Characterizing and Improving WiFi Latency in Large-Scale Operational Networks

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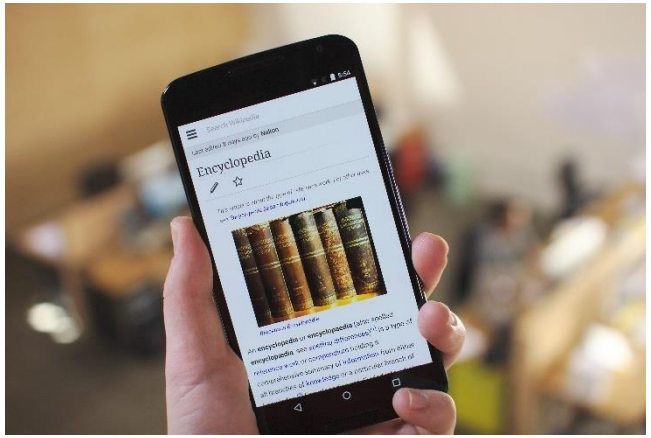
MobiSys 2016

Real-time and interactive mobile applications requires low **latency**

Instant messaging



Web browsing

Online gaming

Latency of mobile devices

WiFi latency is often unpredictable and occasionally high

Questions

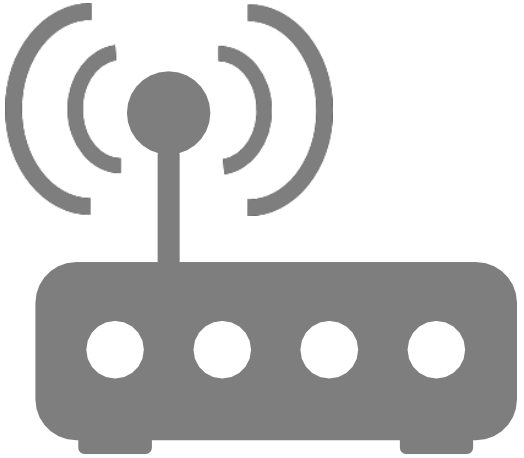
How is WiFi latency?

How related factors impact WiFi latency?

How to improve WiFi latency?

Mobile device

WiFi latency



Access point

WiFi hop latency can be a key bottleneck for latency-sensitive applications.

WiFiSeer

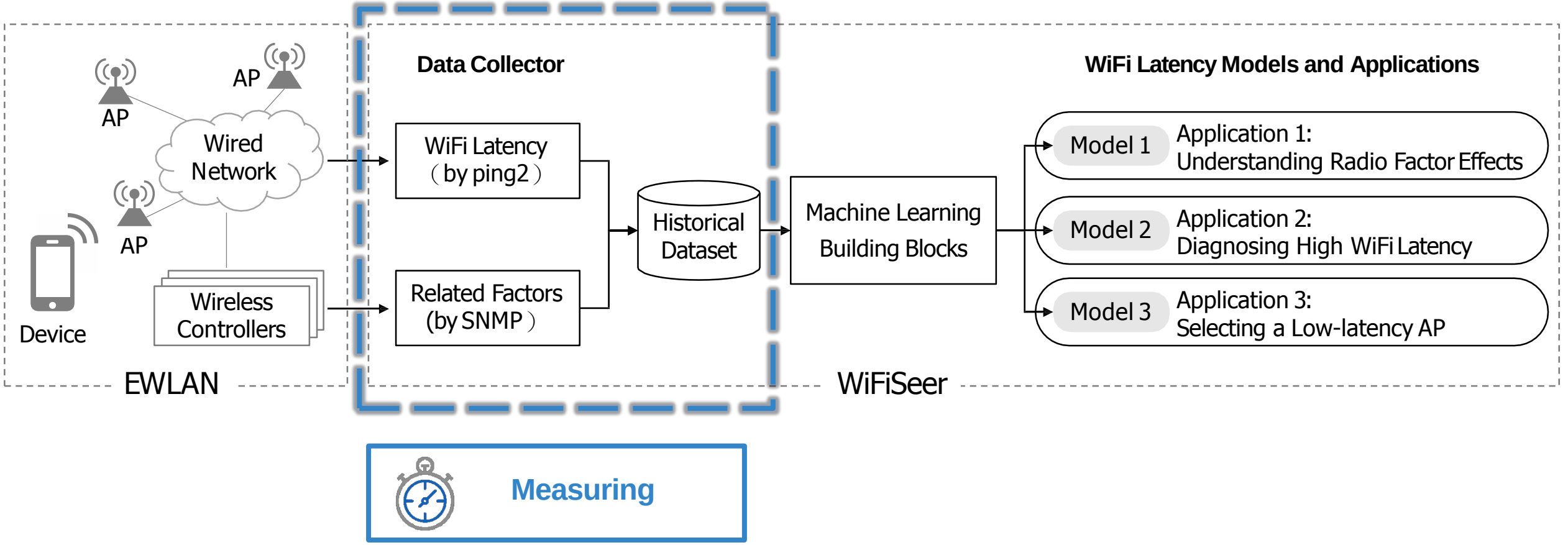
Measuring, Modeling, and Improving

WiFi latency

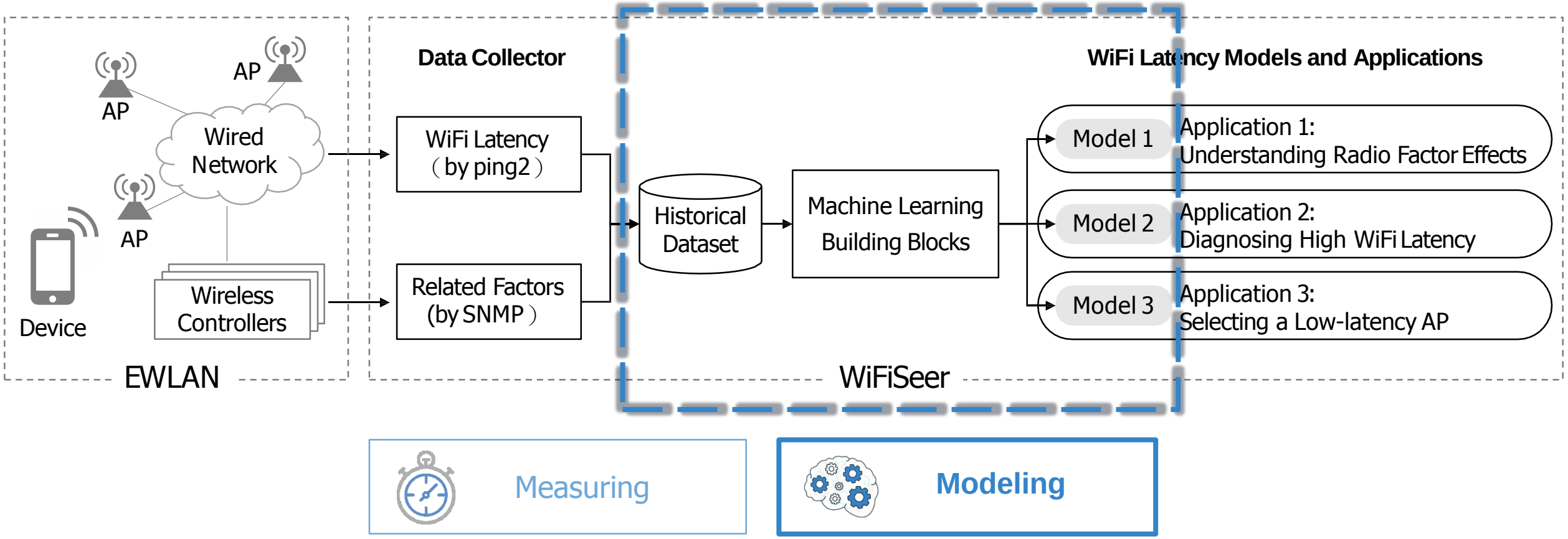
in Large-Scale Operational Networks

WiFiSeer Overview

WiFiSeer Overview



WiFiSeer Overview



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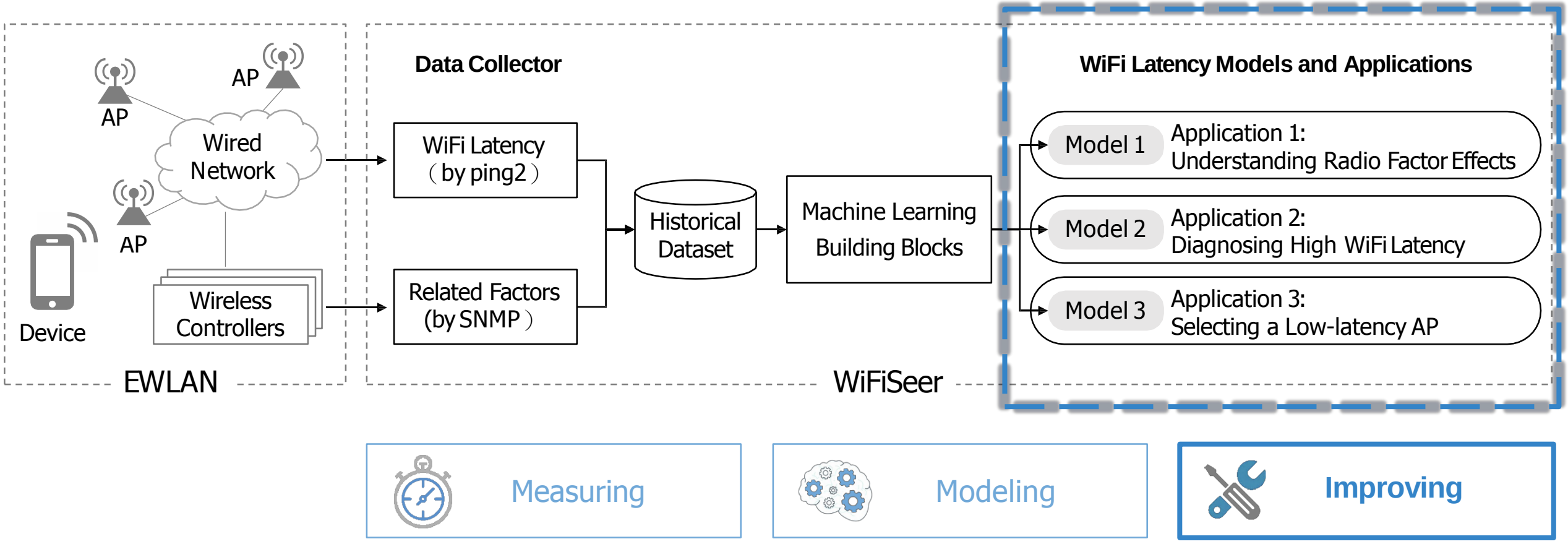

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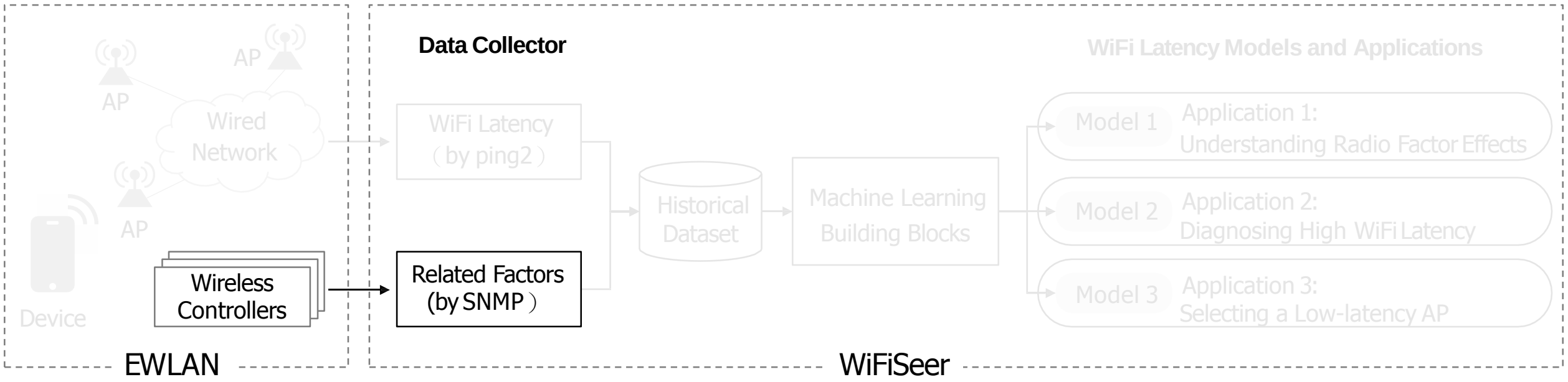
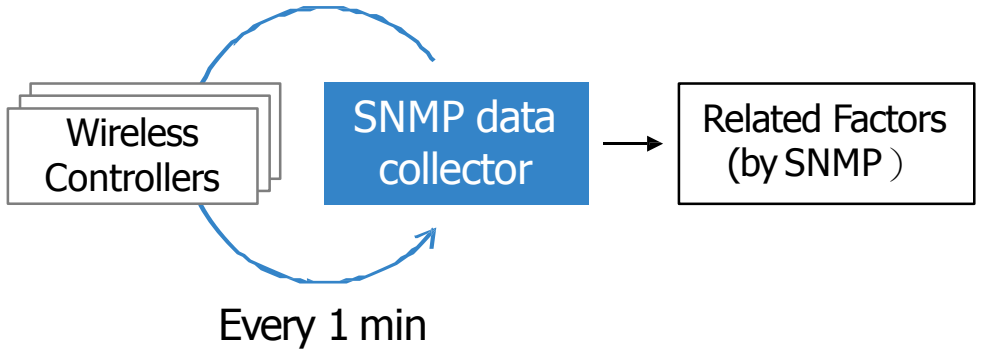


