Revisiting Congestion Control for WiFi Networks

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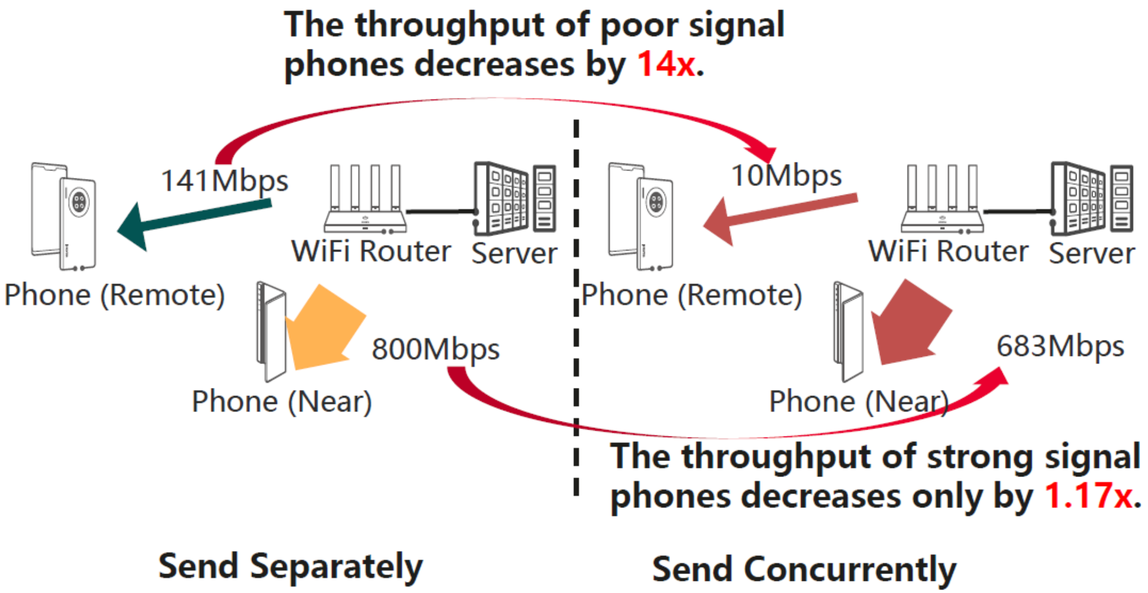
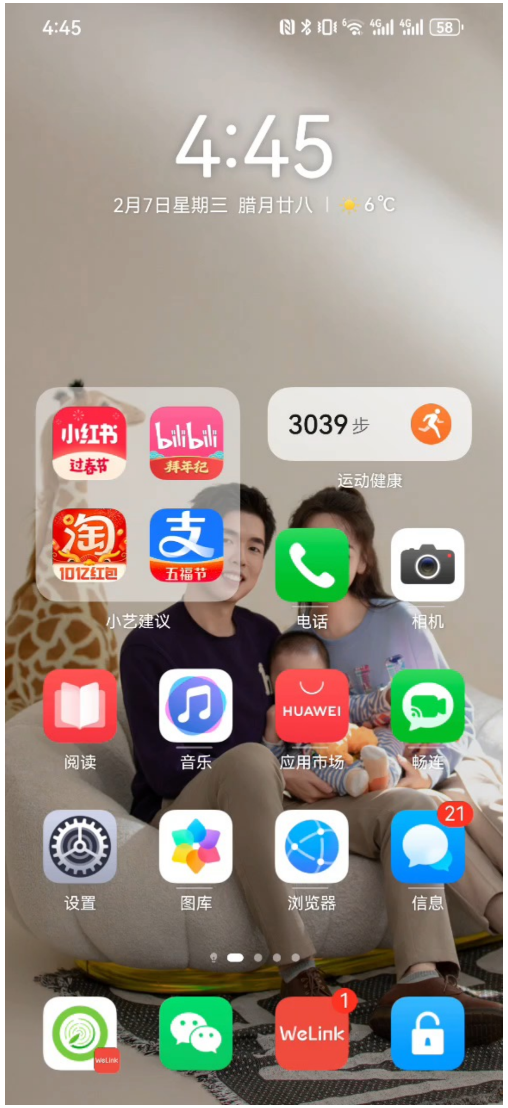
Bad User Experience with Multiple Users on WiFi

■ TCP victim problem in WiFi:

- TCP erroneously detects congestion and interacts with WiFi routers, resulting in a significant throughput decrease for certain hosts.

