WiFi and Multiple Interfaces:
Adequate for Virtual Reality?

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360-degree Panoramic Videos

Stage	Data Rate	RTT
Early	25 Mbit/s	40 ms
Entry	100 Mbit/s	30 ms
Advanced	418 Mbit/s	20 ms
Ultimate	2.35 Gbit/s	10 ms

Table: Network requirements for VR 360

Image source: www.vectorstock.com

Data source: Huawei Technologies, Whitepaper on the VR-Oriented Bearer Network Requirement, 2016

WiFi Support for VR Headsets

- High-quality VR headsets: Cable transmission (HDMI or USB3)
  - Drawback:
    - Not user-friendly (limited mobility)
    - Potential safety hazard

- Ubiquitousness of WiFi

Win-Win Situation

Image source: www.vectorstock.com

Preliminary Study of IEEE 802.11ac

1. Working on 5G frequency bands
2. Supported maximum data rate: **6.9** Gpbs
   - 160 MHz Frequency band
   - 256-QAM
   - 8 Spatial Streams (NSS=8)
   - 400 ns Guard Interval (GI)

Ultimate VR 360	**2.35** Gbit/s	10 ms

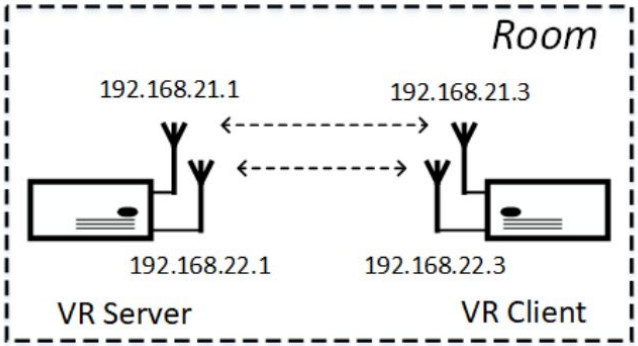
Data Rate 

Latency 

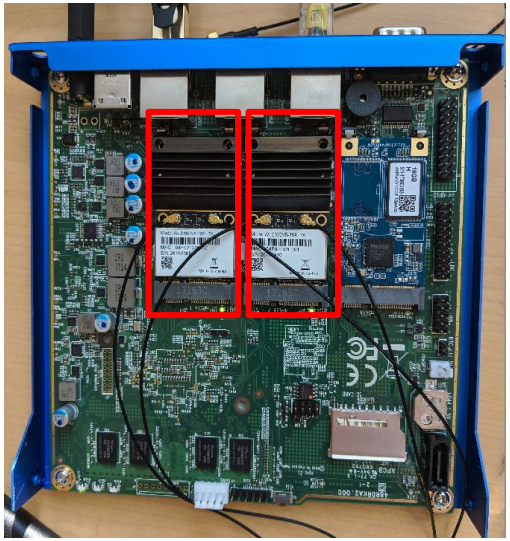
Image source: www.vectorstock.com

Data source: 802.11ac-2013 part 11: Wireless lan medium access control (MAC) and physical layer (PHY) specifications. Standard, IEEE, 2013