Measuring | Modeling | Improving

Measuring Related Factors



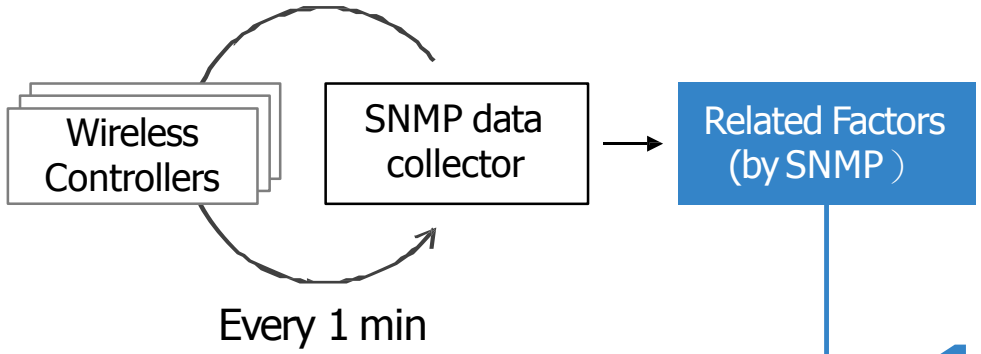
SNMP data

- Commonly used to monitor WiFi performance
- Readily available for enterprise WLAN

(AP) Access point

Wireless controller

Measuring Related Factors



11 Radio factors

- Channel utilization
- RSSI
- # of devices
- …

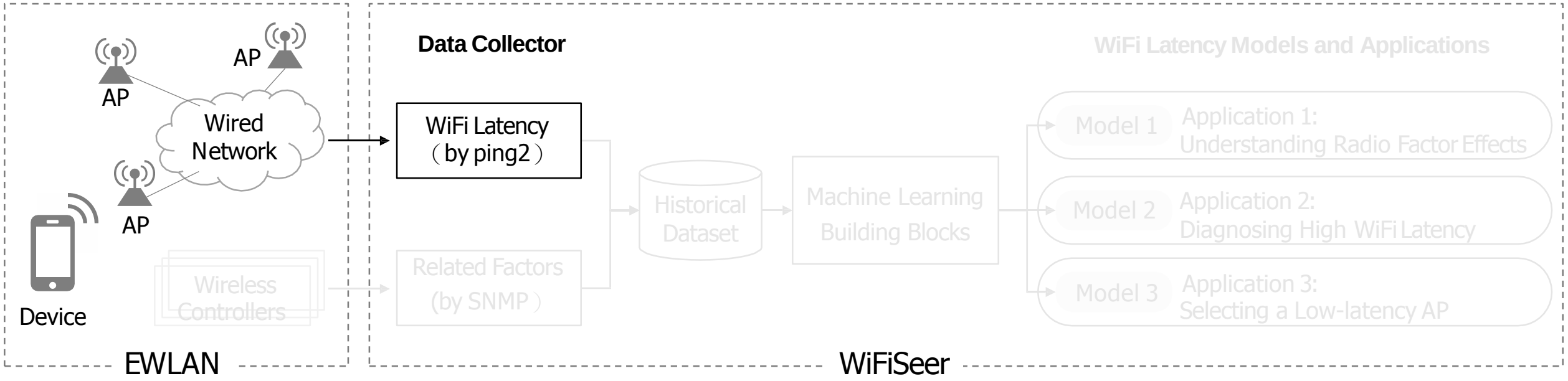
3 Protocol factors

- Channel number
- Band (2.4 GHz, 5 GHz)
- Protocol (802.11a, b, g, n, ac)

6 External factors

- Location
- Time of day
- WiFi chip manufacture
- …

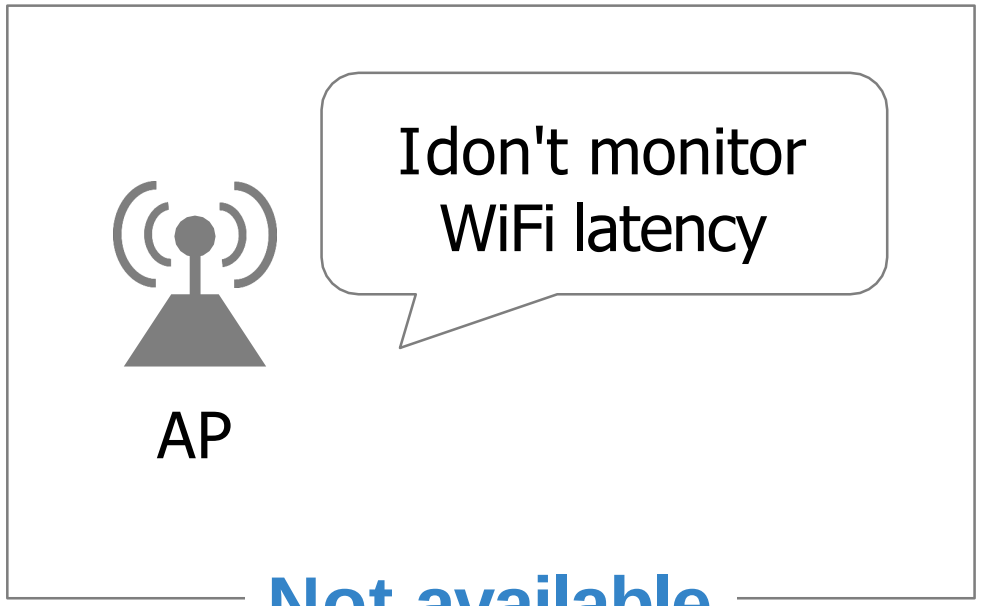
WiFiSeer Overview



Measuring | Modeling | Improving

Measuring WiFi Latency

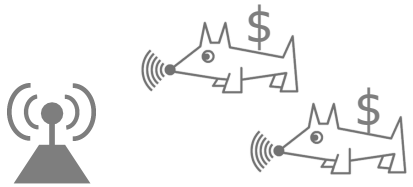
Challenges



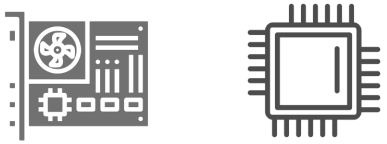
Measuring WiFi Latency

Challenges

Not available



Costly



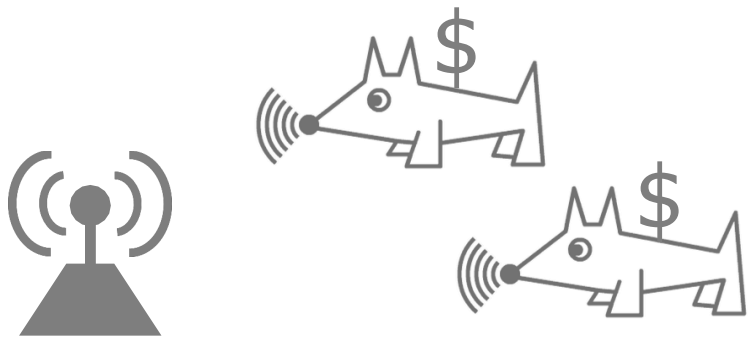
Deploy problems

Naïve ping inaccurate

Measuring WiFi Latency

Challenges

Not available



Costly

Jiasaw [1], Shaman [2], Wit [3]

Modify hardware or firmware

Deploy problems

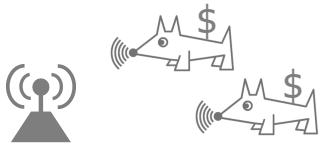
Energy saving mode

Naïve ping inaccurate

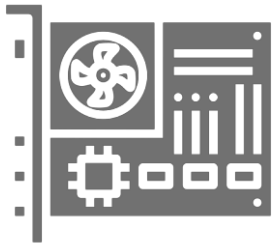
Measuring WiFi Latency

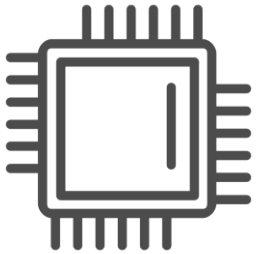
Challenges

Not available



Costly





Modify hardware or firmware

Deploy problems

PIE [4], WiSe [5], BISmark [6], WiLy [7]

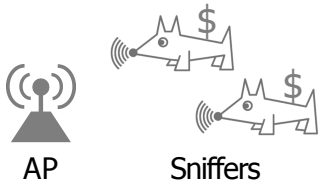
Energy saving mode

Naïve ping inaccurate

Measuring WiFi Latency

Challenges

Not available



Costly

Deploy problems

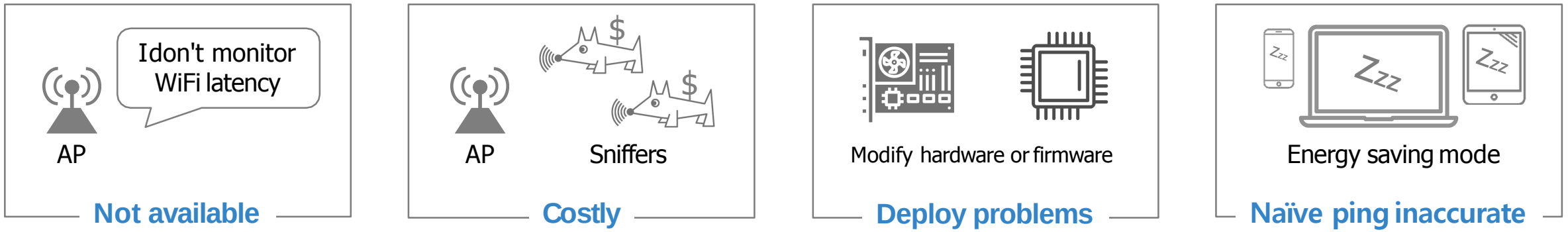
Energy saving mode

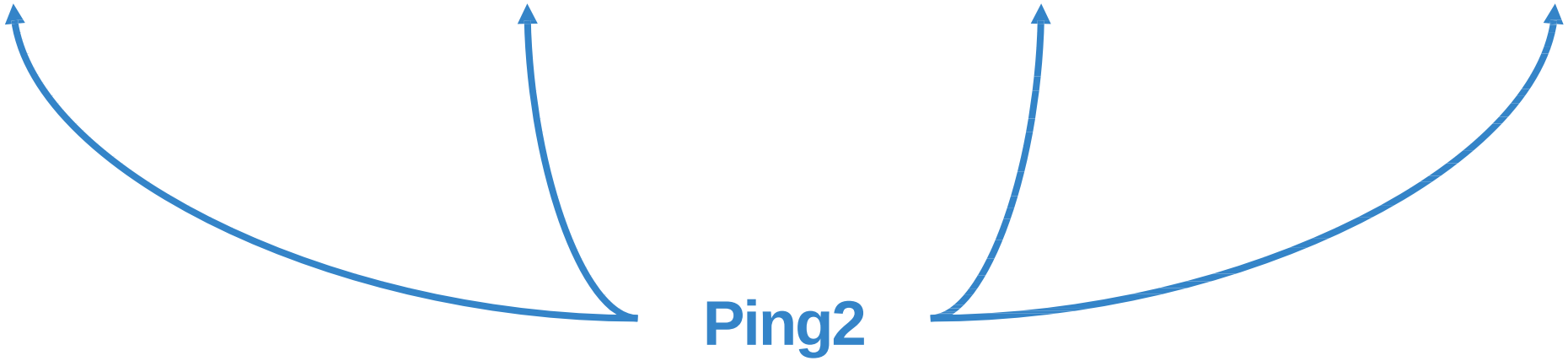
Naïve ping inaccurate

MobiPerf [8], SpeedTest [9]

