

Characterizing and Improving WiFi Latency in Large-Scale Operational Networks

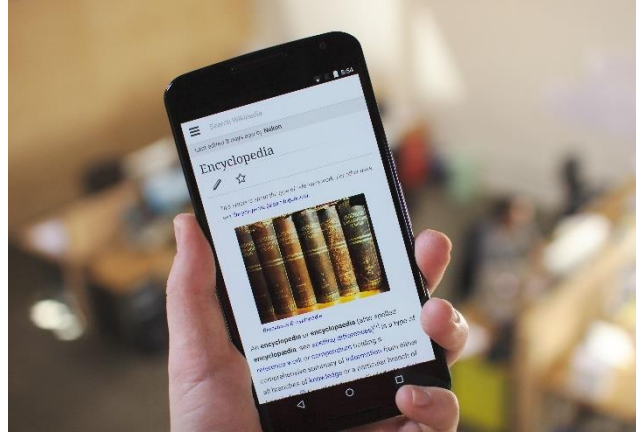
Kaixin Sui, Mengyu Zhou, Dapeng Liu, Minghua Ma
Dan Pei, Youjian Zhao, Zimu Li, Thomas Moscibroda

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?

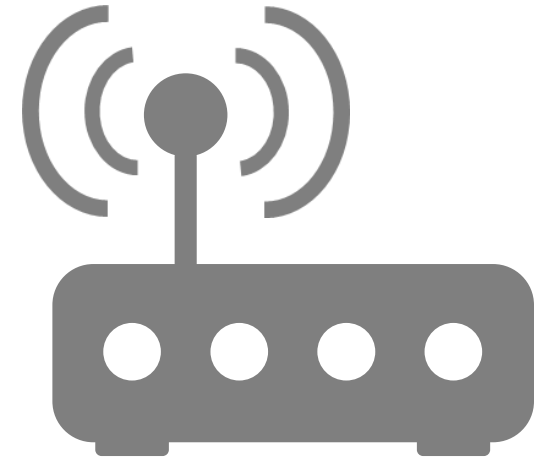


Mobile device

How related factors
impact WiFi latency?

←... WiFi latency ...→

How to improve
WiFi latency?



Access point

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

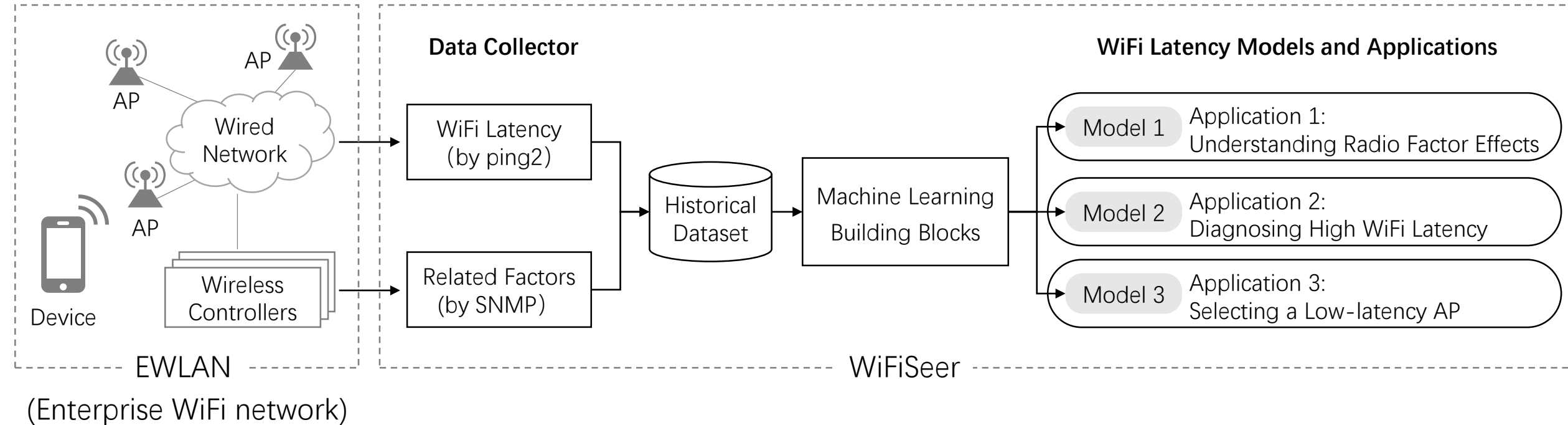
WiFiSeer[📶]

Measuring, Modeling, and Improving

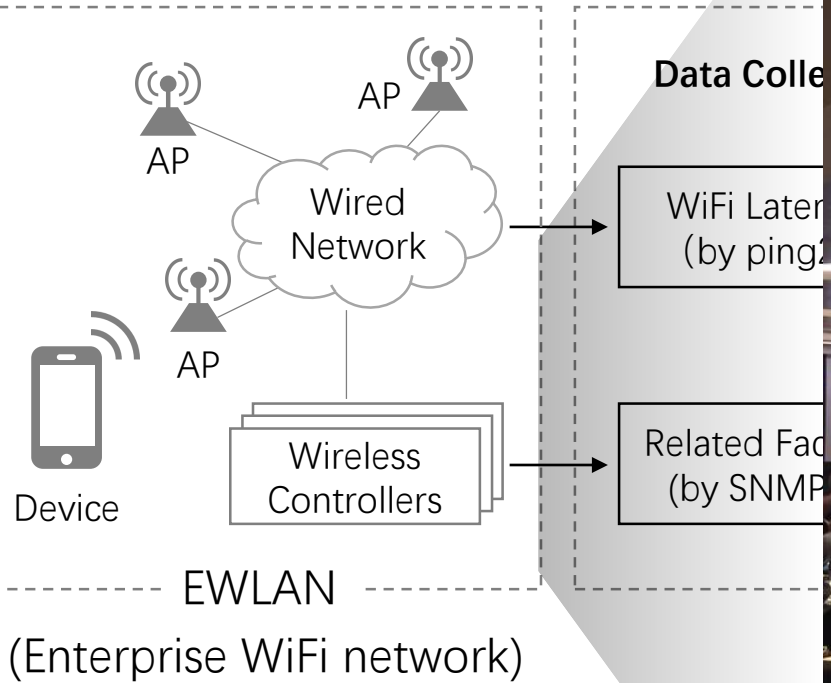
WiFi latency

in Large-Scale Operational Networks

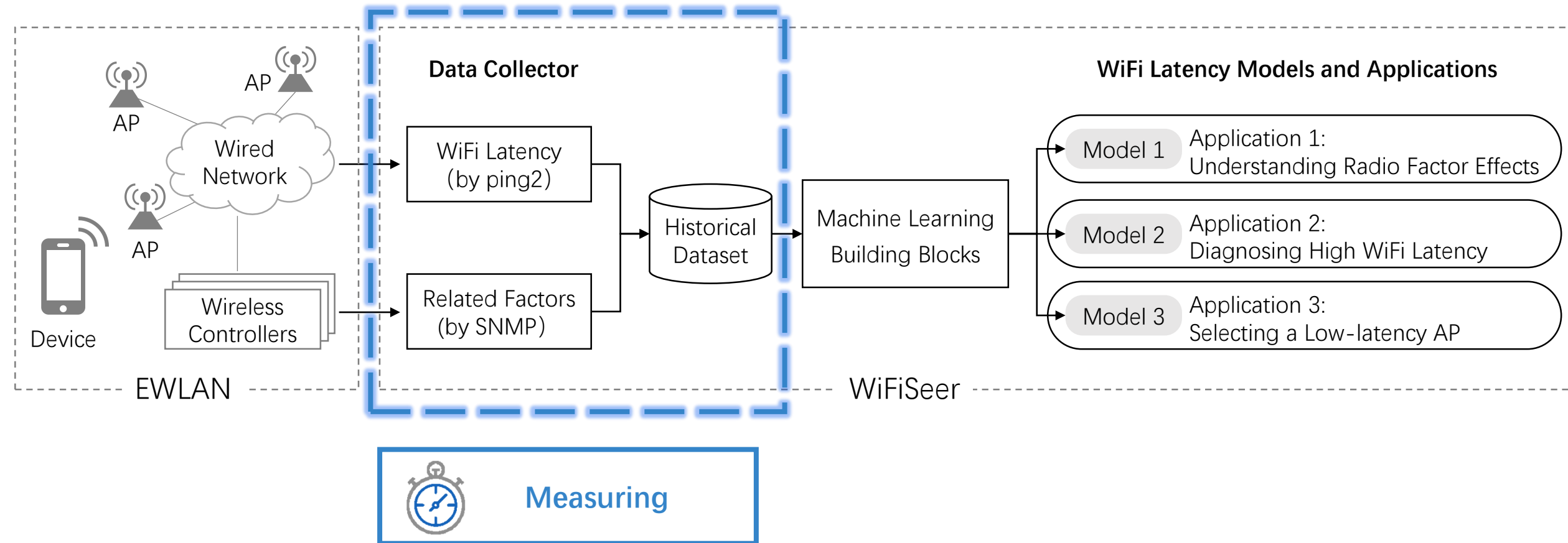
WiFiSeer Overview



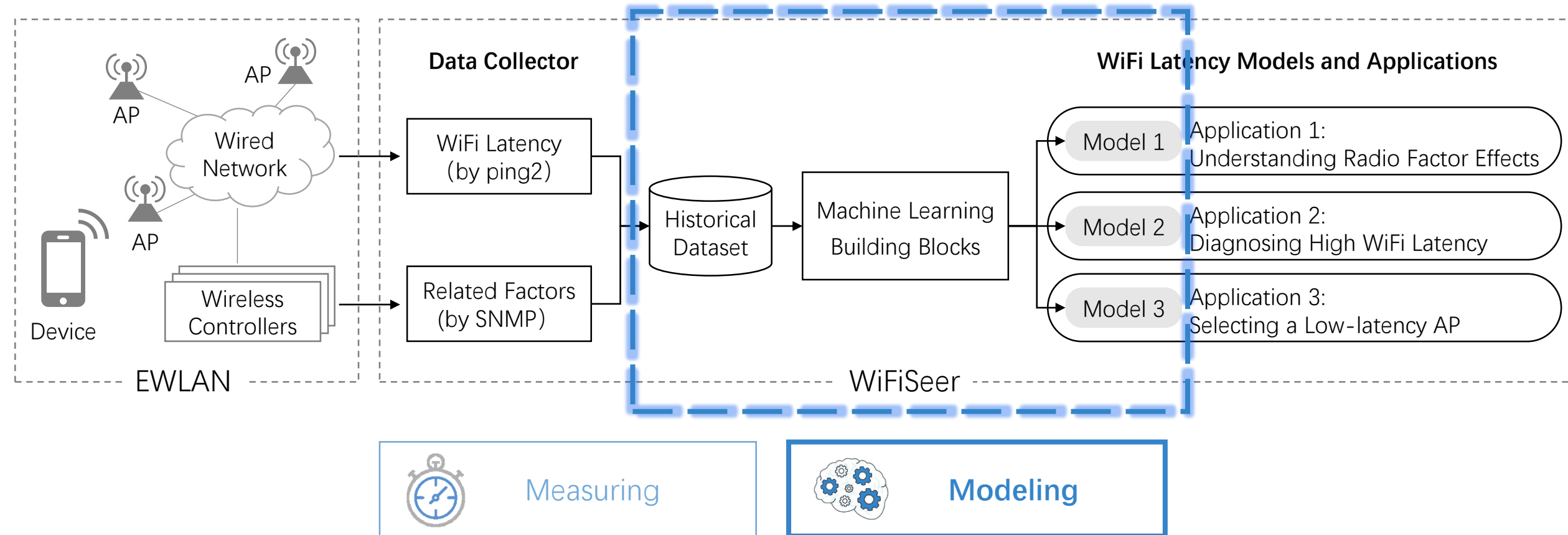
WiFiSeer Overview



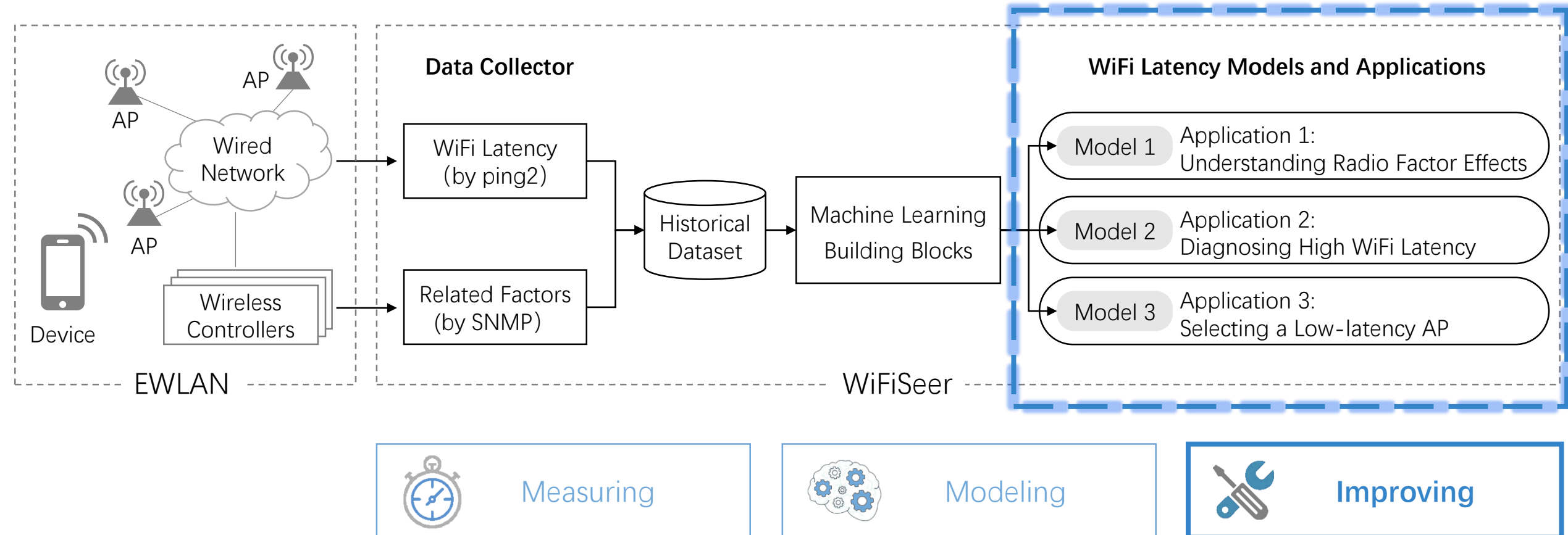
WiFiSeer Overview



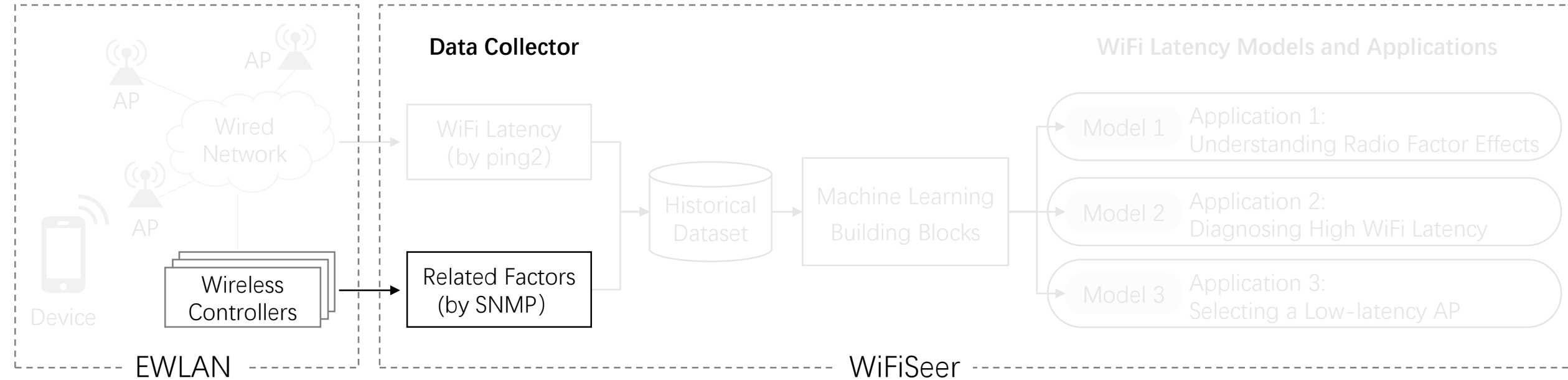
WiFiSeer Overview



WiFiSeer Overview



WiFiSeer Overview



Measuring

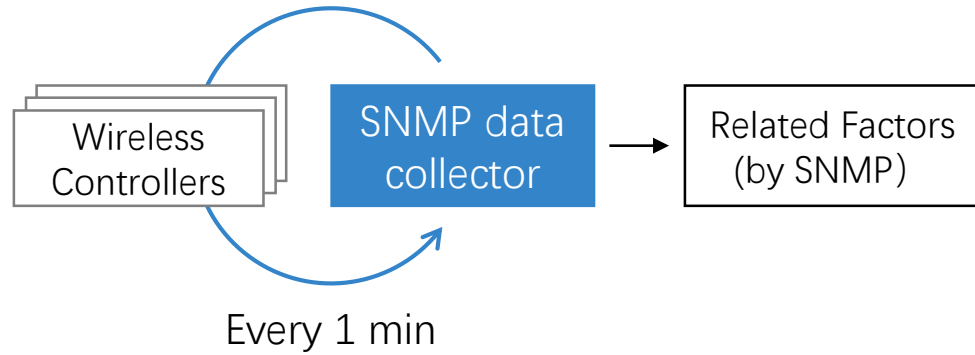


Modeling



Improving

Measuring Related Factors



SNMP data

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

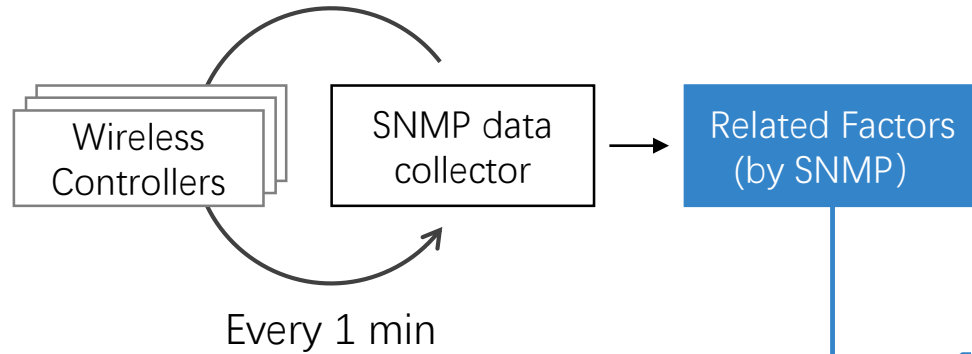


(AP) Access point



Wireless controller

Measuring Related Factors



→ **11 Radio factors**

- Channel utilization
- RSSI
- # of devices
- ...