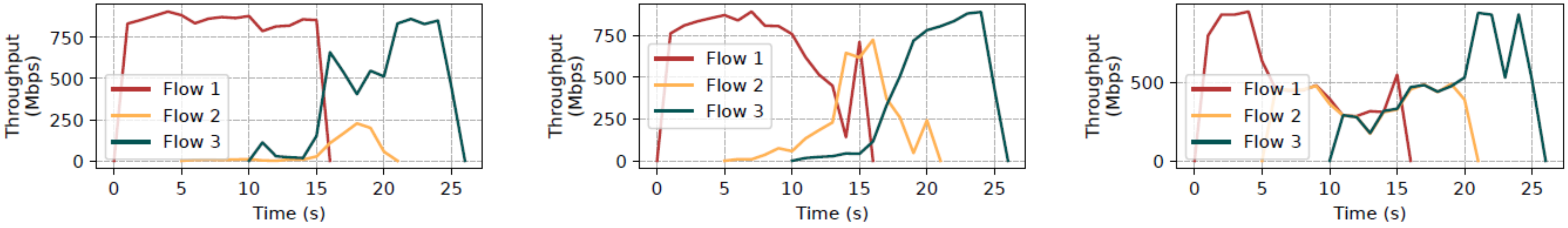


An example of TCP victim problem in WiFi



Observations 1: Unfair Bandwidth for Different Users

- Three users are downloading data simultaneously.
- The TCP is unfair, the user who connects later can't access the traffic.

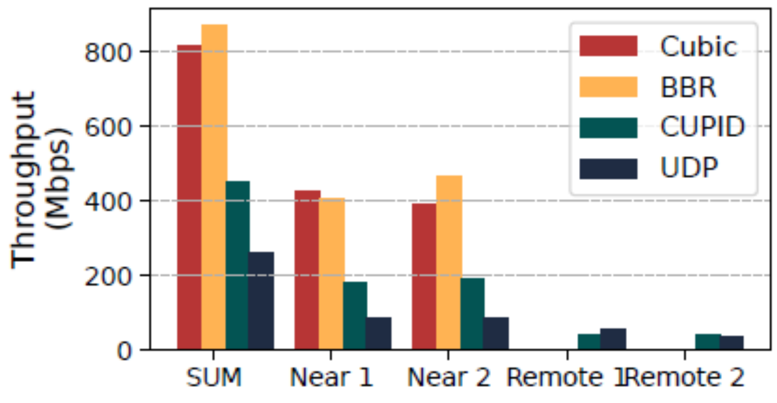


(a) Cubic (b) BBR. (c) Cupid.

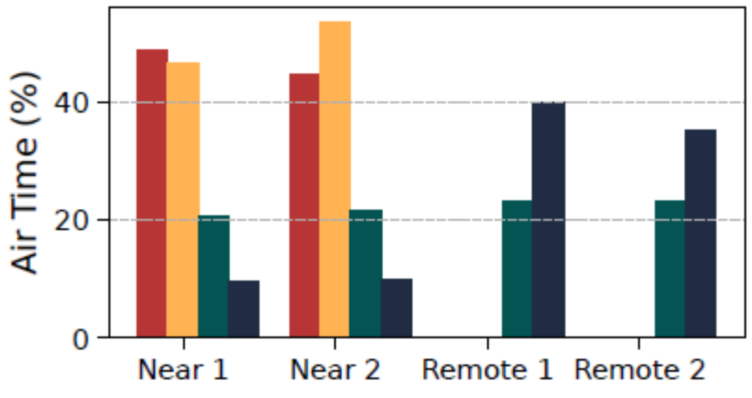
Fairness results among the three smartphones for the TCP victim problem.

Observations 2: Unequal Airtime at Different Signal

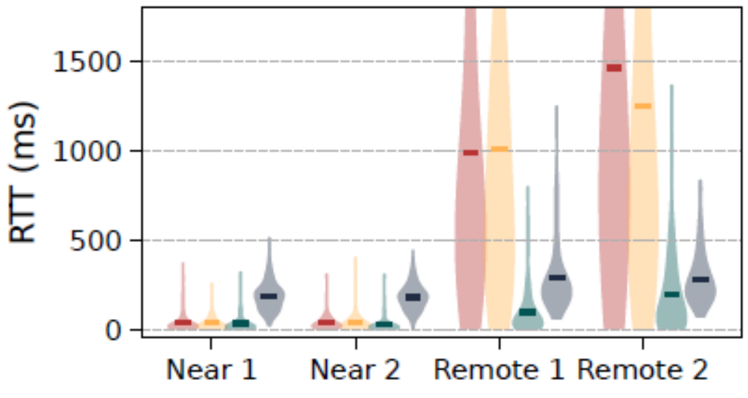
- Four users (two remote users and two near users) are downloading data simultaneously.
- For TCP, the throughput for the weak hosts is 0.03-0.51 Mbps, while the strong host achieves a throughput of 388-465 Mbps.
- For UDP (without congestion control), the weak host is 35-54 Mbps, while the strong host achieves a throughput of 83-86 Mbps.



(a) Throughput.



(b) Airtime utilization.



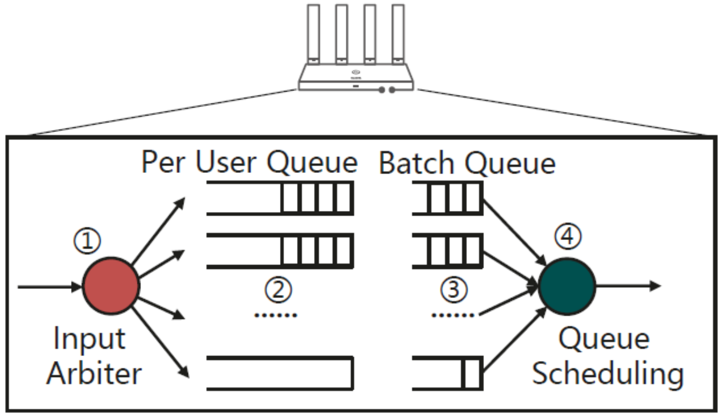
(c) RTT.

