26. ITG-Symposium on Mobile Communication – Technologies and Applications
Session 4 – Full Paper Talk

Improving Connectivity In Multipath PLMN Setups: An MPTCP Scheduler Using Link Quality Indicators

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Background & Motivation

Context

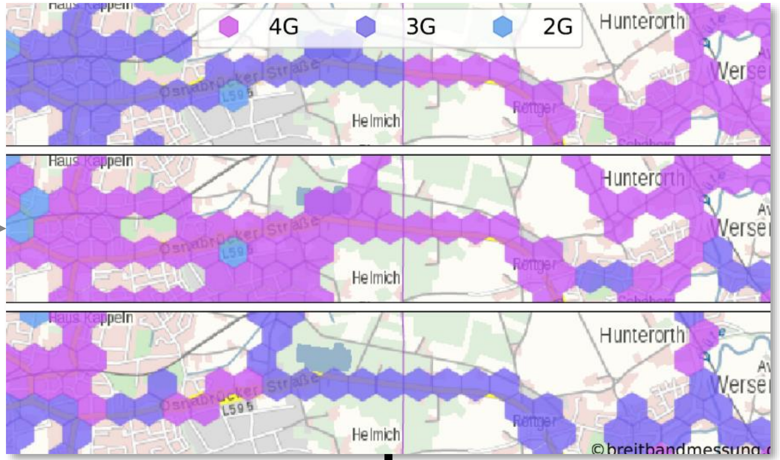
Stock Image of a moving train

travel scenarios

→ heterogeneous network quality / connectivity [1]

Carrier

Three PLMNs show heterogeneous service coverage within a single area. Source: https://breitbandmessung.de/kartenansicht-funkloch



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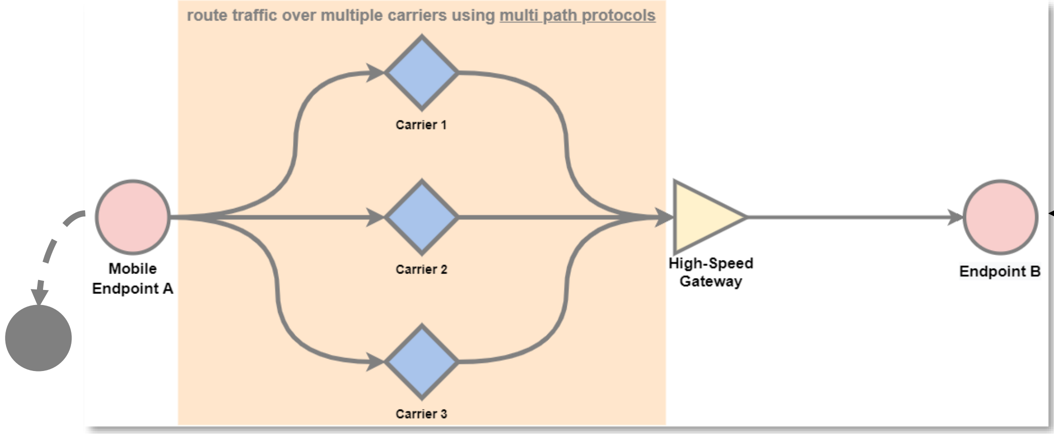
aggregate links to improve connectivity?

LaL system design: A mobile endpoint aggregates multiple carrier links using multi path protocol tunnel that terminates on a high-speed internet gateway



via multipath tunnel

The "Link-a-Lot" Box developed by UOS Students is a battery-powered device enabling wifi access to an aggregate of mobile links

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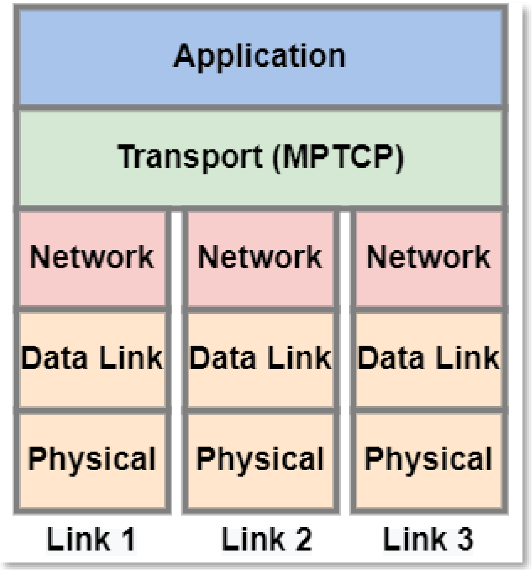
Background & Motivation