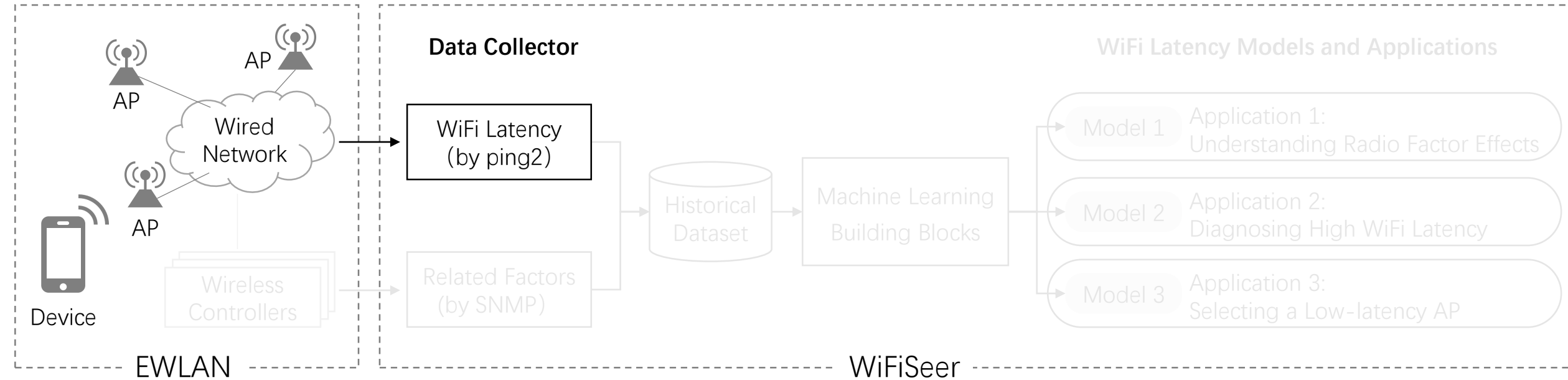
→ **3 Protocol factors**

- 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



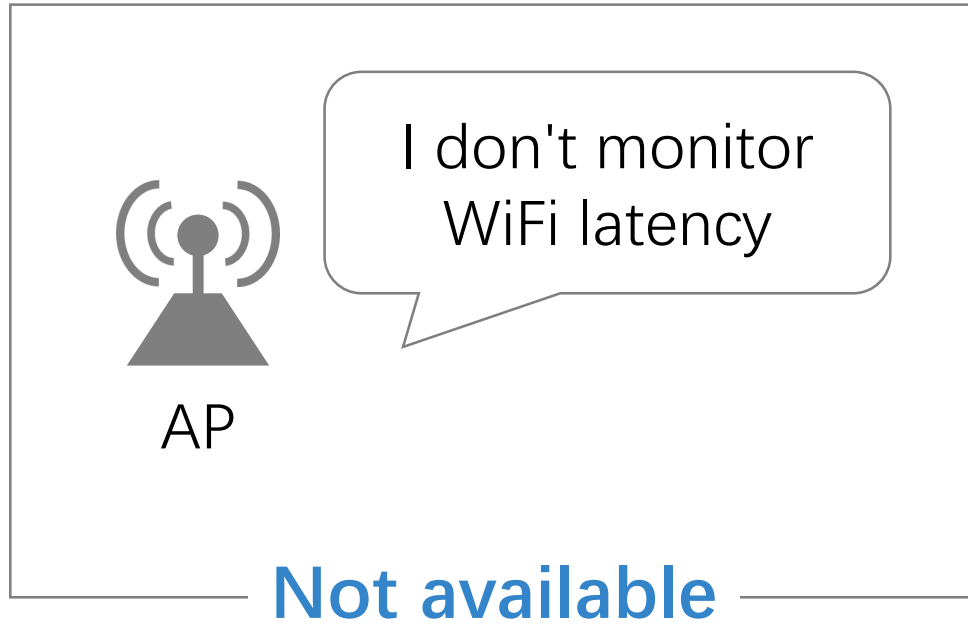
Modeling



Improving


Measuring WiFi Latency

Challenges



Measuring WiFi Latency



Challenges



I don't monitor WiFi latency

AP

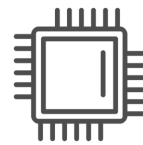
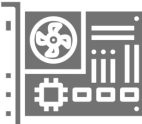
Not available



AP




Sniffers

Costly



Modify hardware or firmware

Deploy problems




Energy saving mode

Naïve ping inaccurate

Measuring WiFi Latency


Challenges



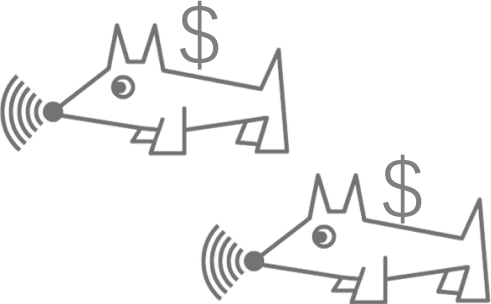
I don't monitor WiFi latency

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Not available

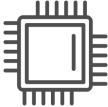



AP




Sniffers

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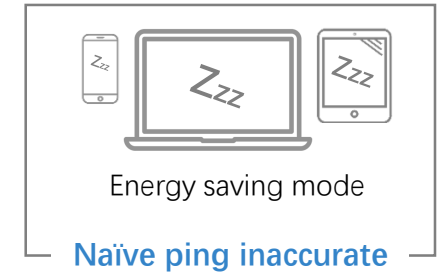
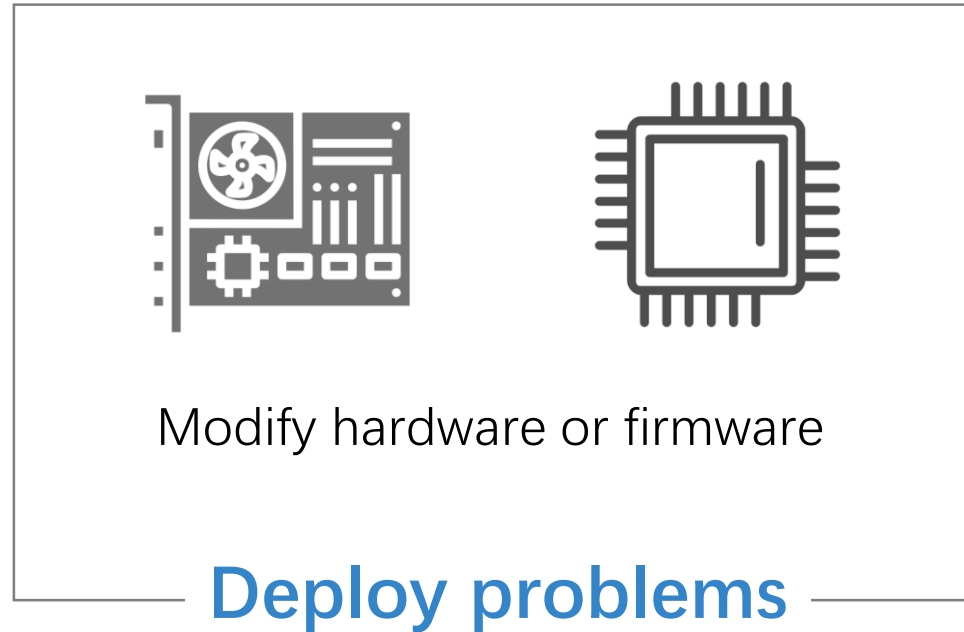
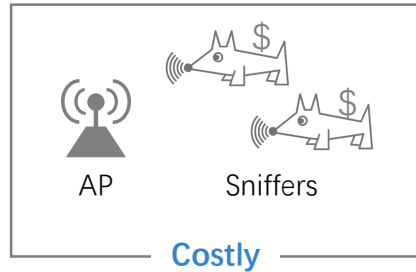
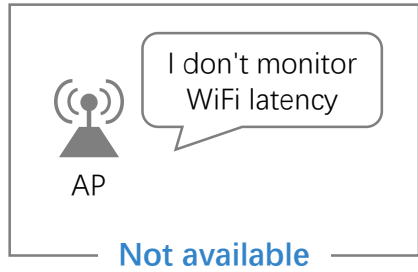
Energy saving mode

Naïve ping inaccurate

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

Measuring WiFi Latency

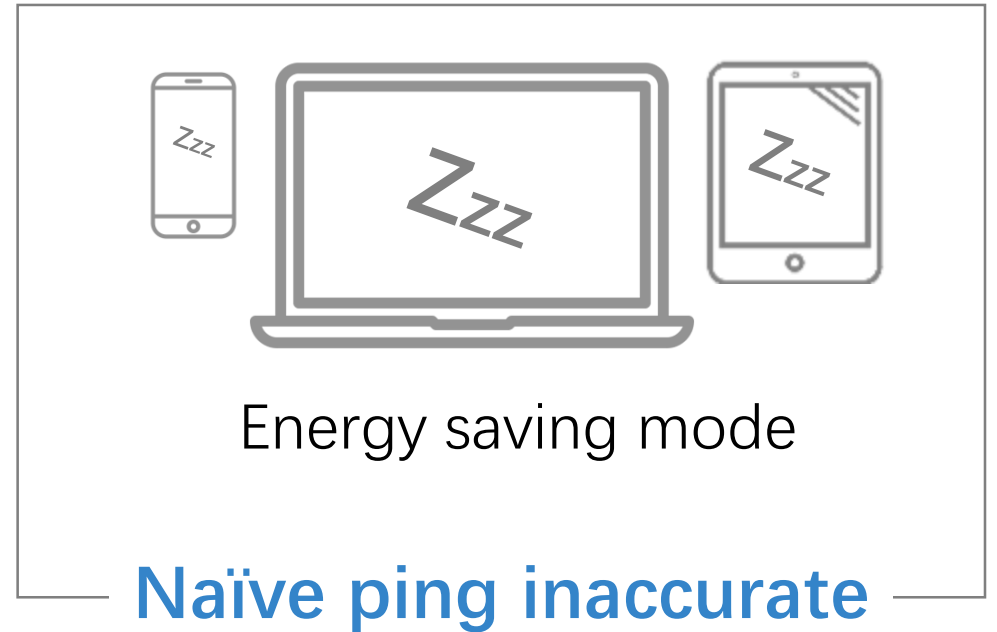
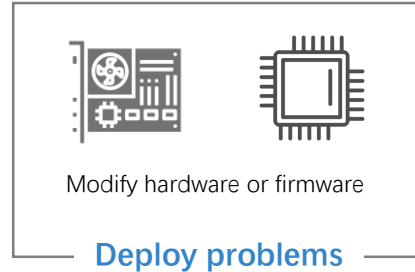
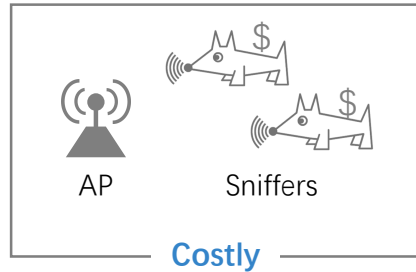
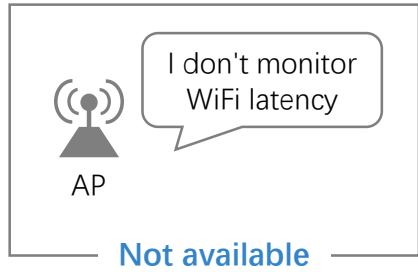
Challenges



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

Measuring WiFi Latency

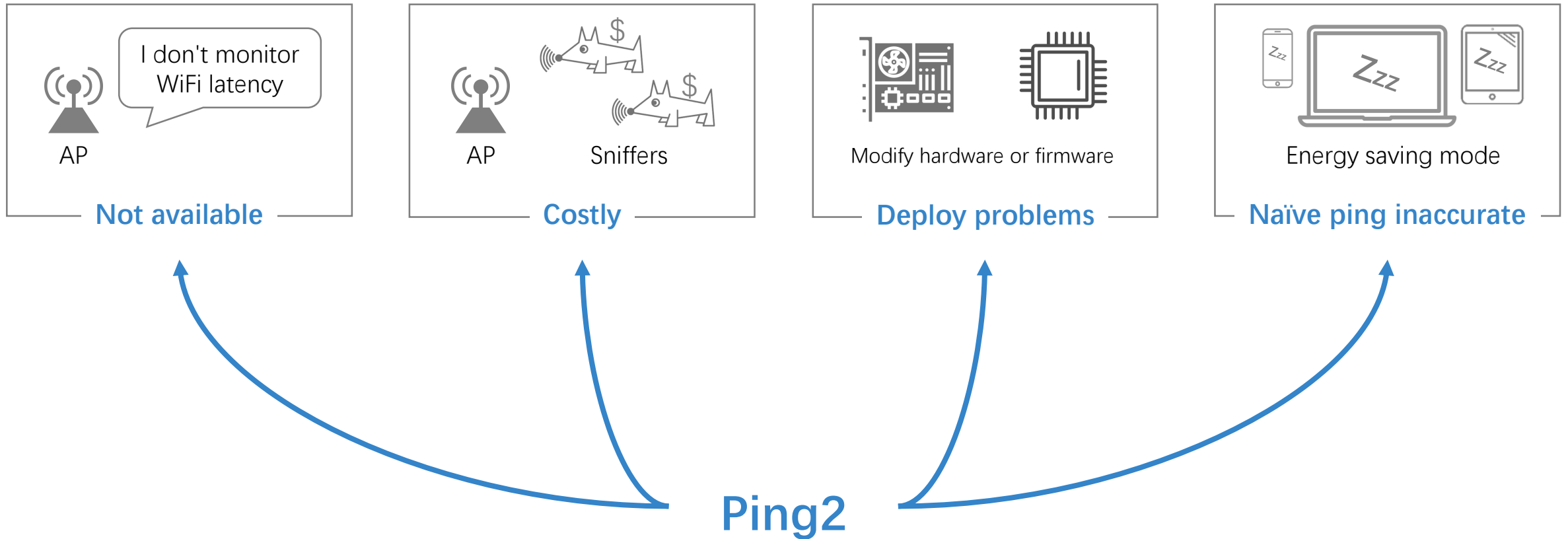
Challenges



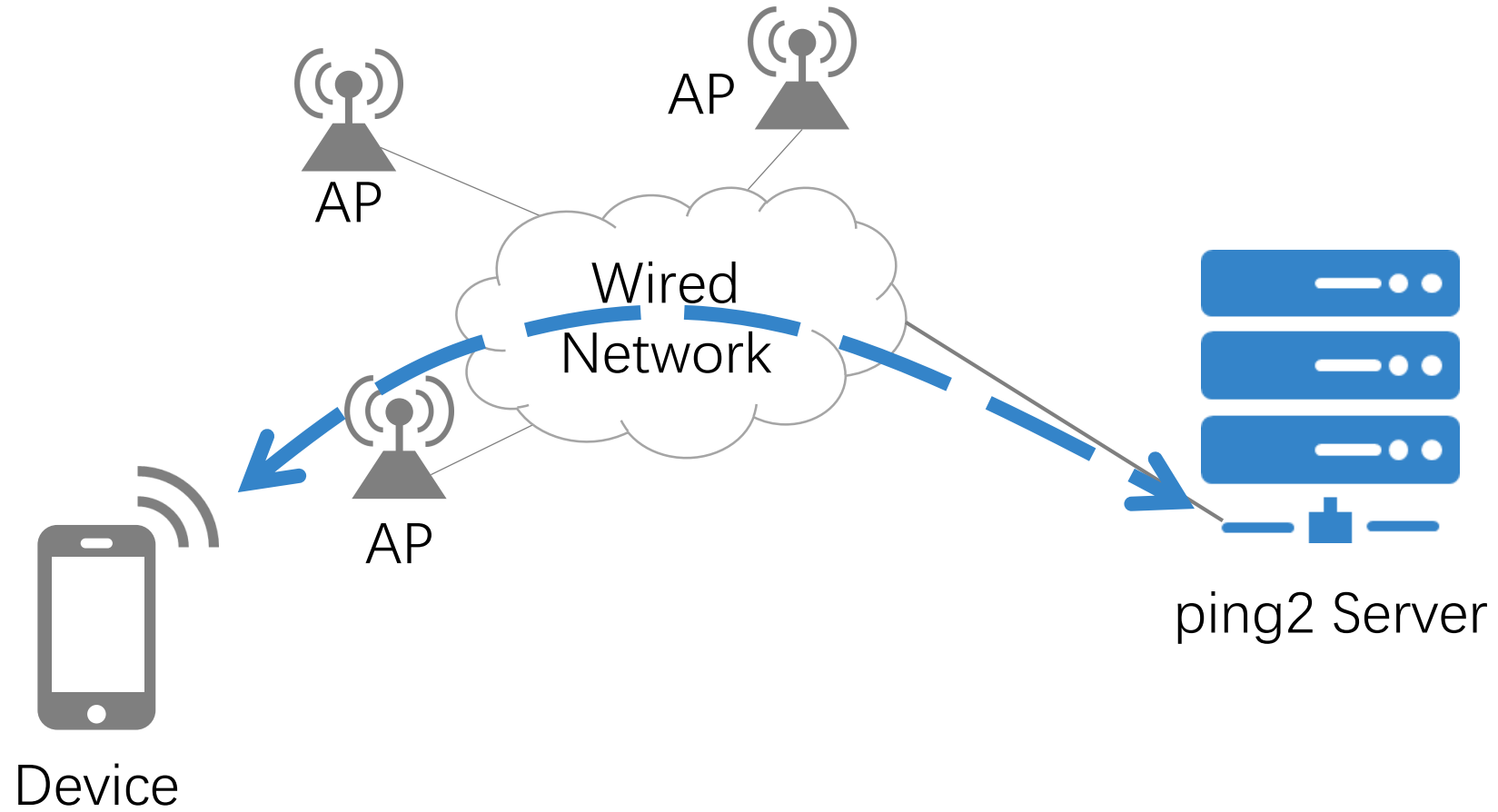
MobiPerf [8], SpeedTest [9]