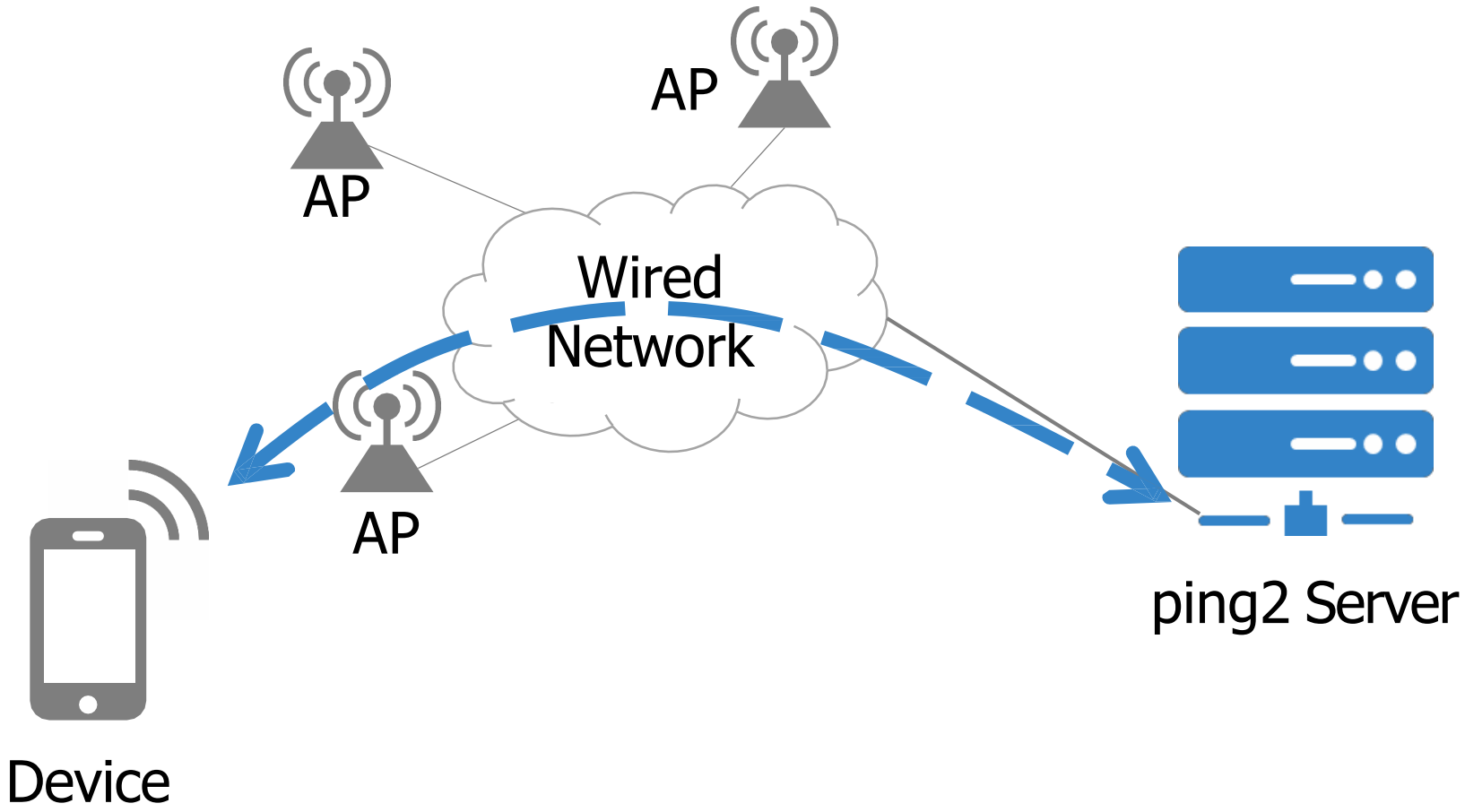
Measuring WiFi Latency

Challenges

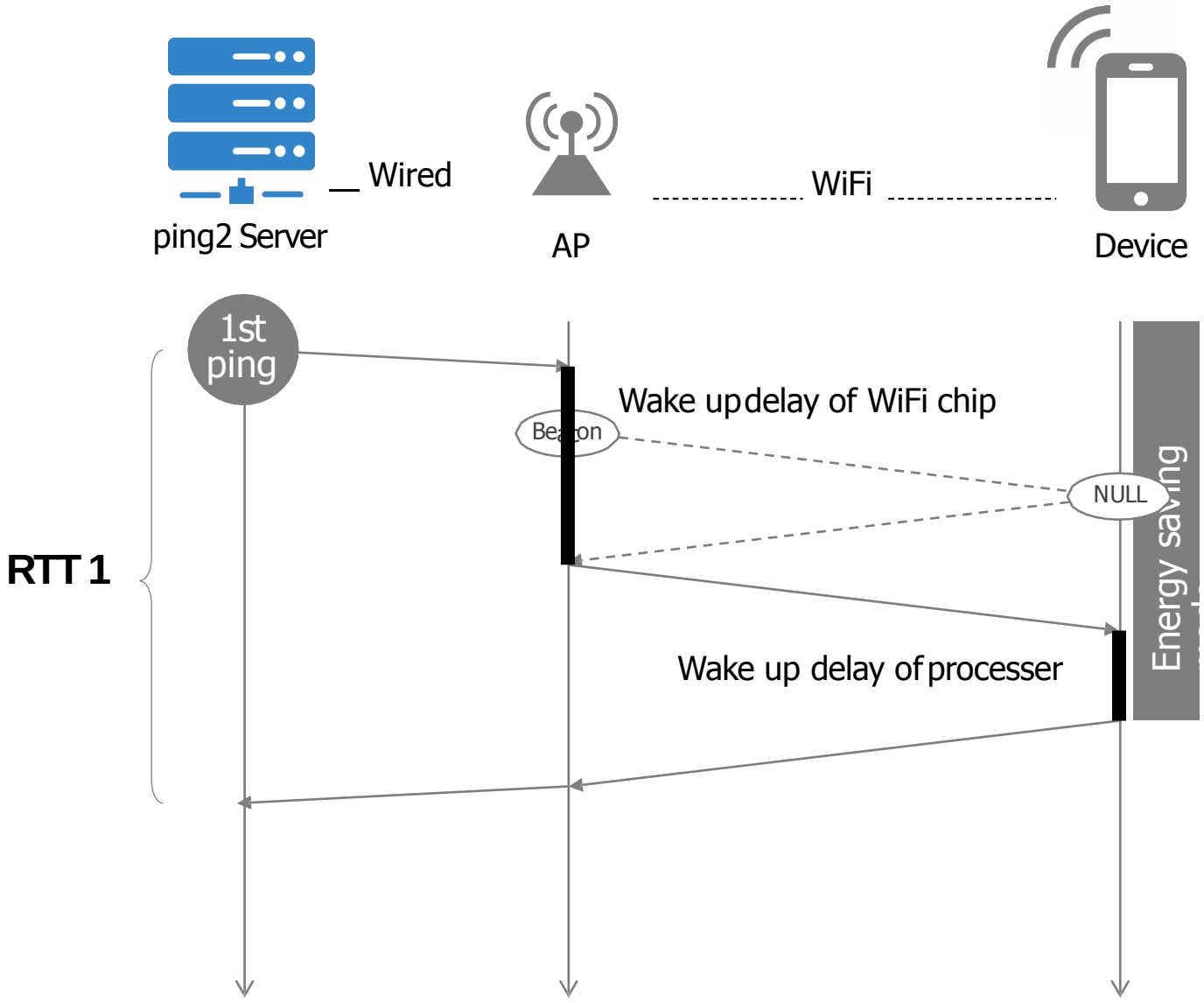




Key Ideas of ping2

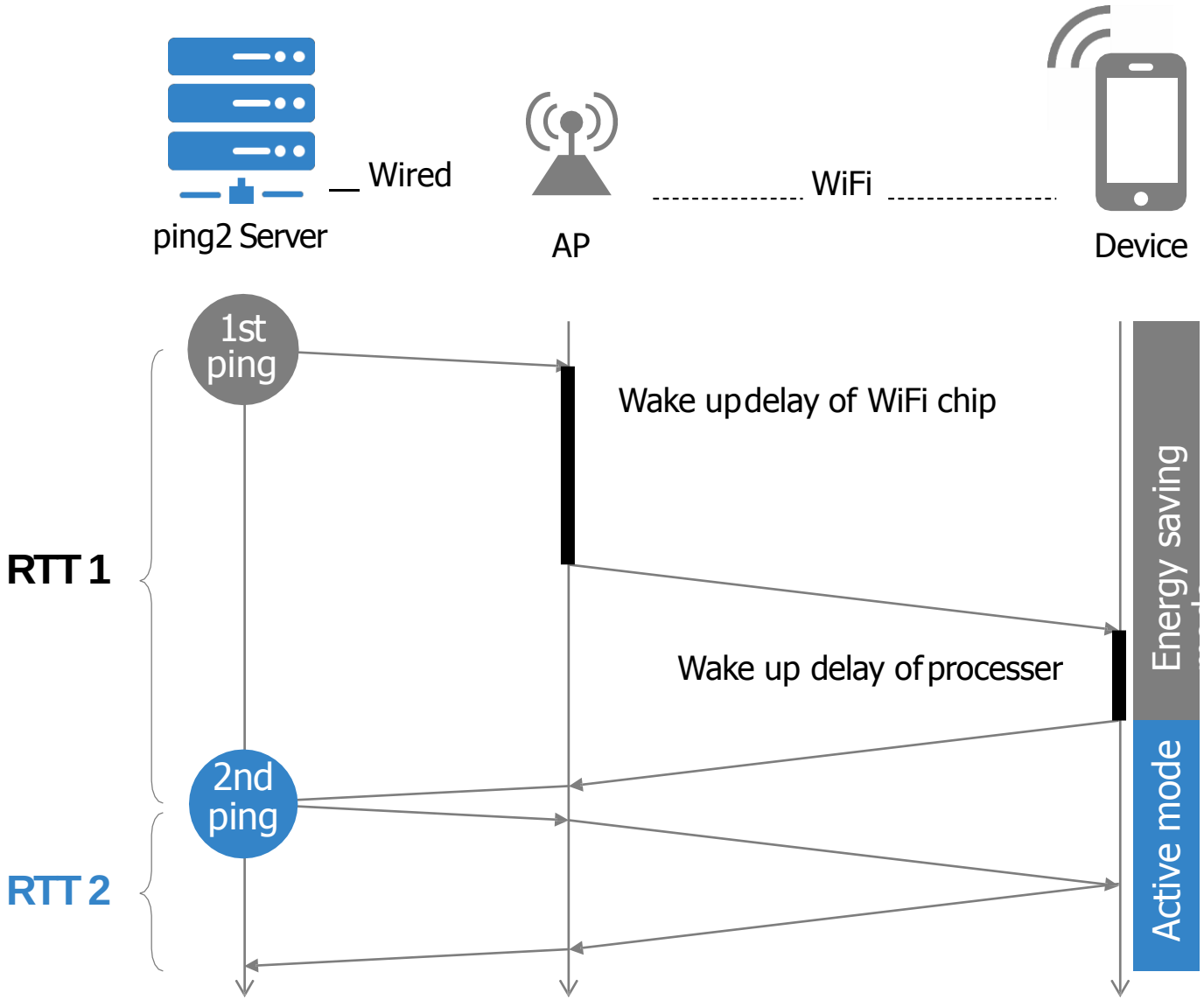


Key Ideas of ping2



Naïve ping RTT can be Inflated by the device energy saving mode

Key Ideas of ping2

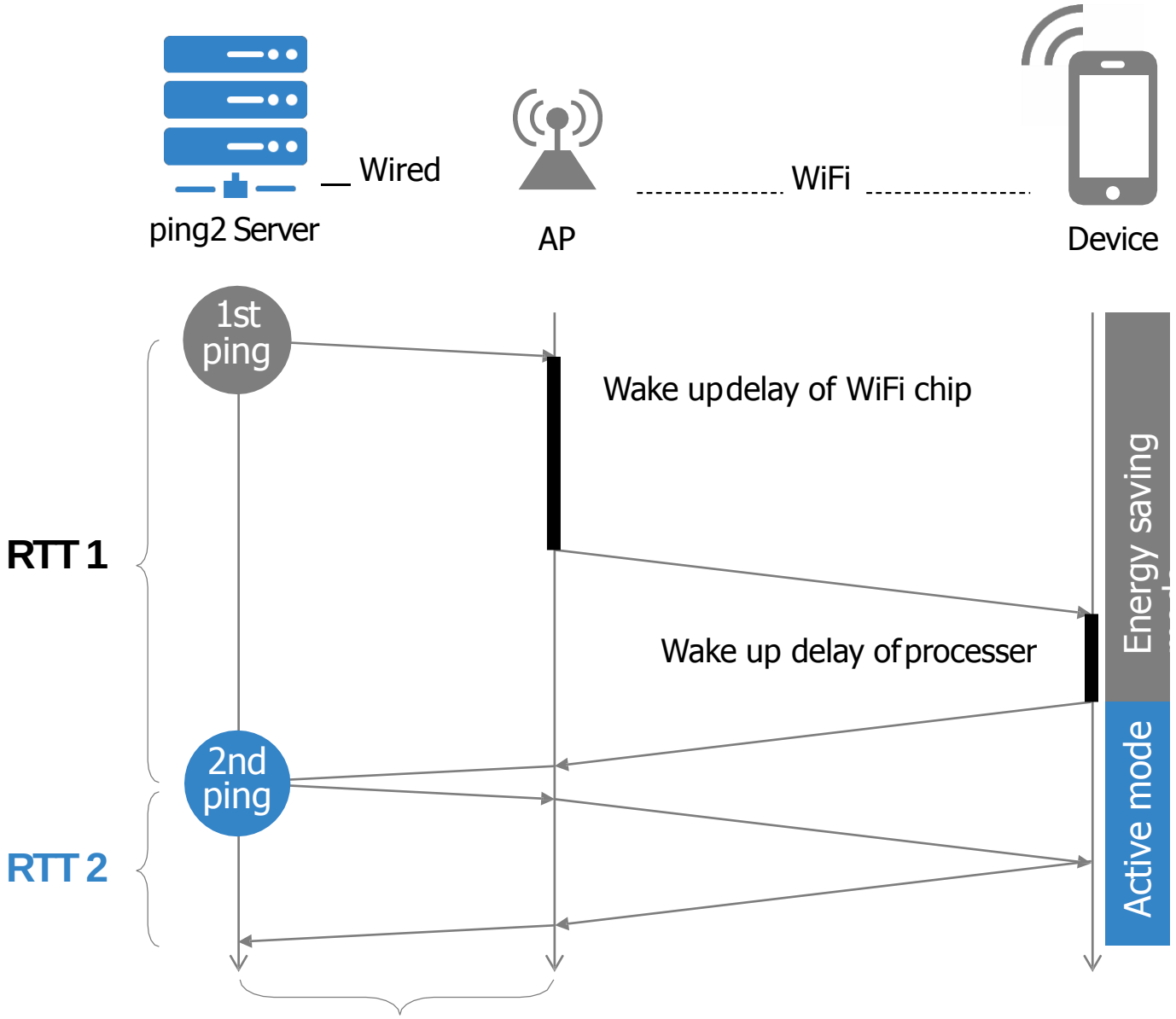


Naïve ping RTT can be Inflated by the device energy saving mode

Ping2 uses two consecutive pings

- **1st one to activate devices**
- **2nd one as WiFi latency**

Key Ideas of ping2



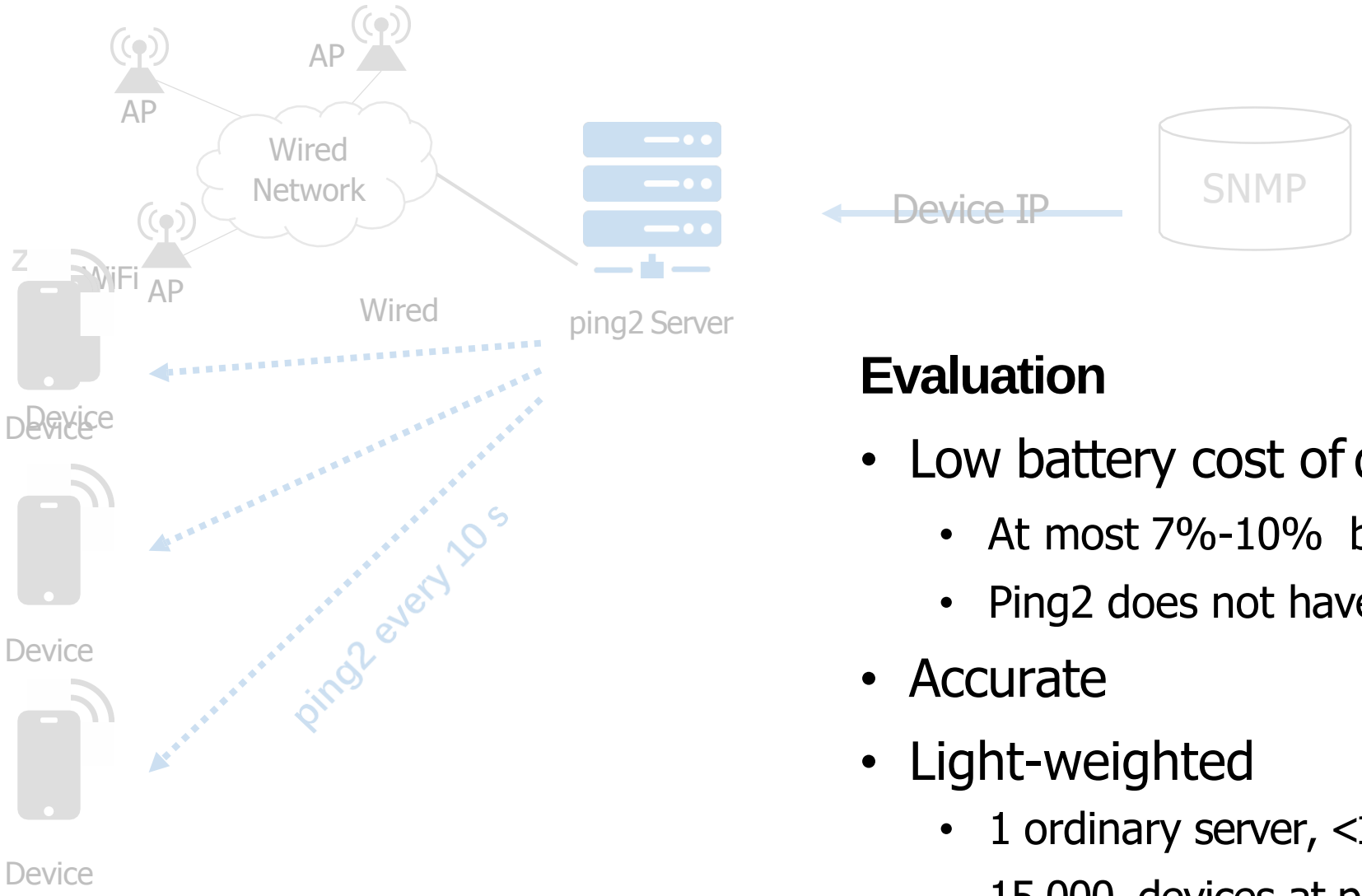
