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Mobile Access Bandwidth in Practice: Measurement, Analysis, and Implications

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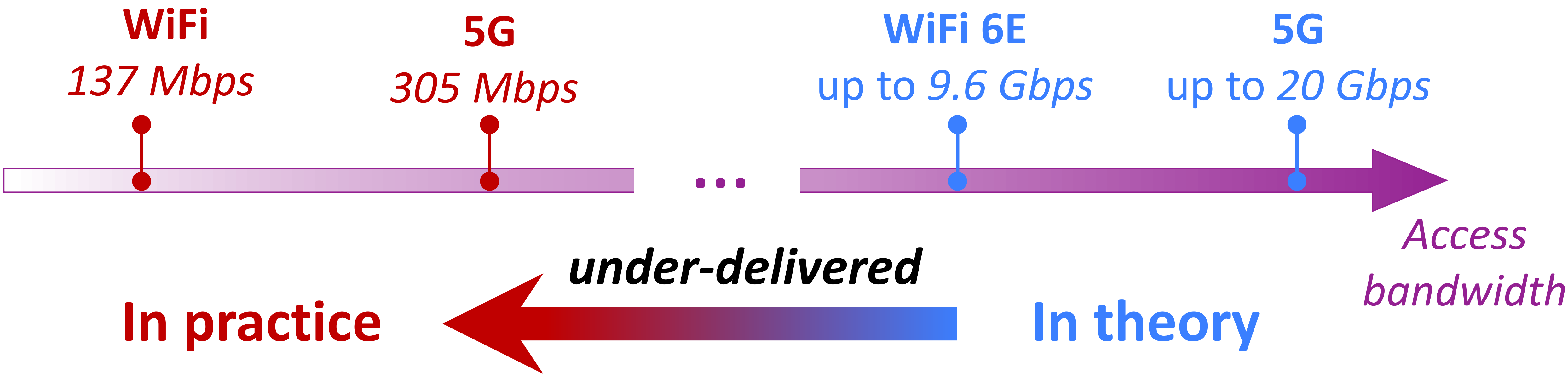
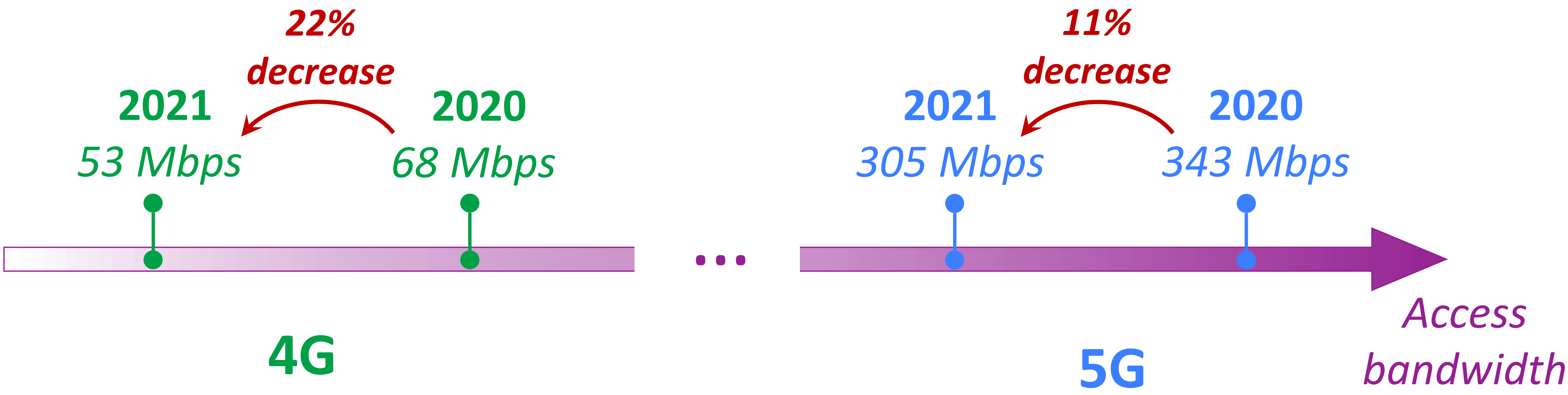
Mobile bandwidth is under-delivered in practice

- Public reports reveal that the median 5G and WiFi access bandwidths are **significantly lower** than the theoretical limits



Worse still, bandwidth has decreased in 2021

- Our measurement on 3.54M end users shows that the average access bandwidths of 4G/5G **decrease remarkably** from 2020 to 2021



What’s wrong with the current deployments and how can we deliver the theoretical promises?