Measuring WiFi Latency

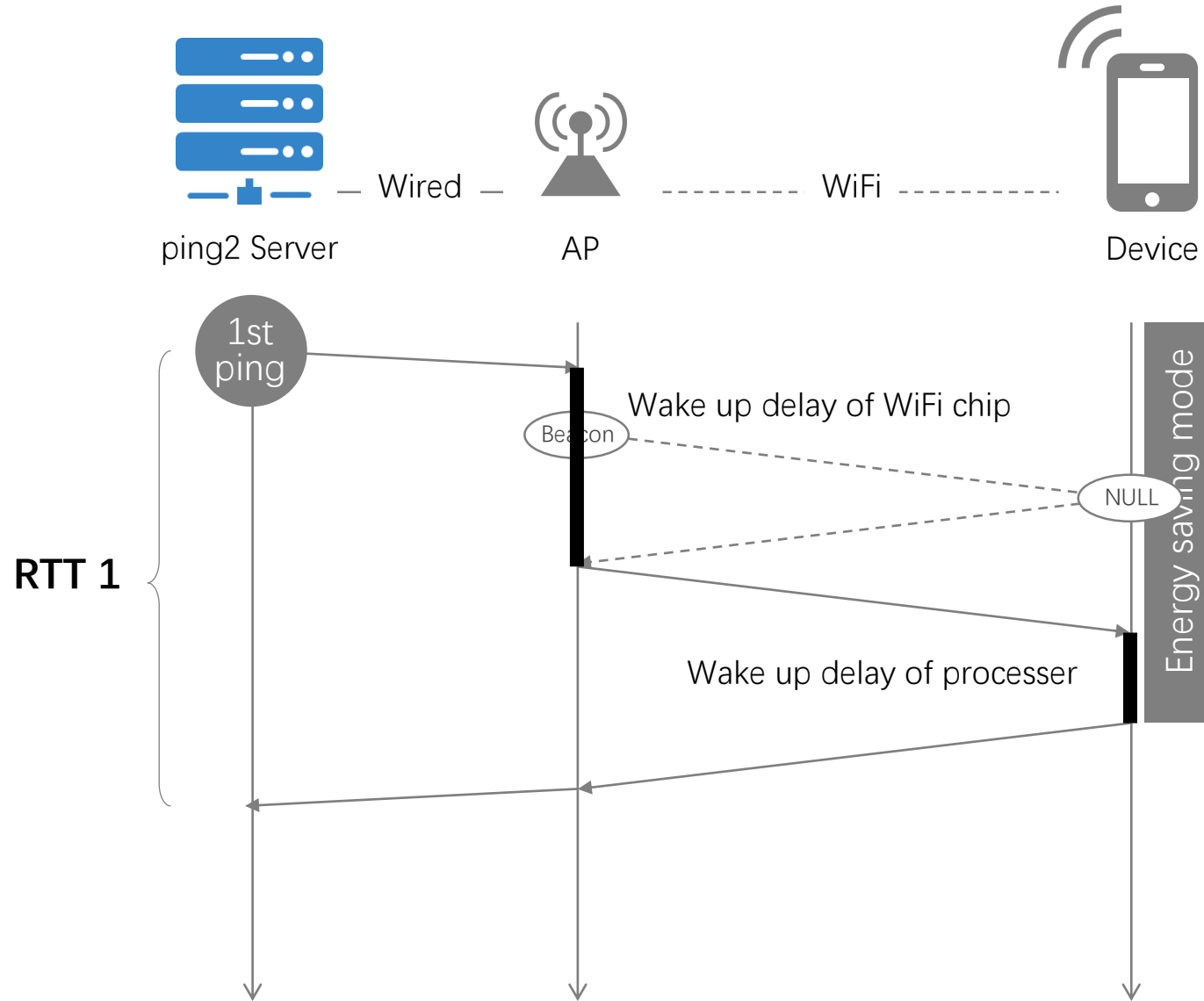
Challenges



Key Ideas of ping2

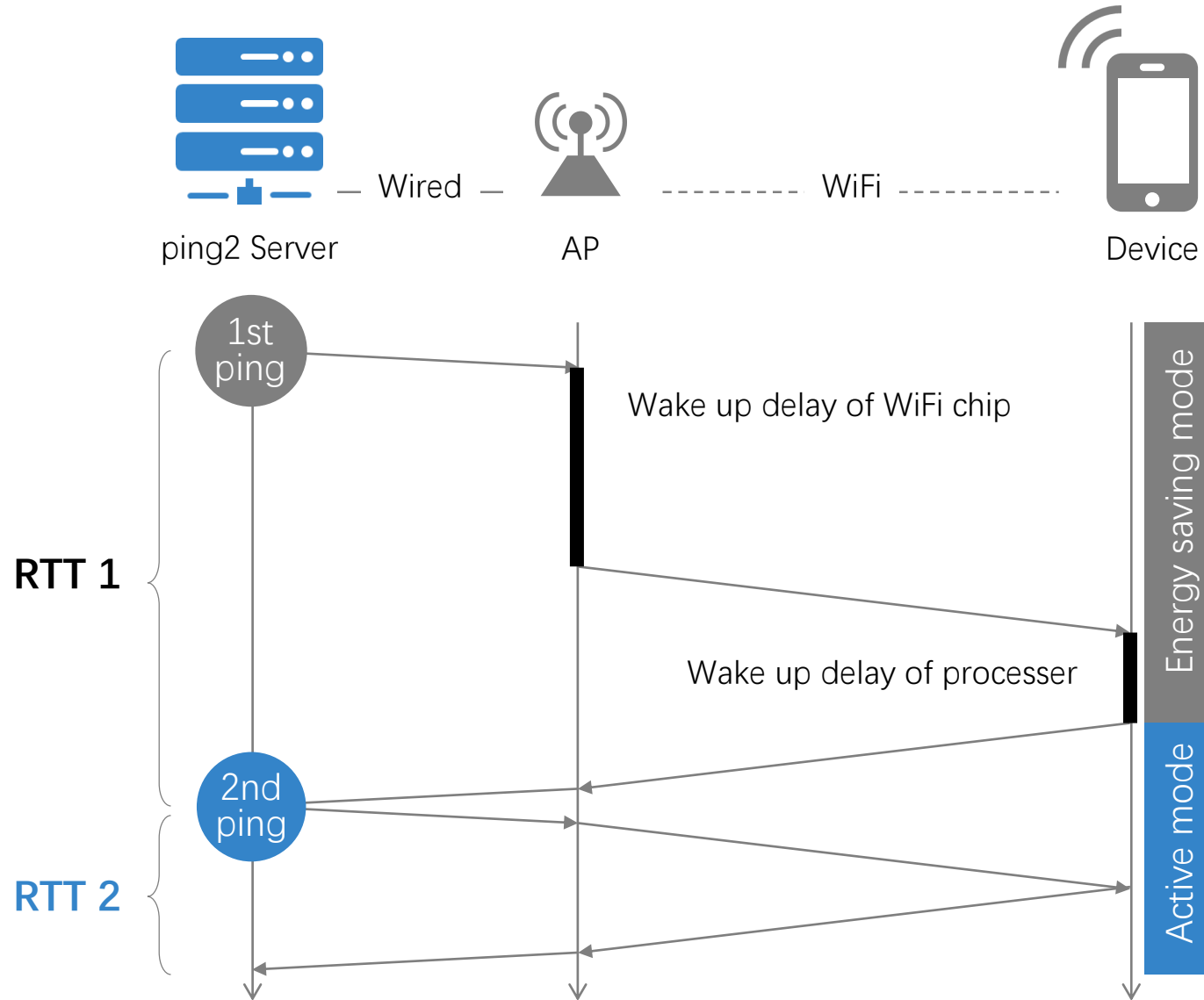


Key Ideas of ping2



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

Key Ideas of ping2

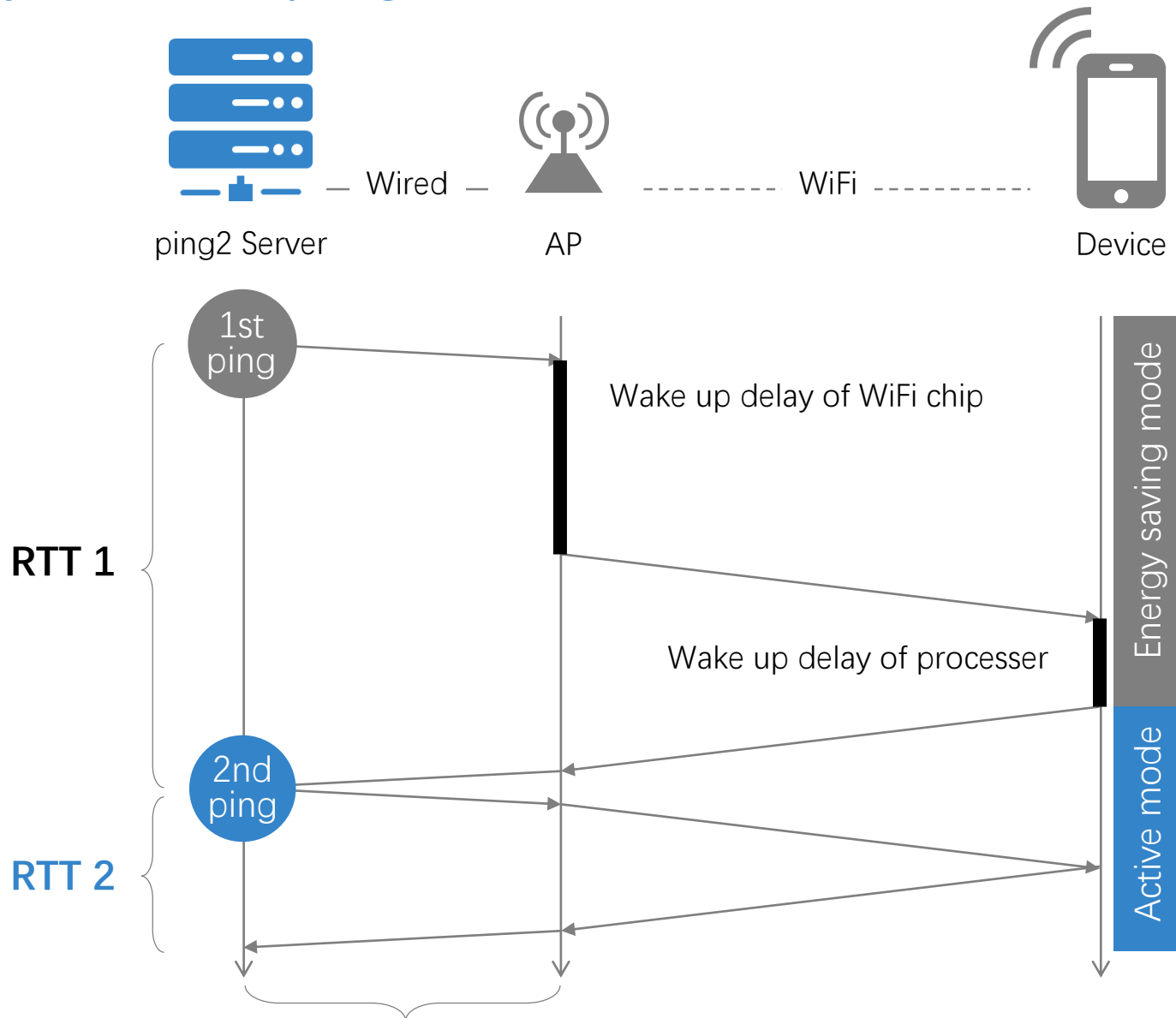


Naïve ping RTT can be Inflated by the device energy saving mode

Ping2 uses two consecutive pings

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

Key Ideas of ping2



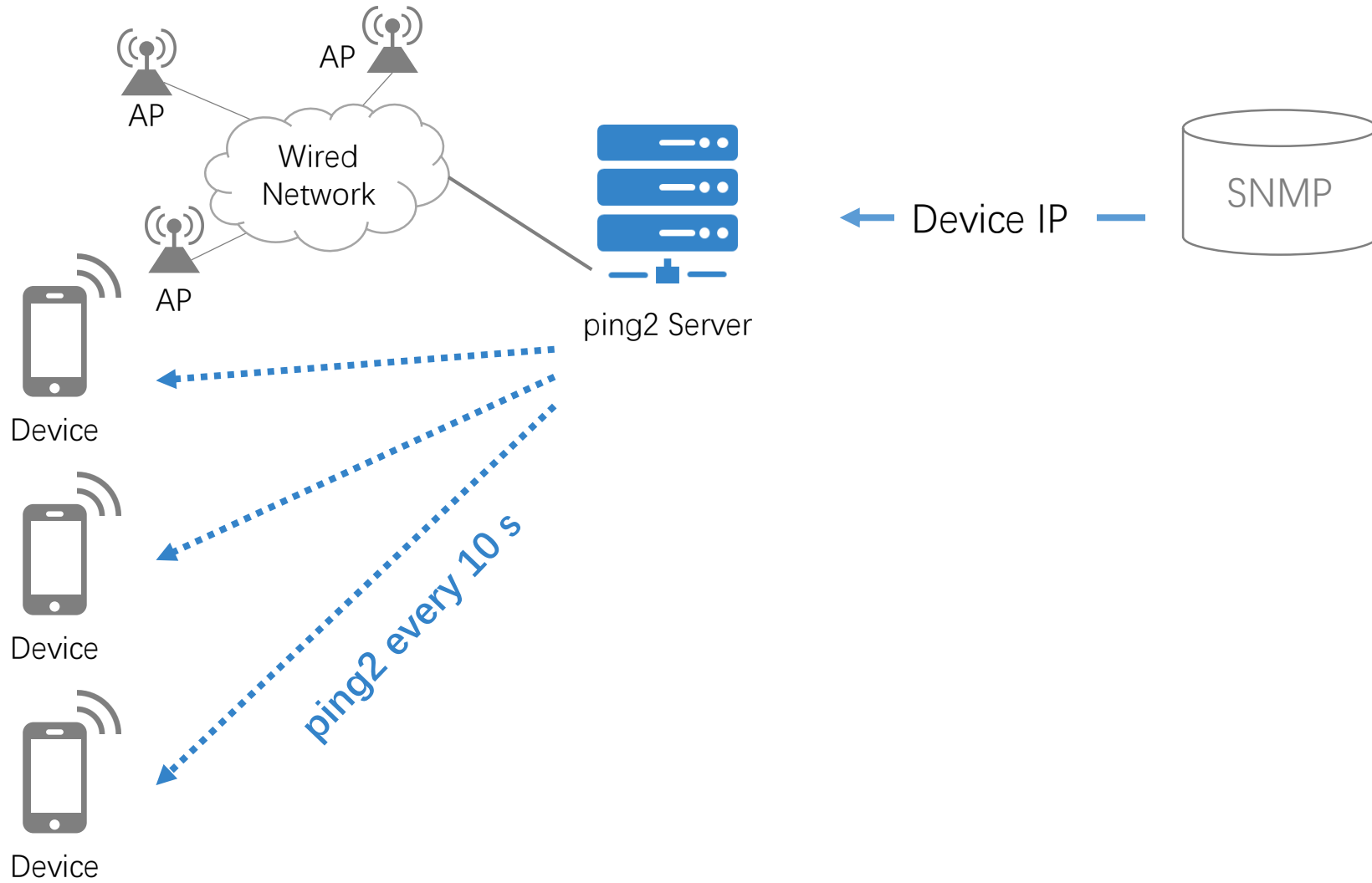
Naïve ping RTT can be Inflated by the device energy saving mode

Ping2 uses two consecutive pings

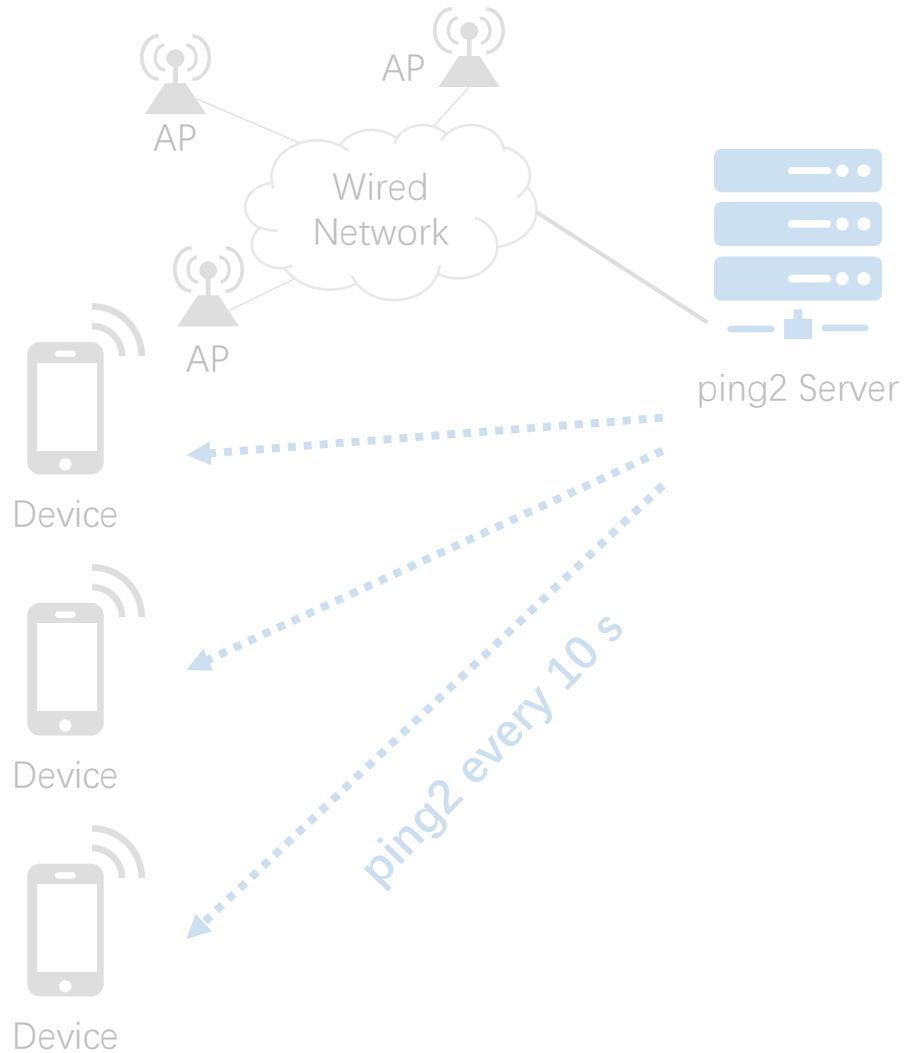
- 1st one to activate devices
- 2nd one as WiFi latency

