When Mobile Network Meets AI …

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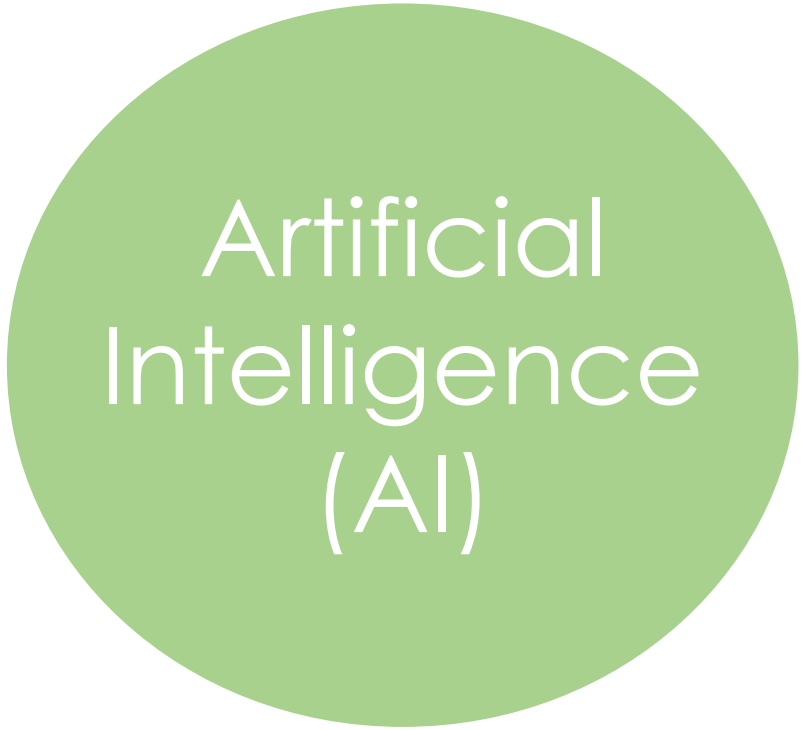
Purdue University

December 2017

Be Connected!



Be Intelligent!

World Internet Conference

- The 4th Wuzhen Summit (Dec 2-6, 2017)

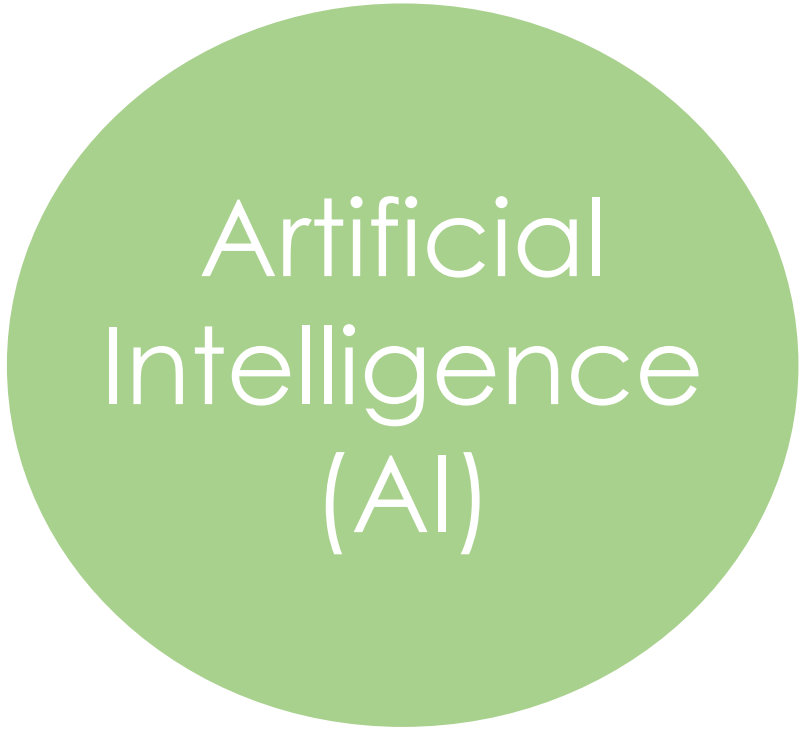
Source: Xinhua

World Leading Achievements and Innovations of Internet Science

still most important to offer critical network infrastructure **remains** as one disruptive technology (5G)

hot, one spotlight that **will lead** the upcoming revolution

Vision: Mobile Network Intelligence



Be Connected!

Be Intelligent!

Be Intelligently Connected!