Contribution

- APP-based **cross-layer and cross-technology measurement**

  - capture rich low-level diagnostic information at scale

- Revealing the **root causes** of undesirable access bandwidths

  - *radio resource migration from 4G to 5G*

  - *dense deployment of 5G base stations in crowded areas*

  - *WiFi bandwidth limited by wired networks*

- Swiftest: an **ultra-fast, ultra-light** bandwidth testing service (BTS)

  - *quick bandwidth probing with statistical guidance*

  - *test time around one second*

Opportunities

- UUSpeedTest, a major bandwidth testing service (BTS) in China
- An Android APP with **17M** users & **~0.2M** tests per day
- Nearly one-year collaboration between us and UUSpeedTest

  - large-scale measurement to help understand the root causes

23.6M Tests	**3.54M** End users	**2.04M** Base stations
4.47M WiFi APs	**191** Phone vendors	**2,381** Device models

Bandwidth testing method & analysis challenges

- Standard "**probing by flooding**" approach

  1. **PING test:** selecting test server(s)
  2. **Bandwidth probing:** transferring large file via HTTP
  3. **Bandwidth estimation:** sampling throughput statistics

- Testing results cannot support in-depth analysis

  *- **coarse-grained** results: bandwidth & latencies only (**web-based** design)*

  - though its customers are eager to learn the reasons

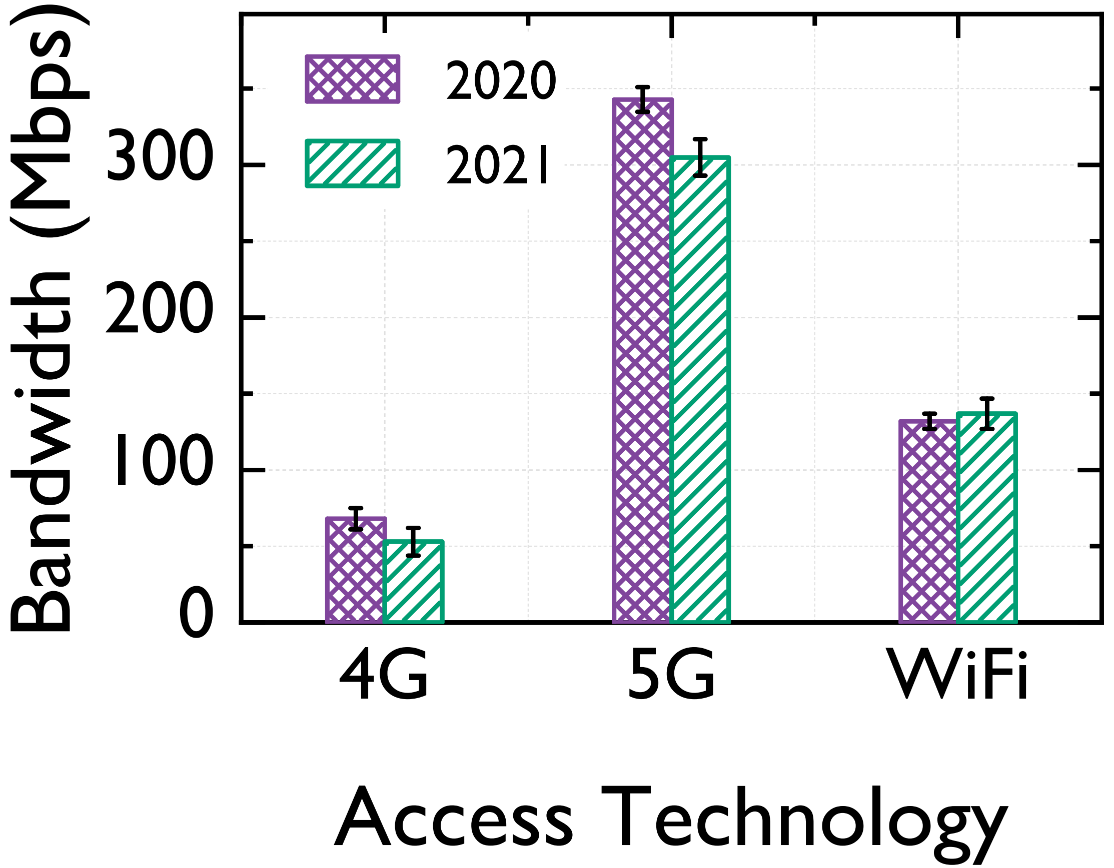
Cross-layer and cross-technology measurement

- **Web-based → APP-based**: **passively** and **selectively** collecting PHY- and MAC-layer information through standard Android APIs
- A lightweight plugin for UUSpeedTest with **no additional privileges** and **negligible CPU/memory overhead**

	4G	5G	WiFi
MAC layer	LTE band, Cell bandwidth, EARFCN code, ...	5G band, Cell bandwidth, NRARFCN code, ...	WiFi standard, Max TX/RX Linkspeed, Current Linkspeed, ...
PHY layer	Signal strength, SNR, RSSI, ...	Signal strength, SNR, RSSI, ...	WiFi RSSI, WiFi frequency, Channel width, ...