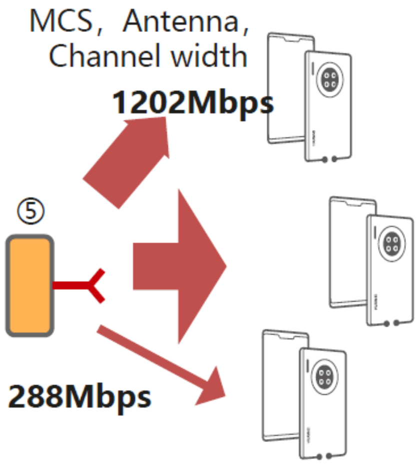
Near-Remote results among the four smartphones for the TCP victim problem.

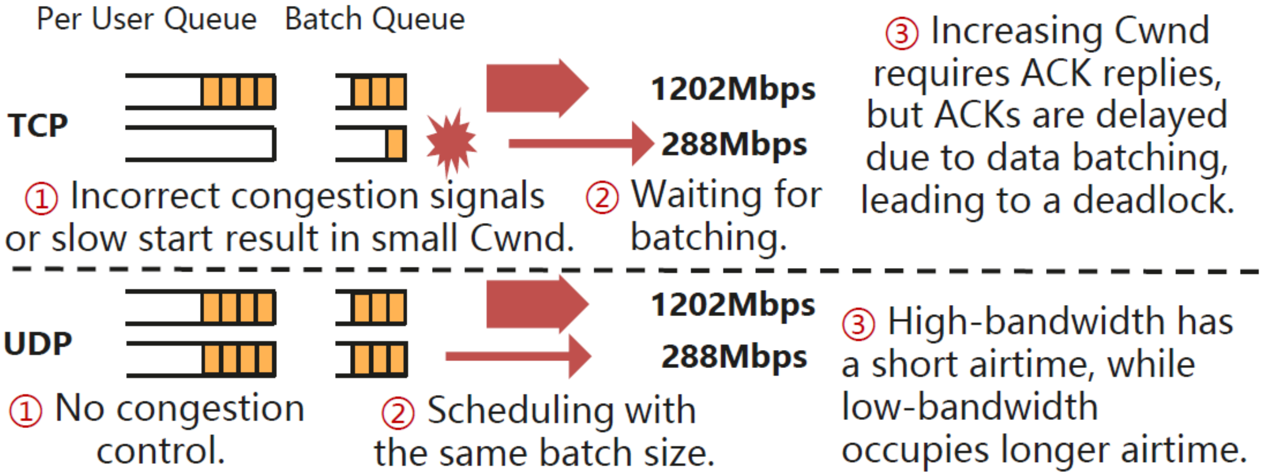
Why can't TCP users and UDP users fairly occupy WiFi?

■ The congestion signal causes the target rate to be incorrect.

- Per User Queue: Each user has its own queue.
- Batch Queue (A-MSDU, A-MPDU): Improve utilization, multiple data packet group batch.
- MCS，Antenna，Channel width: Different users have different physical base rate.







Why can't TCP users and UDP users fairly occupy WiFi?

■ The congestion signal causes the target speed to be incorrect.

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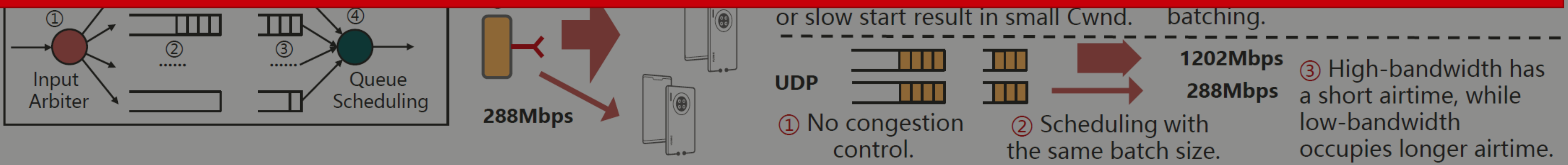
- Batch Queue: Improve utilization, multiple data packet group batch.

WiFi requires a new congestion signal to converge to the correct sending rate.