Measurement Setup



Measurement setup



Device

Measuring Network Latency

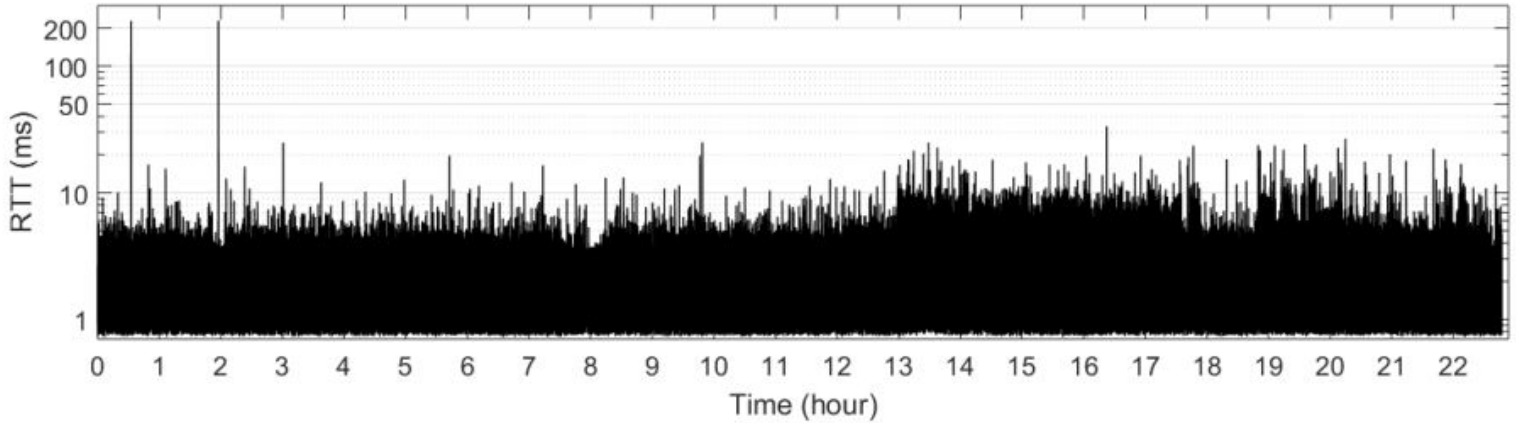


Figure 1. One day trace of RTT

Observation (862650 packets):

1. 50% packets RTT < 1.8 ms
2. 0.04% packets RTT > 10 ms
3. Maximum RTT = 227 ms
4. 24.2% packets jitter > 1ms
5. Maximum jitter = 226 ms