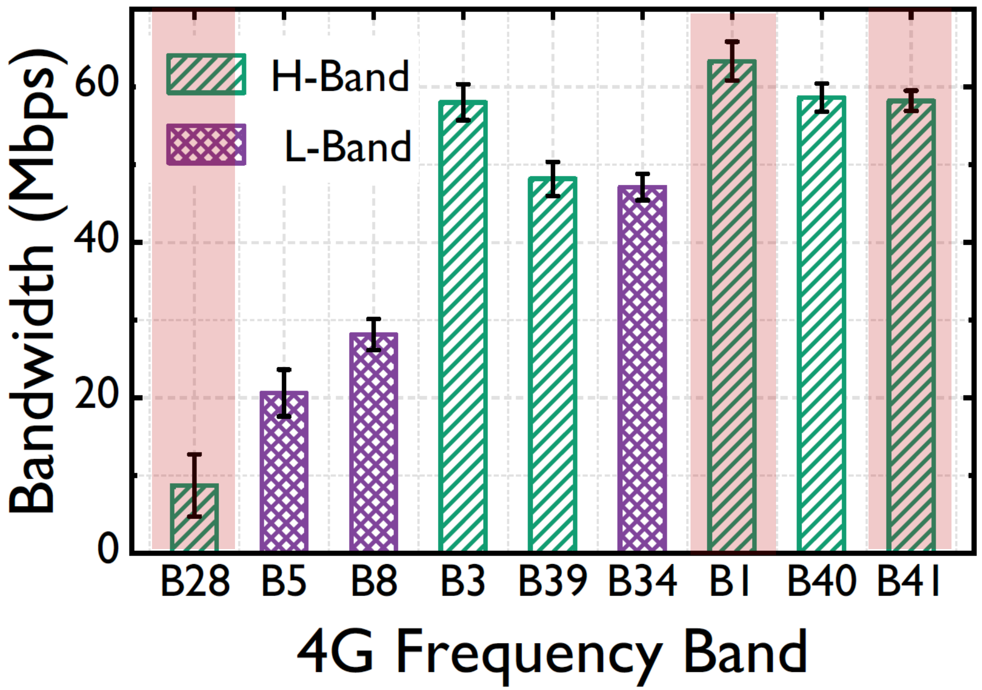
Our key finding

From 2020 to 2021, the average 4G/5G bandwidth **decreases by 22% and 11%**, while the average WiFi bandwidth **remains largely unchanged (3.6% increase)**



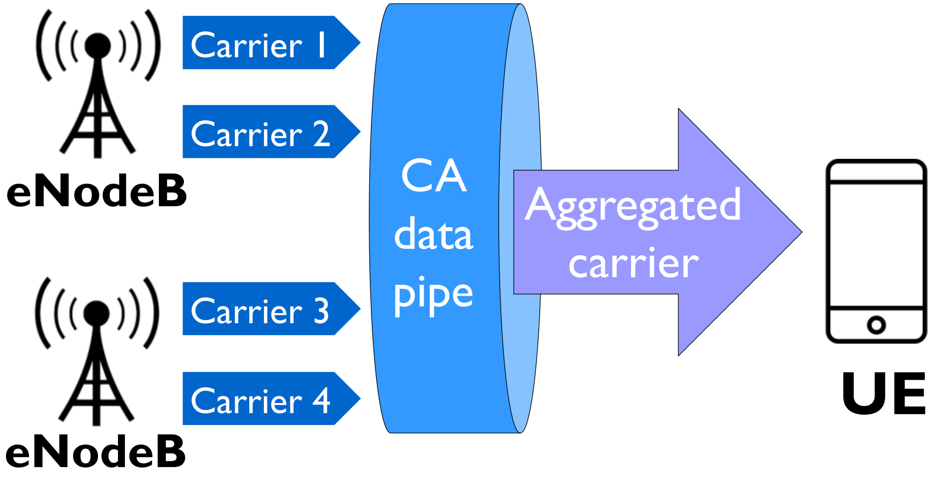
4G bandwidth decrease due to spectrum refarming

- Part of LTE Bands **B28, B1, B41** are **refarmed for 5G use**
- The original 4G workloads are **crowded in the remaining LTE bands**, leading to the decrease in 4G access bandwidth



Still some good news brought by LTE-Advanced

- **6.8%** LTE bandwidth test results **≥300 Mbps** (comparable to 5G)
- Benefit from LTE-Advanced key functionalities, *e.g.*, ***carrier aggregation (CA)***, *enhanced MIMO, Coordinated Multi-Point Tx/Rx (CoMP), relay nodes*
- Deployed **alongside urban main roads** to cope with large traffic volume



Carrier aggregation

LTE-Advanced base station

Spectrum refarming also decreases 5G bandwidth

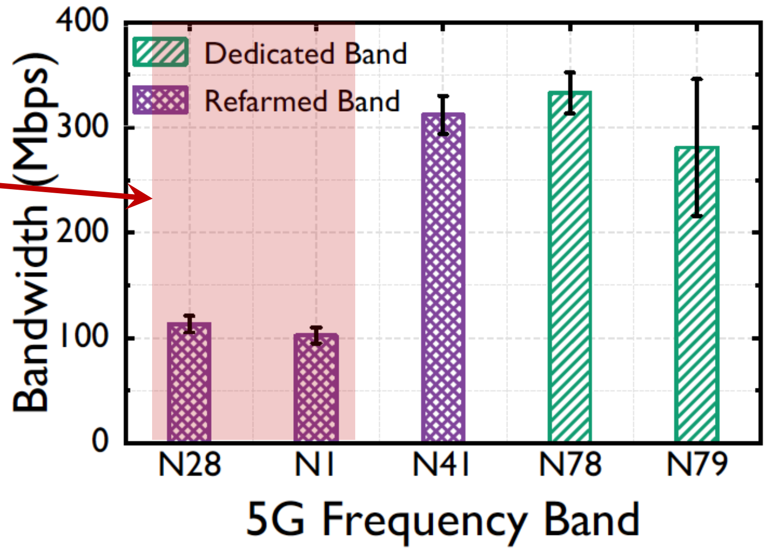
- **Fragmented spectrum resource** of refarmed 4G→5G bands (N28, N41)