This Talk

1. What is Mobile Network Intelligence?
   - Different from the existing one
2. Why Mobile Network Intelligence?
   - Motivation
3. How to achieve Mobile Network Intelligence?
   - Our very preliminary efforts
4. What remain open questions?
   - Many opportunities

2. Why Mobile Network Intelligence?

10 Years Ago

9 January 2007

Picture: https://commons.wikimedia.org/wiki/File:Steve_Jobs_presents_iPhone.jpg

Today

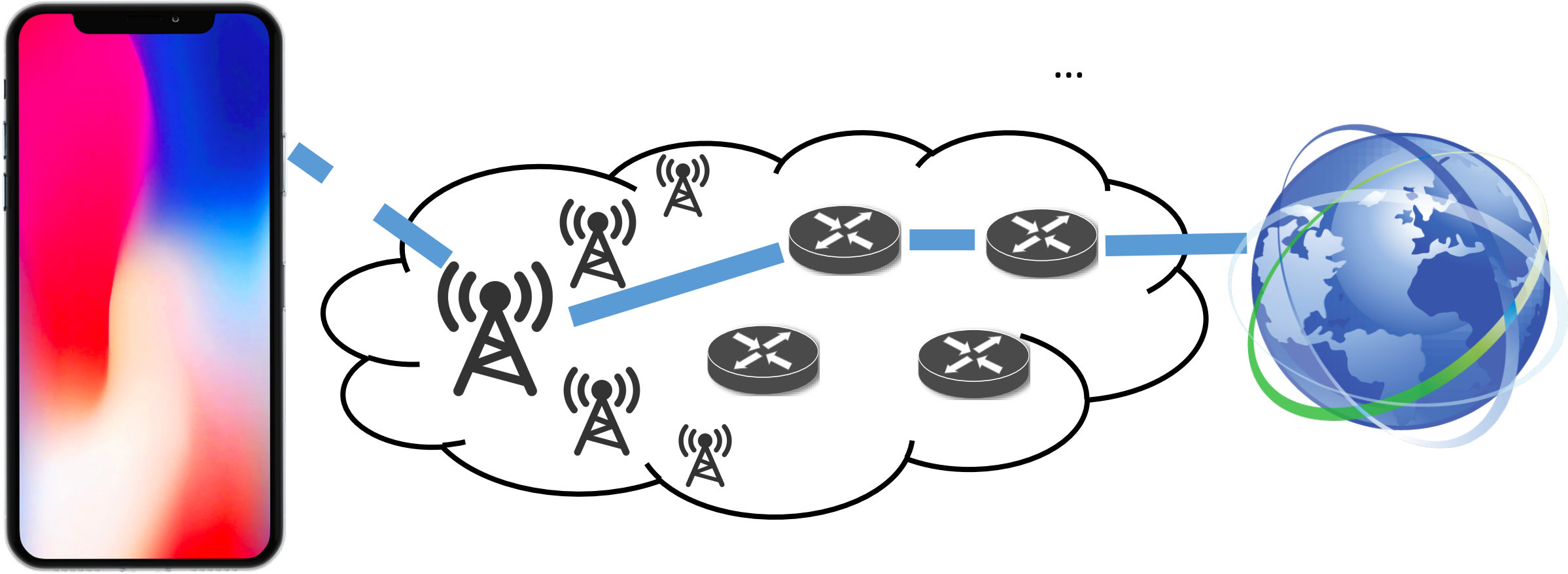
9 January 2007

3 November 2017

Picture: https://commons.wikimedia.org/wiki/File:Steve_Jobs_presents_iPhone.jpg

Only Smartphone?

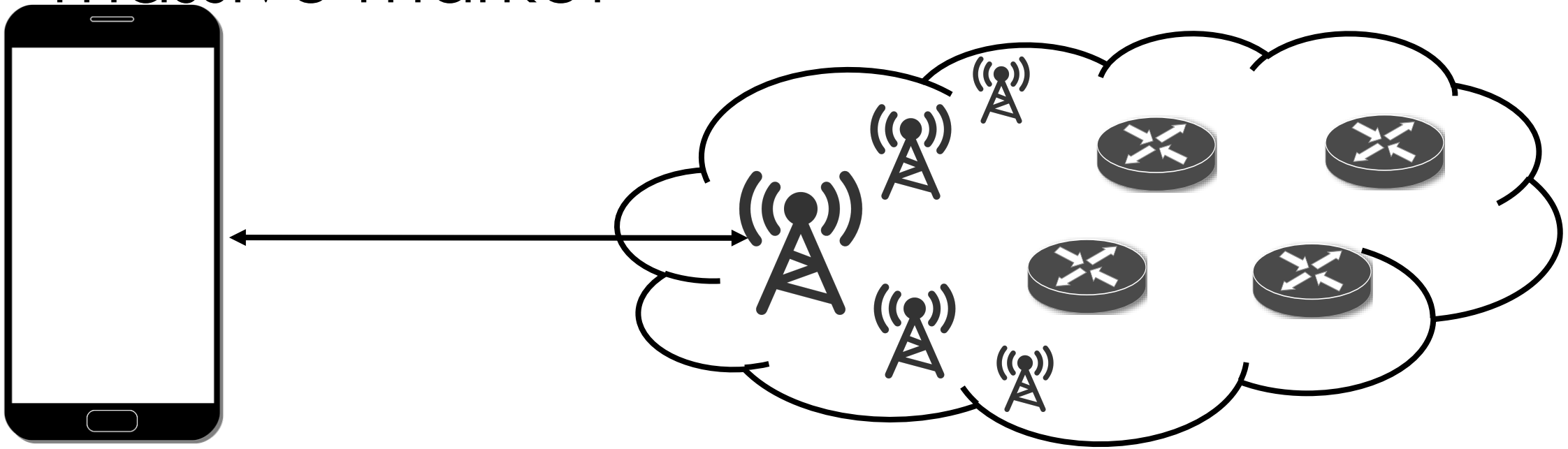
Smartphone only is Not Enough



Mobile Internet

Be Connected!