High delay and High jitter

Locating Root Cause: Dissecting Network Stack

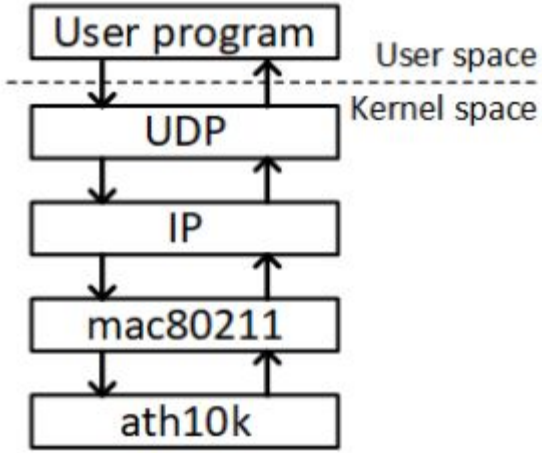


Figure 2. Network stack from the perspective of Linux code structure

Record **timestamp** of packets entering and leaving each network layer

Debugfs virtual file system to log data

Latency from Upper Layers

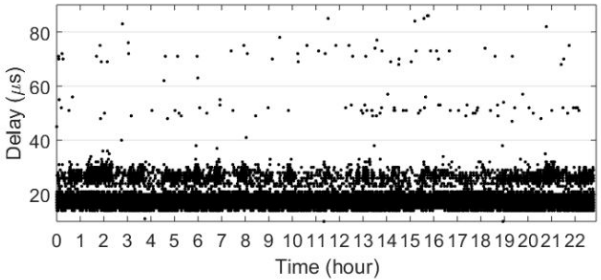


Figure 3. UDP to IP delay

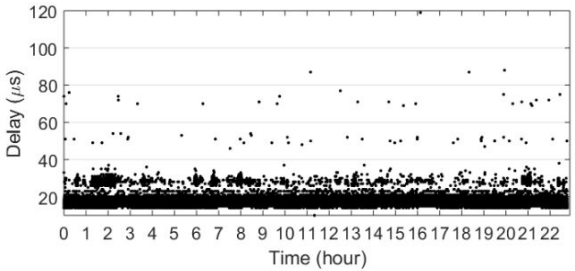


Figure 4. IP to UDP delay

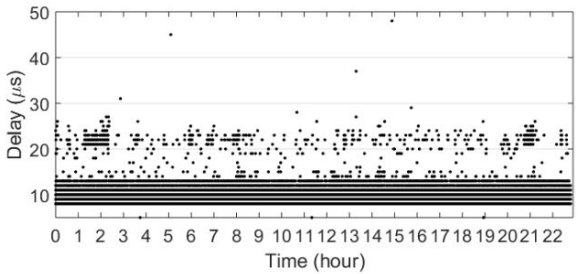


Figure 5. UDP to mac80211 delay

Min: 24 us, Median: 41 us, Max: 145 us

Negligible

Image source: www.vectorstock.com

Latency from Channel Transmission

Channel transmission time: a packet enters the ath10k driver layer until the driver receives ACK from the peer driver

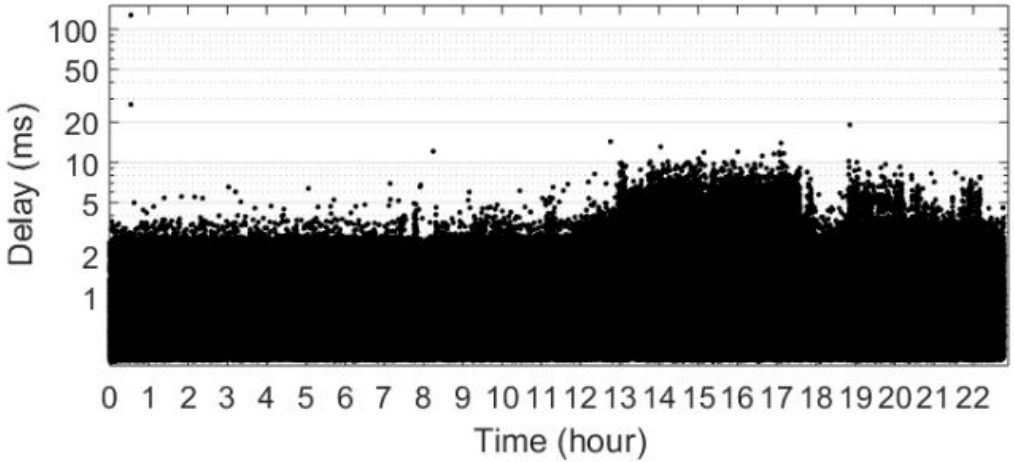


Figure 6. Channel transmission time

Observations of channel transmission time:

1. **Dominates** RTT (min: 0.3ms, median: 0.9ms, max: 127ms)
2. Increases with the background traffic (e.g., 13PM-17PM)
3. Good indicator for RTT (envelope correlation coefficient: 0.71)