→ **Low** max channel bandwidth

→ **Low** 5G access bandwidth

Band	DL Spectrum	Max Channel Bandwidth	ISPs
N28	758 – 803 MHz	20 MHz	ISP-4
N1	2110 – 2170 MHz	20 MHz	ISP-2, 3
N41	2496 – 2690 MHz	100 MHz	ISP-1
N78	3300 – 3800 MHz	100 MHz	ISP-2, 3
N79	4400 – 5000 MHz	100 MHz	ISP-1, 4

Dedicated Band   Refarmed Band



Carrier aggregation (CA) is not a panacea

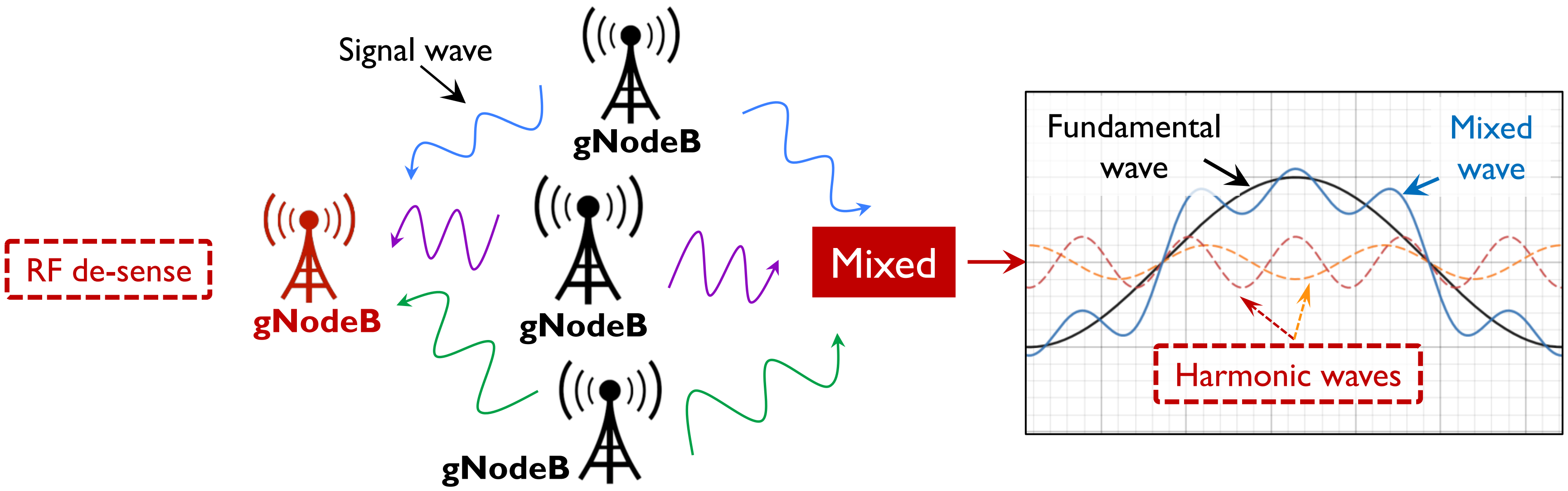
- Most 5G devices/base stations in China support **multiple** CA techniques

  - ***TDD-TDD CA*** *(2.6GHz + 4.9GHz) &* ***TDD-FDD CA*** *(700MHz + 2.6GHz or 2.1GHz + 3.5GHz)*

- Two-fold **realistic problems**

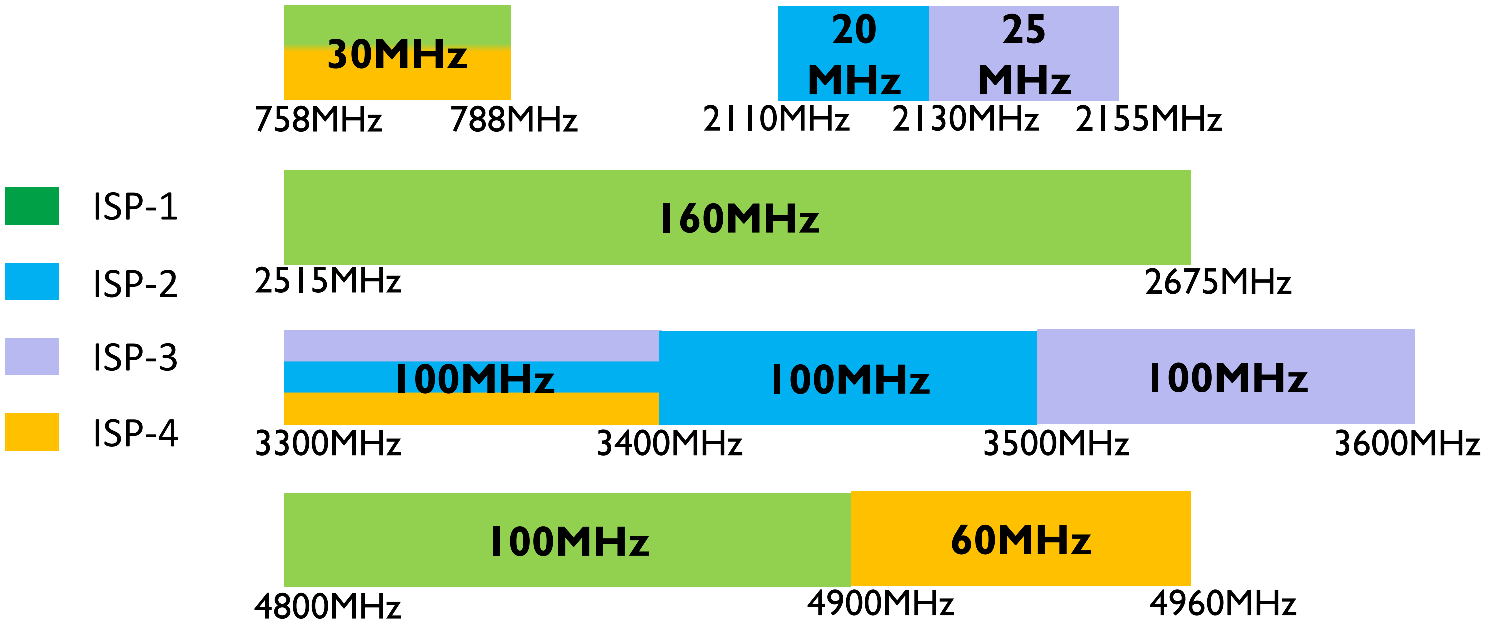
  - ***design difficulties:*** *harmonic disruption, RF de-sense, UE/BS energy consumption*