Key Insight: Revisiting Congestion Control for WiFi

- The essence of congestion control is to **converge the sending rate to the target rate** through **congestion signals.**

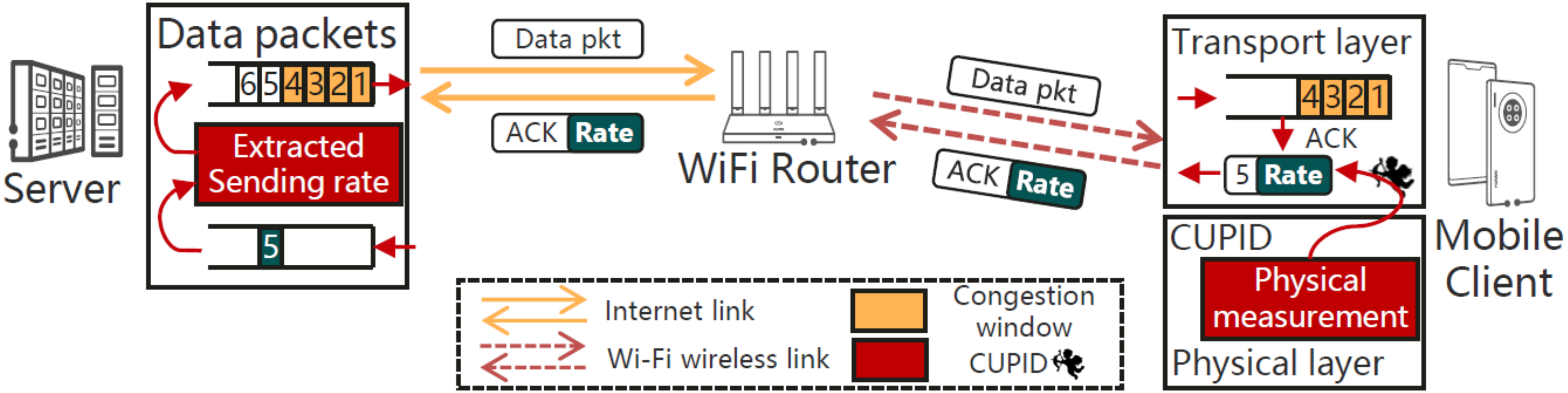
New target：
Airtime Fairness

+

New signals：
WiFi Physical Layer Measurements

Cupid: Receiver-driven WiFi Physical Layer Measurements

- **Mobile: Measure available wireless capacity based on decode packet in the air**
  - Cupid accurately assesses congestion by measuring parameters such as airtime utilization, concurrency, and rates, allowing for precise rate adjustments.
- **Sender: Explicit rate control (similar in spirit to XCP) based on the mobile’ s report**



Cupid Rate Estimation: Connection Start

■ Connection Start：Airtime Fairness Rate

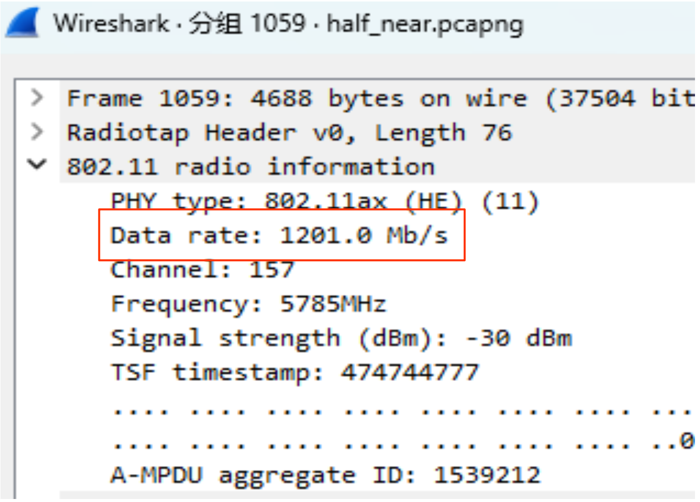
$$R_i^{init}(t) = \eta \frac{\delta(C_i(t))}{N}$$

Physical Bandwidth(distance, interference, MCS, # antennas)

Mapping Function (physical bandwidth -> transport layer throughput)

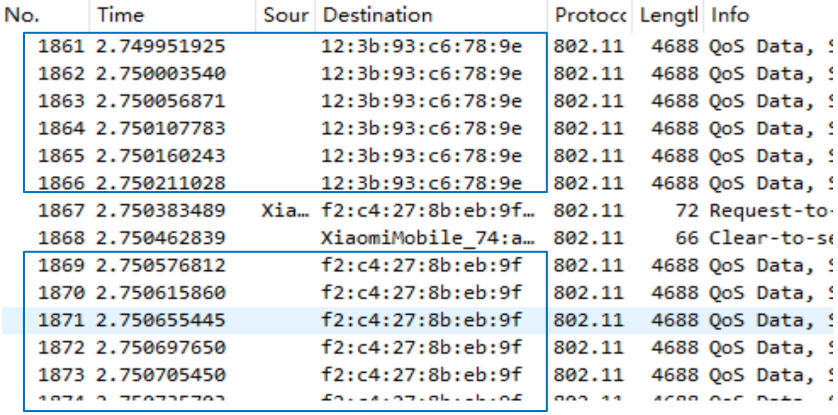
Concurrent Users

Constant (e.g., 0.8), the expected air channel bandwidth utilization.