MPTCP

- **M**ulti**P**ath **T**ransport **C**ontrol **P**rotocol (MPTCP) [2]
- First Version: RFC6824 (2013)
- Latest Version: RFC8684 (2020)
- TCP Extension: aggregate multiple links via TCP session bundling
  - *Subflow*

Visualization of the ISO/OSI Model combined with multiple physical links that are aggregated on transport layer by MPTCP



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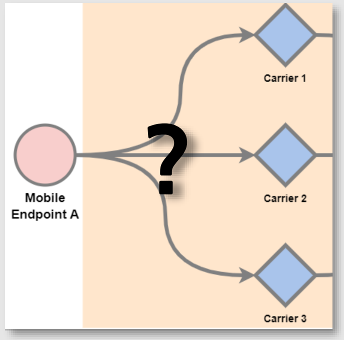
Background & Motivation

MPTCP Subflow Scheduling

Application and Subflow Scheduler dictacte performance [3]



MPTCP Kernel Implementation Schedulers [4]

- Round Robin ➔ ✗ no link quality metrics
- Redundant ➔ ✗ high overhead, capped traffic plans
- minRTT ➔ ✗ poor performance when moving (e.g., train)

minRTT Strategy [4]

Subflow with lowest Round-Trip-Time (RTT),

migrate if congestion window full

➔ High-Speed Travel Scenarios: Loss & RTT <u>bursty</u> [5]

➔ Congestion window might fill in infeasible time

➔ Subflow may not migrate fast enough when connectivity drops

Background & Motivation

Related Work & Link Quality Measures

Research Gap: Schedule via physical link quality measures

e.g.,

- Received Signal Strength Indicator (**RSSI**)
  - Correlation RSSI ➔ packet loss [6]
- Link Quality Indicator (**LQI**) [7]
  - Formless metric → LQI ϵ [0, 255]
  - (Commonly) based on RSSI, *!vendor-specific!*
    - Enrich link quality approximation *(e.g., packet error rates)*

MPTCP scheduling for heterogeneous networks

- LAMPS [10] ➔ minRTT + packet loss on transport layer
- QAware [11] ➔ cross-layer metrics, device driver queue

LQI as loss predictor for subflow scheduling?

(mitigate loss-induced connectivity drops)

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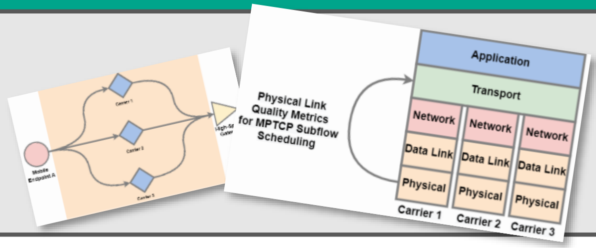
Contributions

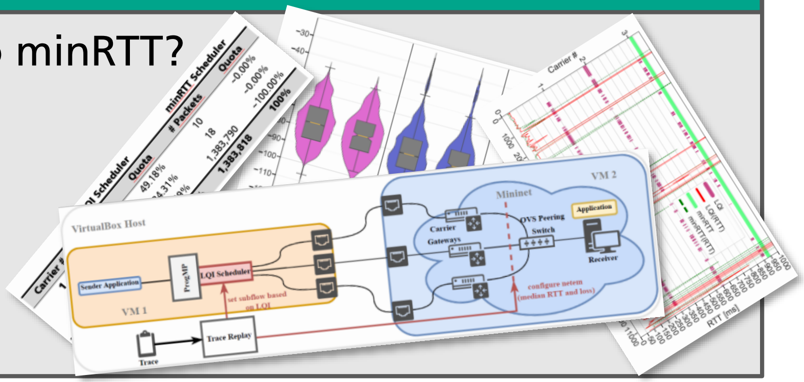
C1: Cross-layer MPTCP scheduler using LQI as loss-predictor

- Goal: Mitigate loss-induced connectivity drops
- Extensible LQI based on live RSSI data from 4G modems
- MPTCP scheduler using LQI for subflow migration



C2: Emulative trace-based performance evaluation

- RQ: Does our scheduler reduce packet loss on the aggregate in comparison to minRTT?
- Real world trace: 3 hour train ride
  - Three german mobile carriers: RSSI, RTT, packet loss
- Virtual testbed, emulate link quality using NetEm