Naïve ping RTT can be Inflated by the device energy saving mode

Ping2 uses two consecutive pings

- **1st one to activate devices**
- **2nd one as WiFi latency**

Wired part latency is negligible. *e.g.* 99th ile < 1 ms in Tsinghua

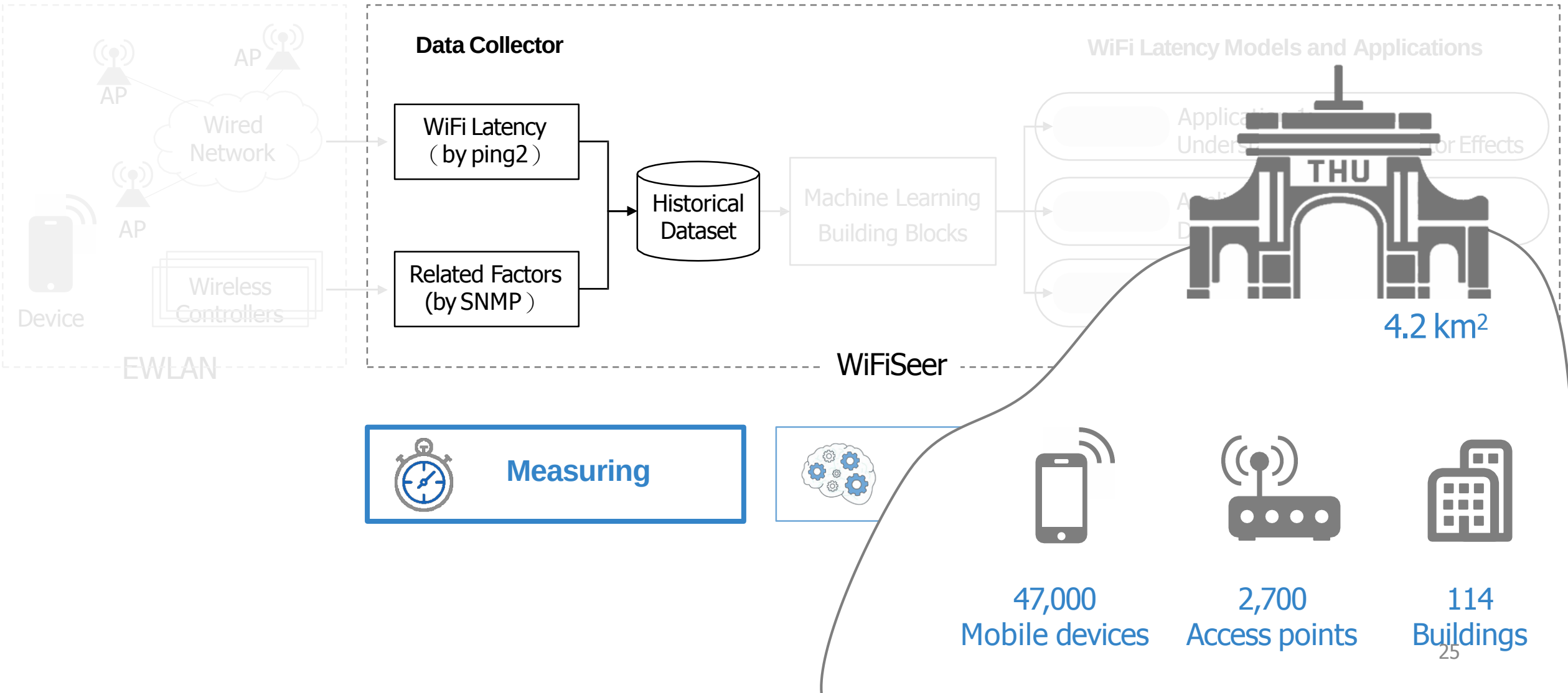
Key Ideas of ping2



Evaluation

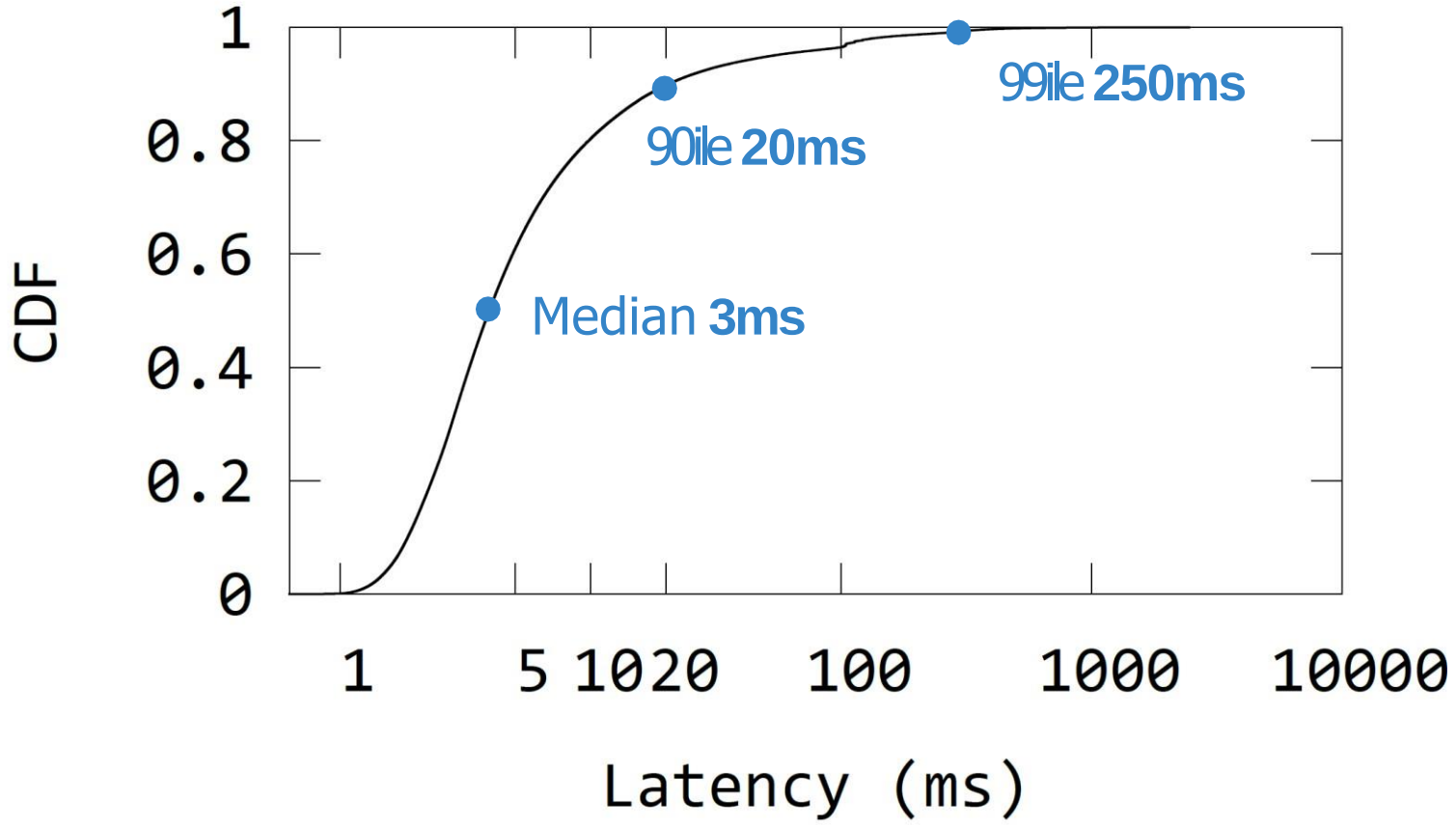
- Low battery cost of devices
  - At most 7%-10% battery for 24-hour tests
  - Ping2 does not have to always run!
- Accurate
- Light-weighted
  - 1 ordinary server, <10% utilization, for 15,000 devices at peak hour