Physical Bandwidth

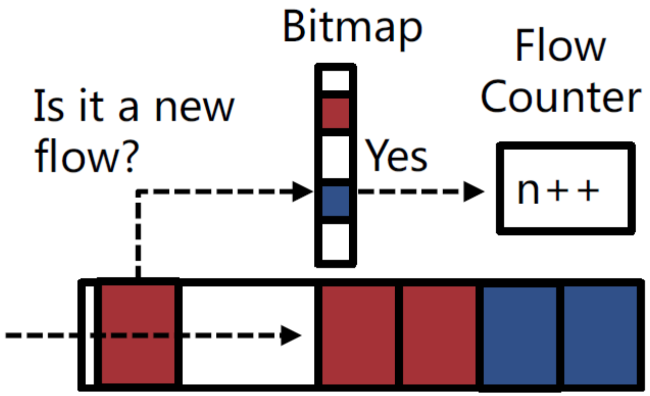
User 1



No.	Time	Sour	Destination	Protoco	Length	Info
1861	2.749951925		12:3b:93:c6:78:9e	802.11	4688	QoS Data,
1862	2.750003540		12:3b:93:c6:78:9e	802.11	4688	QoS Data,
1863	2.750056871		12:3b:93:c6:78:9e	802.11	4688	QoS Data,
1864	2.750107783		12:3b:93:c6:78:9e	802.11	4688	QoS Data,
1865	2.750160243		12:3b:93:c6:78:9e	802.11	4688	QoS Data,
1866	2.750211028		12:3b:93:c6:78:9e	802.11	4688	QoS Data,
1867	2.750383489	Xia…	f2:c4:27:8b:eb:9f…	802.11	72	Request-to-
1868	2.750462839		XiaomiMobile_74:a…	802.11	66	Clear-to-se
1869	2.750576812		f2:c4:27:8b:eb:9f	802.11	4688	QoS Data,
1870	2.750615860		f2:c4:27:8b:eb:9f	802.11	4688	QoS Data,
1871	2.750655445		f2:c4:27:8b:eb:9f	802.11	4688	QoS Data,
1872	2.750697650		f2:c4:27:8b:eb:9f	802.11	4688	QoS Data,
1873	2.750705450		f2:c4:27:8b:eb:9f	802.11	4688	QoS Data,

User 2

2 Users Examples



Concurrent Users

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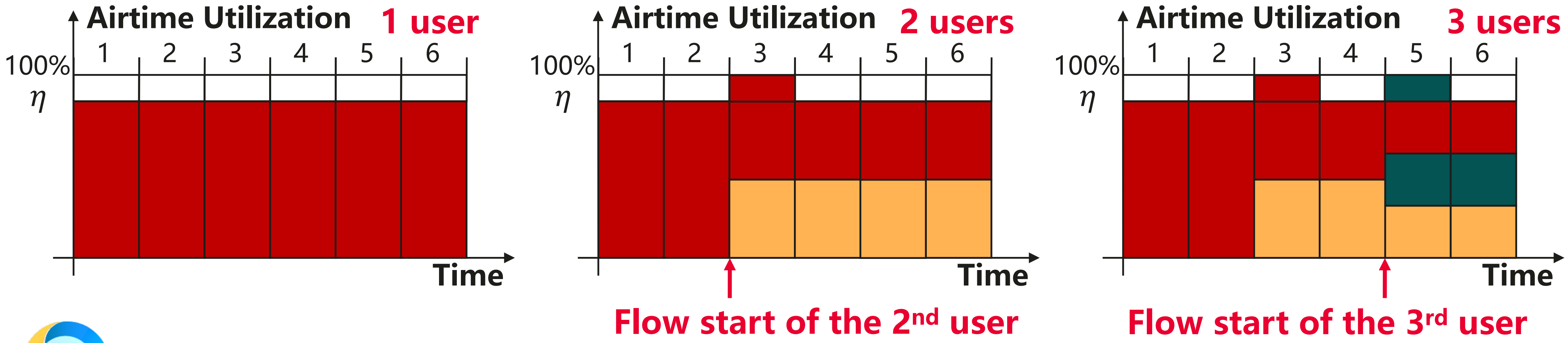
Physical Bandwidth(distance, interference, MCS, # antennas)

Mapping Function (physical bandwidth -> transport layer throughput)

Concurrent Users

Constant (e.g., 0.8), the expected air channel bandwidth utilization.

■ All the mobile equally share the bandwidth



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Cupid Rate Estimation: Steady State

■ Steday state: Airtime Fairness Rate

$$R_i(t) = \begin{cases} \boxed{\eta \frac{\delta(C_i(t))}{N}} & \text{if } U(t) \geq \eta \ (MD) \\ \boxed{R_i^{receiver}(t-1)} + R_{AI}(t) & \text{if } \boxed{U(t)} < \eta \ (AI) \end{cases}$$

