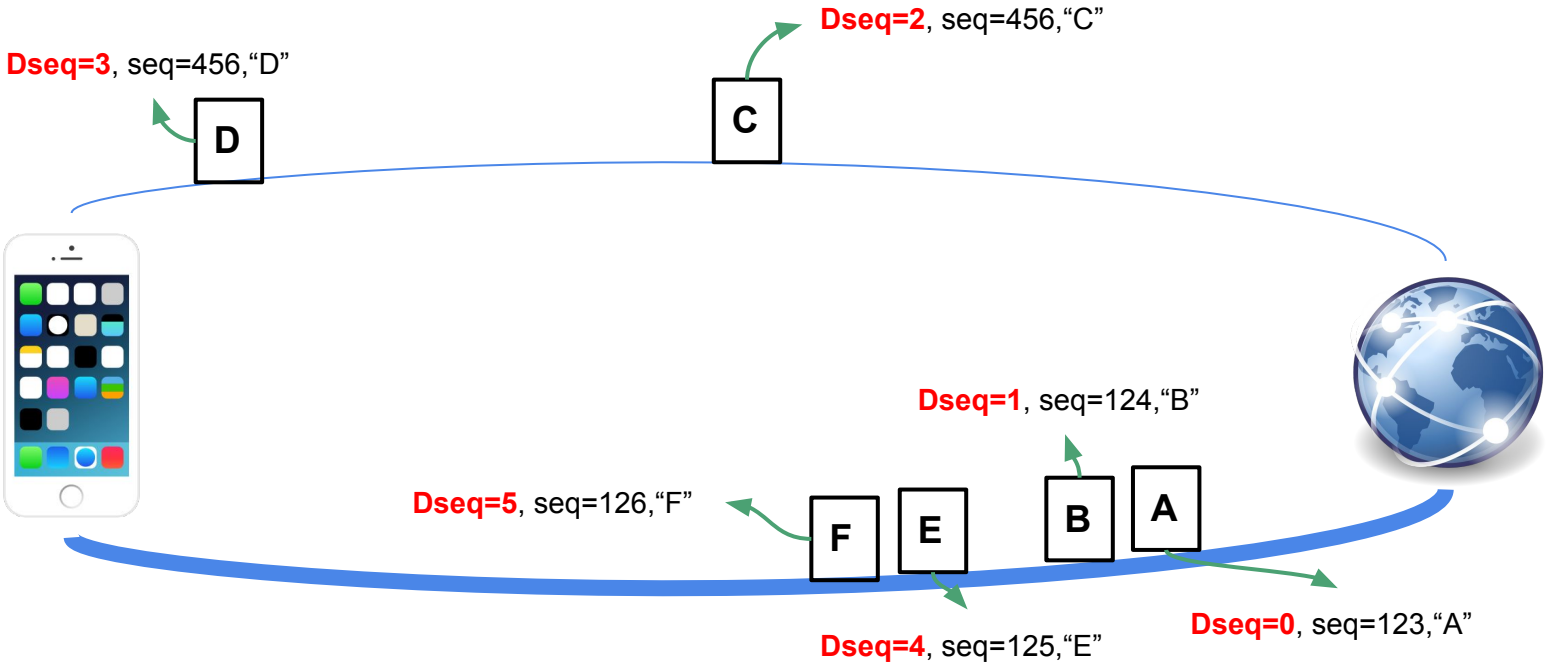

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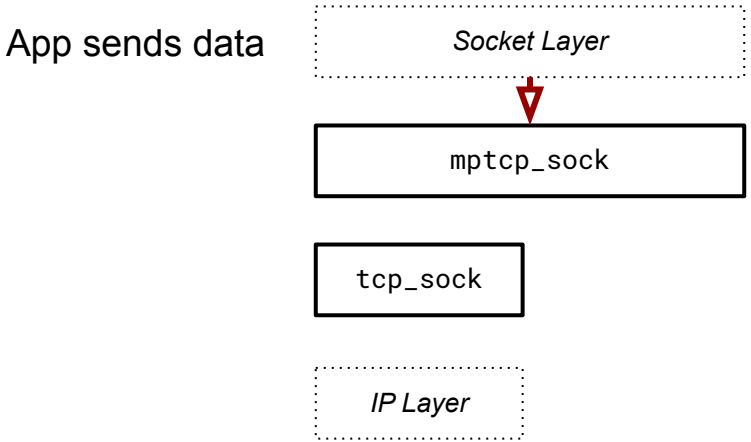