WiFiSeer Overview



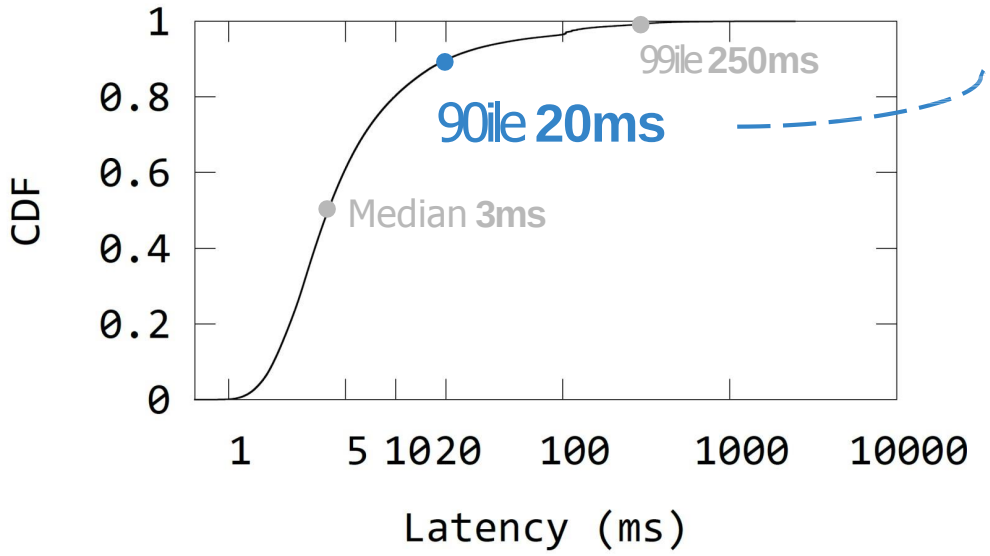
WiFi Latency in the Wild

Long-tailed distribution of WiFi latency



WiFi Latency in the Wild **NOT good enough**

Long-tailed distribution of WiFi latency



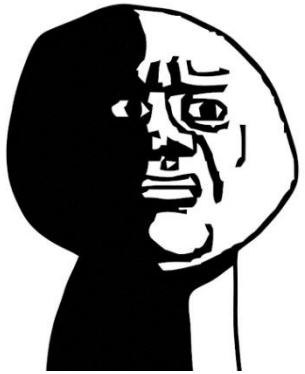
20 ms last-mile latency

[1] S. Sundaresan et al., IMC 2013

3 seconds of web page load time

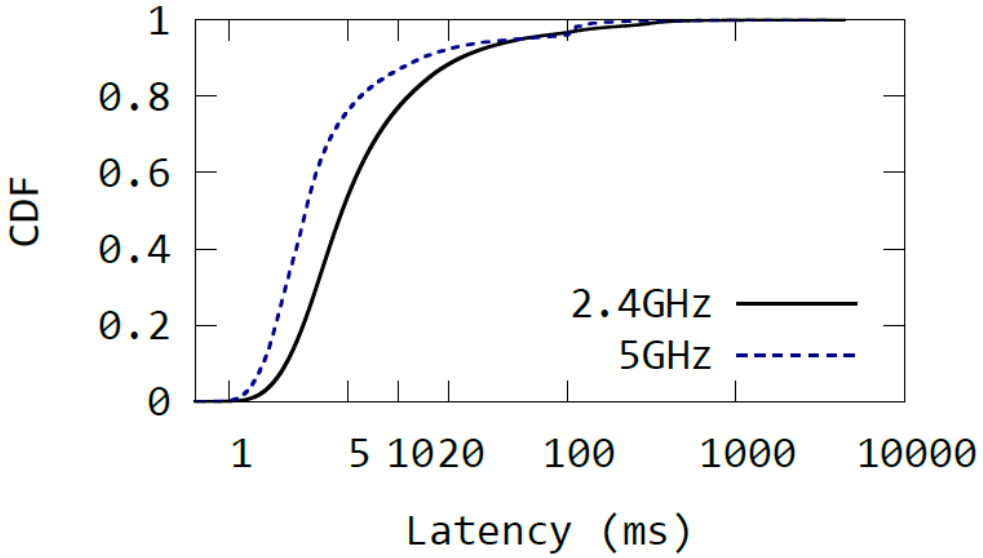
[2] JetNEXUS, Report

Slower than **47%** of users' expectation

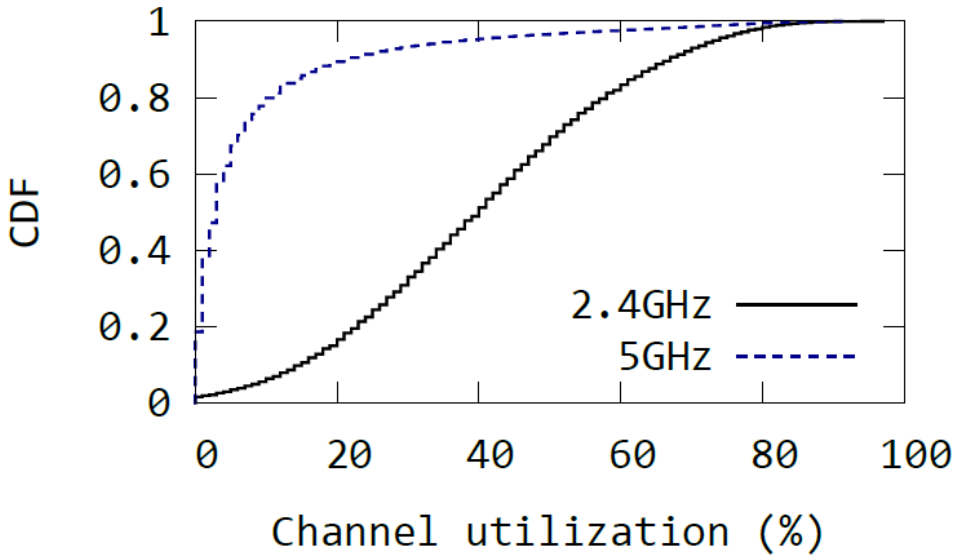


WiFi Latency in the Wild

5 GHz has lower latency than 2.4GHz



Over-utilized 2.4 GHz



WiFi Latency in the Wild

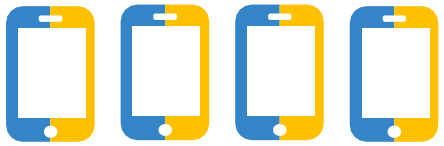
Add 5 GHz only SSID "Tsinghua-5G"

User

I will use 5 GHz!

Solution

No, we want to use 2.4 GHz



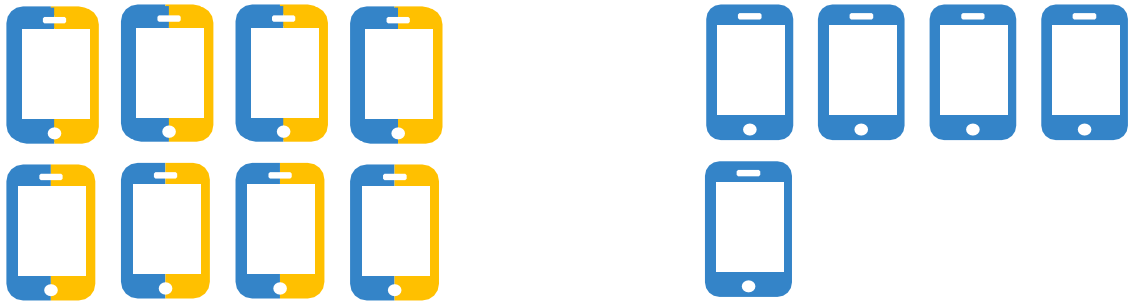
Devices

(See the paper)

But in Tsinghua

1

Dual-band devices **1.6×** 2.4 GHz only devices



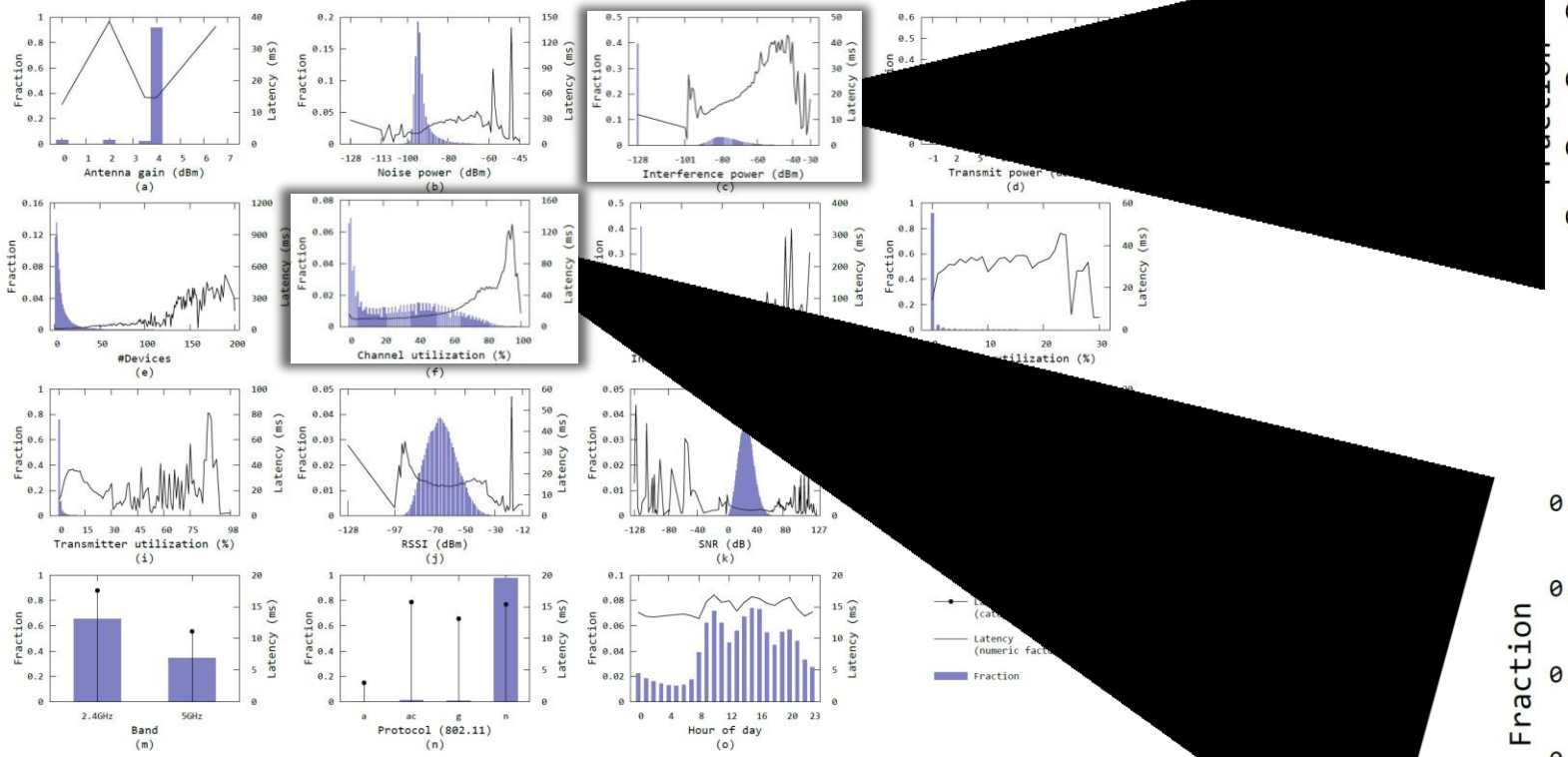
2 **Cisco band steering is used**

Please connect to 5GHz if you can

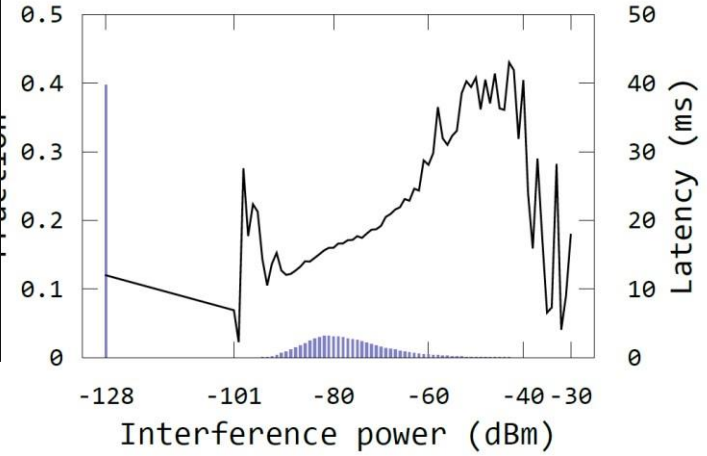
AP

WiFi Latency in the Wild

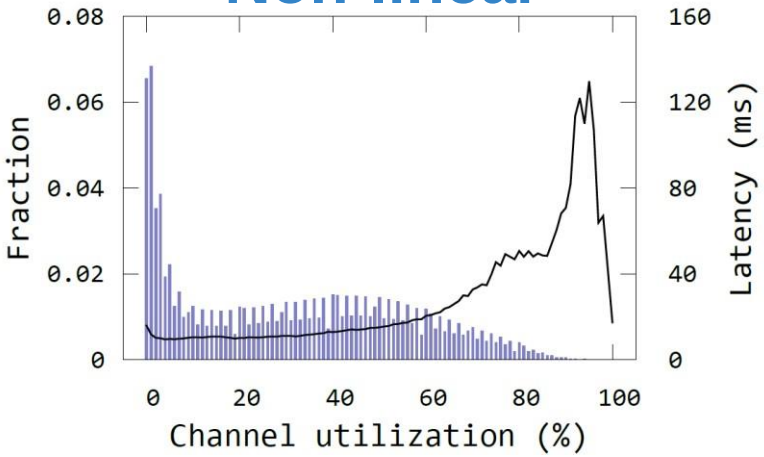
Complex relationships between WiFi latency and related factors