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

Key Ideas of ping2



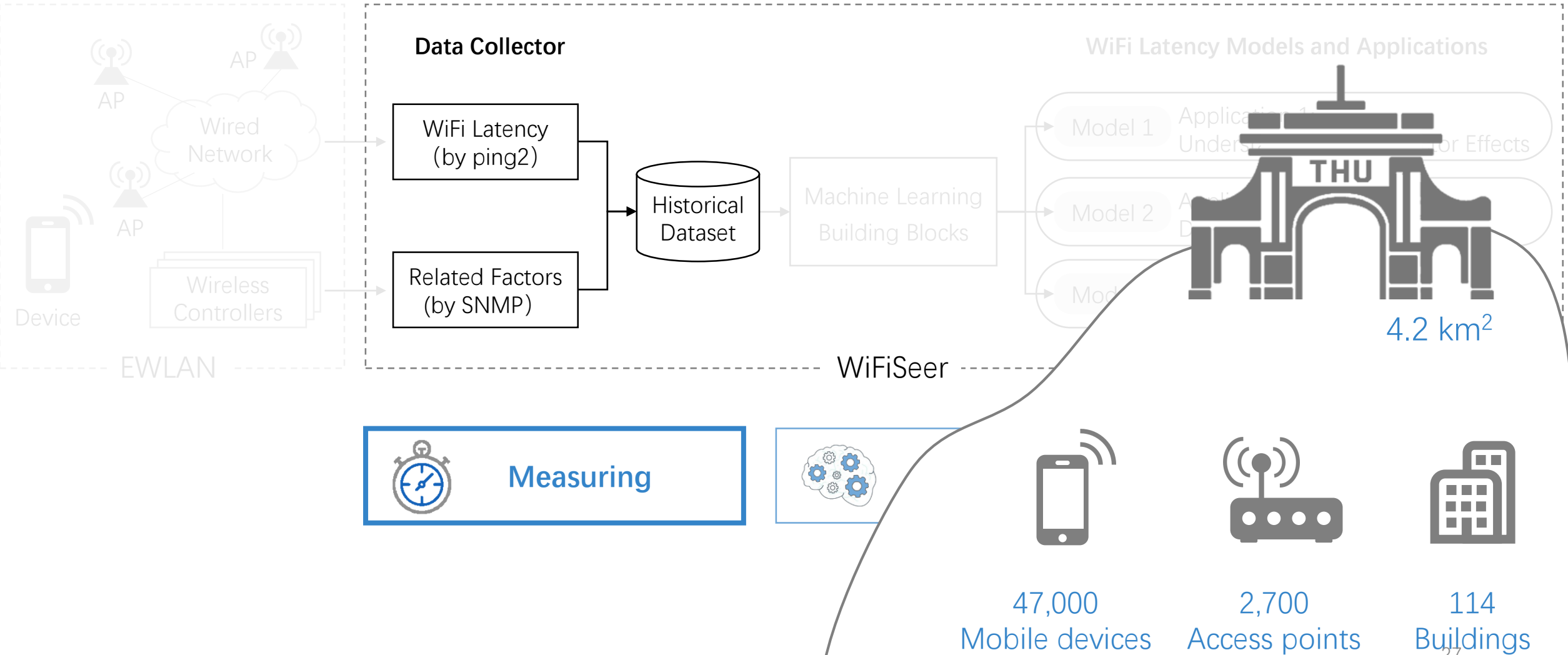
Key Ideas of ping2



Evaluation

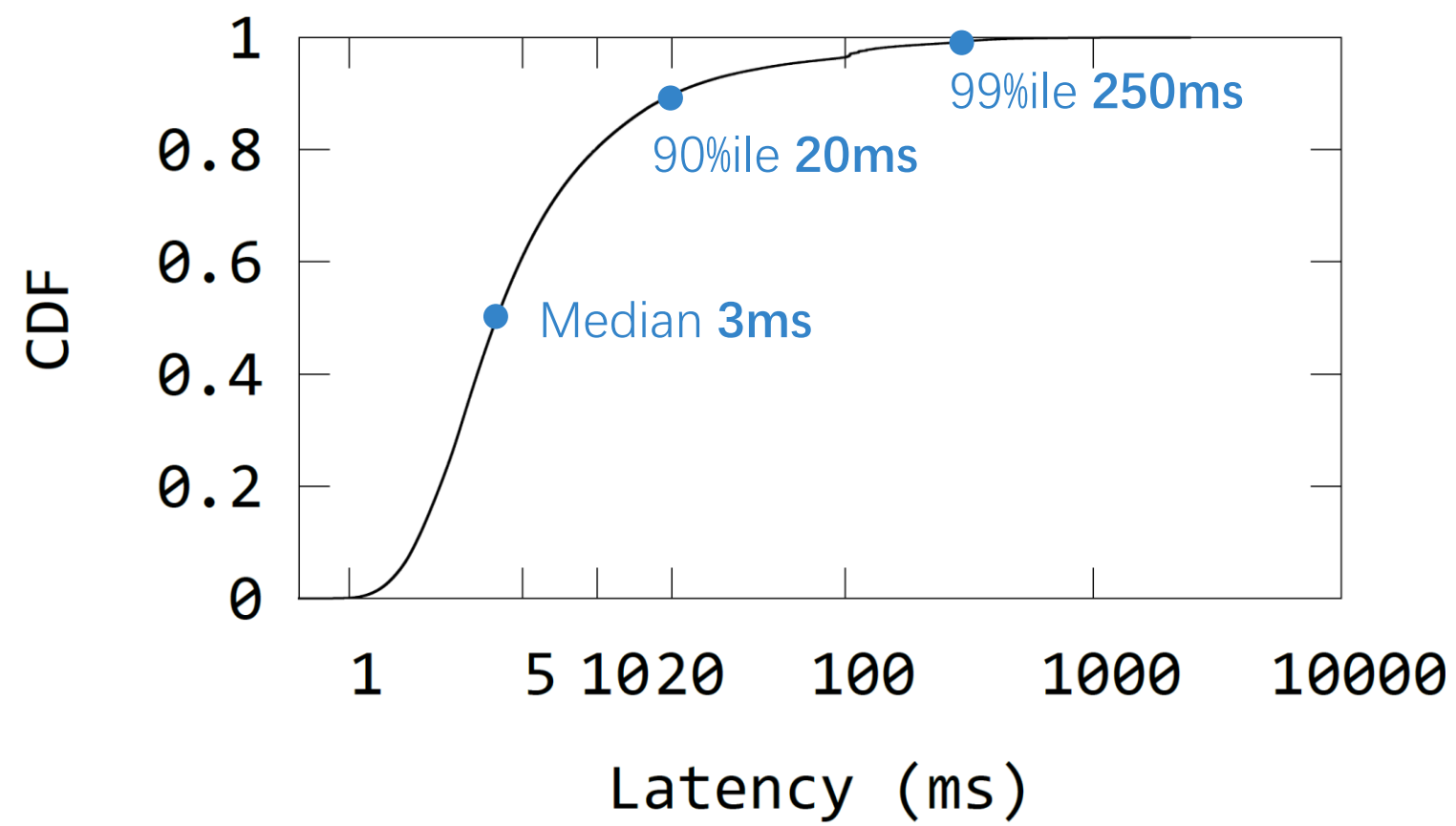
- Low battery cost of devices
 - At most 7%-10% for 24-hour tests
 - Ping2 does not have to always run!
- Accurate
- Light-weighted
 - 1 ordinary server, <10% utilization, for 15,000 devices at peak hour

WiFiSeer Overview



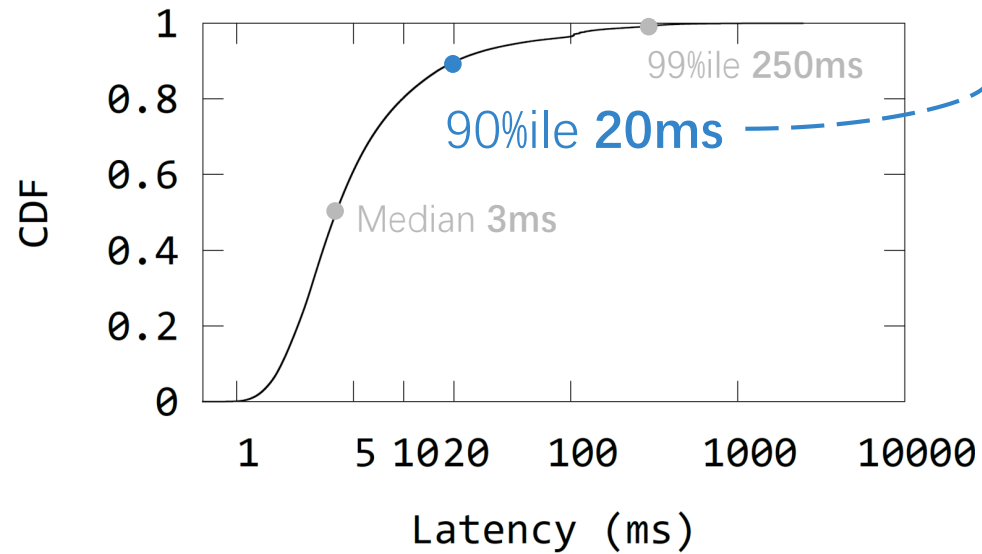
WiFi Latency in the Wild

Long-tailed distribution of WiFi latency



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

Long-tailed distribution of WiFi latency



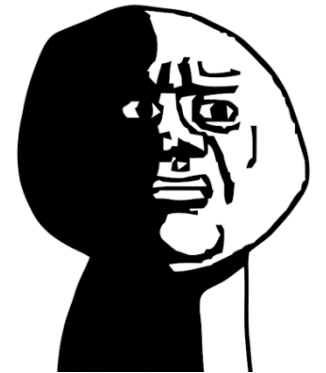
20 ms last-mile latency

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

3 seconds of web page load time

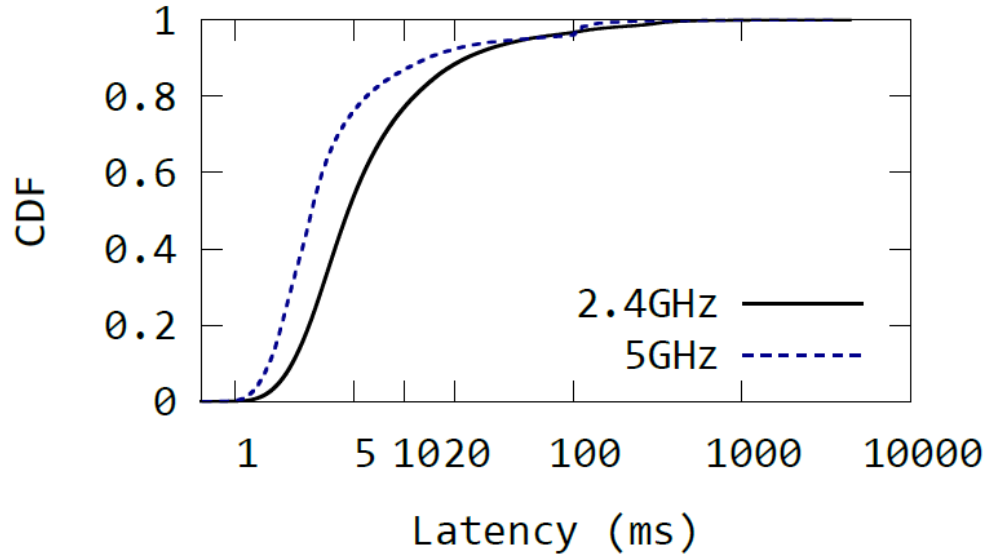
[2] JetNEXUS, Report

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

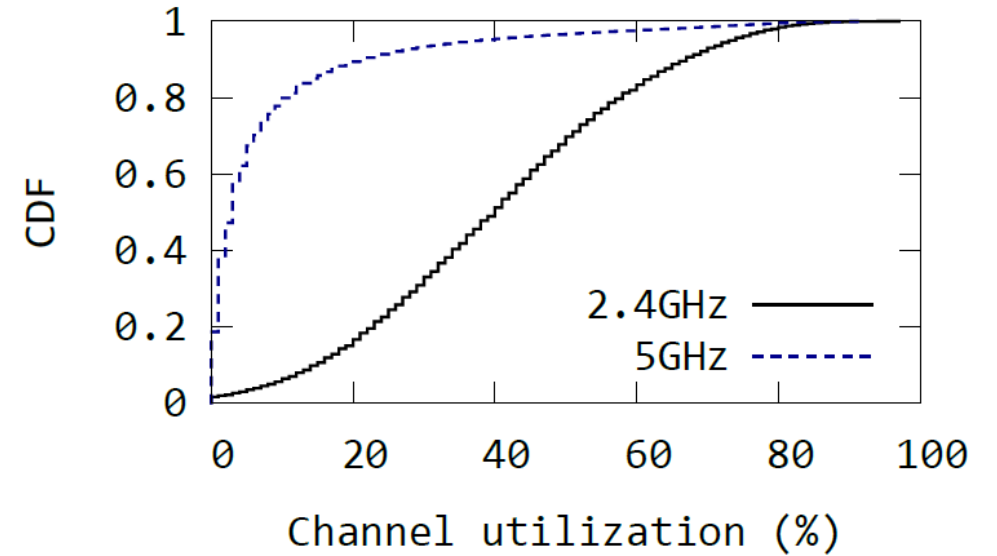


WiFi Latency in the Wild

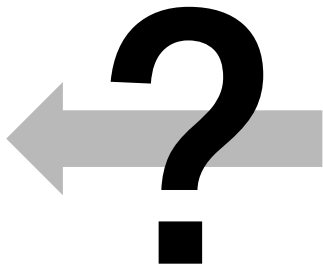
5 GHz has lower latency than 2.4 GHz



Over-utilized 2.4 GHz



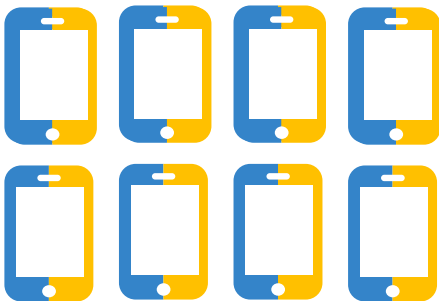
Over-utilized
2.4 GHz



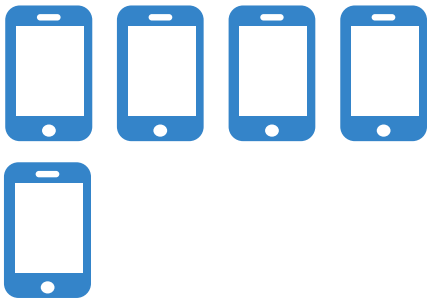
But in Tsinghua

1

Dual-band devices 1.6×



2.4 GHz only devices



2

Cisco band steering is used

Please connect to 5GHz if you can



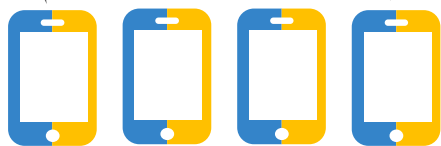
AP

Over-utilized
2.4 GHz

Because



No, we want to use 2.4 GHz

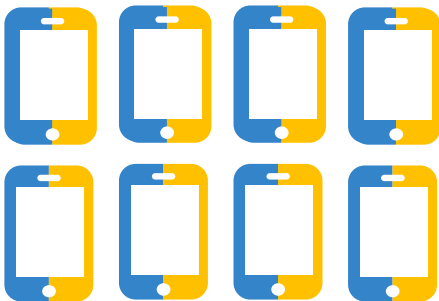


Devices

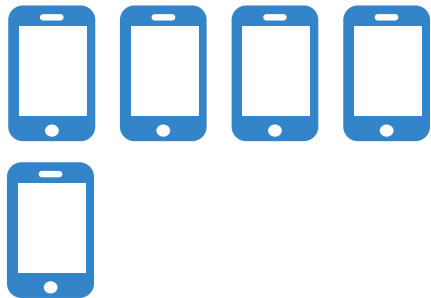
But in Tsinghua

1

Dual-band devices 1.6×



2.4 GHz only devices



2


Cisco band steering is used

Please connect to 5GHz if you can



WiFi Latency in the Wild

Add 5 GHz only SSID
"Tsinghua-5G"

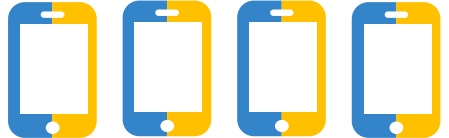


I will use 5 GHz!

User

Solution

No, we want to use 2.4 GHz



Devices

(See the paper)

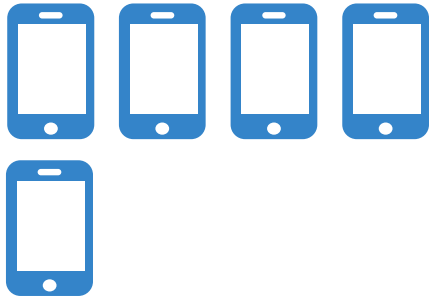

But in Tsinghua

1

Dual-band devices

1.6×

2.4 GHz only devices



2

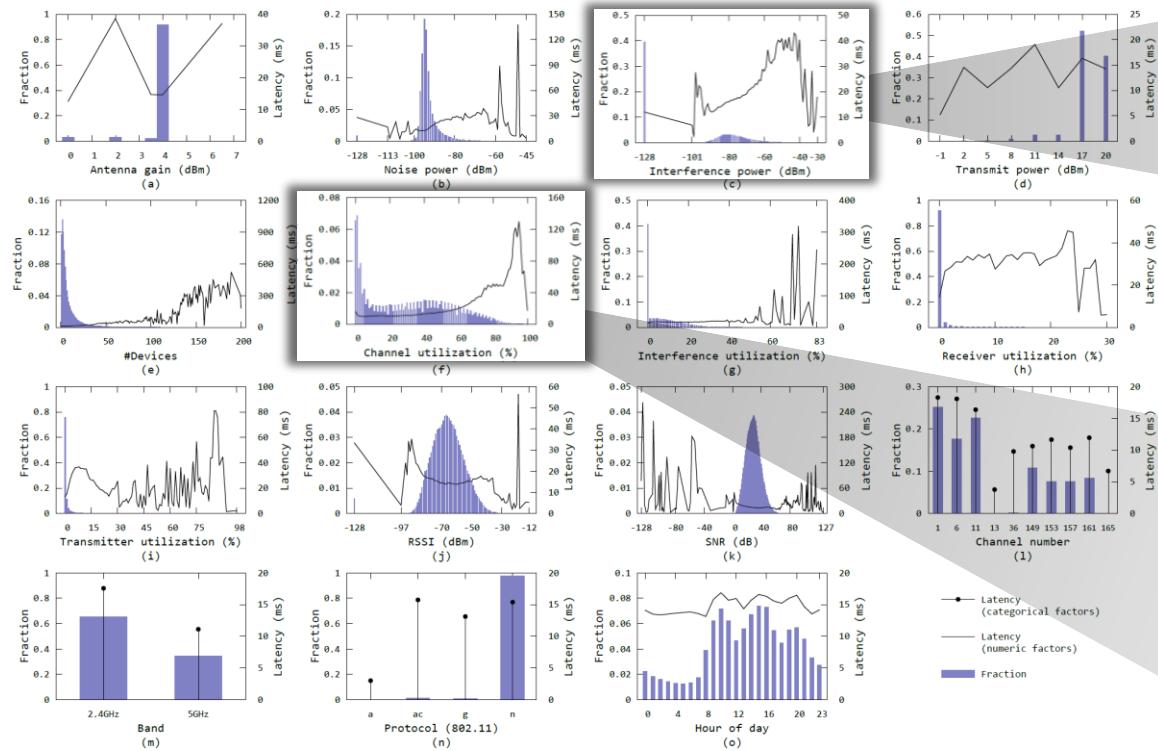
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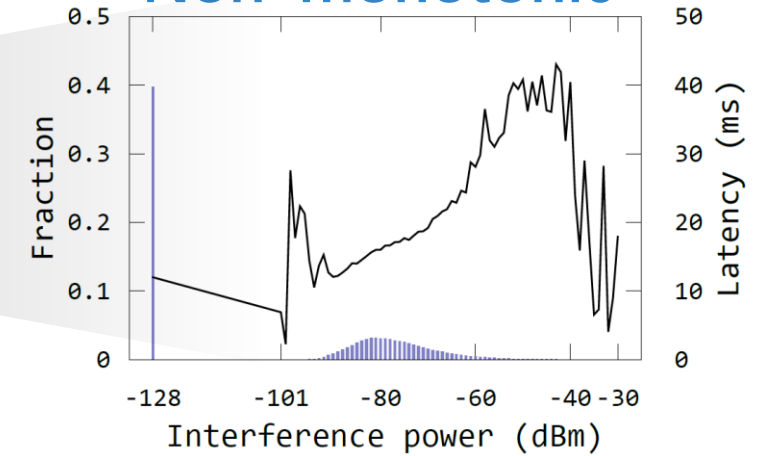