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C1: Scheduler

Constructing the LQI

$t = Timestamp$

$$LQI_l(t) = \underbrace{\|RSSI_l(t)\|}_{\substack{\|r\| = 2.55(r+25)+255 \\ r \in [-125,-25]dBm}}$$

$l = Link$

$linear\ RSSI\ scaling$

$to\ [0, 255]$

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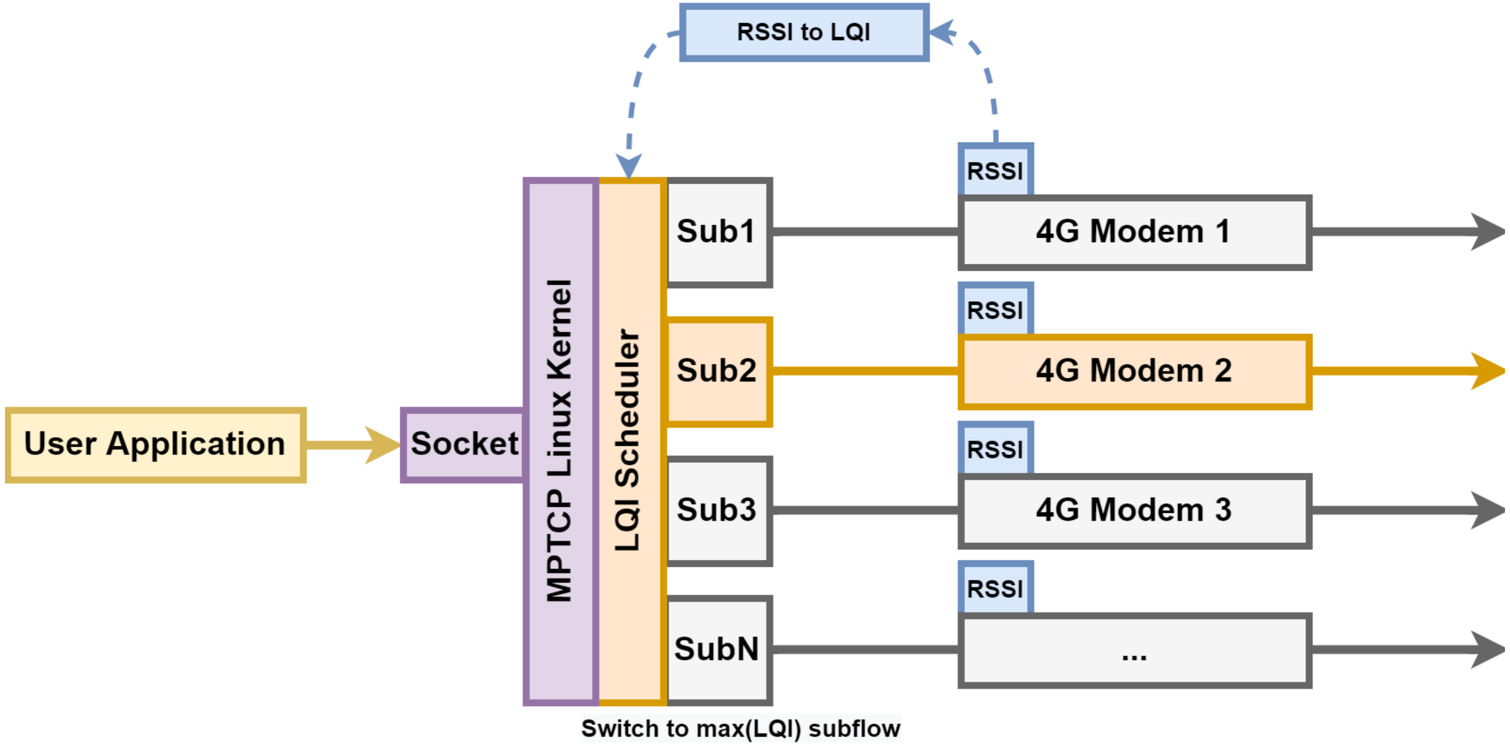
C1: Scheduler

