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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Smartphone and WiFi icons by Blurred203 and Antü Plasma under CC-by-sa, others from Tango project, public domain
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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
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.
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 \texttt{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

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- **MP_CAPABLE, MP_JOIN, DATA_FIN**
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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

- **Socket Layer**
- **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:

```c
socket(AF_INET(6), SOCK_STREAM, IPPROTO_MPTCP);
```
Userspace API

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  - `IPPROTO_MPTCP = IPPROTO_TCP | 0x100; /* = 262 */`
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● `getsockopt()` / `setsockopt()` with MPTCP socket or its TCP subflows?
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  ```

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- `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](https://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
Protocol challenges

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)
Protocol challenges
Protocol challenges

Data sequence numbers and mappings
Protocol challenges

Data sequence numbers and mappings
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Data sequence numbers and mappings
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Data sequence numbers and mappings

Dseq=3, seq=456, "D"

Dseq=2, seq=456, "C"

Dseq=1, seq=124, "B"

Dseq=5, seq=126, "F"

Dseq=4, seq=125, "E"

Dseq=0, seq=123, "A"

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Protocol challenges

Data sequence numbers and mappings

App sends data

Socket Layer

mptcp_sock

tcp_sock

IP Layer
Protocol challenges

Data sequence numbers and mappings
Protocol challenges

Data sequence numbers and mappings

TCP header: What DSS to set?
Protocol challenges

Sending of ACKs to signal options, e.g. REMOVE_ADDR in a TCP ACK
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Sending a ACK not from TCP stack
Protocol challenges

Reception of ACKs with signaling options, e.g. REMOVE_ADDR in a TCP ACK
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TCP ACK is not dropped
Protocol challenges

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Signaling with MPTCP:

- MP_CAPABLE
- MP_JOIN
- DSEQ / DACK
- FAST_CLOSE
- ADD_ADDR
- REMOVE_ADDR

SYN
SYN
ALL
ACK followed by RST
ACK
ACK