Airtime Fairness Rate

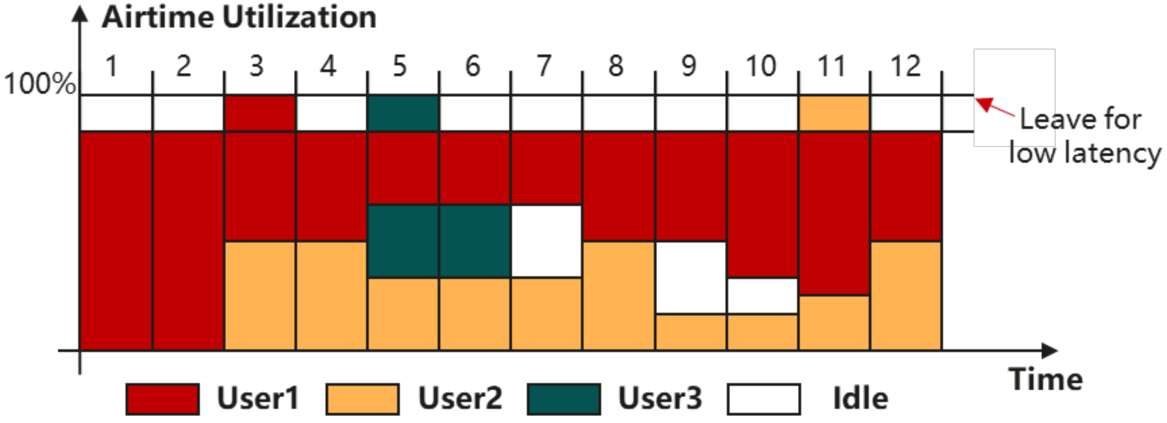
Airtime Utilization

Receiver Goodput

$$R_{AI}(t) = (\eta - U(t))\frac{\delta(C_i(t))}{N}$$

Increase by 1/N of idle Utilization

■ All users get an equal portion of the idle capacity



Example 1: a user finishes its traffic

Example 2: a user becomes app-limited

Cupid Rate Estimation: Steady State

■ Steday state： Airtime Fairness Rate

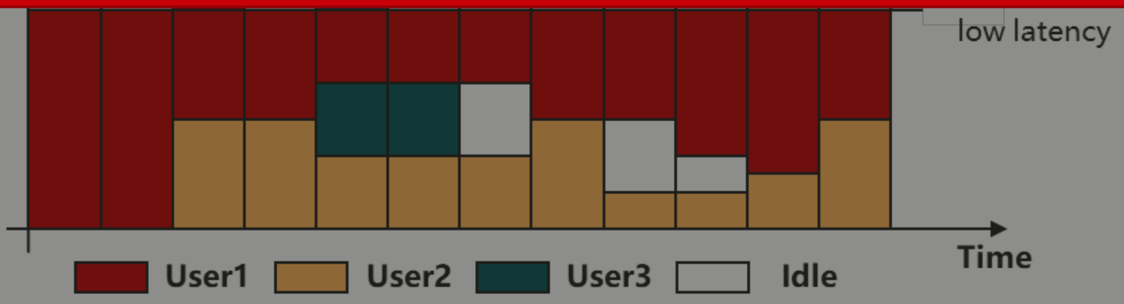
Airtime Fairness Rate

$$R_i(t) = \begin{cases} \boxed{\eta \frac{\delta(C_i(t))}{N}} & \text{if } U(t) \geq \eta \ (MD) \\ \boxed{R_i^{receiver}}(t-1) + R_{AI}(t) & \text{if } \boxed{U(t)} < \eta \ (AI) \end{cases}$$

$$R_{AI}(t) = (\eta - U(t))\frac{\delta(C_i(t))}{N}$$

Increase by 1/N of idle

Cupid **immediately detect emerging idle capacity**, inform senders to increase rate to grab an airtime fairness portion