Non- monotonic

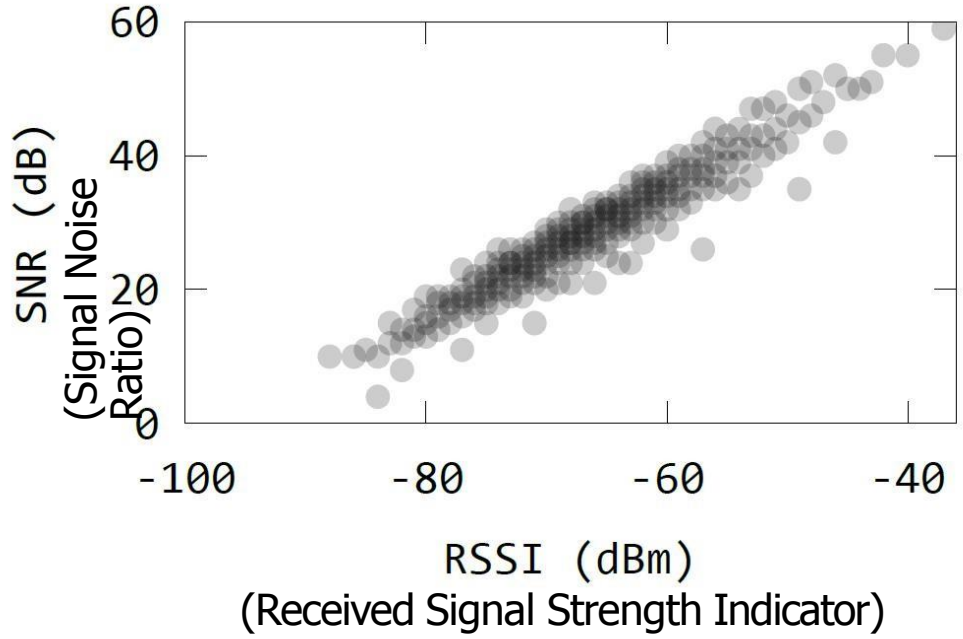


Non-linear



WiFi Latency in the Wild

Interdependencies between related factors



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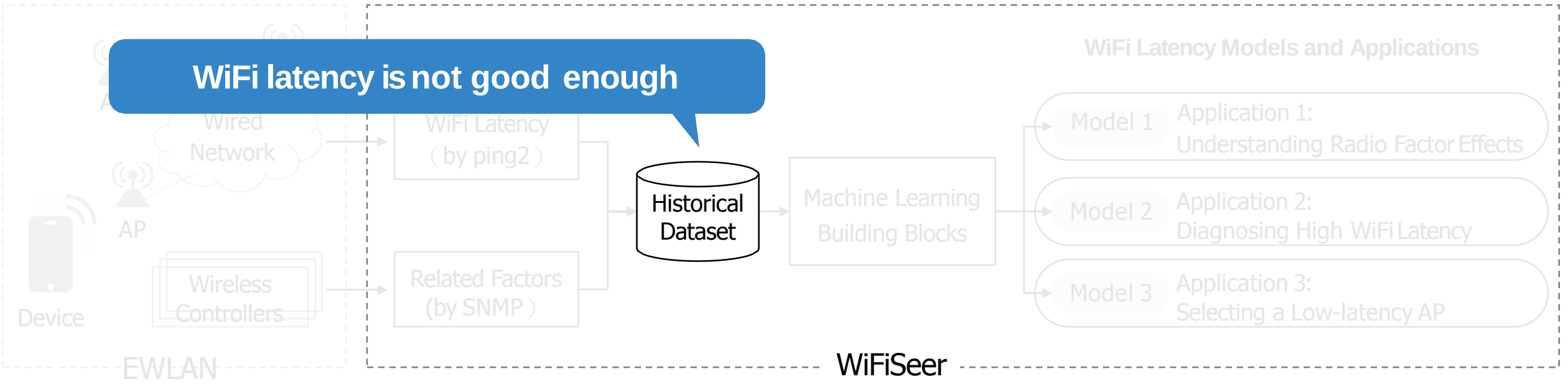
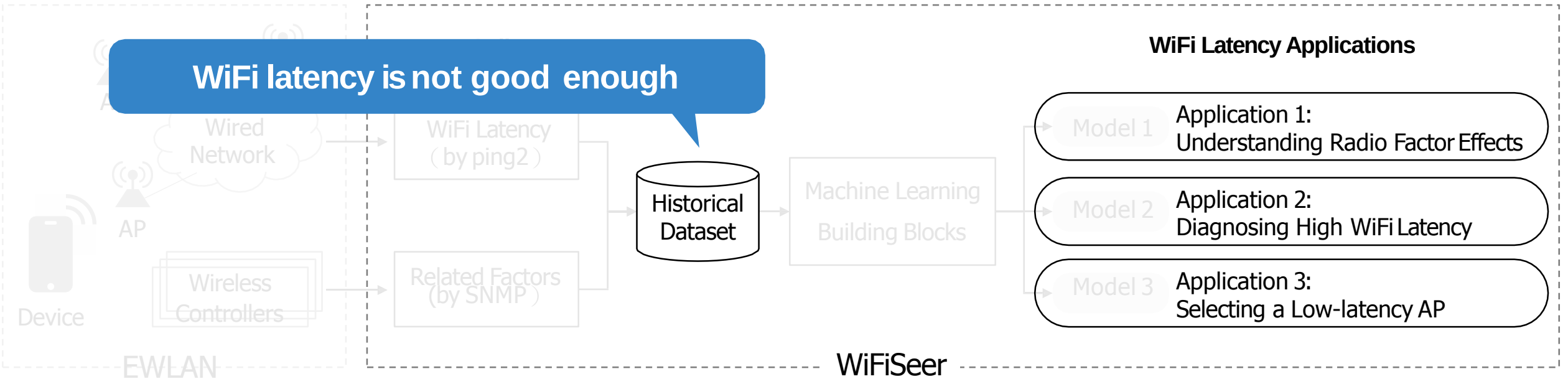


Measuring

How to improve?

WiFiSeer Overview

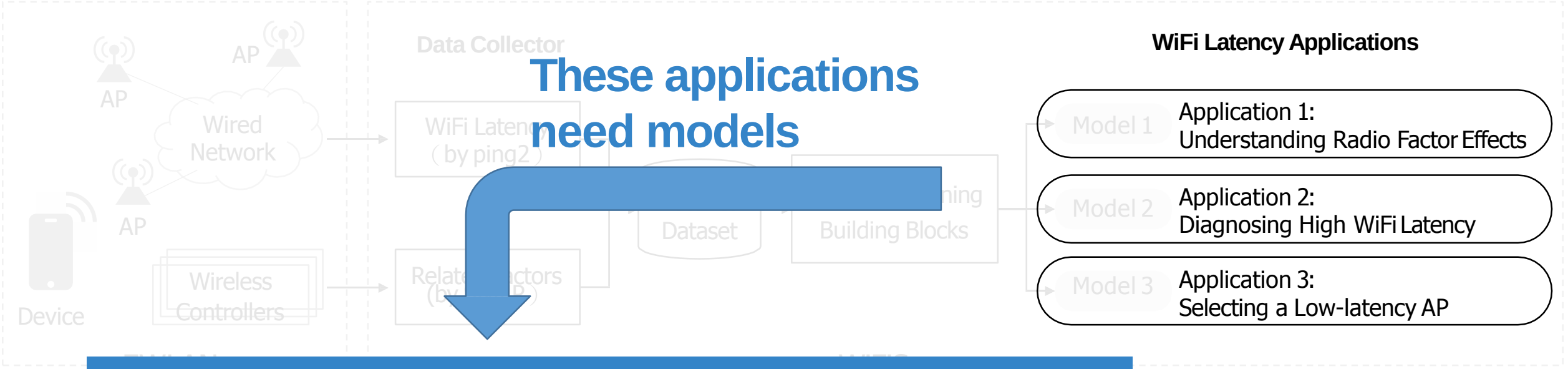


Measuring

Modeling

Improving

WiFiSeer Overview



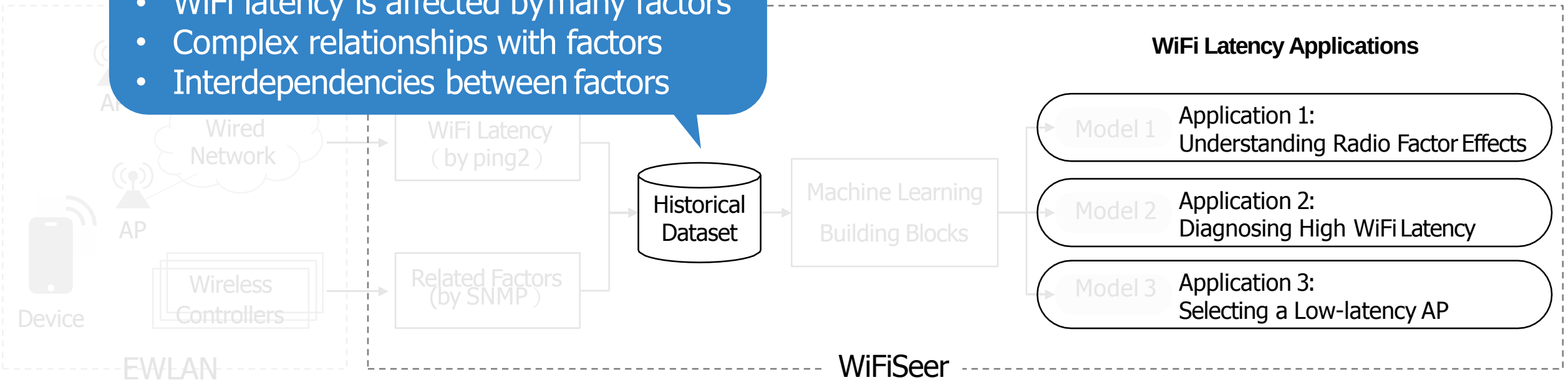
$$f(\underbrace{\text{Channel utilization},\ \#\text{ of devices},\ \text{Time of day},\ \ldots,\ \text{RSSI},\ \text{Band},\ \text{Location},\ \ldots}_{\text{Related factors}}) = \text{latency}$$

Improving

WiFiSeer Overview

Modeling Challenges

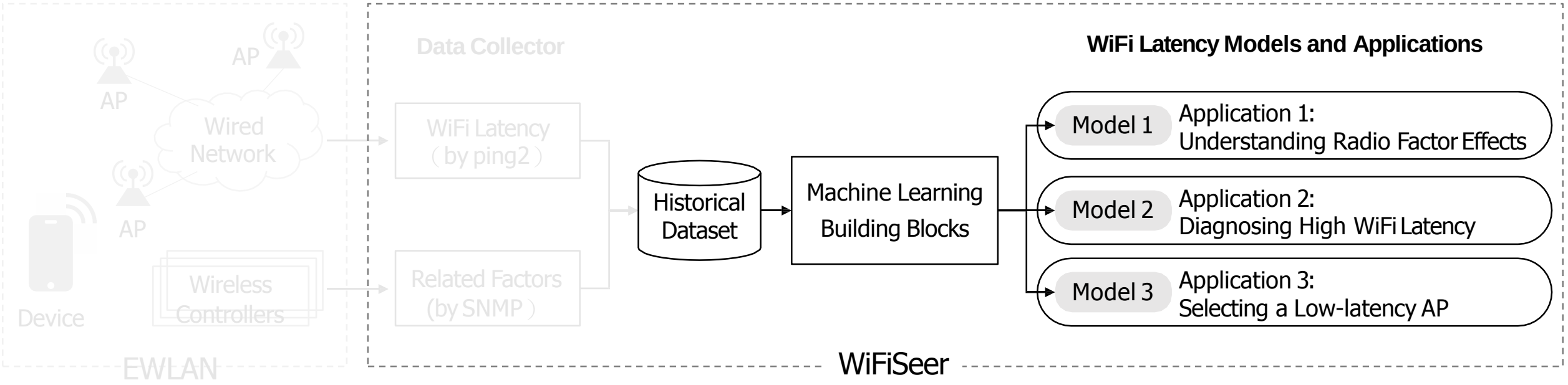
- WiFi latency is affected by many factors
- Complex relationships with factors
- Interdependencies between factors



How to model?