WiFi Latency in the Wild

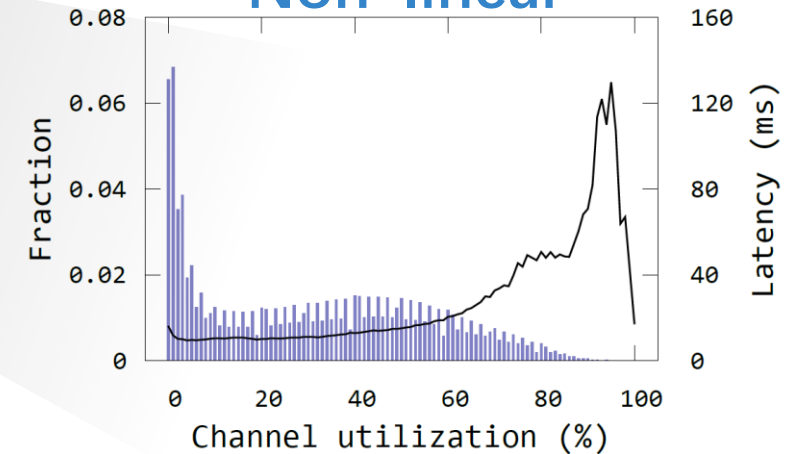
Complex relationships between WiFi latency and related factors



Non-monotonic

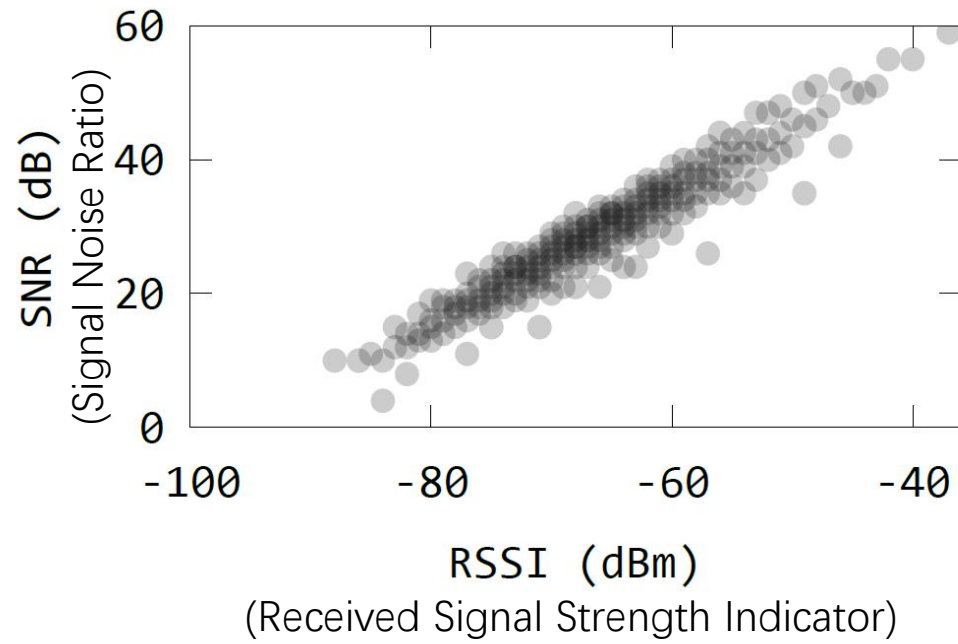


Non-linear

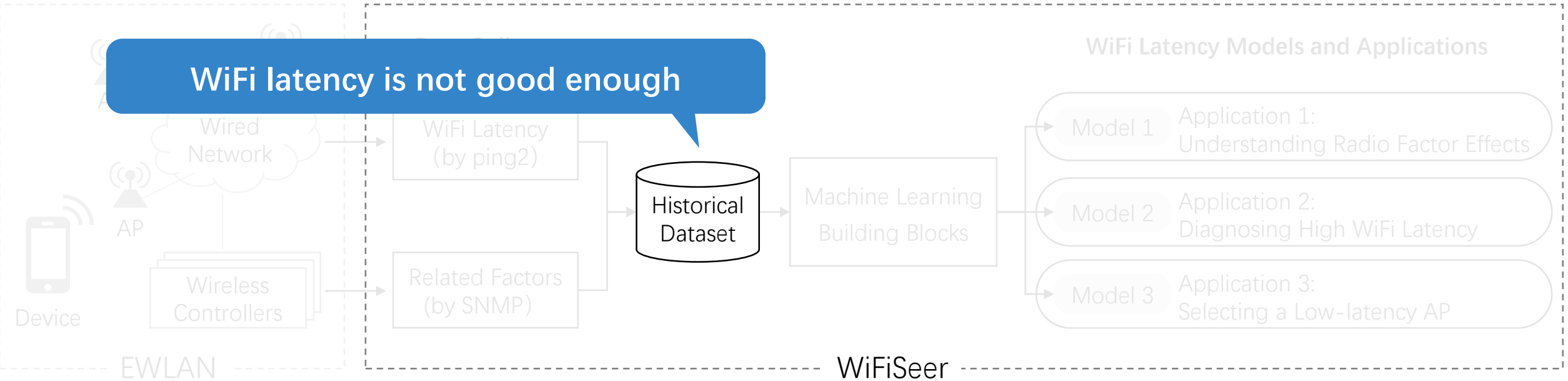


WiFi Latency in the Wild

Interdependencies between related factors



WiFiSeer Overview

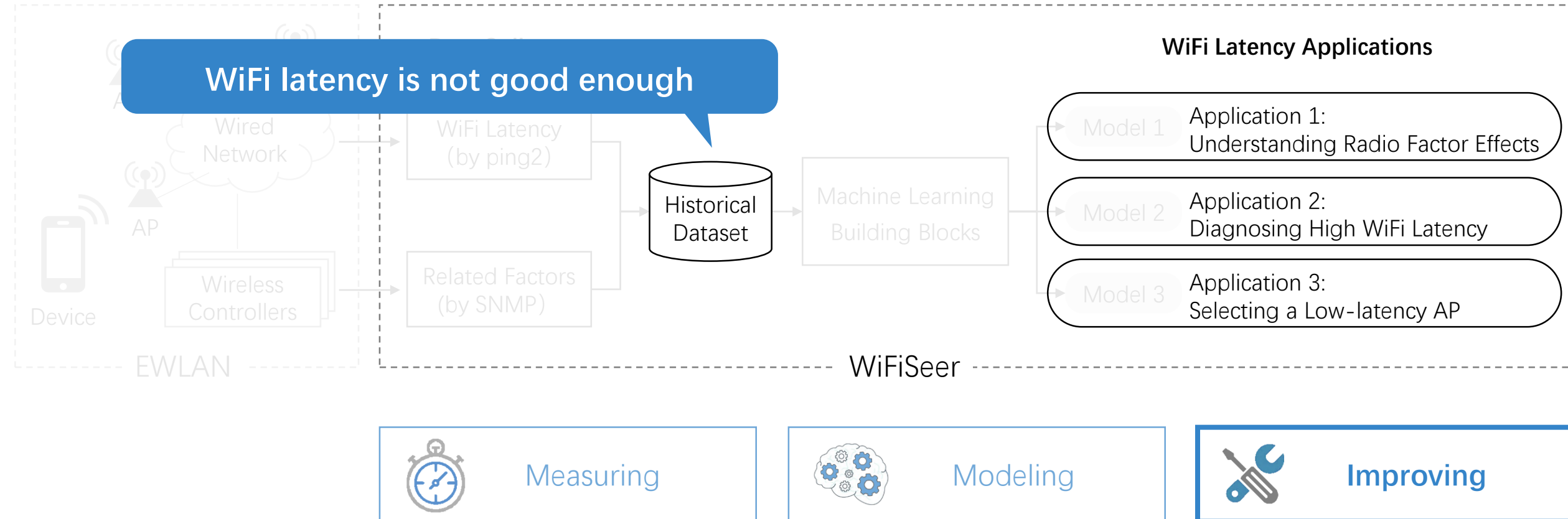




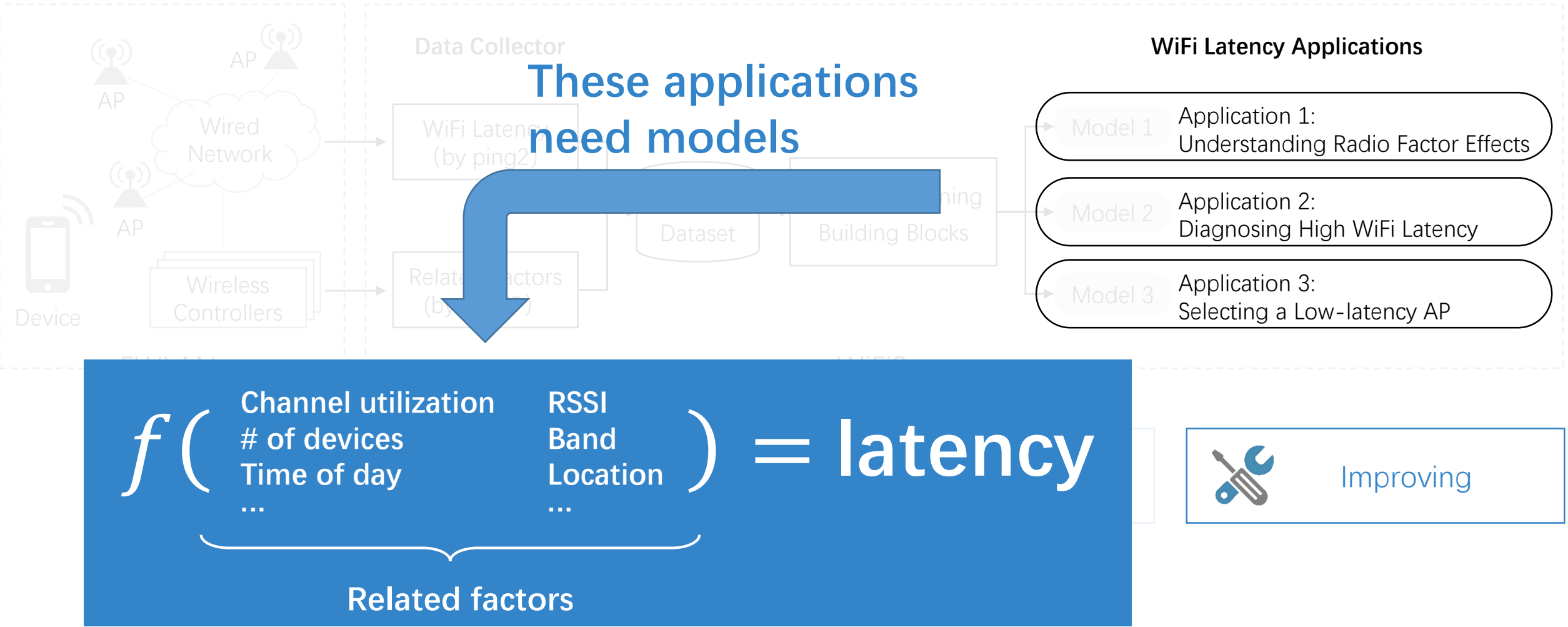
Measuring

How to improve?

WiFiSeer Overview



WiFiSeer Overview



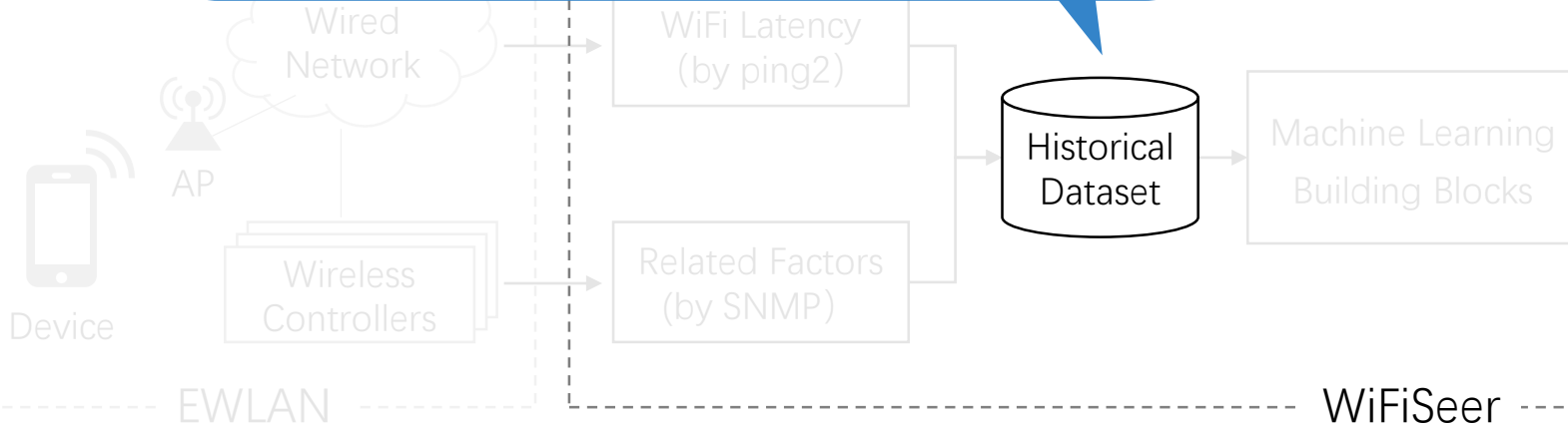
WiFiSeer Overview

Modeling Challenges

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

WiFi Latency Applications

- Model 1 Application 1: Understanding Radio Factor Effects
- Model 2 Application 2: Diagnosing High WiFi Latency
- Model 3 Application 3: Selecting a Low-latency AP



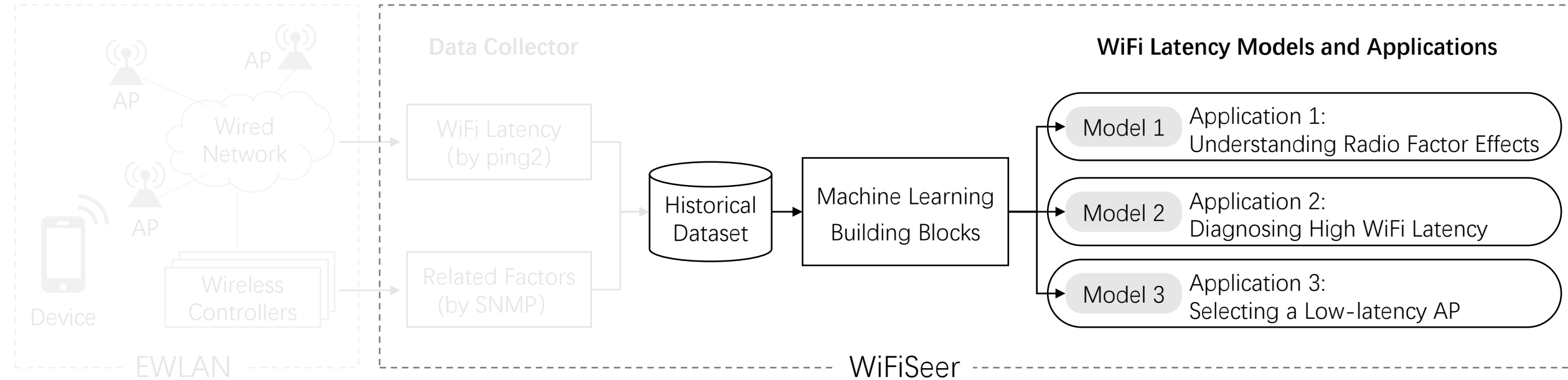
Measuring

How to model?



Improving

WiFiSeer Overview



Measuring



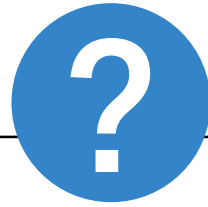
Modeling



Improving

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

Different applications require different models



Machine Learning
Building Blocks

Different applications require different models

 Factors used

 Classes

...

Machine Learning
Building Blocks

 Interpretable

 Algorithm

...

Tailor models for applications

Different applications require different models

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



Building Blocks

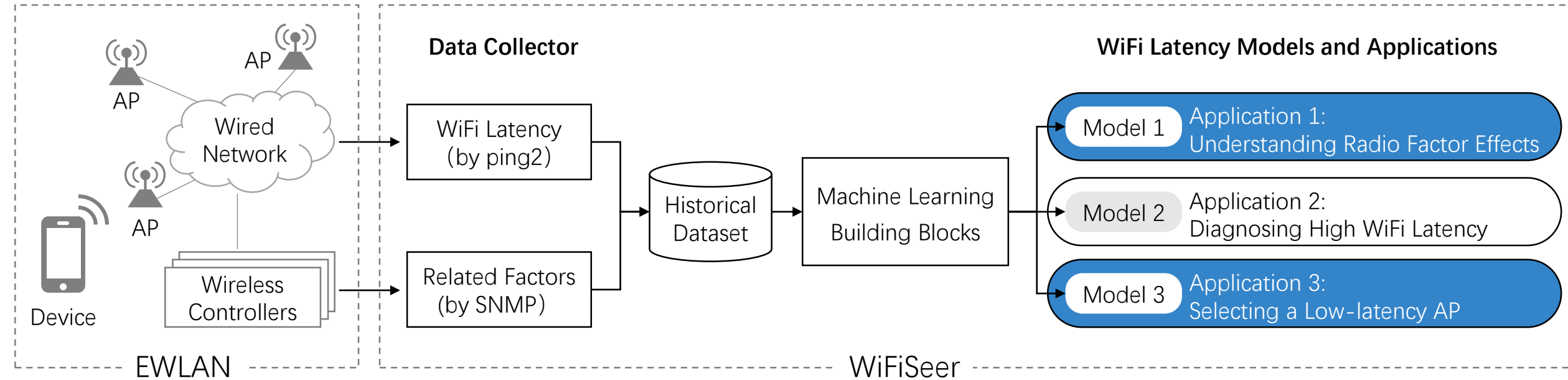
Application 3: Selecting a Low-latency AP
Random forest (more accurate)



...