Implementation



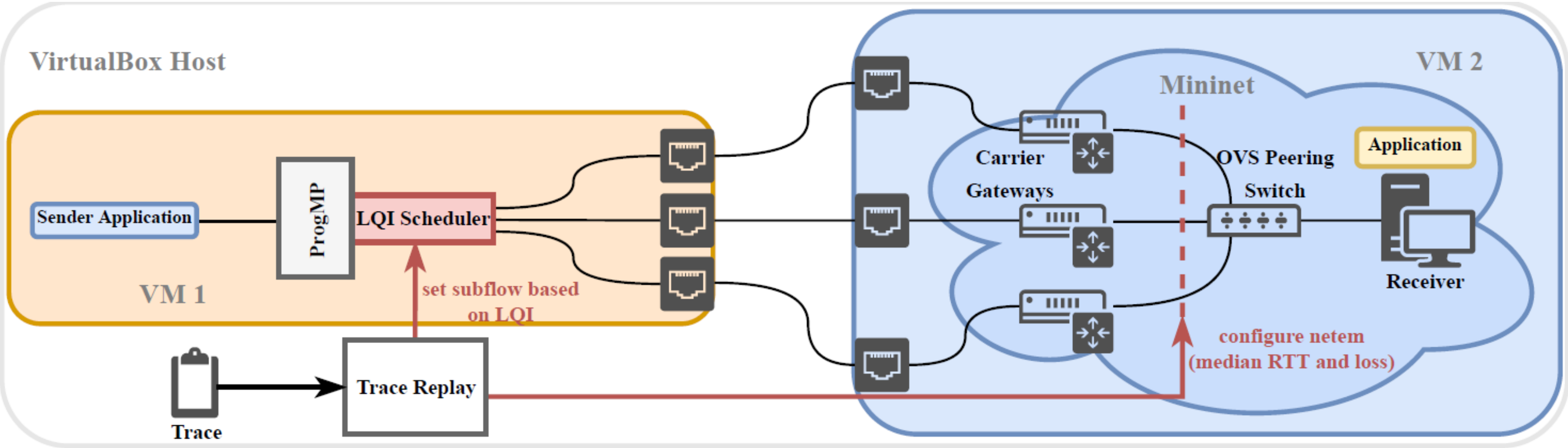
C2: Trace-based Evaluation

Methods – Research Question, Virtual Testbed, and Scenario

RQ: Does our scheduler reduce packet loss on the aggregate?

- Baseline: minRTT
- Sender → Receiver: 1.7 mbps tagged data stream (480p30 webcam)
- 3 hour train ride: replay trace for each link/carrier
  - Replay RTT, packet loss (NetEm) and RSSI
    - Downsampled 30s-median values
  - Collect aggregate RTT & packet loss, scheduling decisions

Virtual Testbed Setup using Mininet, NetEm, and two virtual machines with MPTCP kernels