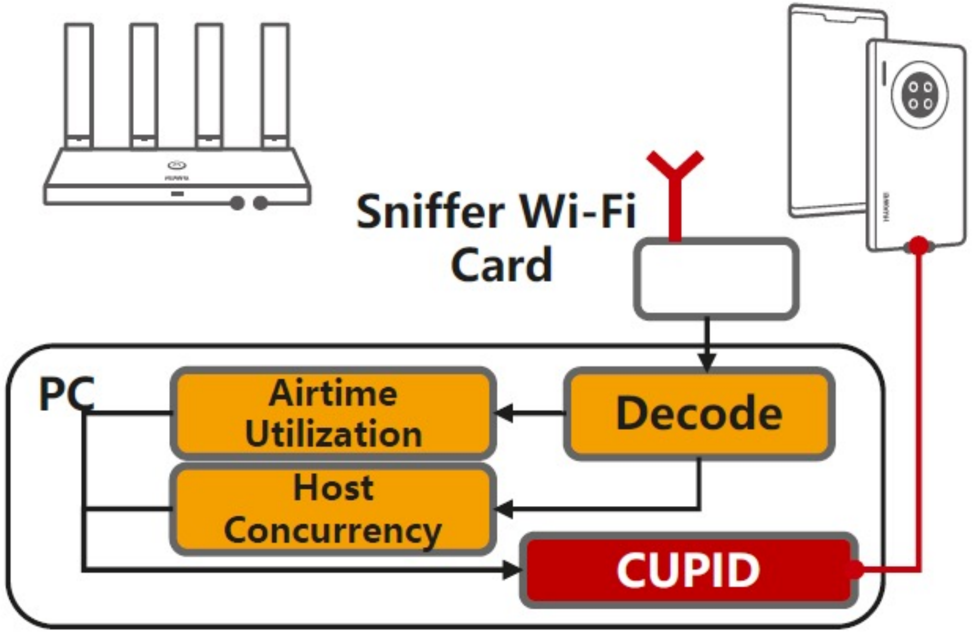


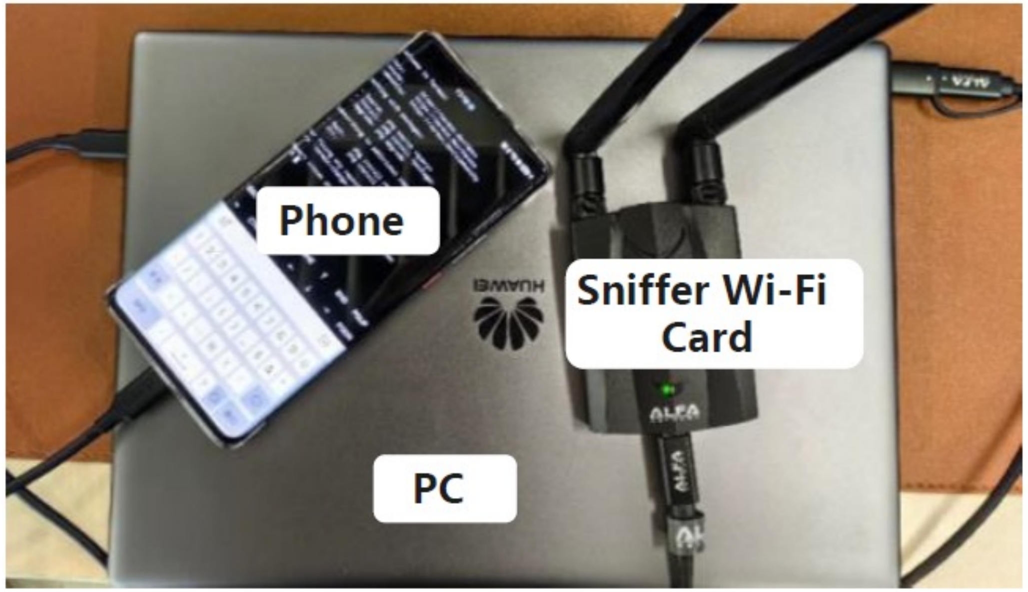
Example 1: a user finishes its traffic

Example 2: a user becomes app-limited

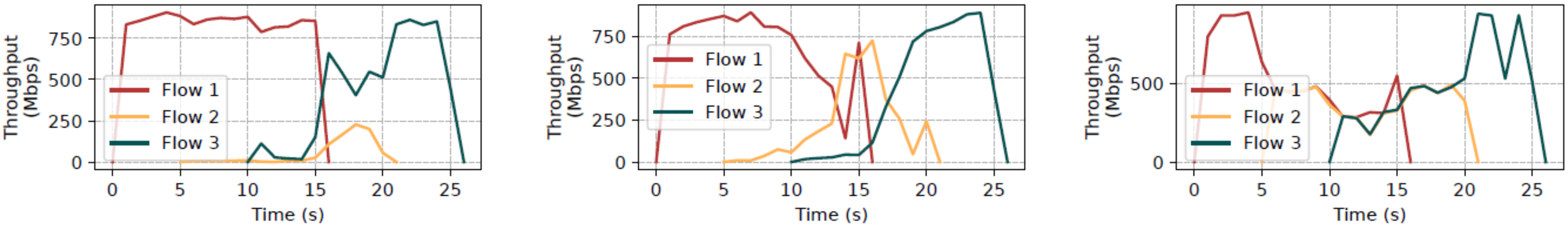
Cupid Implementation

- The client-side Cupid module receives measurements as input and communicates with the sender side through a commercial mobile phone connected to the host PC

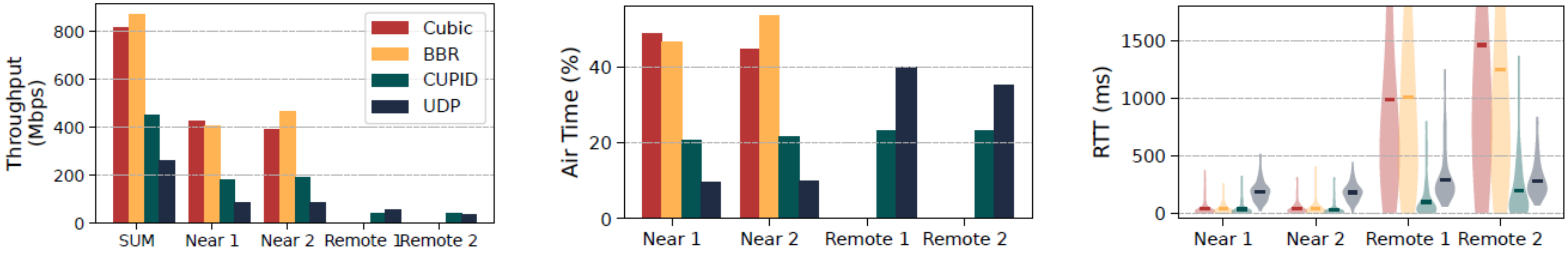




Result: Cupid Ensures Airtime Fairness across All Flows



(a) Cubic (b) BBR. (c) Cupid.