Tailor models for applications

WiFiSeer Overview



Measuring

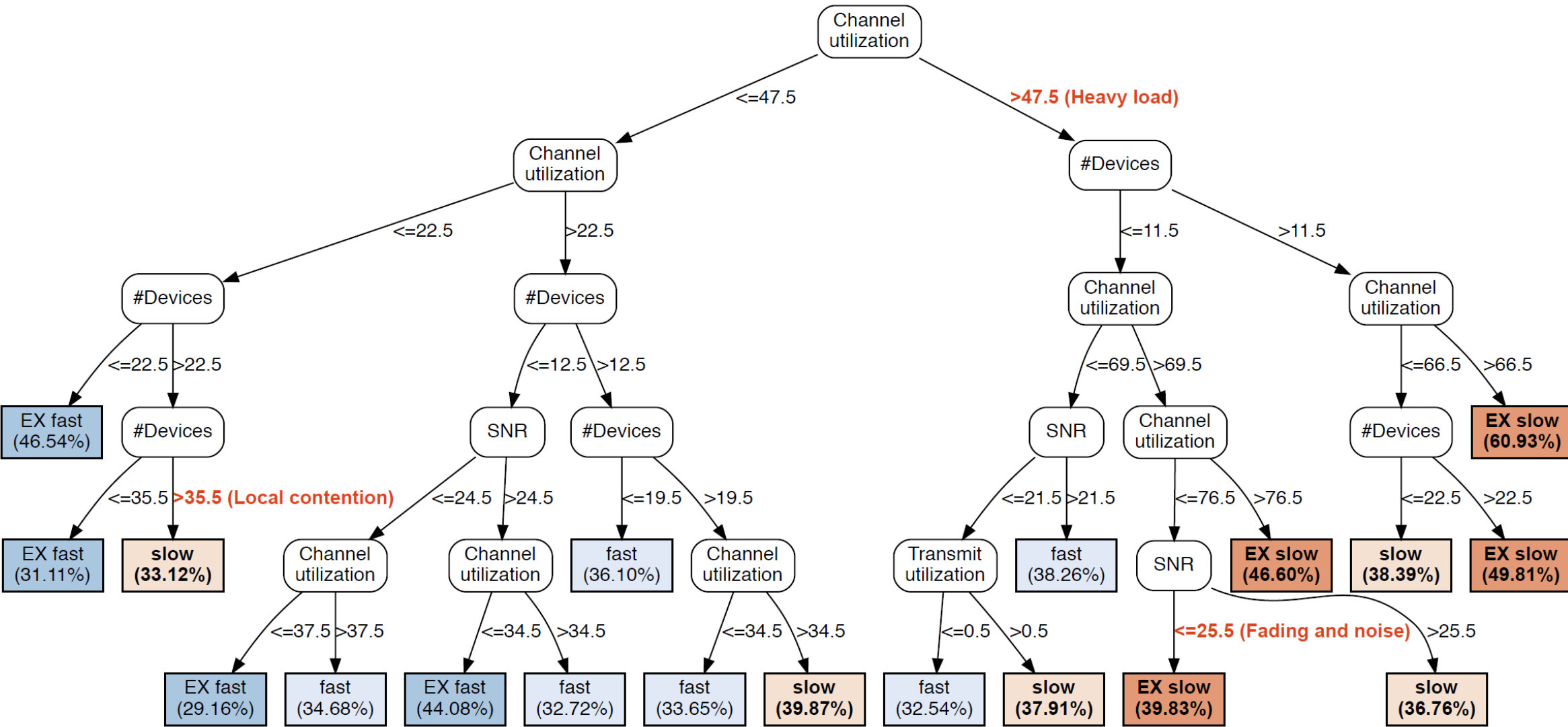


Modeling



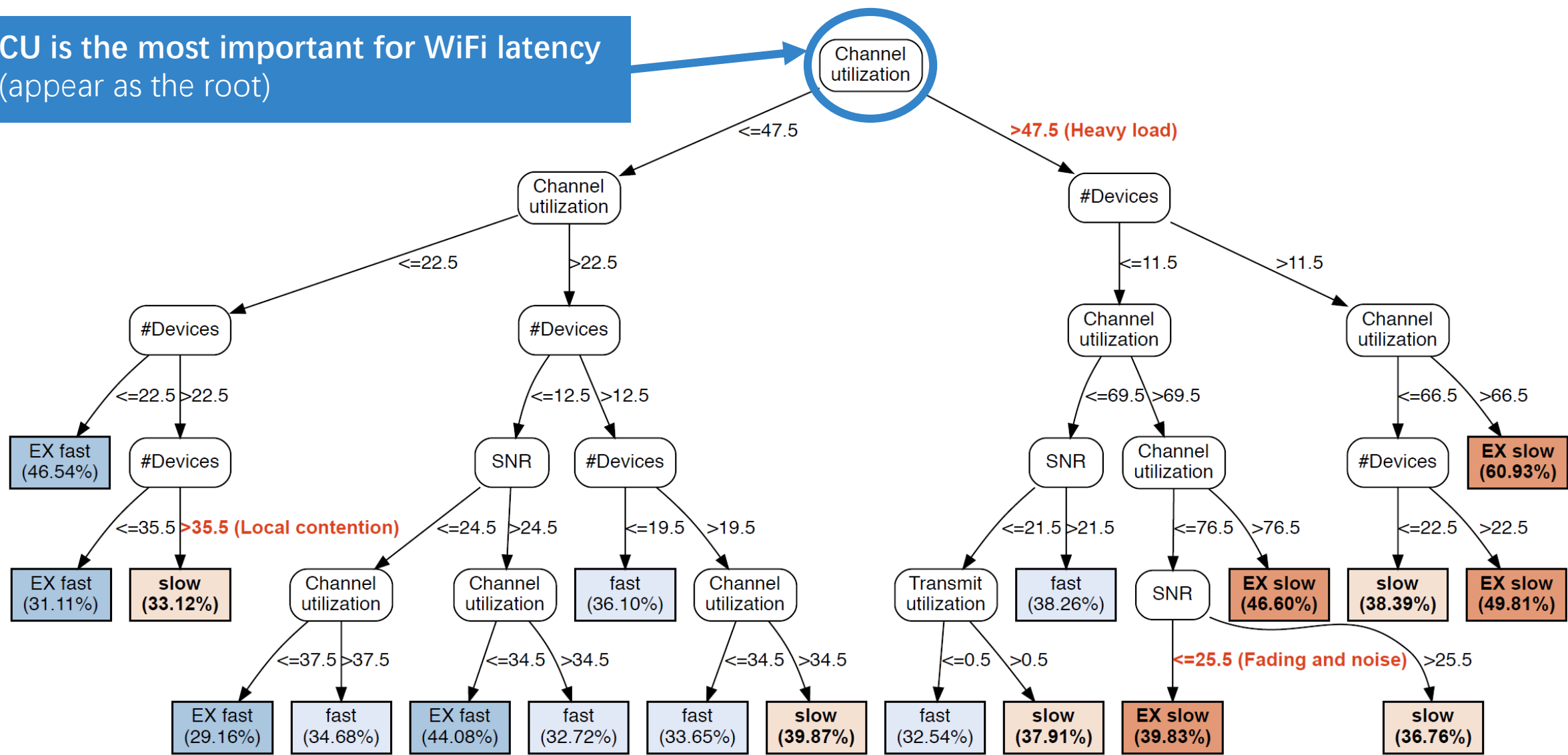
Improving

Application 1: Understanding Radio Factor Effects

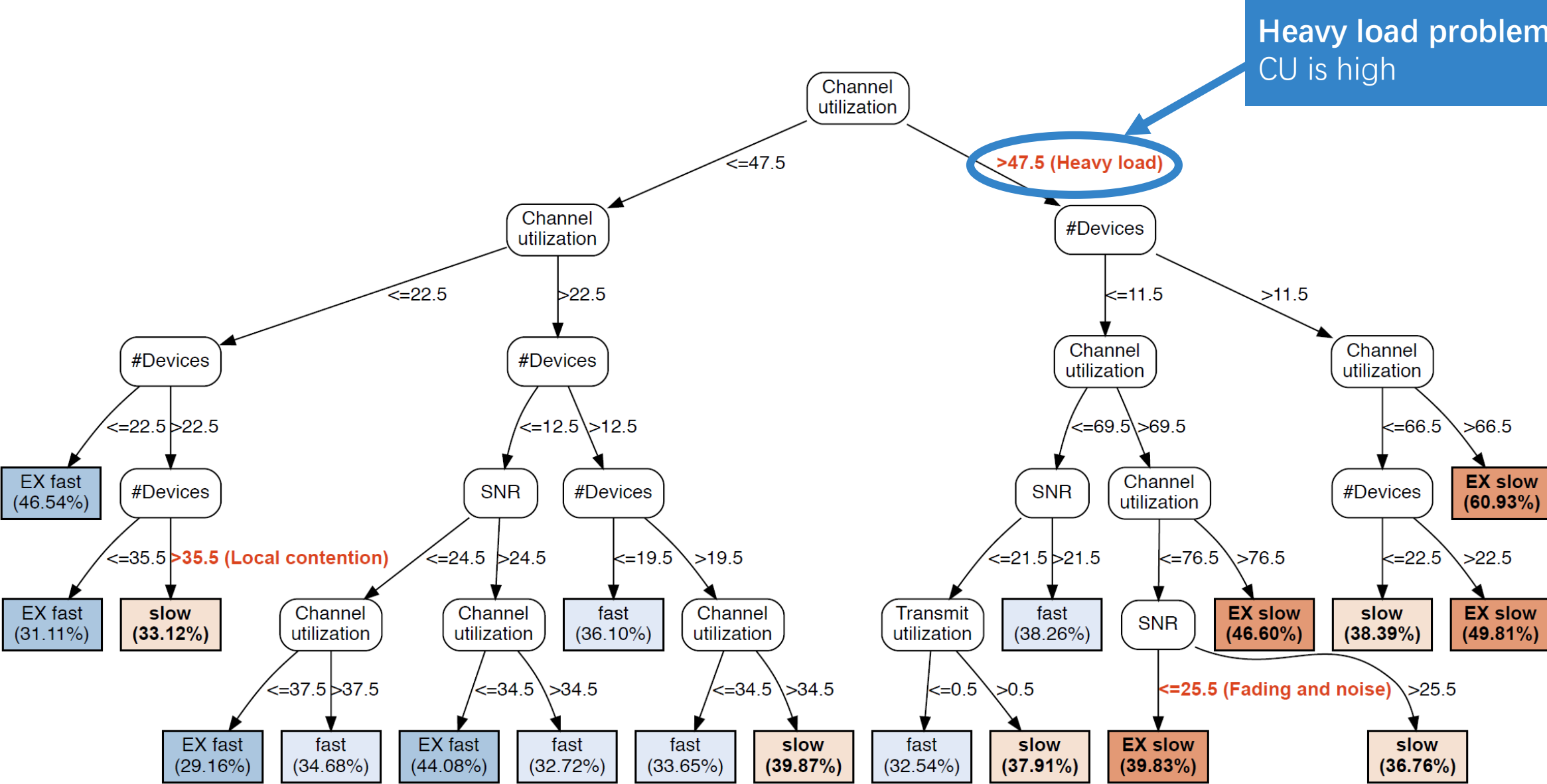


Application 1: Understanding Radio Factor Effects

CU is the most important for WiFi latency
(appear as the root)

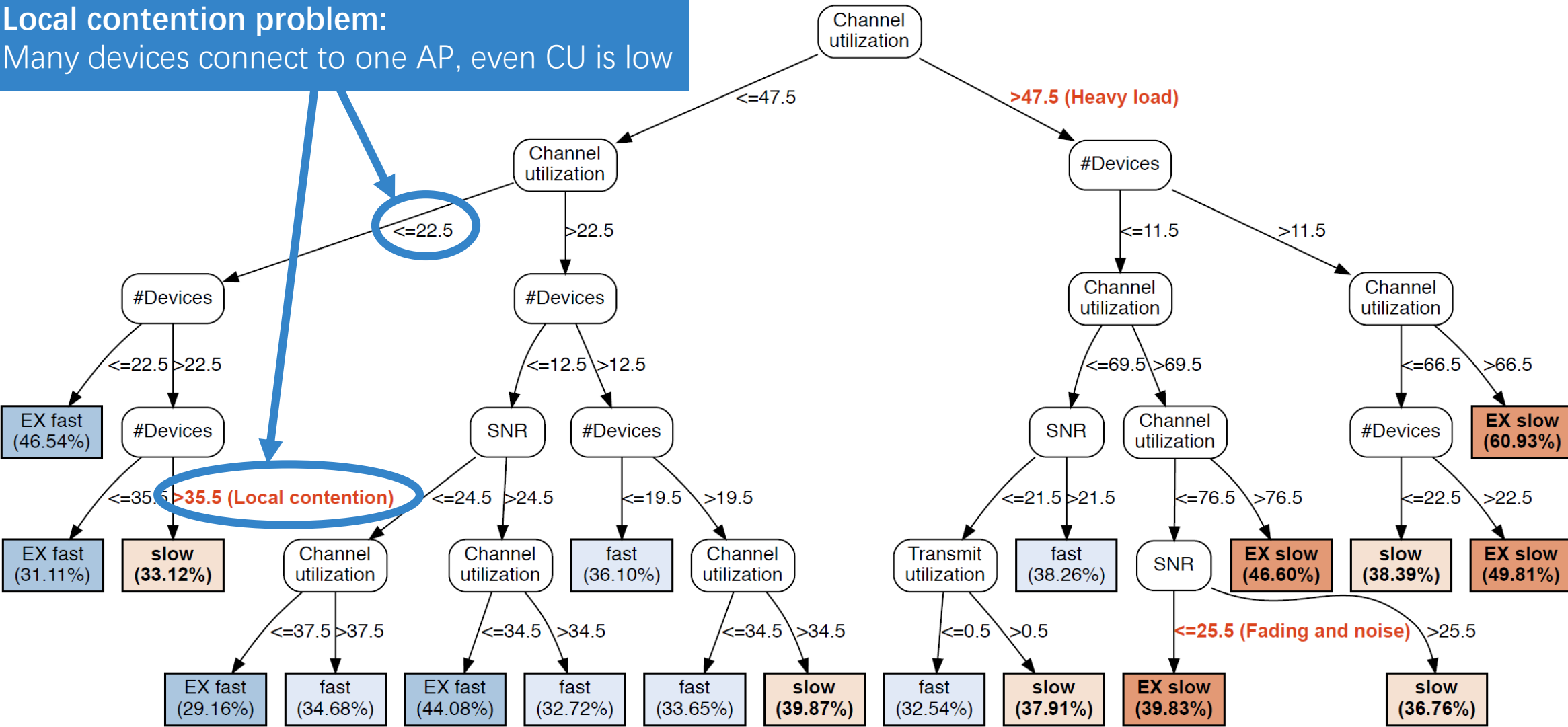


Application 1: Understanding Radio Factor Effects

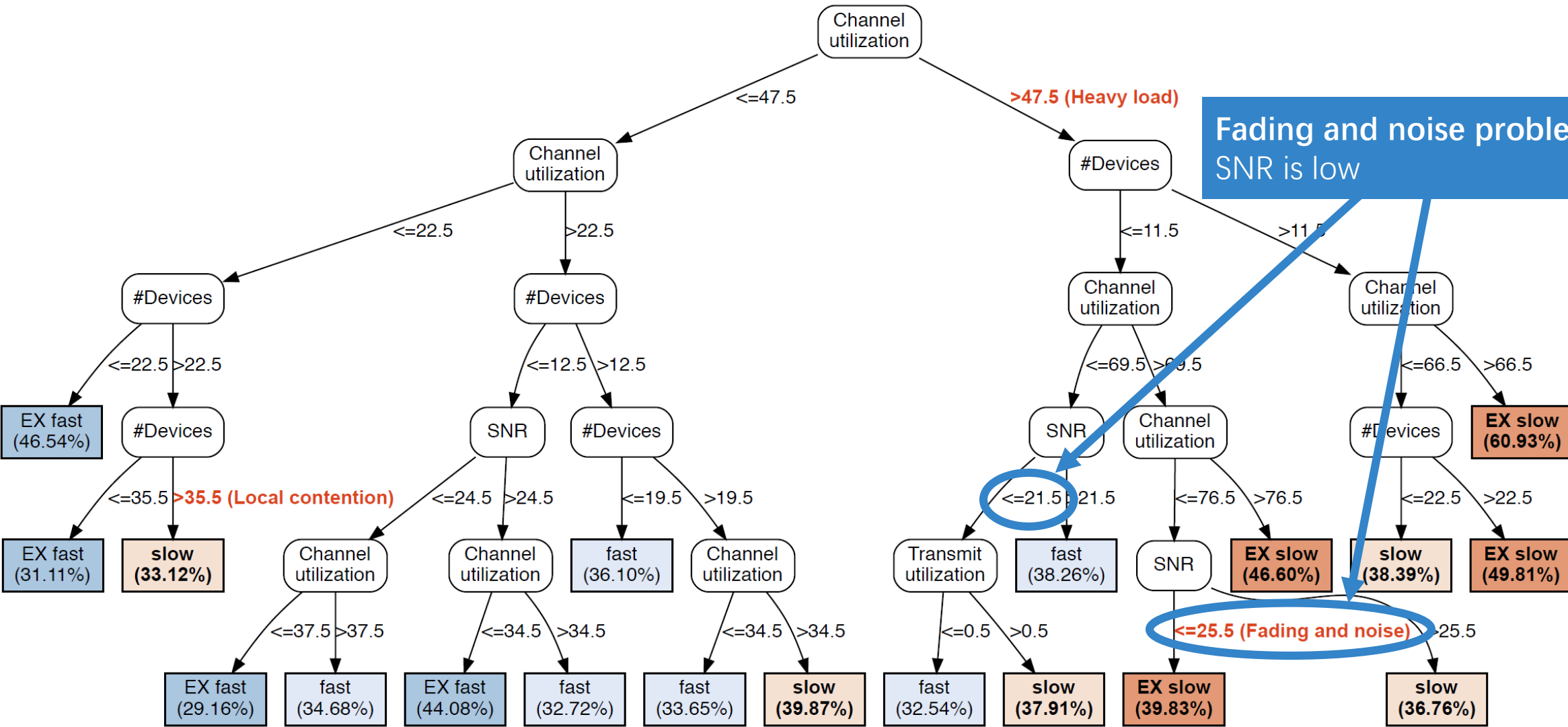


Application 1: Understanding Radio Factor Effects

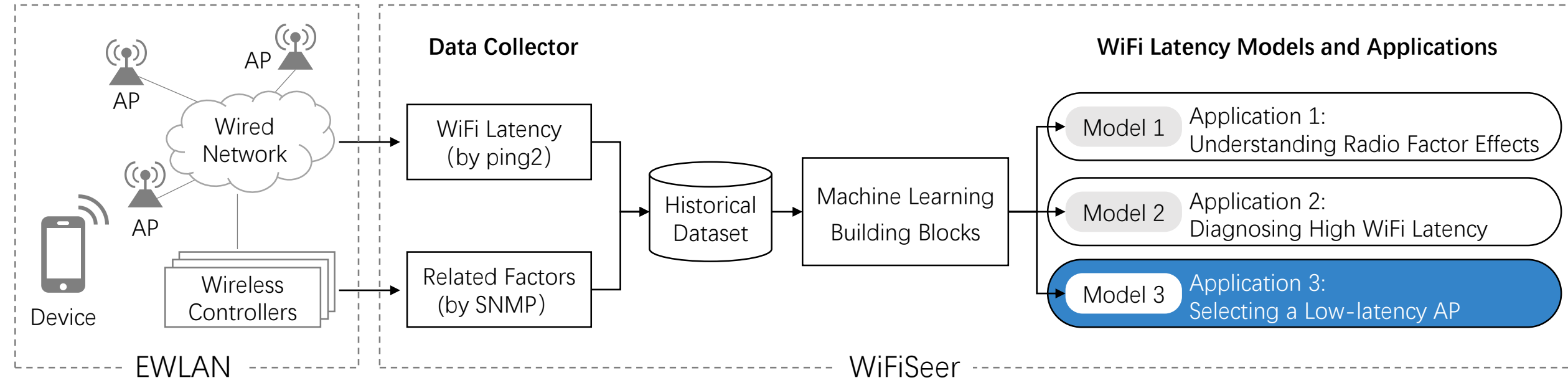
Local contention problem:
Many devices connect to one AP, even CU is low