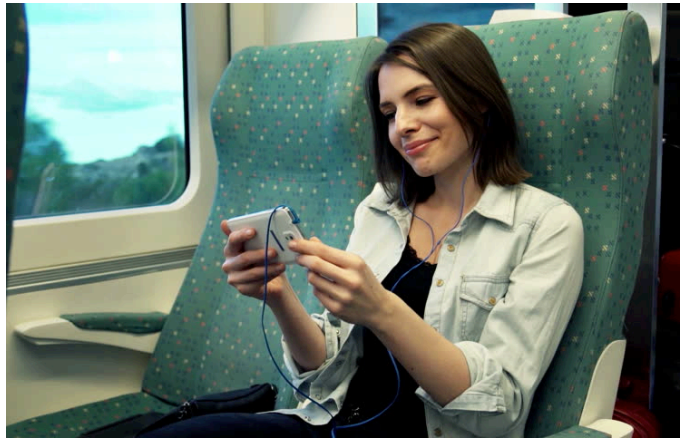
- Mobile networked systems: the only large-scale wireless network infrastructure for the massive market



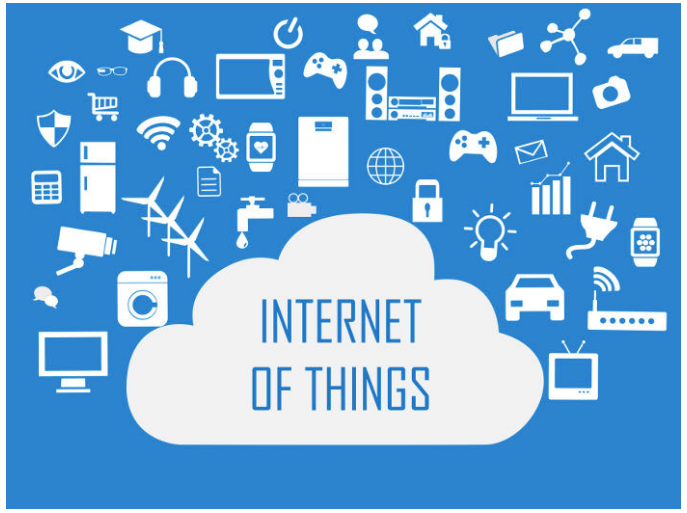
Mobile device
(user equipment)

Cellular network Infrastructure
(radio + core)