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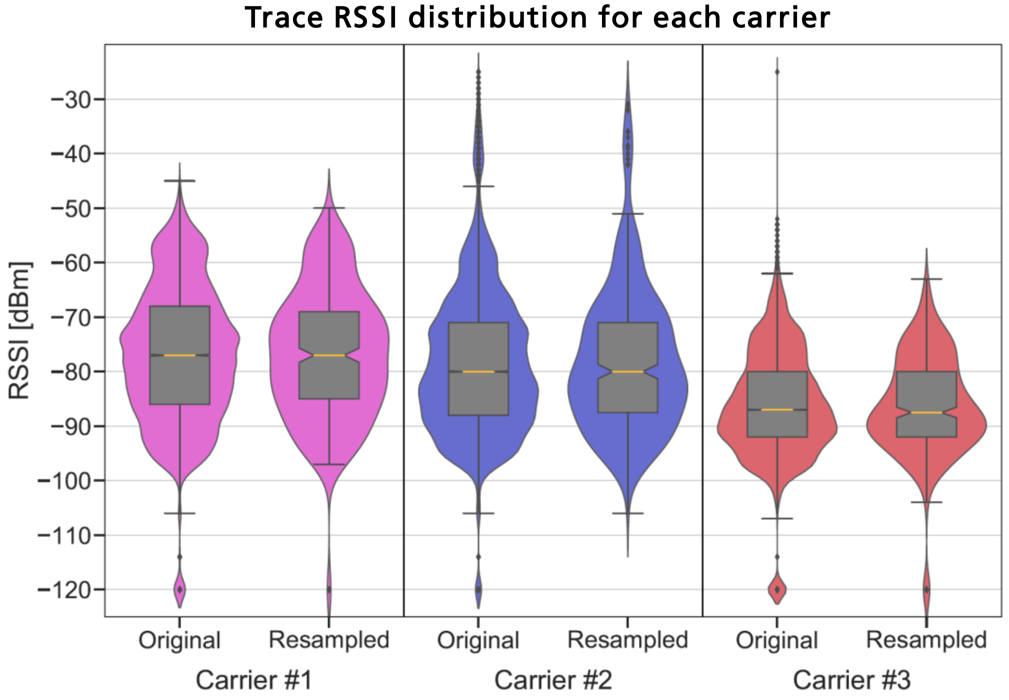
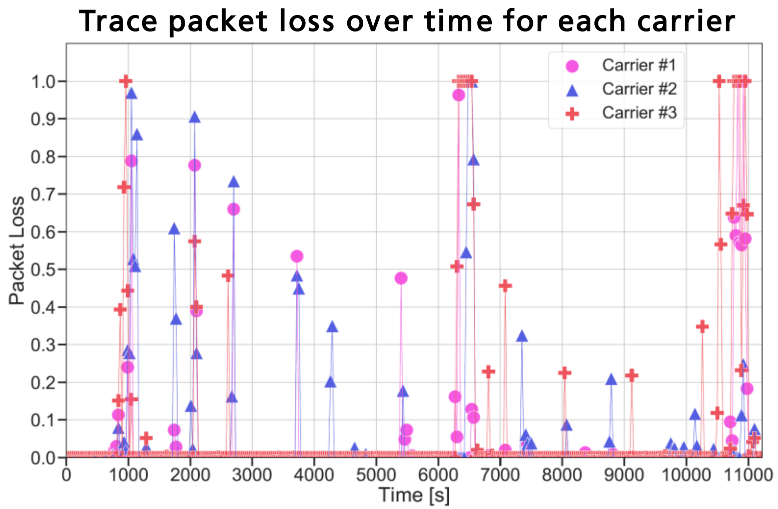
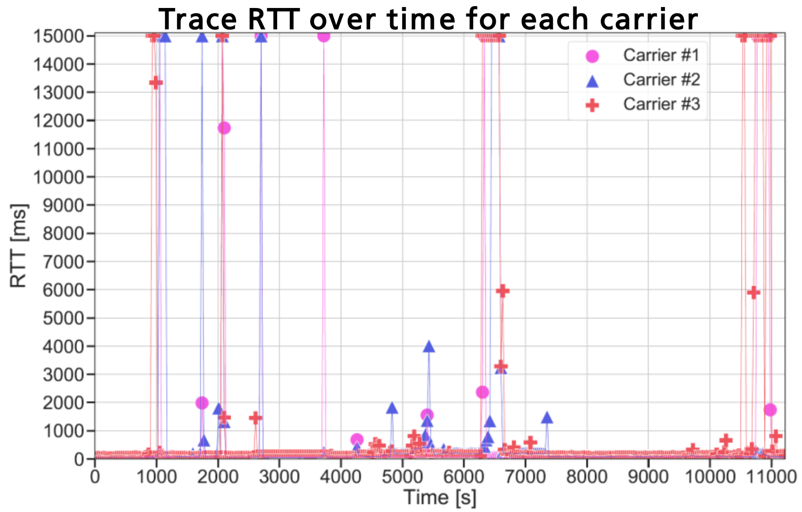
C2: Trace-based Evaluation

Methods – Inside the trace







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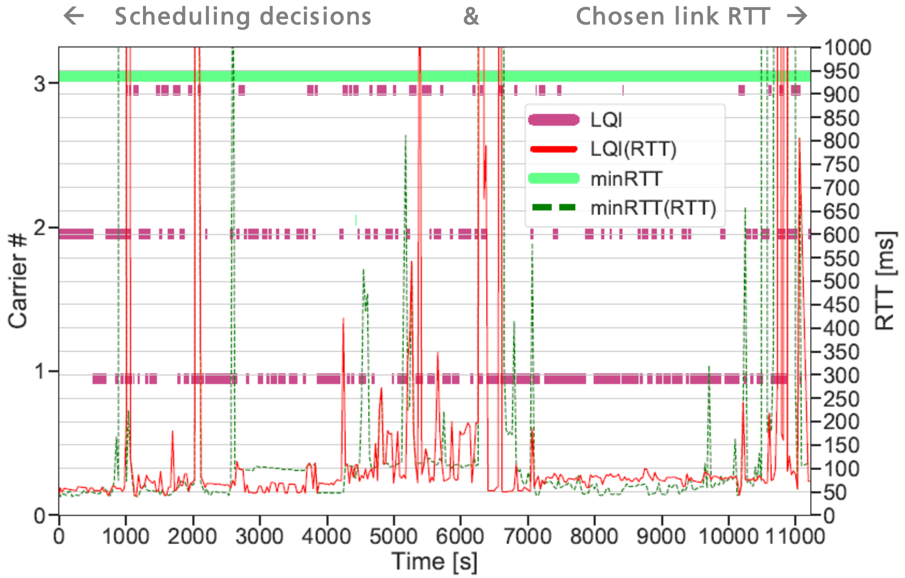
C2: Trace-based Evaluation

Results & Analysis

minRTT did not migrate (CW Issue?)

