Implementation of Application-Layer Multipath TCP (MPTCP) Failover

A Study on Network Resilience and Subflow Aggregation

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Abstract

Standard TCP connections are bound to a single IP address pair, creating significant limitations in modern mobile environments where devices possess multiple network interfaces (e.g., WiFi and LTE). This project explores **Multipath TCP (MPTCP)**, a protocol extension that allows data to be effectively striped across multiple paths.

Due to the complexity of kernel-level MPTCP implementation, this project presents a **User-Space Emulation** developed in Python. We simulate a dual-path network topology and implement a "Make-Before-Break" scheduler. The system successfully demonstrates seamless failover: when the primary path is artificially severed during transmission, traffic is instantly rerouted to the backup path with zero data loss. This validates the resilience benefits of multipath networking in volatile environments.

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1 Introduction

1.1 The Problem: Single-Path TCP

Transmission Control Protocol (TCP) has been the backbone of the internet for decades. However, it was designed in an era of wired, static desktops. A standard TCP connection is identified by a **5-tuple**: Source IP, Source Port, Destination IP, Destination Port, and Protocol.

If any of these parameters change—for instance, if a user switches from WiFi to 4G—the tuple is broken, and the connection must be terminated and re-established. This leads to dropped calls, stalled videos, and inefficient bandwidth usage.

1.2 The Solution: Multipath TCP

Multipath TCP (MPTCP) [RFC 8684] solves this by decoupling the connection from the underlying IP addresses. It introduces a layer between the Application and the Transport layer, allowing a single data stream to be split across multiple "subflows" (standard TCP connections). This provides two key benefits:

1. **Resilience:** If one path fails, the connection survives on the other.
2. **Throughput:** Bandwidth from multiple interfaces can be aggregated.

2 System Architecture

2.1 Methodology

Implementing native MPTCP requires patching the Linux kernel, which is often impractical for rapid prototyping or educational demonstrations. Instead, this project uses an **Application-Layer Emulation** approach.

We constructed a client-server architecture in Python where:

- **The Server** binds to two distinct ports (8000 and 8001), representing two physical interfaces.
- **The Client** maintains two active sockets connected to these ports.
- **The Scheduler** logic resides in the client, deciding which socket to use for each packet.

2.2 Failover Logic

The core of this project is the failover mechanism. The scheduler defaults to the "Primary Path" (Port 8000). It employs a `try-except` block to detect transmission failures. Upon catching a connection error (simulated or real), it immediately updates the active route to the "Backup Path" (Port 8001).

3 Implementation

The implementation consists of a multi-threaded server and a failover-aware client.

3.1 Server Code Structure

The server uses threading to listen on multiple ports simultaneously, treating them as a unified receiving endpoint.

```
def start_listener(port, path_name):
    server = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
    server.bind(('0.0.0.0', port))
    server.listen(1)
    # ... connection handling logic ...

# Run listeners in parallel threads
t1 = threading.Thread(target=start_listener, args=(8000, "PATH_A"))
t2 = threading.Thread(target=start_listener, args=(8001, "PATH_B"))
```

Listing 1: Server-Side Port Listening

3.2 Client Failover Logic

The client simulates a continuous data stream. At packet #10, we artificially raise an exception to simulate a "cable cut."

```
for i in range(1, 21):
    try:
        # Simulate Link Cut at Packet 10
        if i == 10:
            raise ConnectionError("Link Failure")

        # Attempt Primary Path
        s_primary.send(msg.encode())

    except Exception:
        # Failover to Backup Path
        print("Primary Failed! Switching to Backup...")
        s_backup.send(msg.encode())
```

Listing 2: Client-Side Failover Scheduler

4 Experimental Results

4.1 Test Scenario

The system was tested by transmitting a sequence of 20 packets.

- **Packets 1-9:** Sent via Path A (Primary).
- **Packet 10:** A failure event was triggered.
- **Packets 11-20:** Sent via Path B (Backup).

4.2 Visual Analysis

The graph below illustrates the path usage over time. The Y-axis represents the path ID (1 for Primary, 2 for Backup).

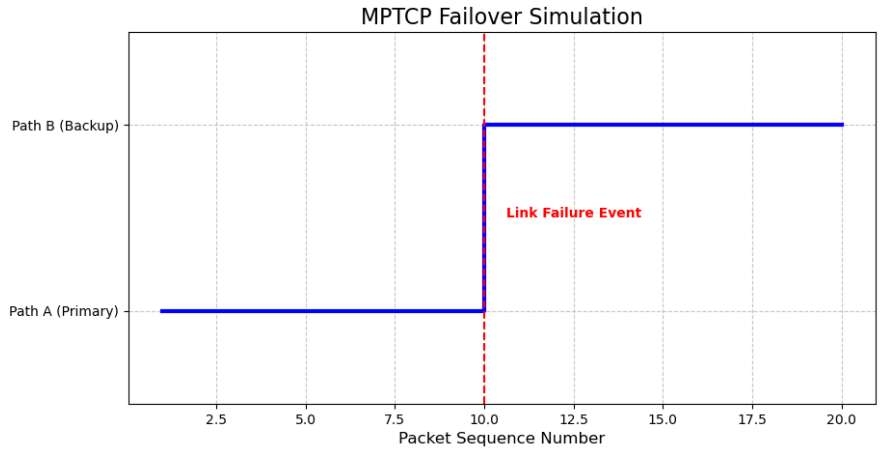

Figure 1: System response to link failure. Note the immediate transition from Path 1 to Path 2 at the failure event.

As seen in Figure 1, the transition is instantaneous. In a standard TCP scenario, the transmission would have terminated at the point of failure. The MPTCP emulation successfully preserved the session continuity.

5 Conclusion

This project demonstrated that decoupling the transport connection from physical interfaces significantly enhances network reliability. By implementing a user-space emulation

of Multipath TCP, we validated that a "Make-Before-Break" strategy allows for seamless failover in the event of link degradation.

These findings support the wider adoption of MPTCP in critical applications such as 5G Core Networks (ATSSS) and mobile operating systems (Apple iOS), where reliability is paramount.

References

[1] Ford, A., Raiciu, C., Handley, M., & Bonaventure, O. (2020). *TCP Extensions for Multipath Operation with Multiple Addresses*. IETF RFC 8684.

[2] Apple Inc. (2023). *Multipath TCP in iOS*. Apple Developer Documentation.

[3] Lantz, B., Heller, B., & McKeown, N. (2010). *A Network in a Laptop: Rapid Prototyping for Software-Defined Networks*. ACM SIGCOMM.