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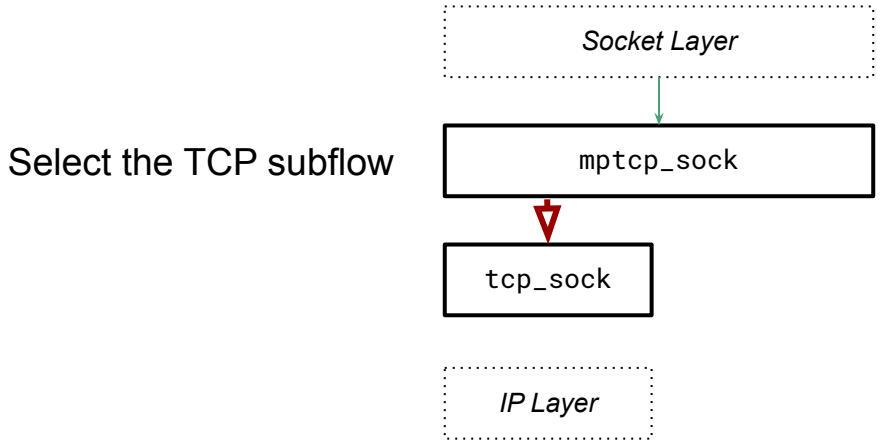

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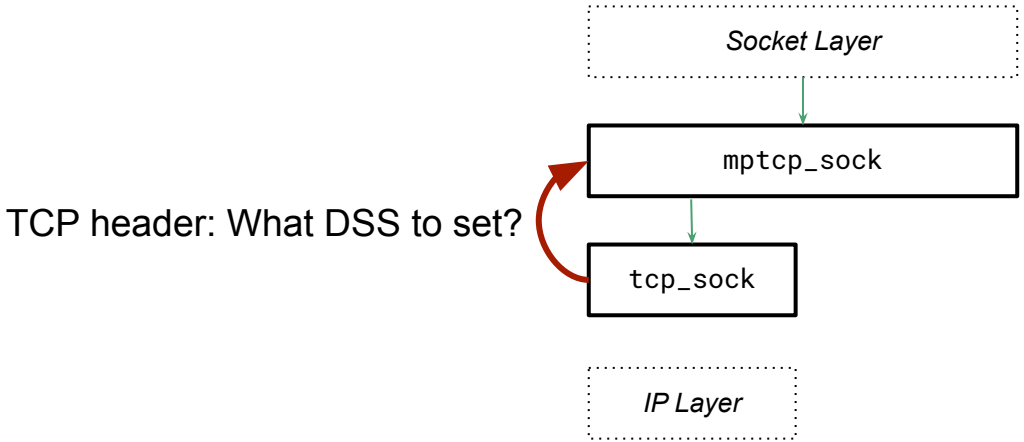

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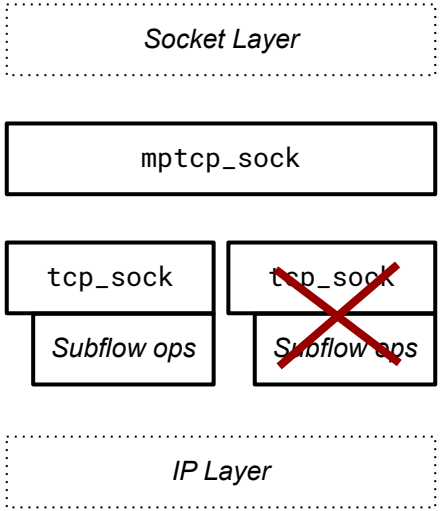
Sending of ACKs to signal options, e.g. REMOVE_ADDR in a TCP ACK



Notification: one iface is down

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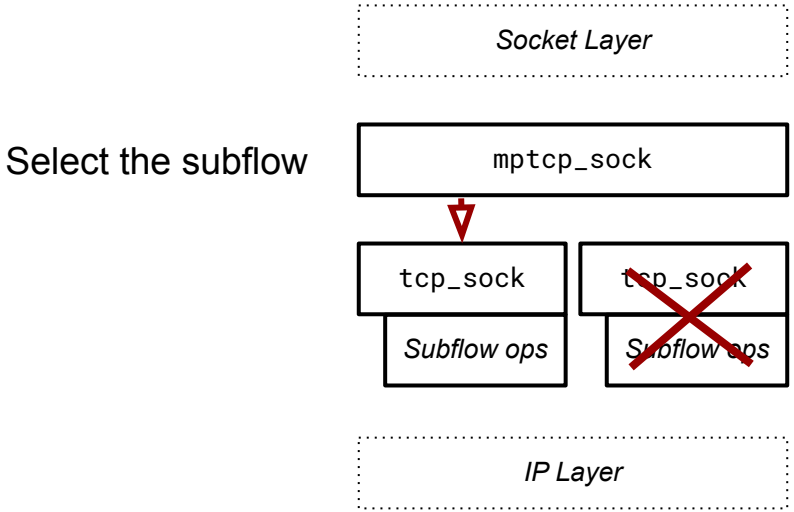
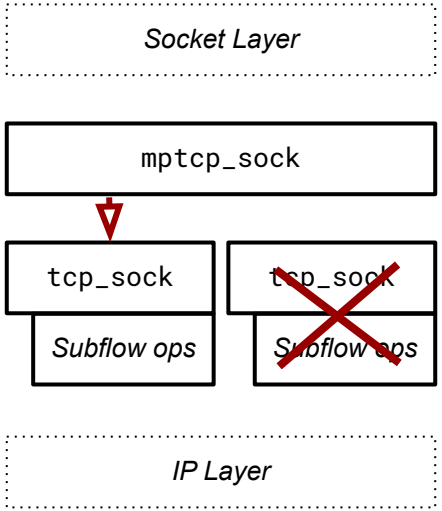