Improving

WiFiSeer Overview



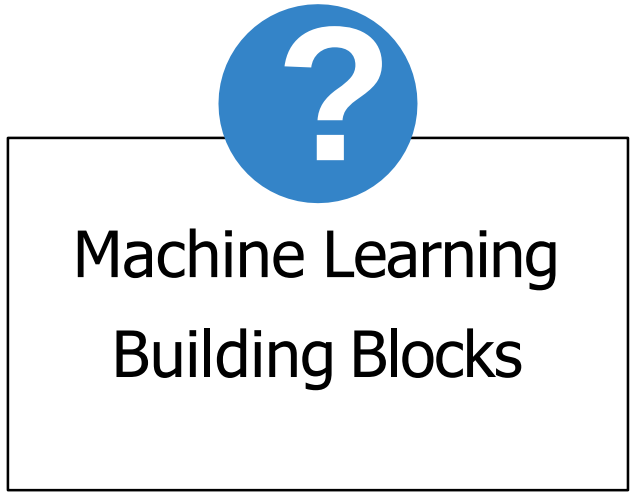
Measuring

Modeling

Improving

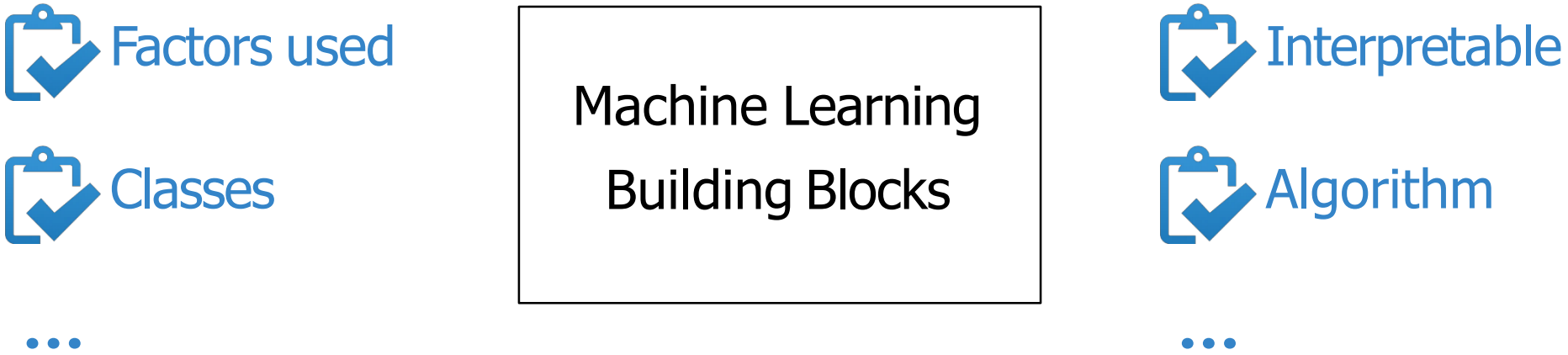
$$f\left(\begin{array}{ll}\text{Channel utilization} & \text{RSSI}\\ \text{\# of devices} & \text{Band}\\ \text{Time of day} & \text{Location}\\ \ldots & \ldots\end{array}\right) = \text{latency}$$

Different applications require different models



Applying Machine Learning

Different applications require different models



Tailor models for applications

Applying Machine Learning

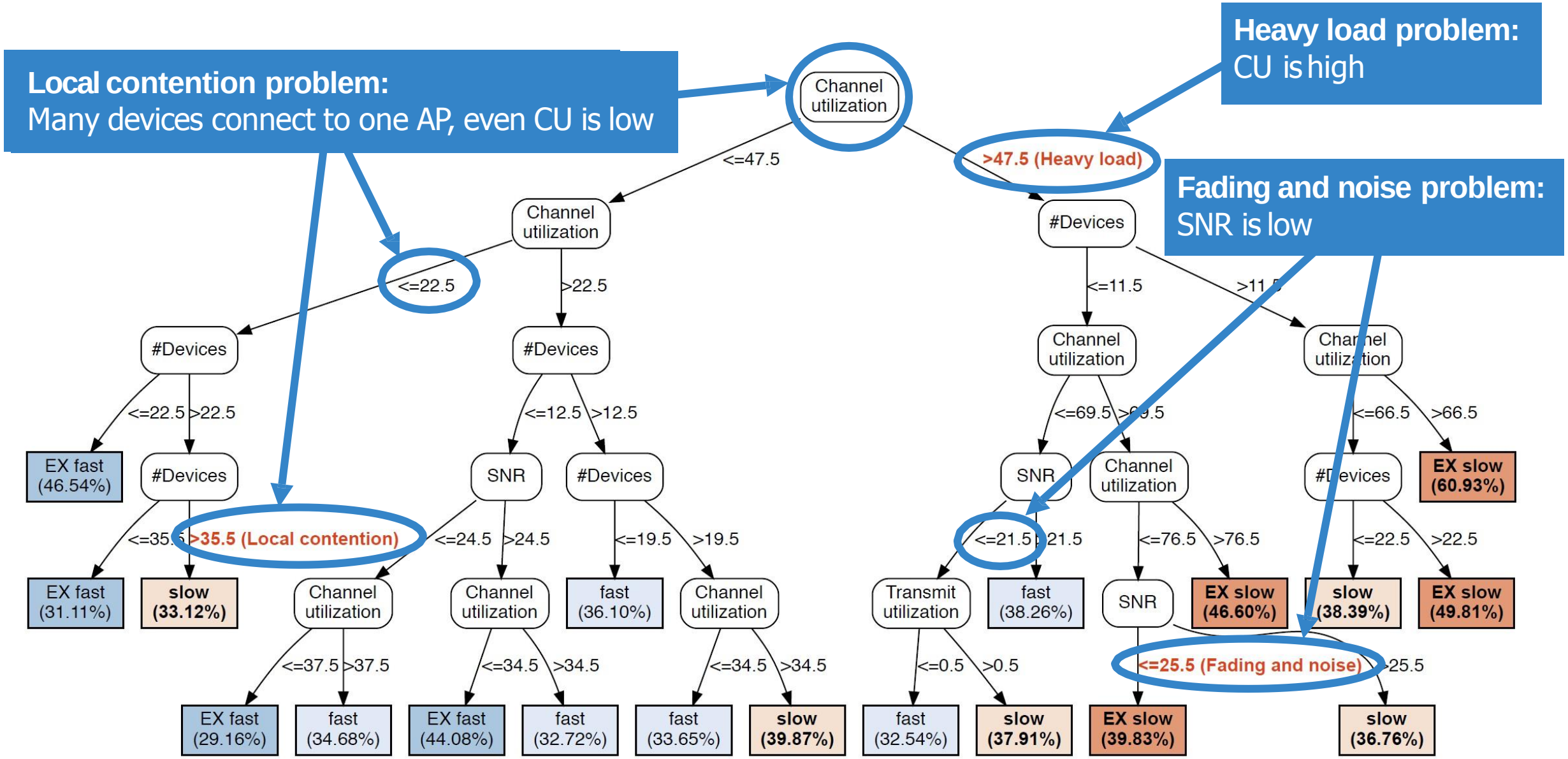
Different applications require different models

Application 1: Understanding Radio Factor Effects
Decision trees (Interpretable)

Application 3: Selecting a Low-latency AP
Random forest (more accurate)

Tailor models for applications

Application 1: Understanding Radio Factor Effects



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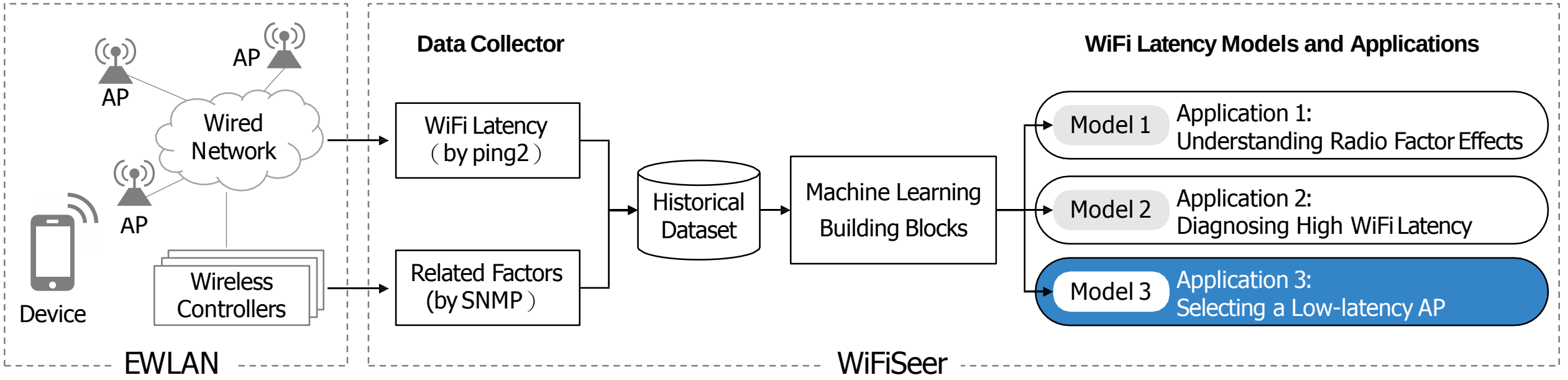
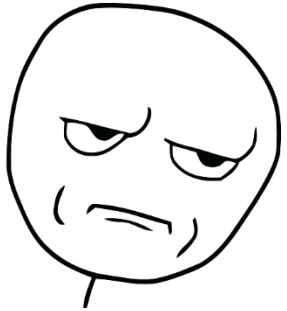


Measuring

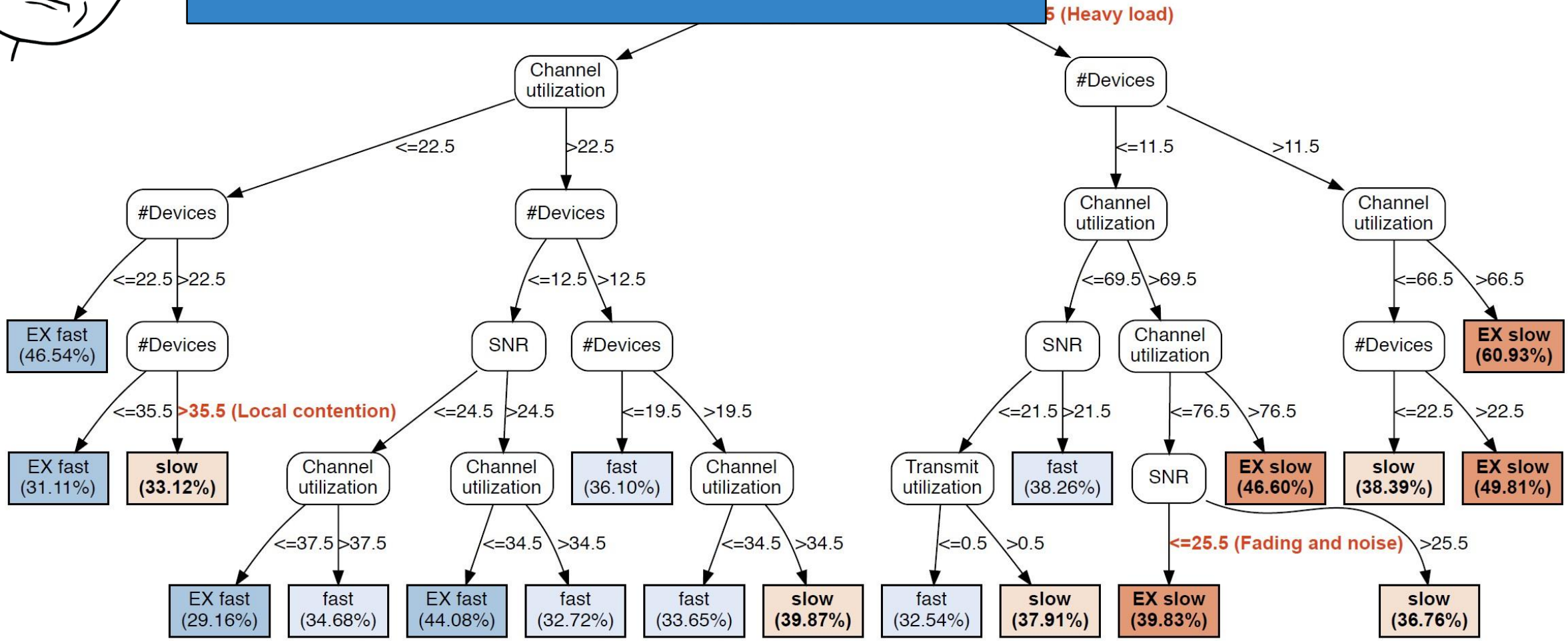
Modeling

Improving

Problem

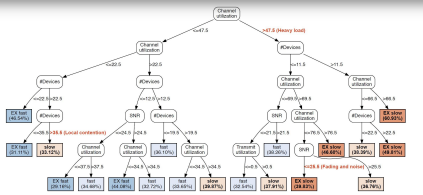


Wait! I can't find RSSI in the tree!
My phone uses it to select AP, and it is not important?