  - ***runtime overheads:*** *scheduling/power control info, CRC, UE feedbacks, L2/L3 signaling*



CA is more challenging in 5G

- Need to aggregate a number of carriers to support high bandwidth
- Number of the aggregated carriers should be small (≤16) for energy concerns

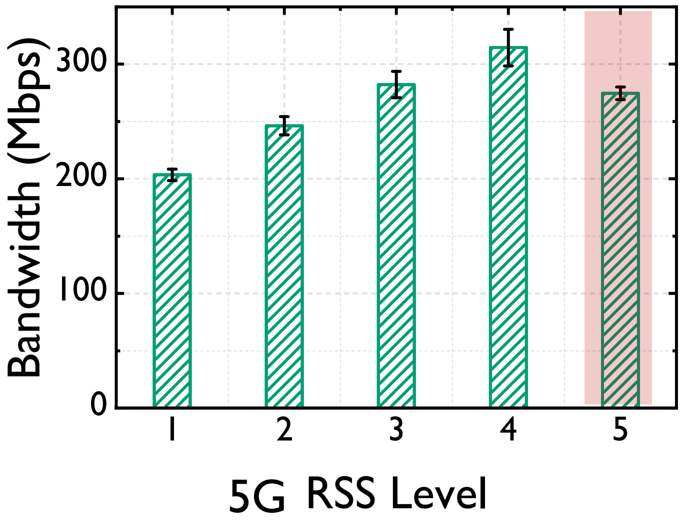


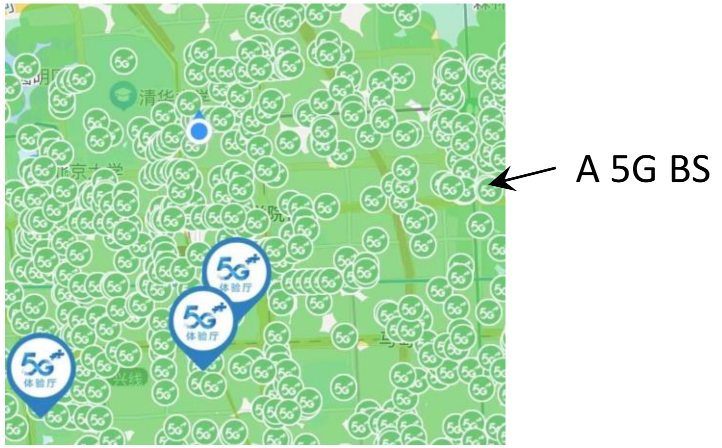
5G spectrum currently used by ISPs in China (downlink only)

Stronger RSS ≠ higher 5G access bandwidth

- Strong received signal strength (RSS) level does not necessarily translate into high 5G access bandwidth
- **Dense** deployment of 5G BSes in crowded urban areas

→ ***Cross-region coverage***, ***multi-path and co-channel interference***, ***load balancing issues***, and ***poor handover problems***

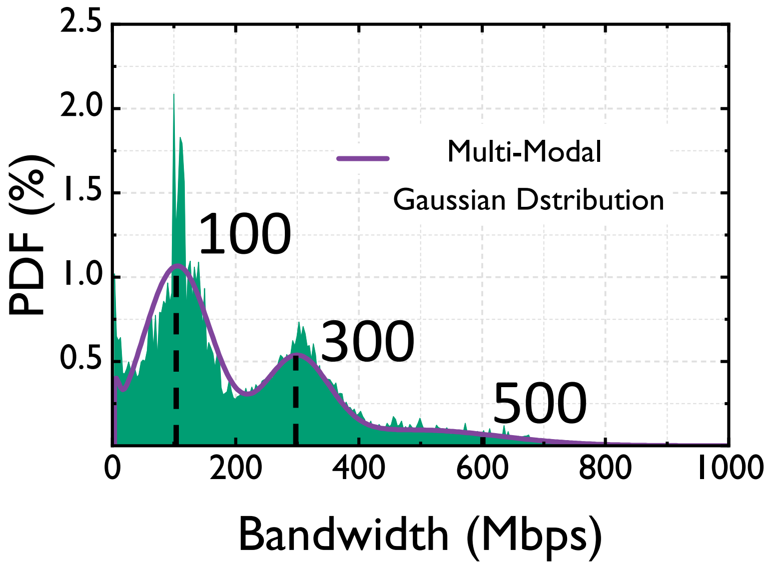




5G BSes around our campus

WiFi bandwidth is limited by wired access

- **132 Mbps (2020) → 137 Mbps (2021)**
- WiFi bandwidth tends to **cluster around certain 100x values,** which well match **ISPs' fixed broadband plans**
- **Around 64%** are using ≤200 Mbps fixed "broadband" Internet access