Protocol challenges

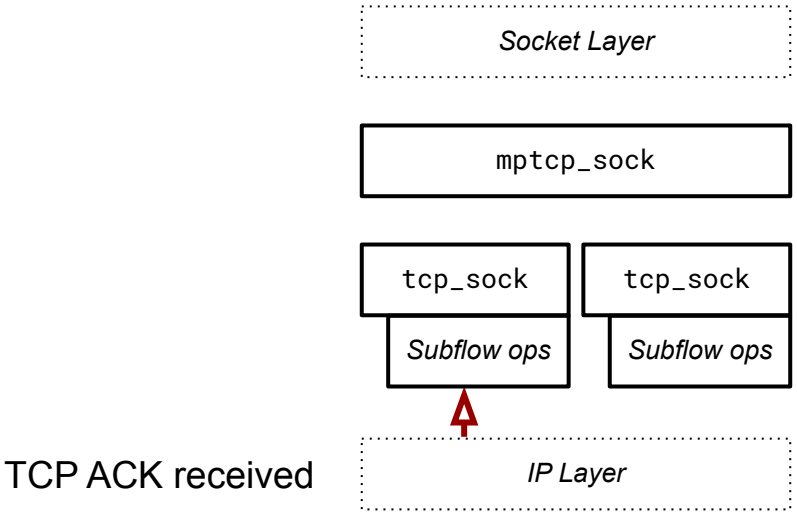
Sending of ACKs to signal options, e.g. REMOVE_ADDR in a TCP ACK

Sending a ACK not from TCP stack



Protocol challenges

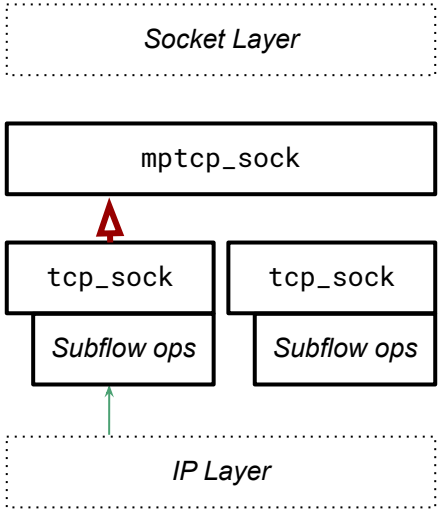
Reception of ACKs with signaling options, e.g. REMOVE_ADDR in a TCP ACK



Protocol challenges

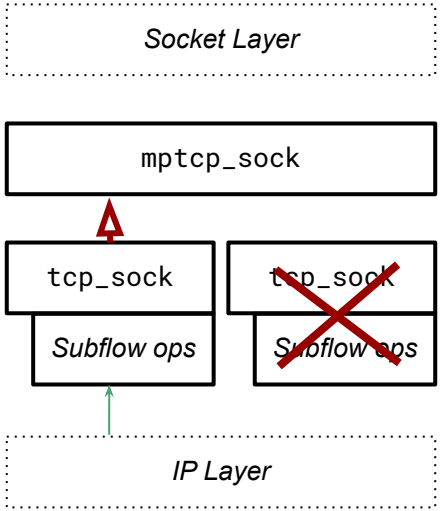
Reception of ACKs with signaling options, e.g. REMOVE_ADDR in a TCP ACK

TCP ACK is not dropped



Protocol challenges

Reception of ACKs with signaling options, e.g. REMOVE_ADDR in a TCP ACK



Protocol challenges

Signaling with MPTCP:

● MP_CAPABLE	SYN
● MP_JOIN	SYN
● DSEQ / DACK	ALL
● FAST_CLOSE	ACK followed by RST
● ADD_ADDR	ACK
● REMOVE_ADDR	ACK