Today: Mobile Internet Anywhere



Tomorrow: More than Mobile Internet

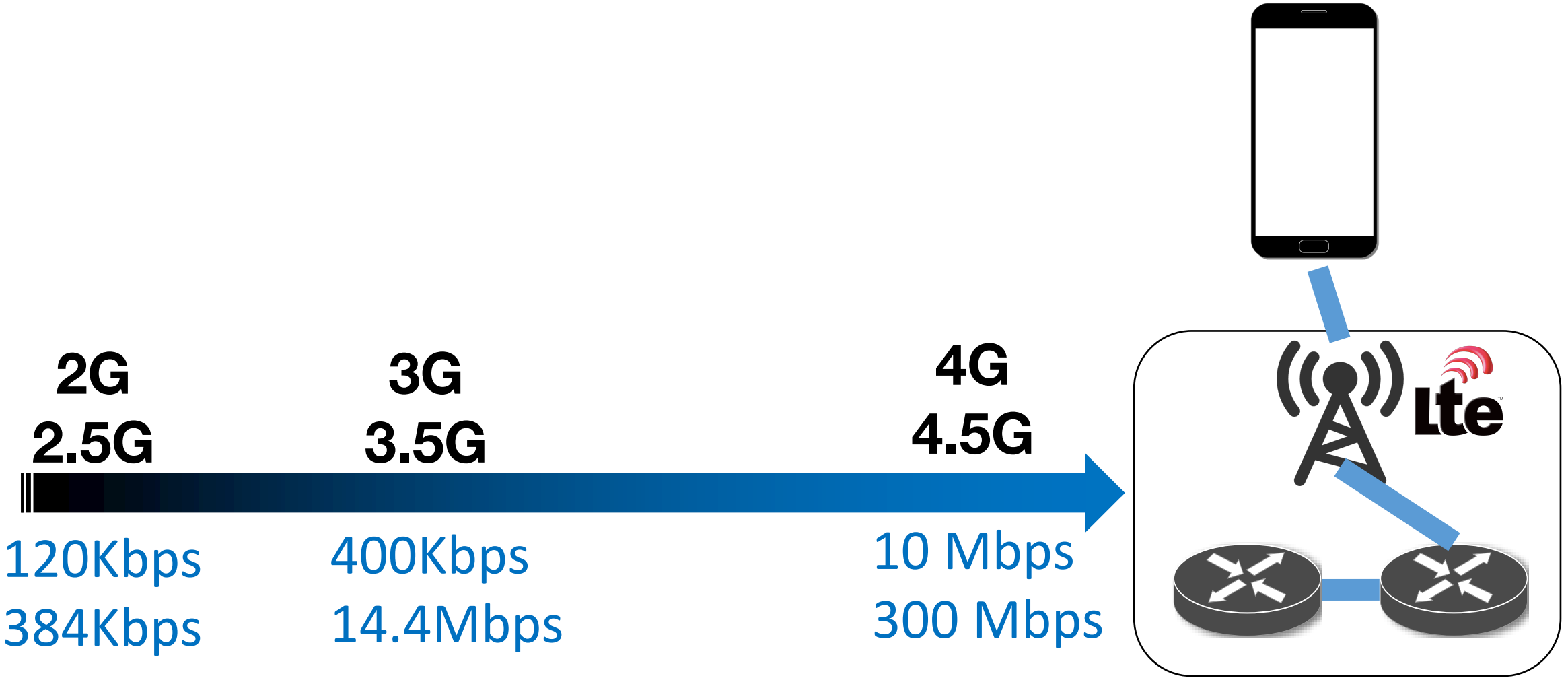


Towards Better Performance & User Experience over Mobile Networks

Our Goal

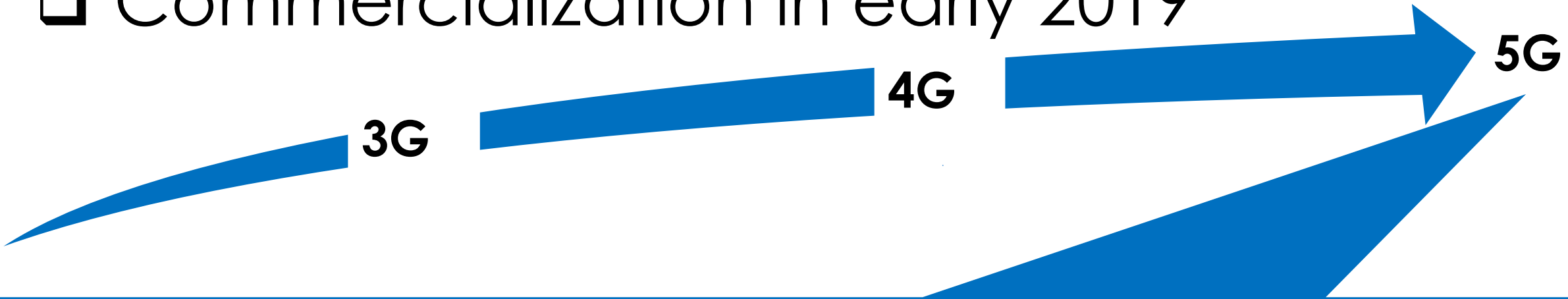
Performance, Efficiency, Reliability …

In the Past 10 Years



Follow the Evolution Story

- Commercialization in early 2019



Much Faster
10Gps peak rate
< 1ms latency

Super-connected
10000x traffic
1000x bandwidth
10-100x devices

Higher mobility
300+ Kmh

Ultra-reliable
99.999%

Energy-efficient

…

…

…

5G Evolution

- Wireless (5G New Radio)
  - mmWave, LTE-U
  - mMIMO, beamforming
  - F-OFDM, LDPC,
  - HetNets, small cells, D2D, …
- Network
  - Network slice (MBB, IoT, V2X)
  - VNF: virtual network function
  - SDN: software defined networks
  - MEC: mobile edge computing
  - MVNO: management and orchestration