Bandwidth distribution of WiFi 5

Takeaways for different stakeholders

- **To ISPs and content providers**

  - adopt effective band defragmentation and refarming strategies

  - widen the deployment of the LTE-Advanced technology

  - consider new access technologies when budgeting network infrastructure

- **To common users**

  - be rational about ISPs’ and phone vendors’ 5G advertisement campaigns

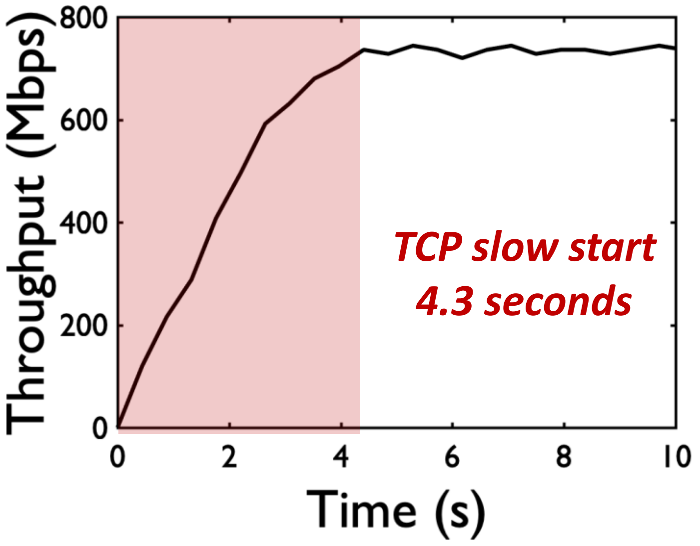
- **To BTS providers**

  - deep insights on mobile bandwidth can help greatly improve BTS design

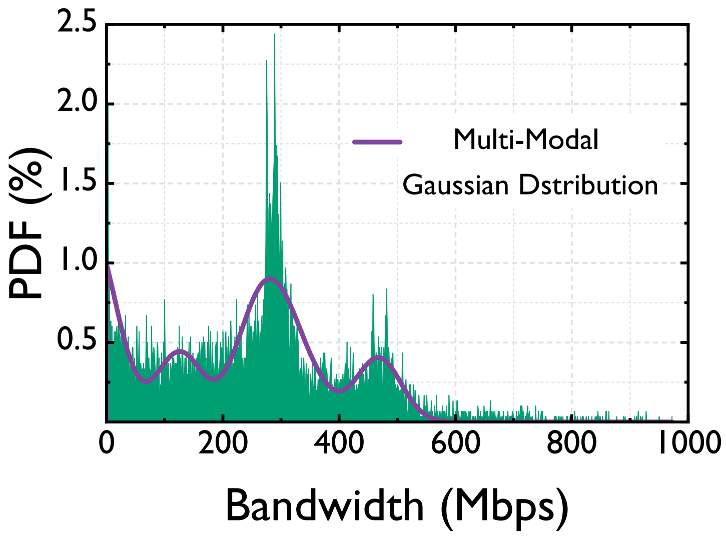
  - real-world implementation and deployment of an ultra-fast, ultra-light BTS

Observations from real-world measurements

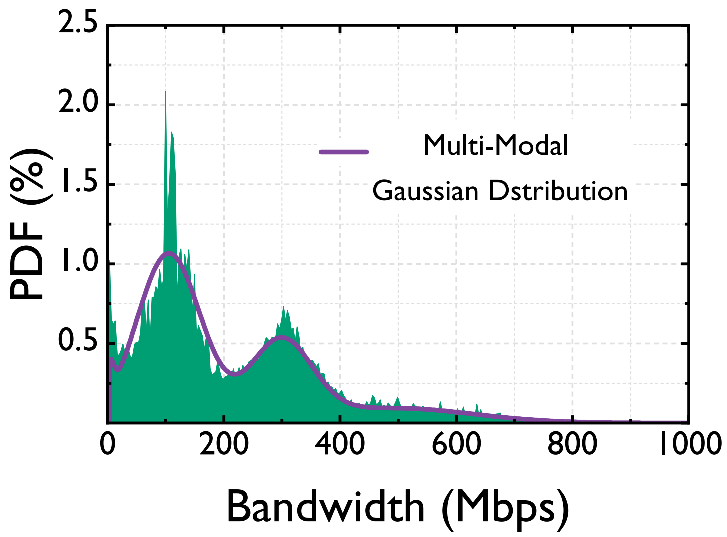
- TCP slow start **accounts for a long time** of bandwidth tests for high-speed networks, but **does not contribute useful bandwidth samples**
- Each access technology's bandwidth follows a **stable multi-modal Gaussian distribution (GMM model)**