Proposal: Multiple WiFi Network Interface Cards

Each NIC runs on non-overlapping channels

Duplicate packets to both NICs

PC Engines apu2 board

QCA9888 802.11ac NIC

OpenWrt OS

MPTCP v0.93

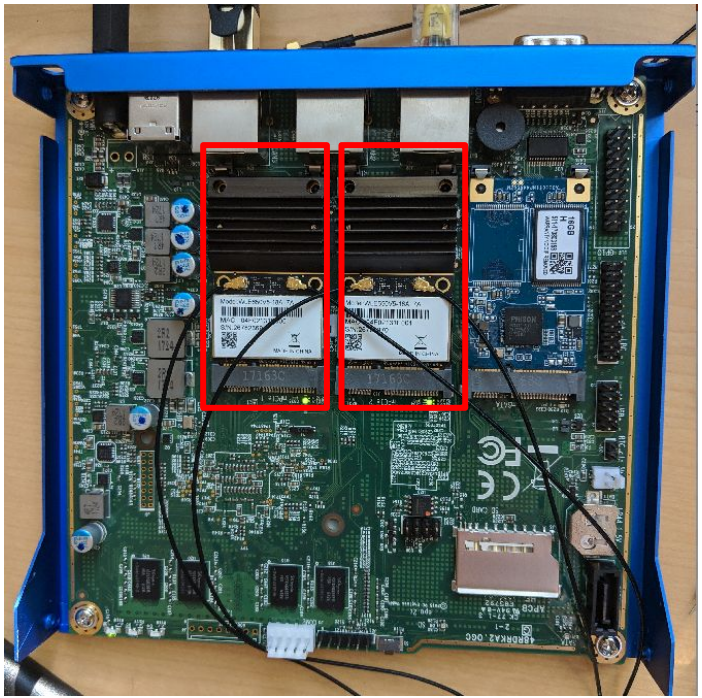


Figure 7. Setup

UDP Improvement

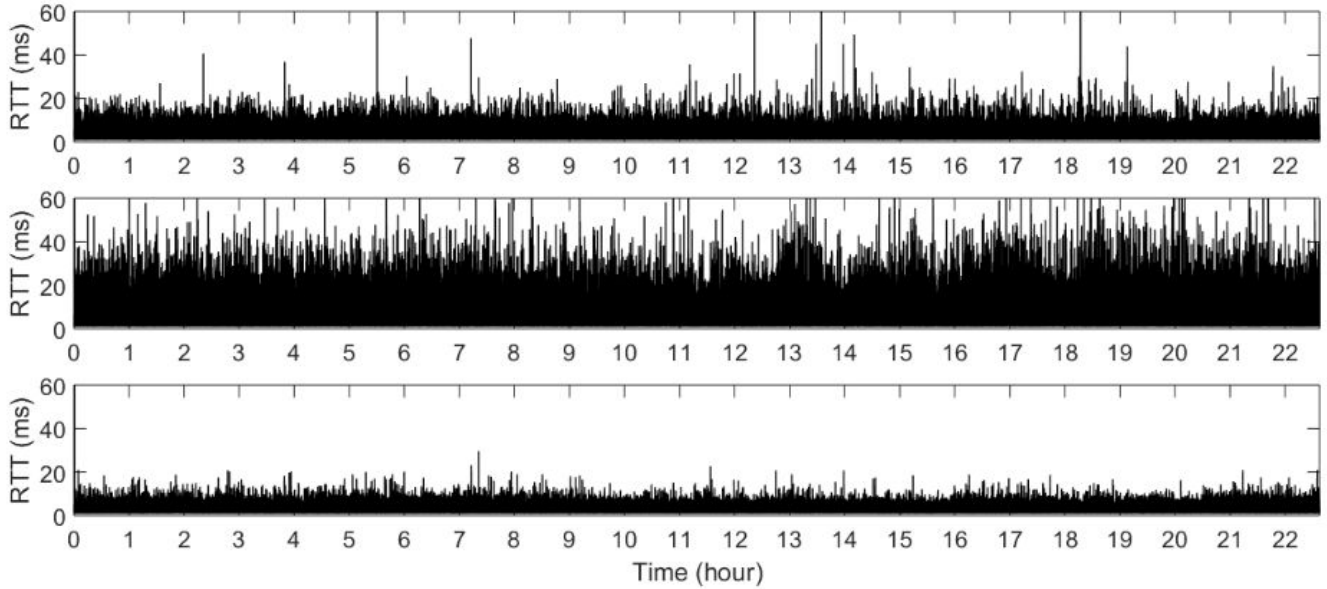


Figure 8. RTT for multiple interfaces. Top to bottom: interface 1, interface 2 and the combined interface