Rule of The Thumb

Phone ➟ Smartphone

\+ Network ➟ FasterNetwork

Better Connectivity

It's surely true, but

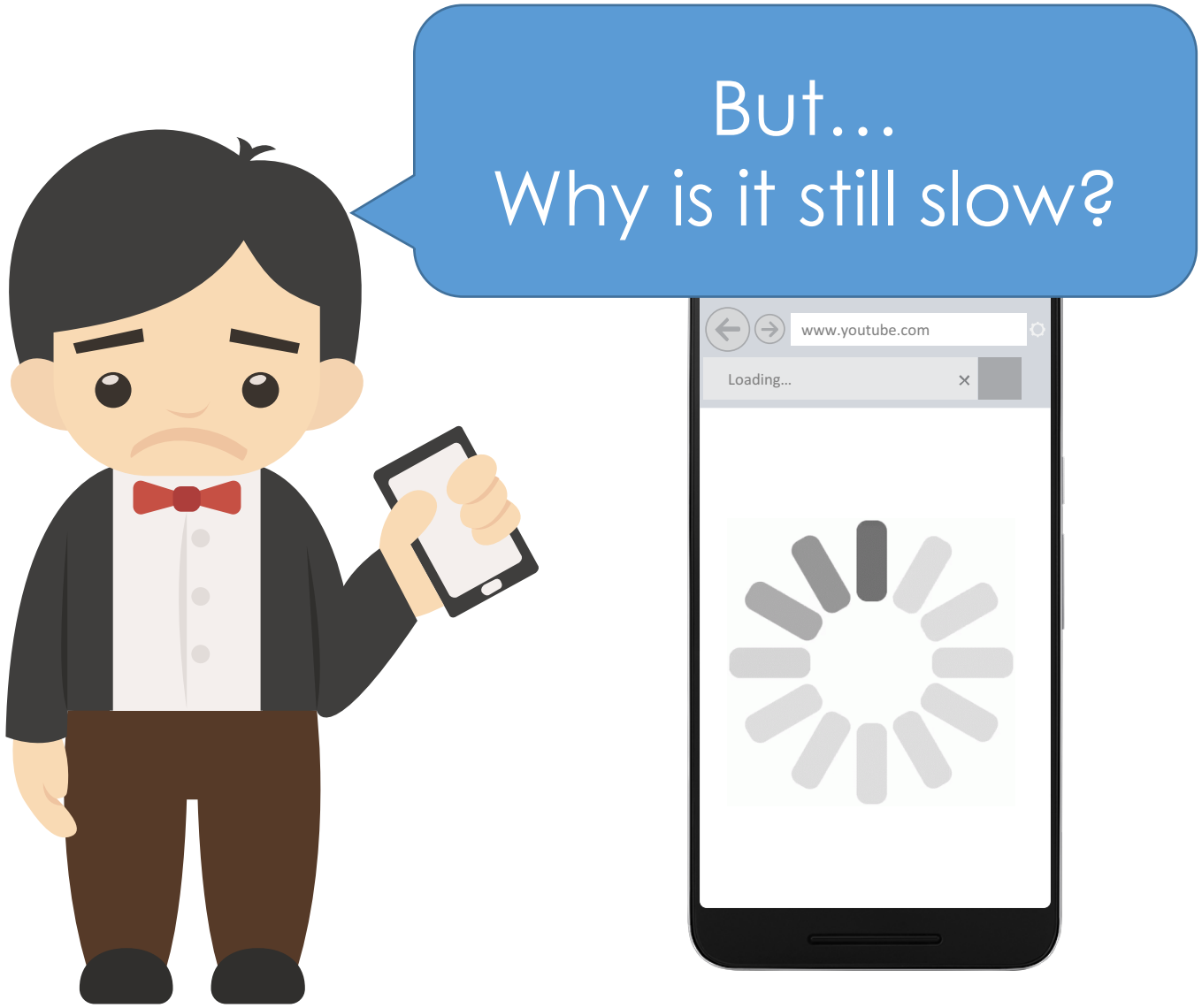
A New Perspective on Mobile Network Evolution

Lessons from Operational 4G/3G

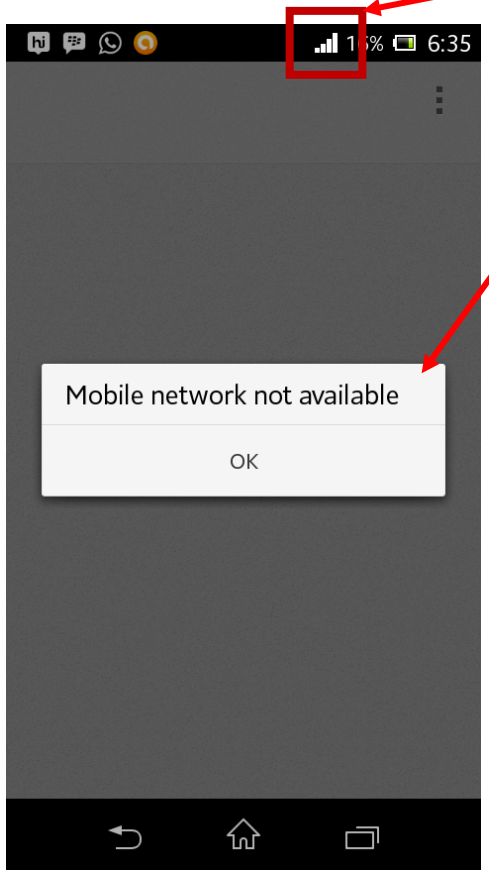
For Example,


5 Signal bars.
Fast network speed.
Awesome!
Advanced Pro
LTE
10
5
20
1
50
0
100+
3.11
Megabits per second
Testing download...