A typical 5G bandwidth test



5G



WiFi 5

Bandwidth probing with statistical guidance

Lengthy, expensive calibration of initial probing bandwidth → **Swift, precise** probing guided by GMM models

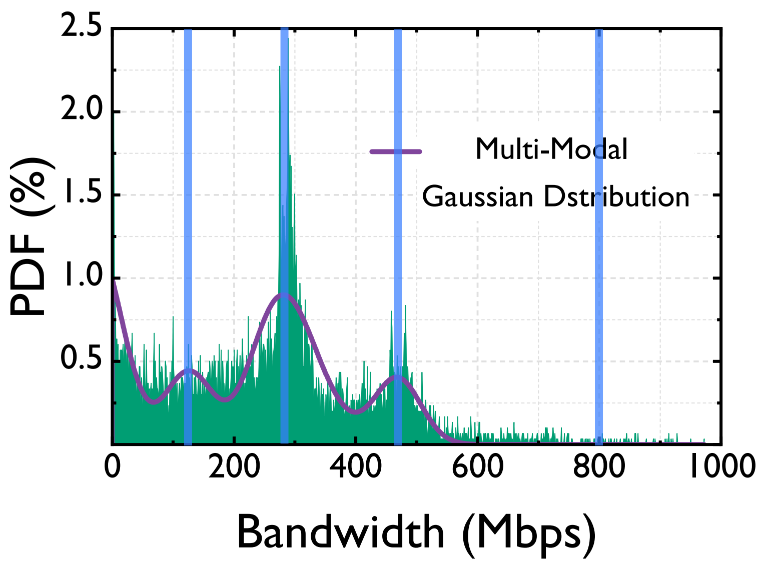
Key idea:

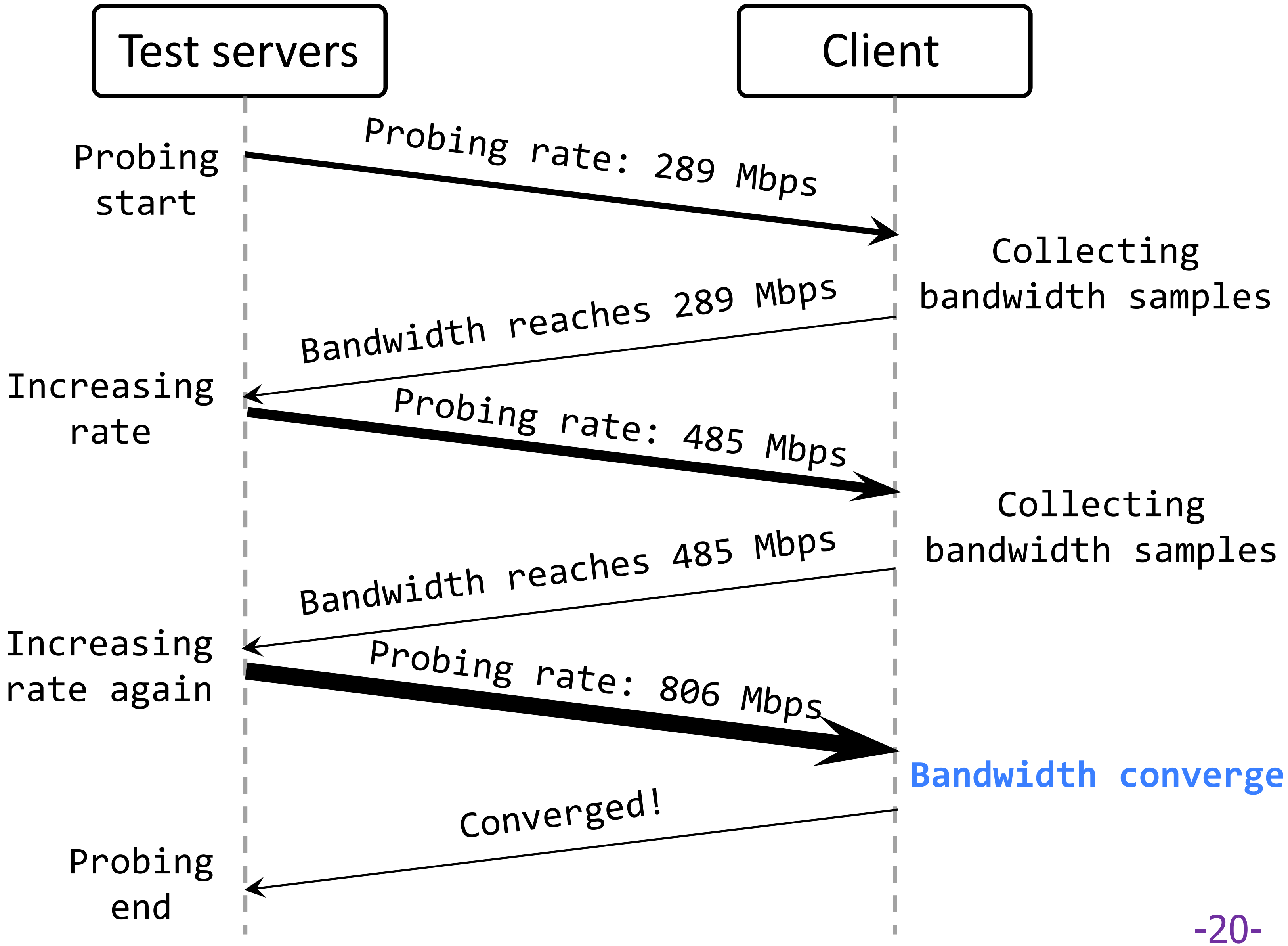
1. Use **the most probable bandwidth** in the GMM model to start up
2. **Fine-tune the probing rate** based on client feedback