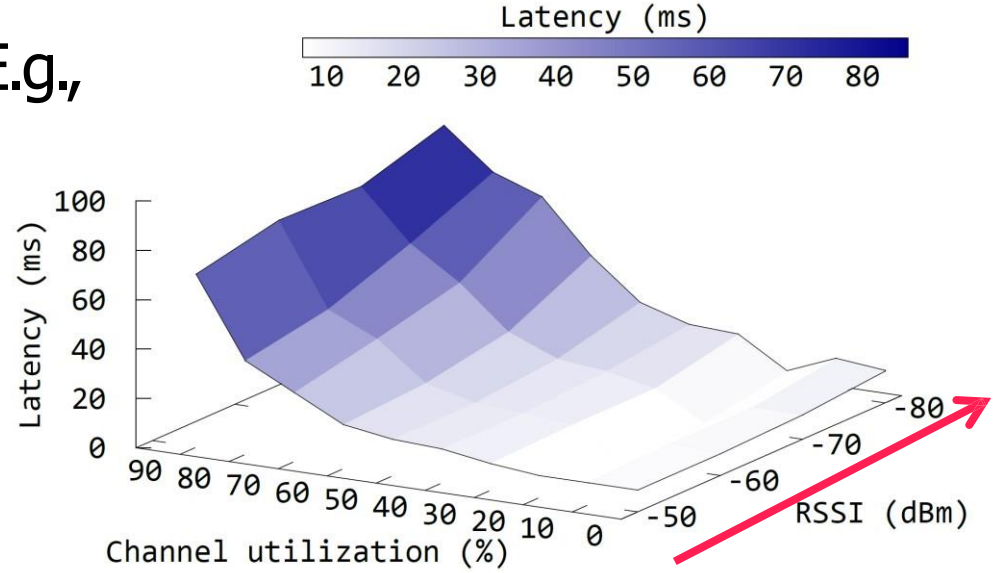


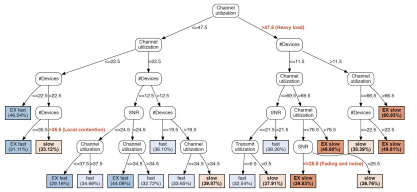
Problem

Yes, RSSI is not that important
for predicting WiFi latency

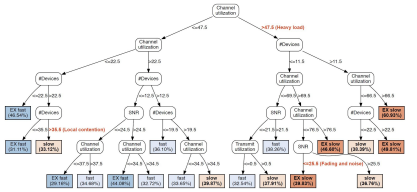


E.g.,

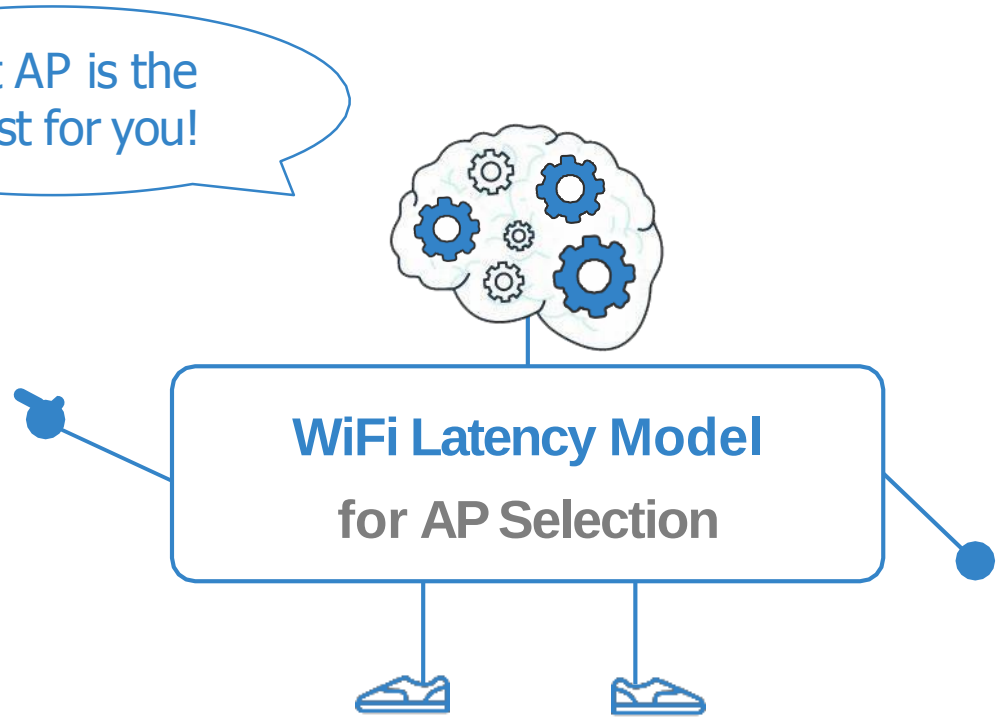




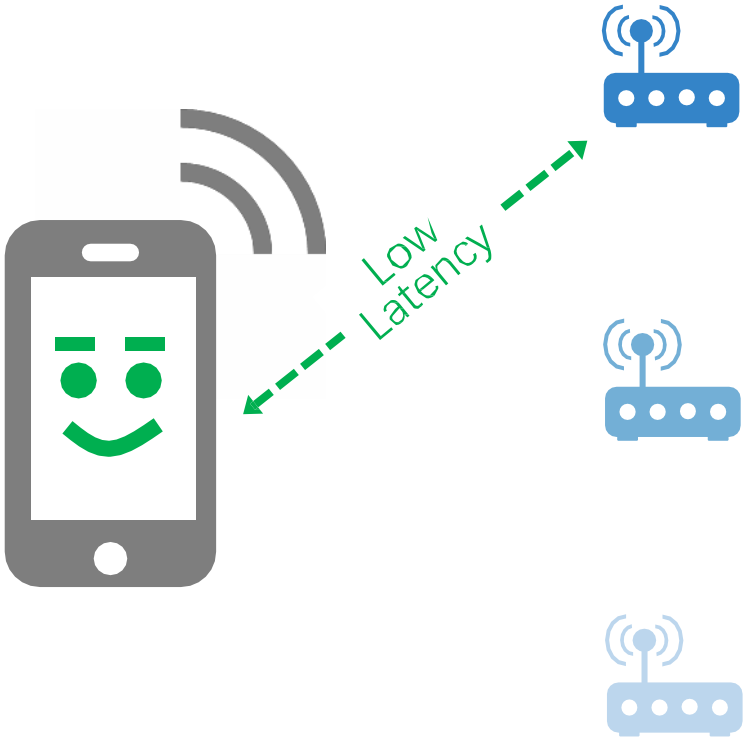
How to select an AP for low latency?

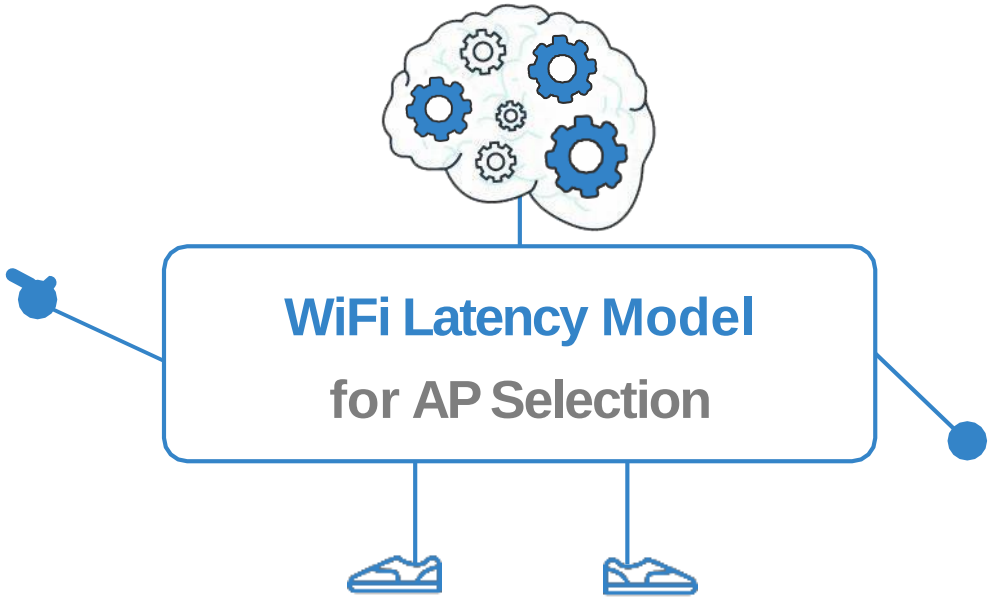


Application 3: Selecting a Low-latency AP



Application 3: Selecting a Low-latency AP

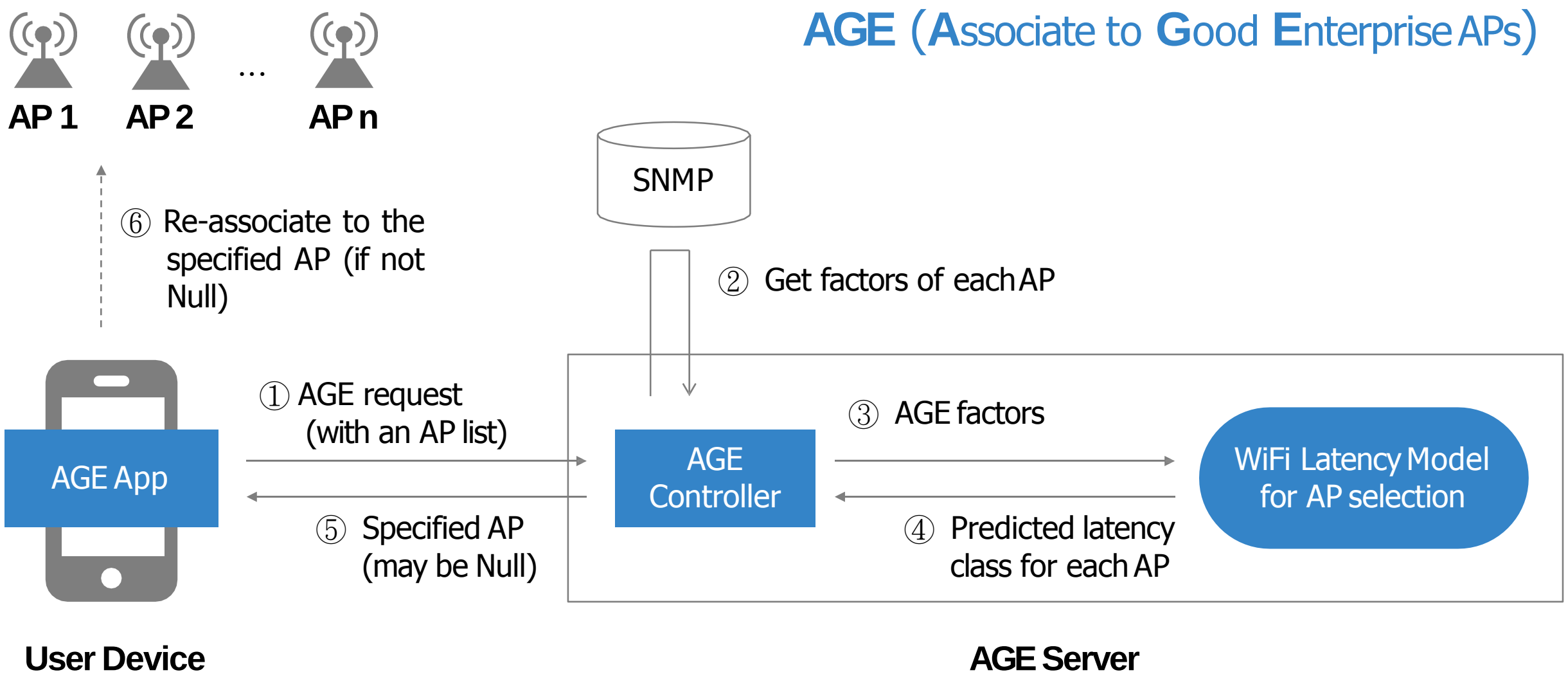




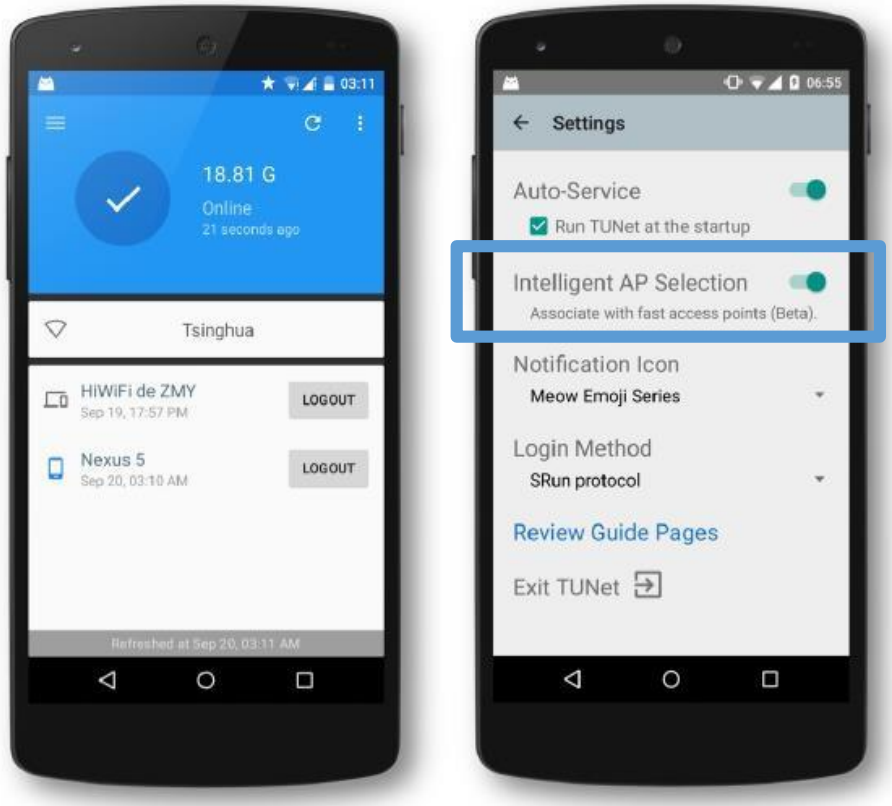
Problem: how to let devices use the AP suggested?

Do this at OS level ? Protocol level ? …

Application 3: Selecting a Low-latency AP



Application 3: Selecting a Low-latency AP



Used by **1000+** devices for 2.5 months

After re-association to the suggested AP

92% of their latencies ↓

72% of their latencies ↓ **50%+**

Conclusion

- **WiFiSeer**
  - A general and practical system for measuring and improving WiFi latency
  - Exploring machine learning for modeling WiFi latency
  - Large-scale deployment in Tsinghua University
  - Several observations → two deployed mitigation approaches, *e.g.* 5 GHz SSID

- **Future work**
  - Latency -> Throughput …
  - AP selection at OS or protocol level, *e.g.* 802.11k/v
  - End of this year, 2,000+ APs → 9,000 APs in Tsinghua University!

Comment

- **Advantages**
  - Working process is complete
  - Latency measurement method（verifiable）
  - Selecting AP method using machine learning
- **Shortcomings**
  - AGE may not be authorized
  - Machine Learning method is not that persuasive
  - Some solutions are che. (eg. Add more APs)

WiFiSeer
MobiSys 2016

Thank you

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