Application 1: Understanding Radio Factor Effects



WiFiSeer Overview



Measuring

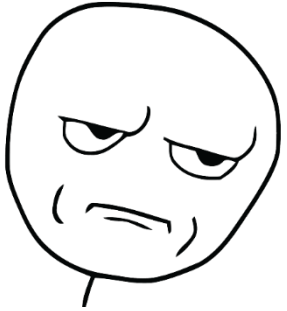


Modeling

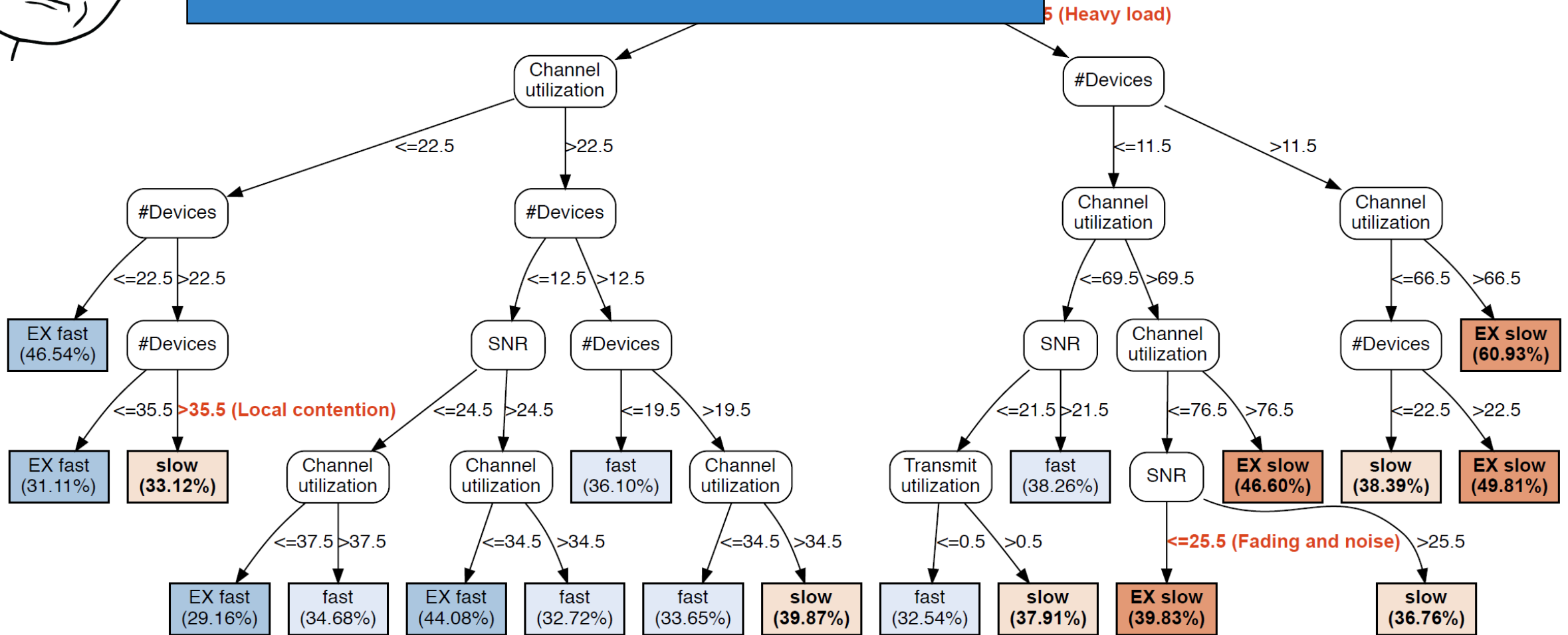


Improving

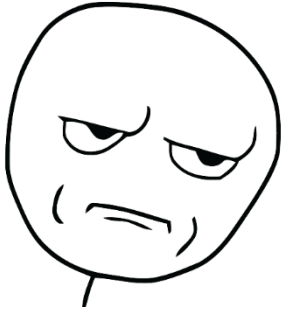
Problem



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

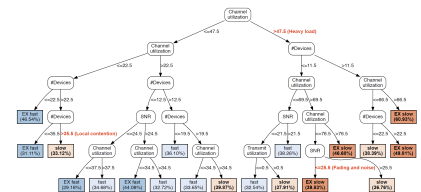
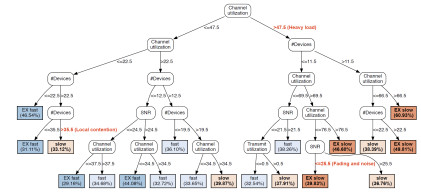


Problem

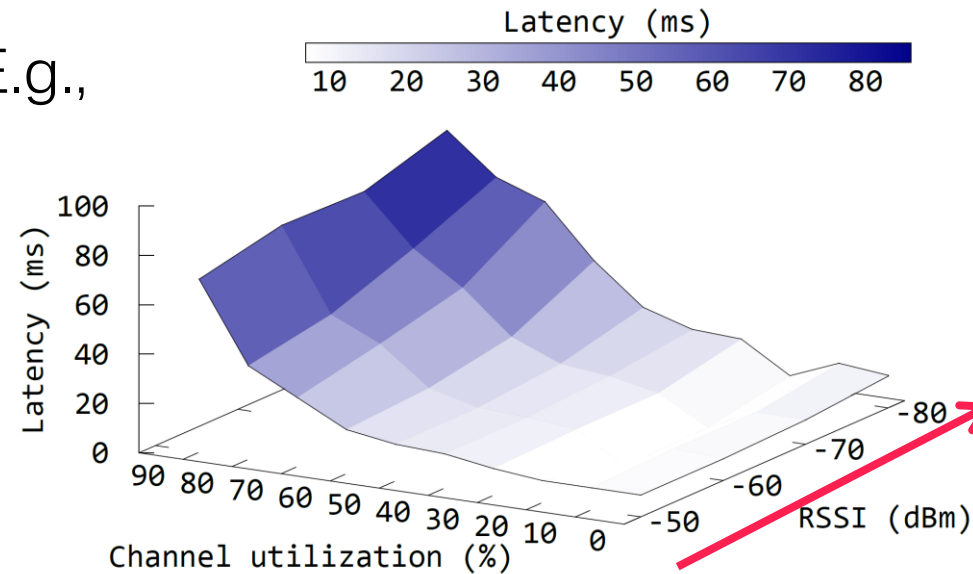


Wait! I can't find RSSI  in the tree!
My phone uses it to select AP, and it is not important?

Yes, RSSI is not that important
for predicting WiFi latency

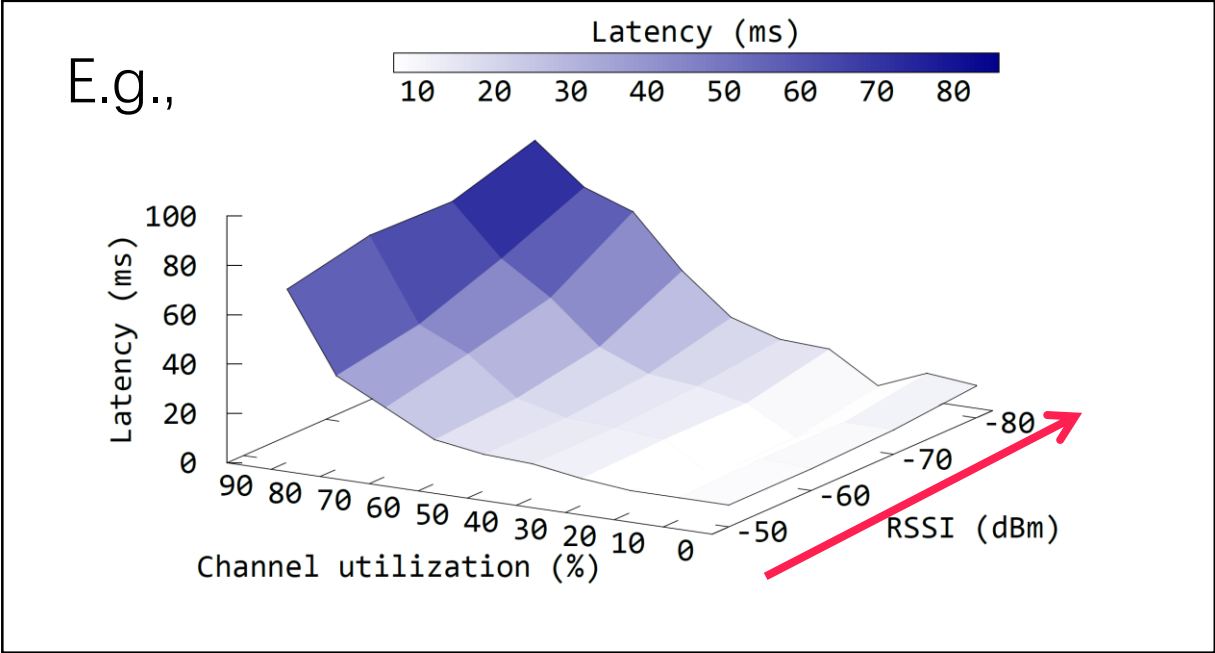


E.g.,

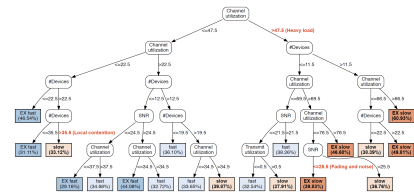
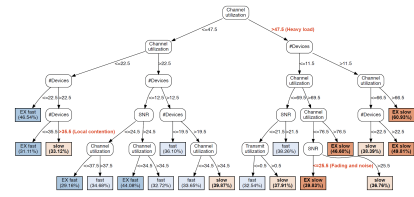
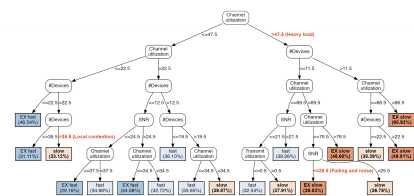


Problem

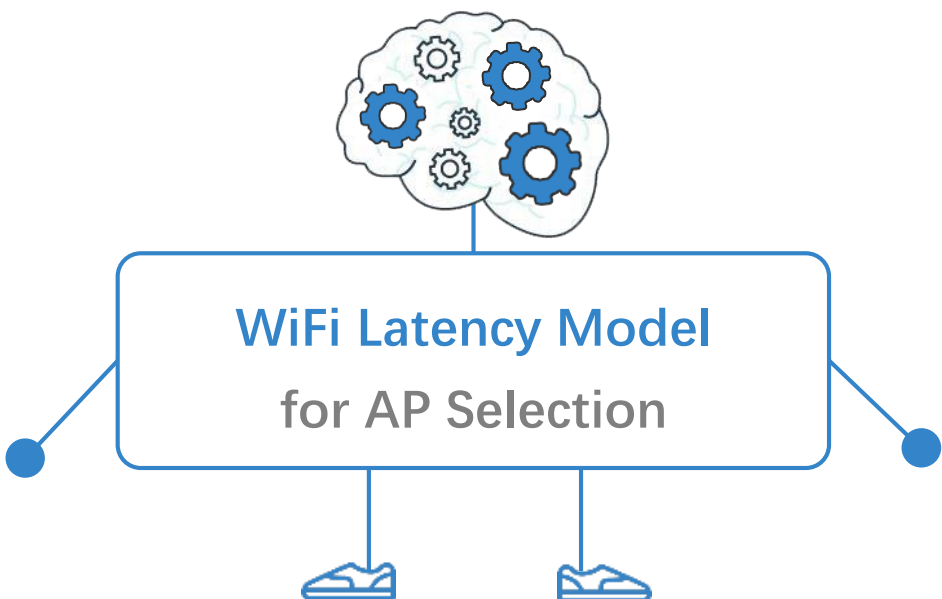
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for predicting WiFi latency



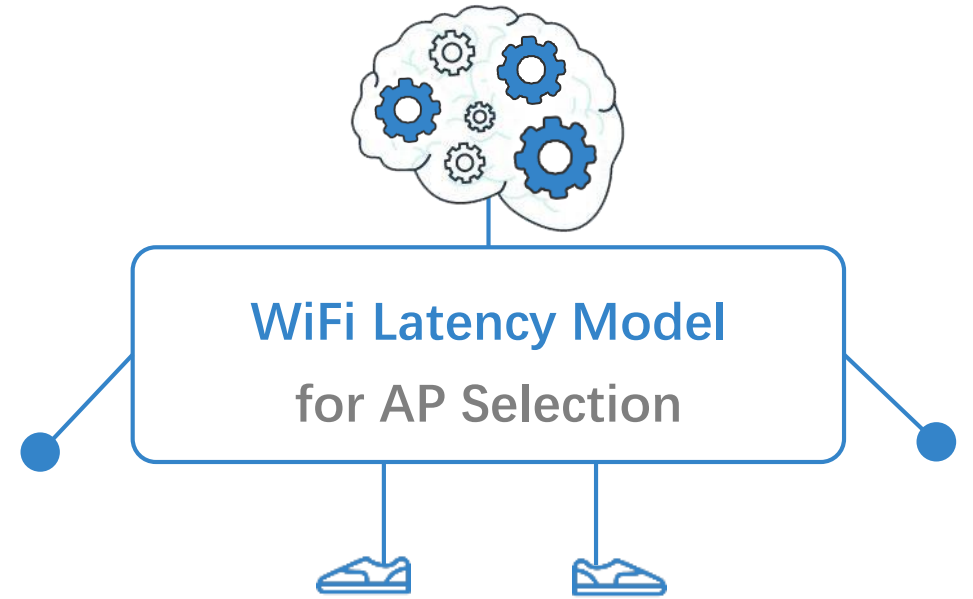
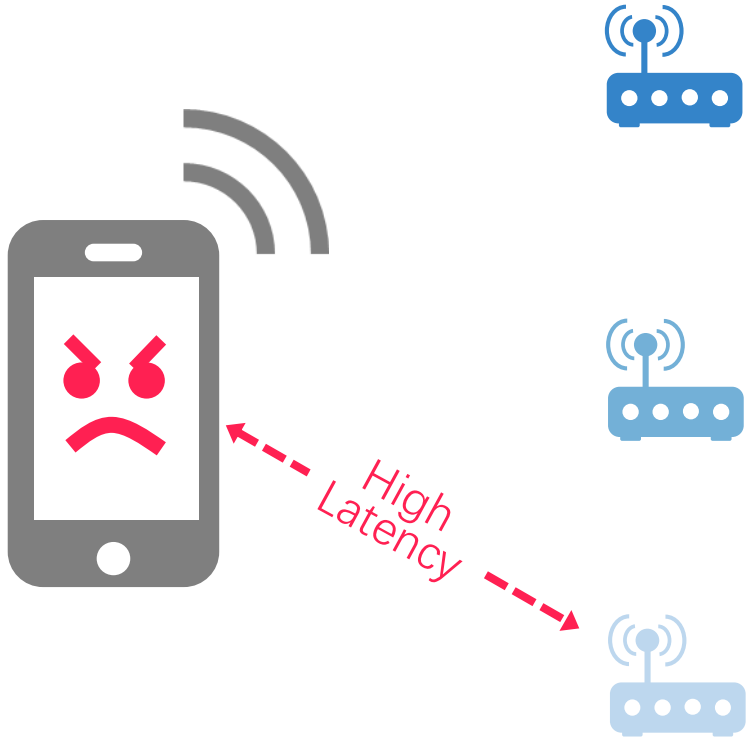
How to select an AP for low latency?



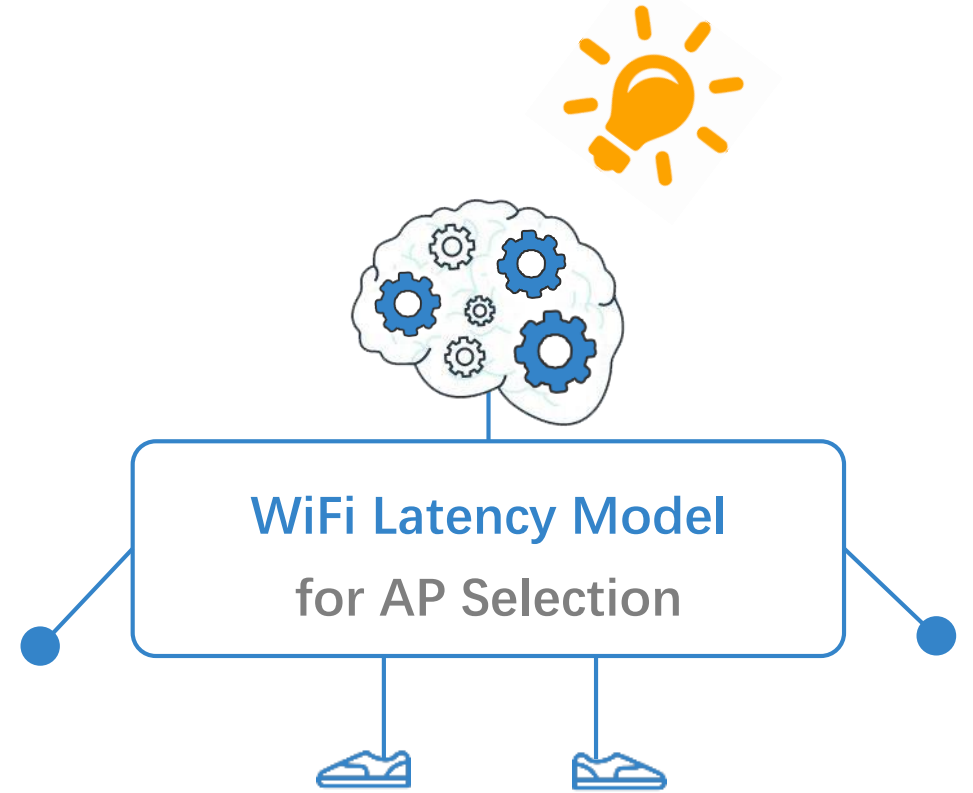
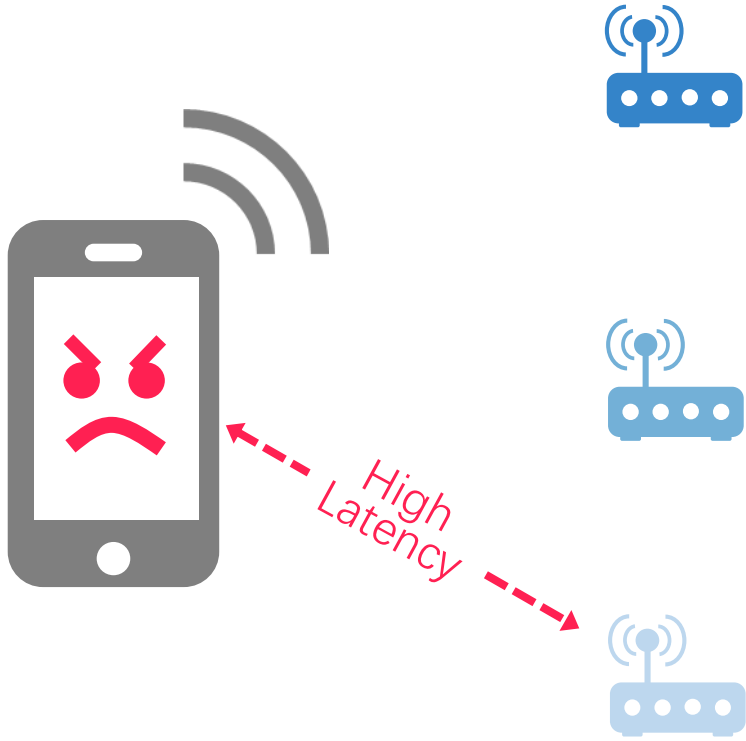
Application 3: Selecting a Low-latency AP