An example of a 5G bandwidth test

"Modal" bandwidths for 5G

[172, 289, 485, 806] Mbps

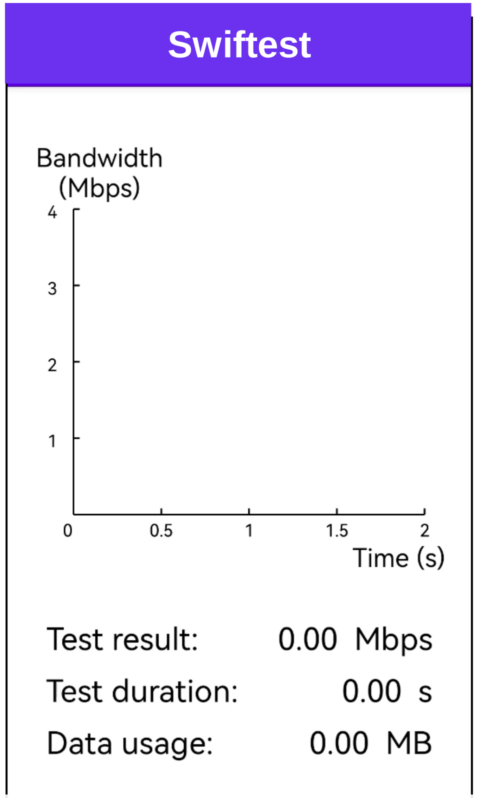




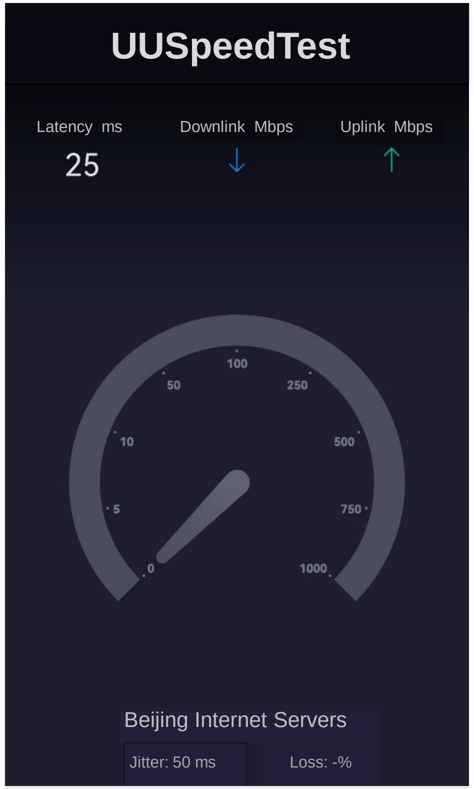
Swiftest: ultra-fast, ultra-light BTS

- 352 1-10Gbps servers (UUSpeedTest) → 20 100-Mbps servers (Swiftest)

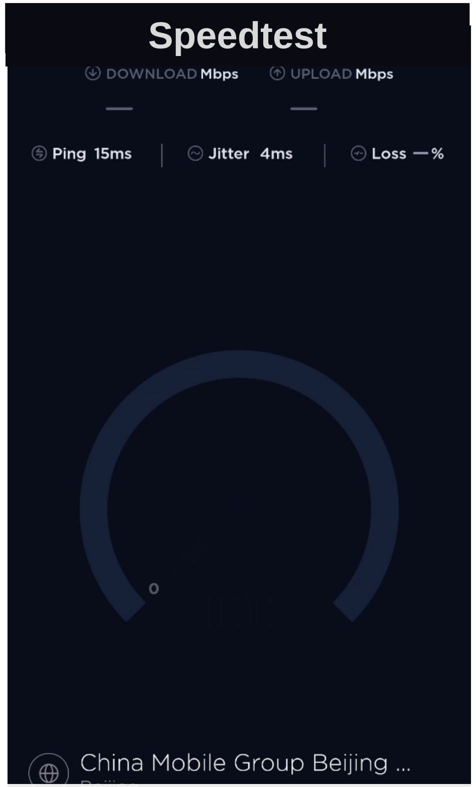
5G network, ~800 Mbps access bandwidth



Duration: 0.81 second
Result: 776 Mbps
Data usage: 69.8 MB



Duration: 10 seconds
Result: 792 Mbps
Data usage: 722.5 MB



Duration: 11.7 seconds
Result: 786 Mbps
Data usage: 1014 MB

Conclusion

Artifacts Evaluated Functional V1.1 · Artifacts Available V1.1 · Results Reproduced V1.1

- Deeply characterizing **3.54M** real-world users' mobile access bandwidth using **cross-layer and cross-technology measurement**
- Revealing the root causes of undesirable mobile access bandwidths
- Providing useful implications to ISPs, content providers, and users
- Building an ultra-fast, ultra-light approach to bandwidth testing service that can finish a test around one second
- https://mobilebandwidth.github.io/

link to artifacts