LQI → frequent migration



Relative Packet Distribution across links, *optimal* scheduling choice for each sent packet & scheduler

	minRTT	LQI
Link scheduling decisions	**Times [%]**	**Quota**
Lowest RTT	**50.19%**	30.42%
Lowest packet loss	82.60%	**90.15%**

LQI sent +7.55% packets over minimal loss link

tradeoff: worse RTT

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Conclusion & Future Work

- RSSI-based LQI → good loss-predictor for MPTCP scheduling
- Tradeoff: worse RTT (compared to minRTT)
  - Aggregate stability vs. performance

- Future Work:
  - Real-world case study
  - Multi-dimensional LQI promising, RSSI +…
    - RTT, transport-layer loss (LAMPS), device queue (QAware)

Improving Connectivity in Multipath PLMN Setups: An MPTCP Scheduler Using Link Quality Indicators

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***Abstract*—Varying link qualities among multiple German PLMNs may lead to significant differences in QoS within a single area. MPTCP enables load balancing of multiple mobile links to compensate infrastructural differences between carriers. Yet, general purpose packet schedulers like minRTT lack important measures to properly estimate link quality in mobile scenarios. Thus, we propose a cross-layer MPTCP scheduler to improve general connectivity. Scheduling decisions are based on a self-constructed LQI that utilizes the physical layer RSSI measure to estimate link qualities. While our trace-based evaluation shows no improvements in RTTs compared to minRTT, packet loss is considerably reduced.**

I. Introduction

A keystone of Public Land Mobile Networks (PLMNs) lies within well-planned and area-wide deployments of modern infrastructure. Otherwise, high network coverage and consistent performance are not achievable. Data collected by the German Breitbandmessung[1] indicate general availability gaps and differences in service across mobile carriers. Figure 1, e.g., visualizes the available service modes of three German PLMNs within an area of $5\,\mathrm{km}^2$. As observed by [1], dependencies between QoS, carrier, and position seem to exist.

To mitigate this problem we built a small battery-powered gateway combining multiple wireless links of different carriers with multipath protocols. Amongst these protocols is MPTCP [2]. Its performance and resilience to link failure depends on the scheduling algorithm and application context [3].

MPTCP's default scheduler [4] (minRTT) does not perform very well when travelling across large areas with varying link quality among network carriers. It selects a subflow based on the lowest Round-Trip Time (RTT) and then sticks to it until the congestion window is full [4]. However, packet loss in travel scenarios appears to be bursty [5]. This implies that a subflow's congestion window may not be exhausted in a feasible period of time to trigger migration, although other flows may provide a more robust link. In this case, the gateway's functionality may not be leveraged upon. To mitigate this issue, the redundant scheduler included in the MPTCP Linux Kernel implementation [4] may be used. It sends every packet on all available subflows and, thus, always

[1] https://breitbandmessung.de/kartenansicht-funkloch, accessed: 2020-02-12

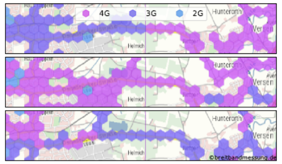

Figure 1: Three PLMNs show heterogeneous service coverage within the same rural area near Osnabrück, Germany.

uses the most capable link. Yet, its network overhead may render this option infeasible, as mobile data plans tend to be expensive and often do not include unlimited data usage.

Motivated by these observations, we propose a context-aware MPTCP scheduler using metrics derivable from lower network layers to estimate link qualities and accelerate subflow migration. Packet loss and the Received Signal Strength Indication (RSSI) appear to share correlative properties [6]. Thus, we construct the formless metric Link Quality Indicator (LQI) [7] as a superset of the RSSI. It is used as loss-predictor for scheduling decisions within the MPTCP Kernel implementation [4]. By doing so, improvements in general connectivity regarding the gateway's mobile scenario are sought.

II. Related work

Context-aware and application-dependent packet scheduling is deeply embodied within the research community around MPTCP. In the following, selected work is discussed, while a comprehensive list of schedulers is provided by Sayit et al. [3].

The authors of ProgMP [8] propose a programming model for implementing and evaluating MPTCP schedulers in a rapid prototyping scheme. Schedulers may be designed by using a programming language which provides high level abstrac-

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