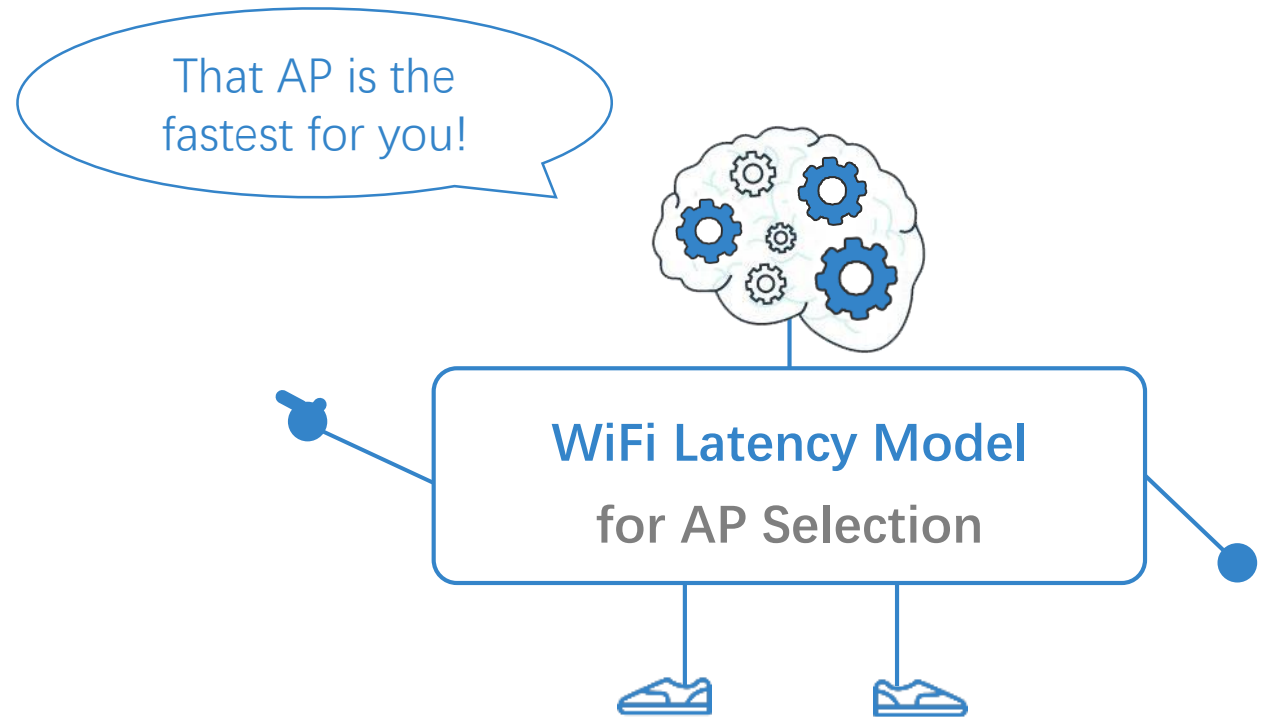
Application 3: Selecting a Low-latency AP



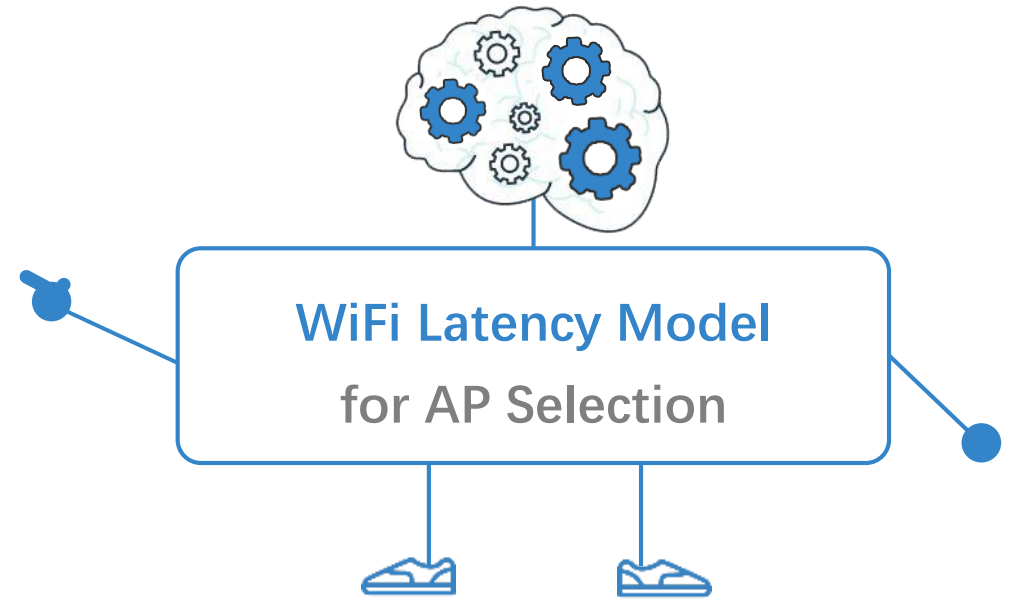
Application 3: Selecting a Low-latency AP



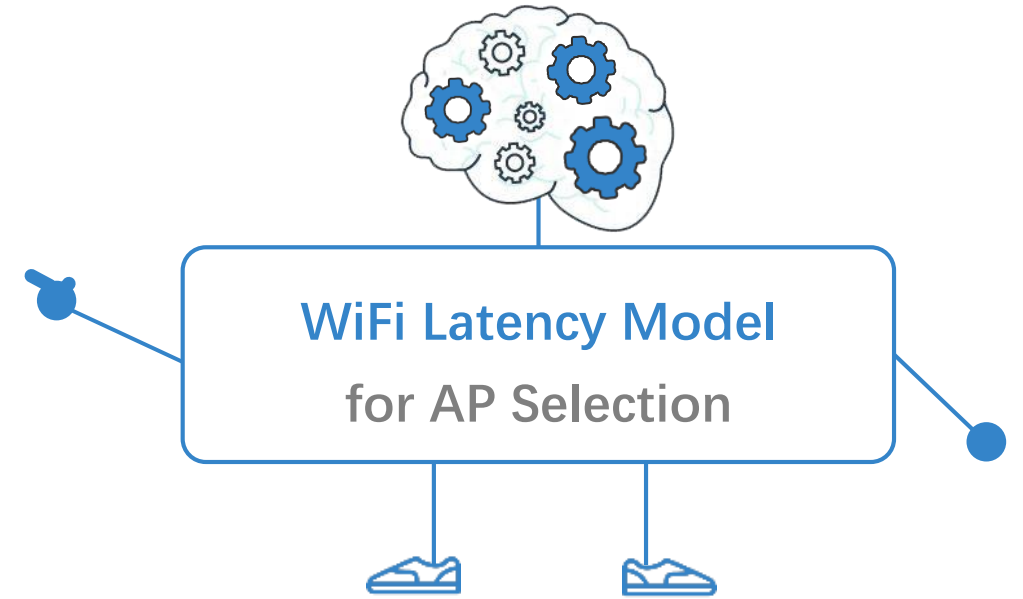
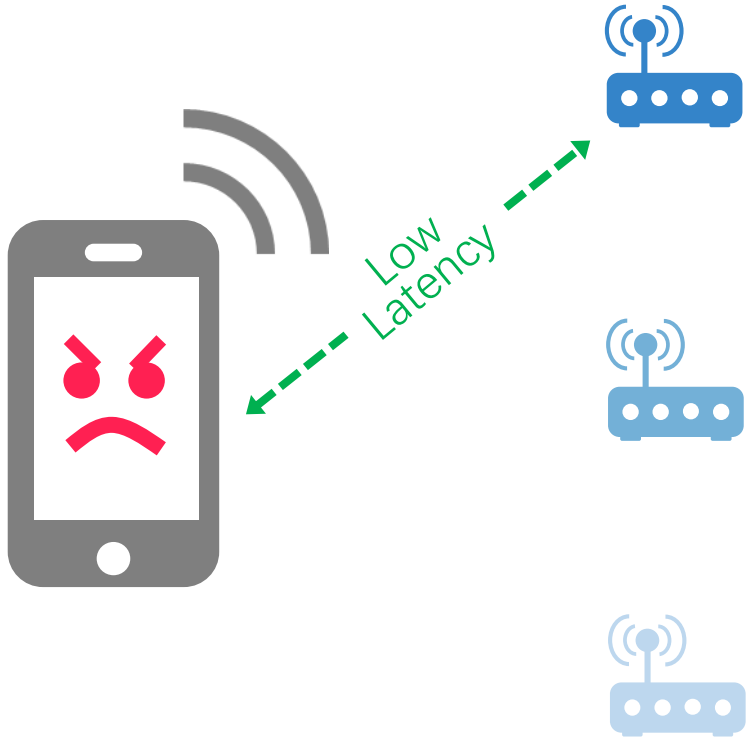
Application 3: Selecting a Low-latency AP



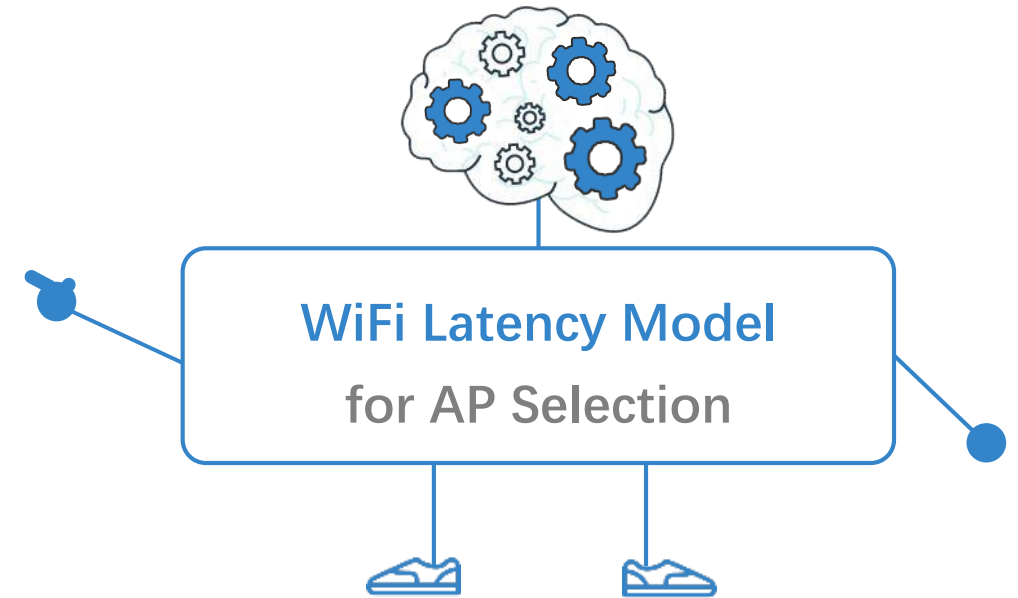
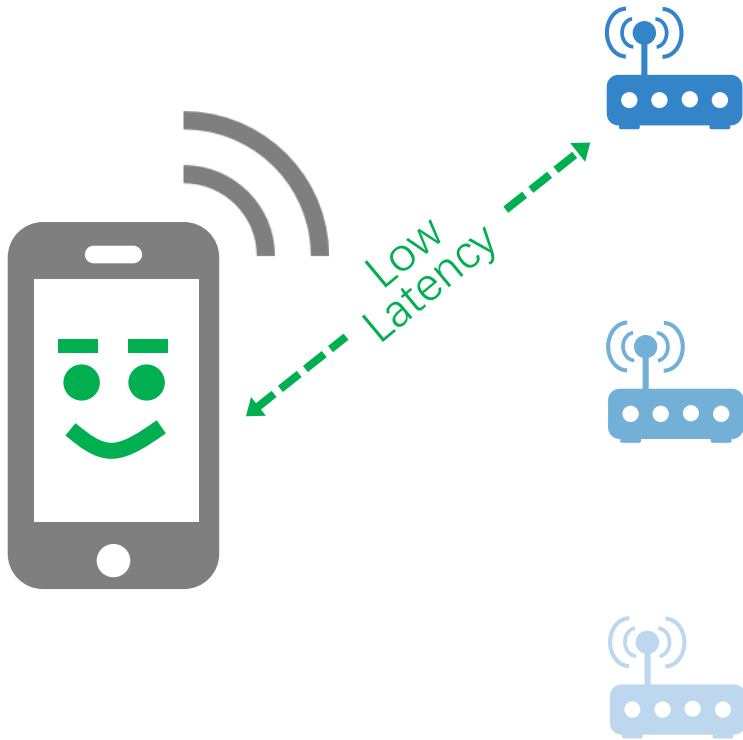
Application 3: Selecting a Low-latency AP



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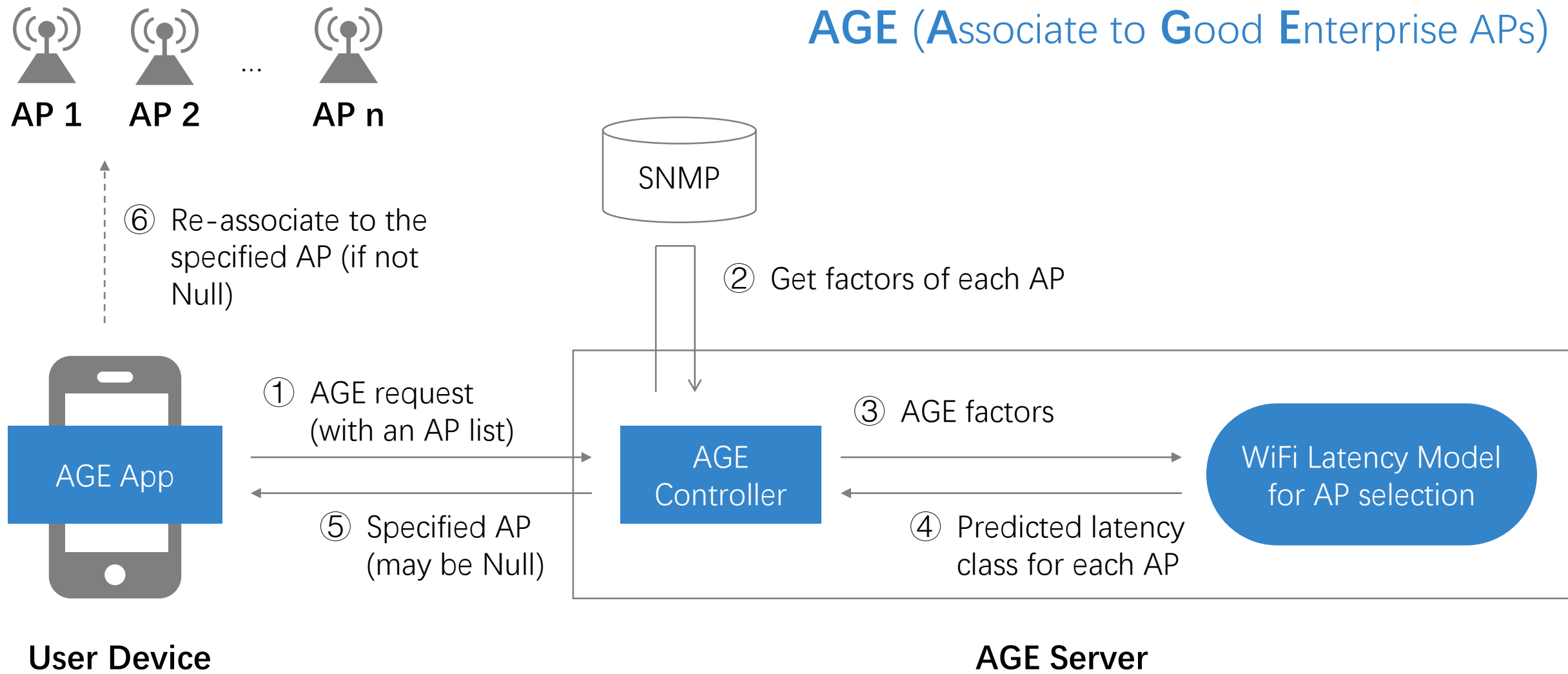
Application 3: Selecting a Low-latency AP



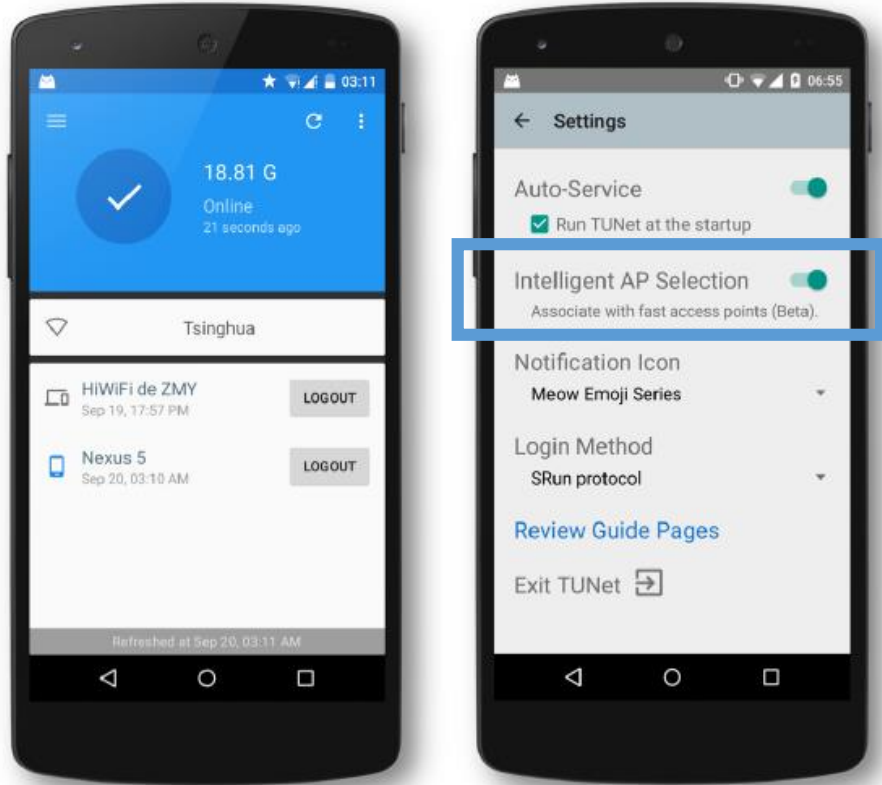
Problem: how to let devices use the AP suggested?

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!

WiFiSeer[📶]
MobiSys 2016

| Thank you

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Microsoft
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