However,

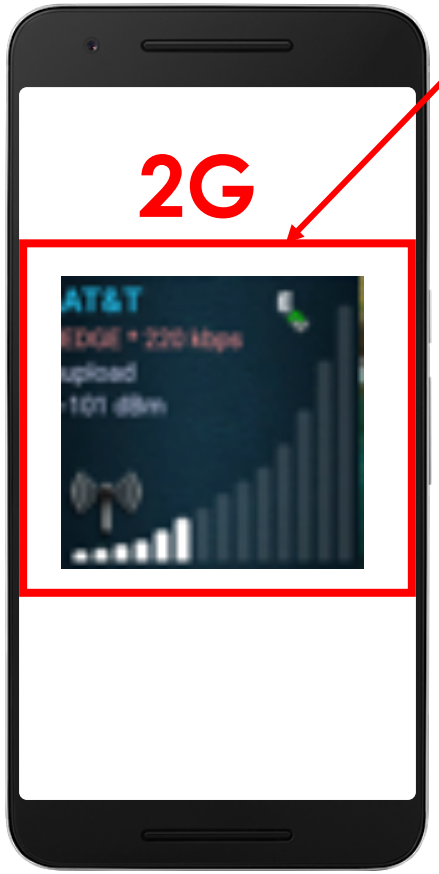


Many Examples in Our Daily Life



Good radio quality,
Why no data?

Many Examples in Our Daily Life



Why 2G, not 4G when 4G available?

Many Examples in Our Daily Life

- Web: 1s-10s seconds
- Video: slow start, stall
- VR/AR: slow response
- Call: drops or fails
- … …