(a) Throughput. (b) Airtime utilization. (c) RTT.

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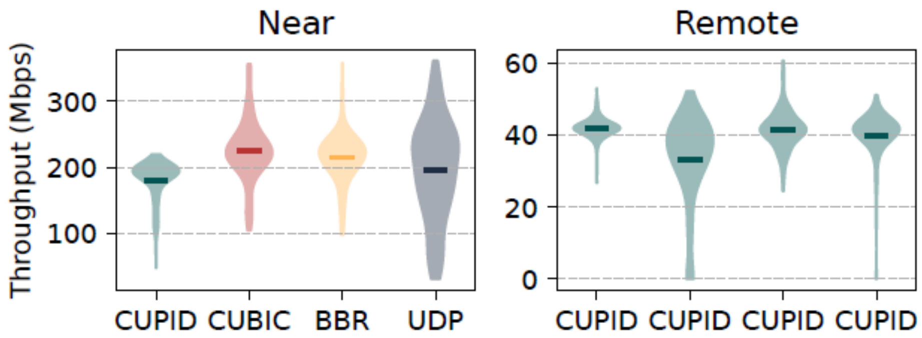
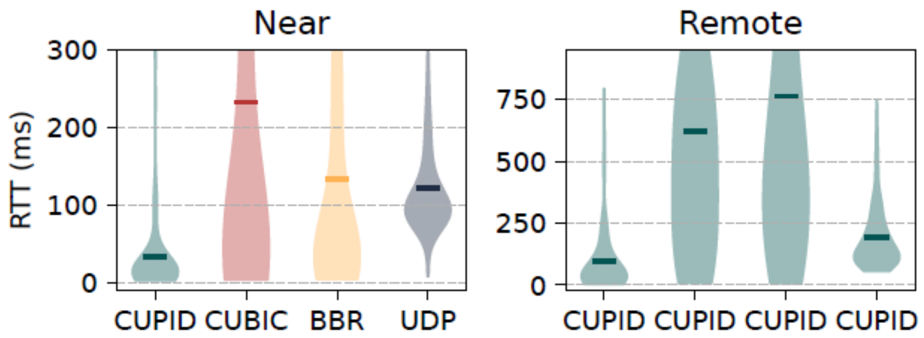
Result: Coexistence with others, Cupid also Ensures Fairness

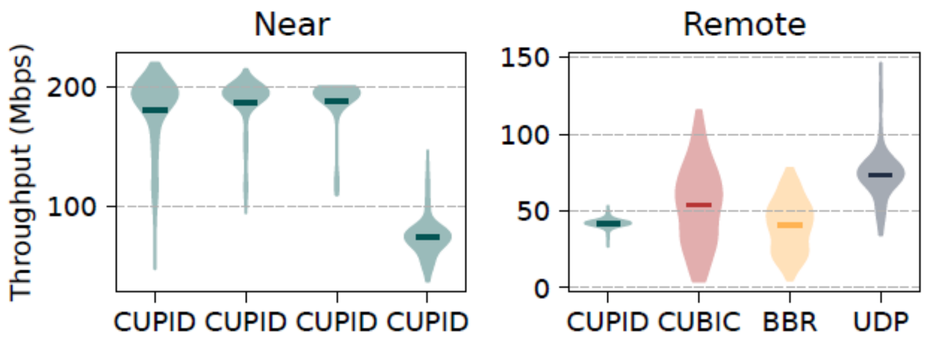


(a) Throughput comparison among the four smartphones.



(b) RTT comparison among the four smartphones.

Figure 8: Cupid results while all remote host use Cupid.



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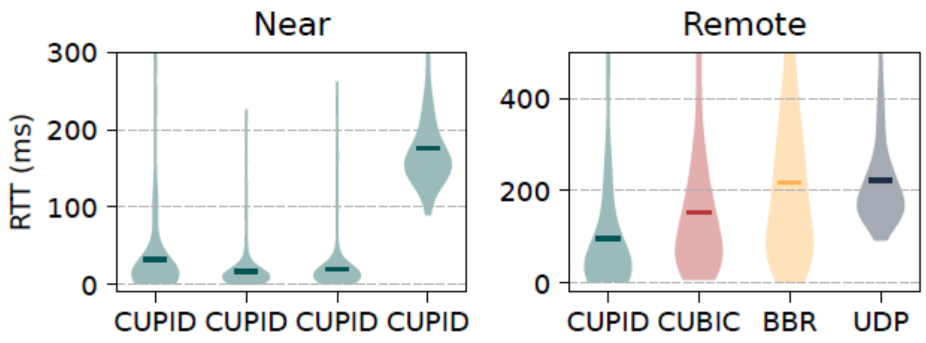

(b) RTT comparison among the four smartphones.

Figure 9: Cupid results while all near host use Cupid.

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Conclusion

- We demonstrates the **TCP victim problem** in WiFi networks, where traditional TCP cannot acquire bandwidth
- First e2e congestion control to **integrate mobile client-side WiFi physical layer measurement** into its design
  - Crucial for the WiFi victim problem
- Cupid effectively addresses the victim problem, improving victim throughput by up to **50 times**

Thank you.

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