28.6% RTT Reduction

TCP Improvement

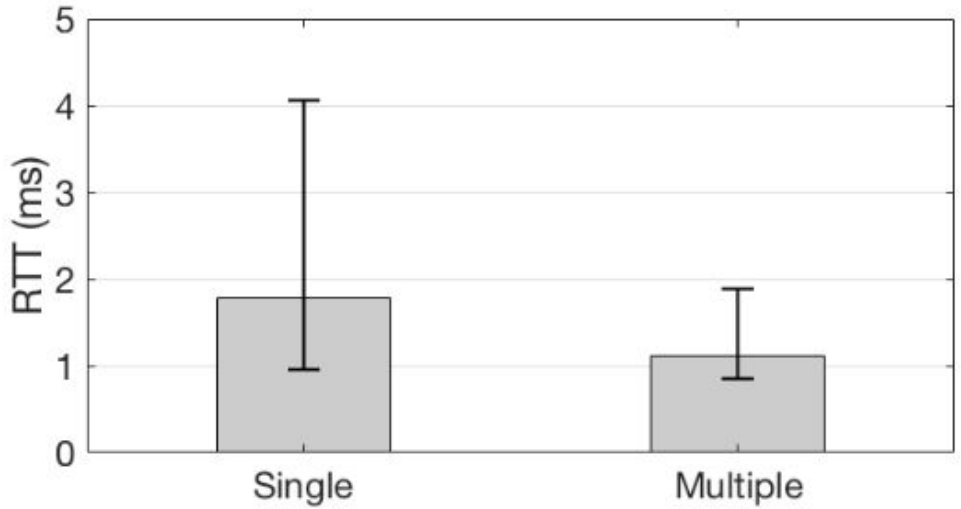
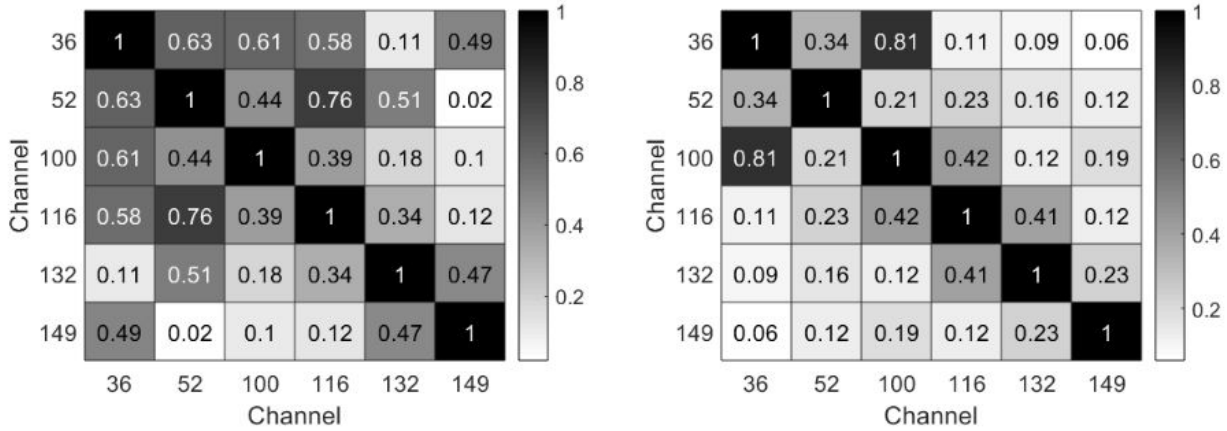


Figure 9. Median, 5 and 95 percentiles of RTTs for the best interface and the combined interface

38.9% RTT Reduction

Channel Correlations

Channels selection is NOT simple!



(a) Experiment one (b) Expriment two

Figure 10. Channel correlations

Future Works

1. More WiFi NICs

2. Multiple Interface Scheduling

Conclusion

Purely Wi-Fi based transmission systems to support VR applications

We believe that using multiple NICs is the right direction for building extremely high throughput, low latency and robust WiFi networks.

Code release:
https://github.com/dtczhl/dtc-openwrt

Q & A

Thank you!!!