We Need to Know

- 4G's full power not achieved all time

What

Why

How

We Need Mobile Network Intelligence

- Need an approach to know

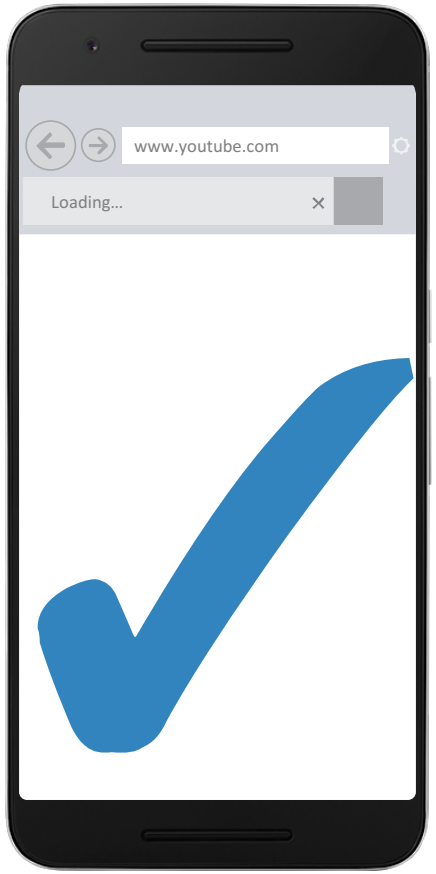
What

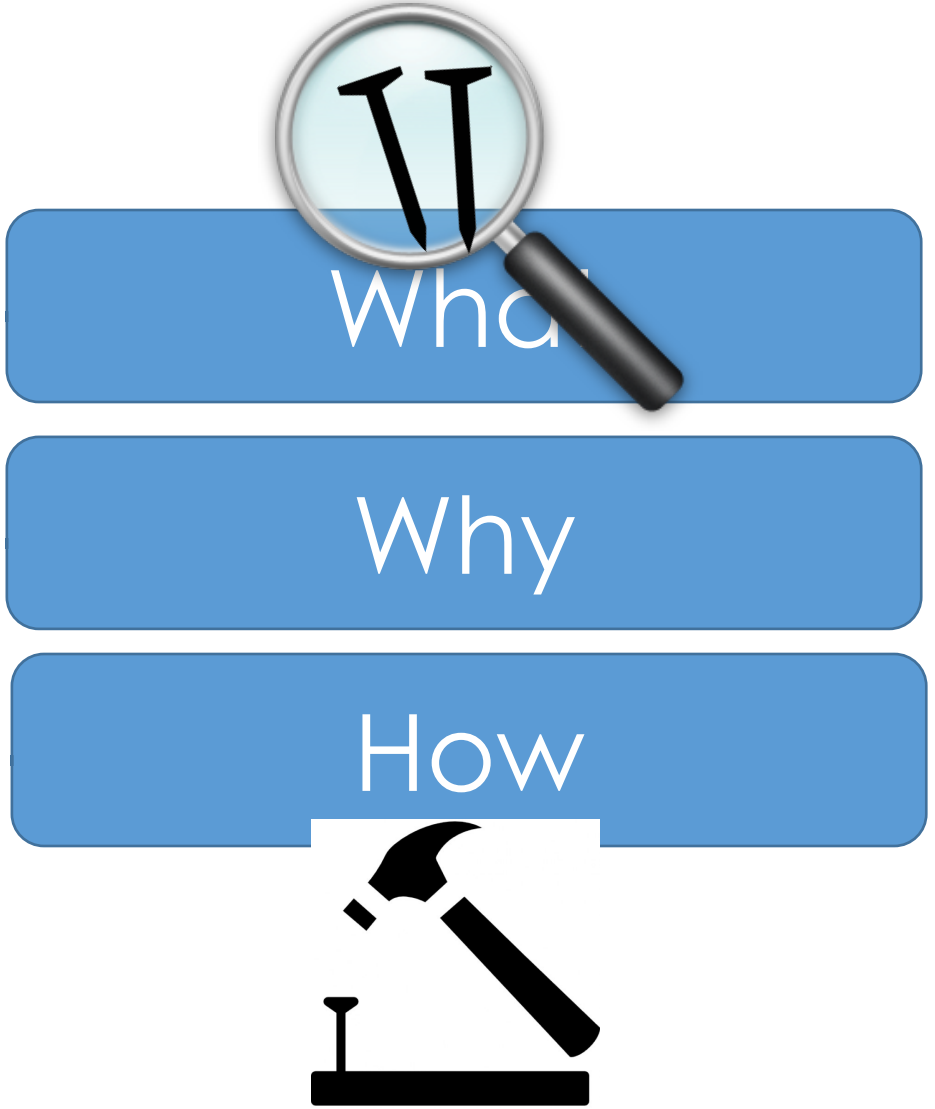
Why

How

So that

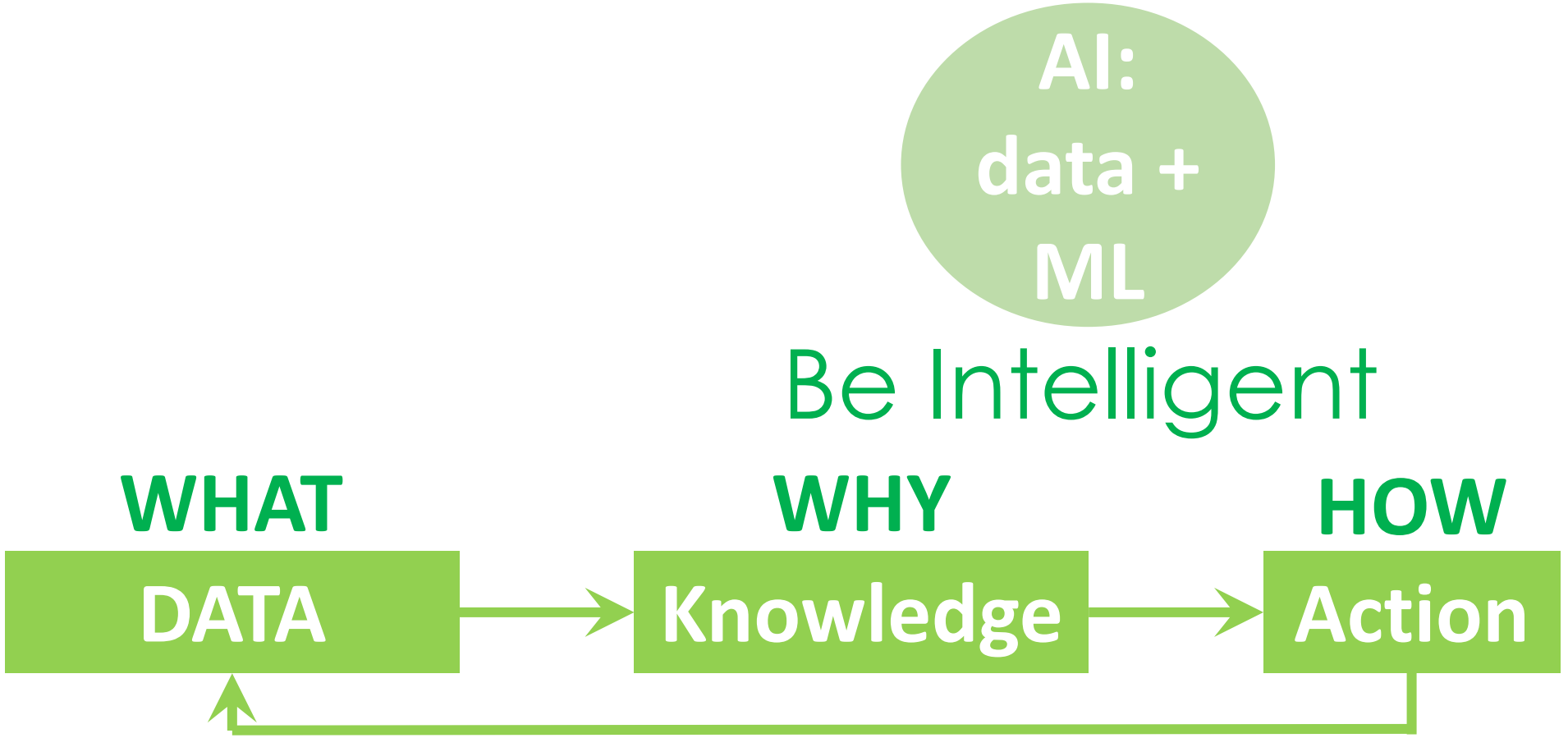
- Smartphones connect "smart"



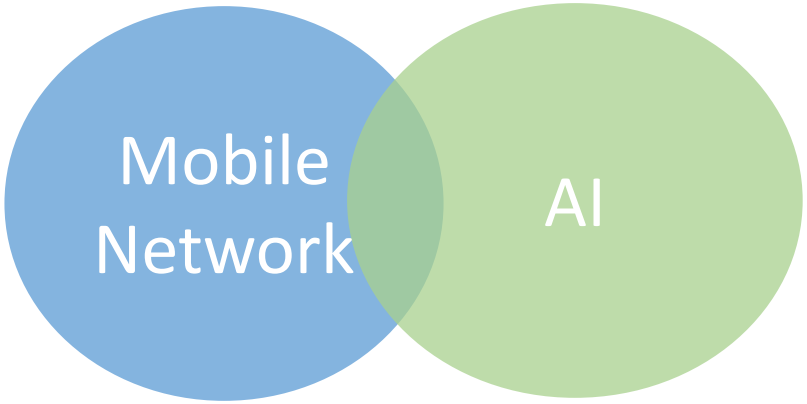


1. What is Mobile Network Intelligence?

How to Be Intelligent?



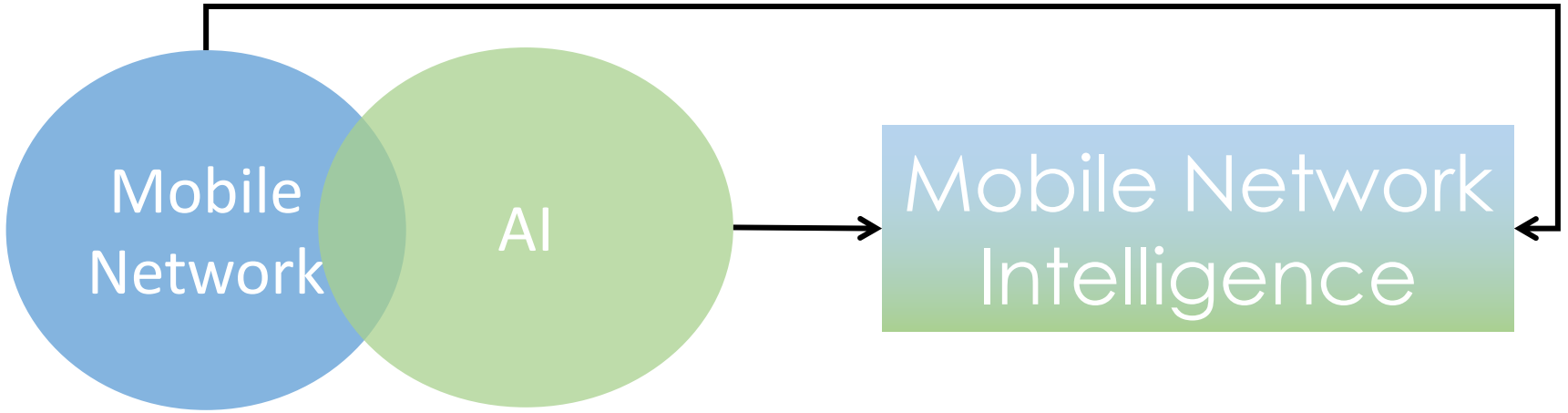
Towards Mobile Network Intelligence



Be Intelligently Connected!

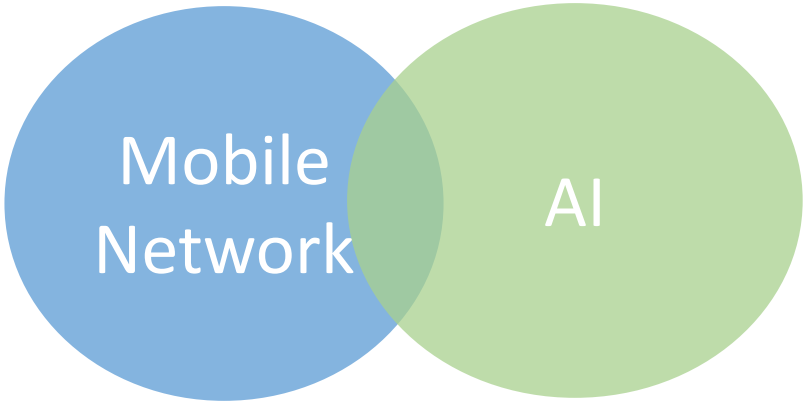
- Run smart (in operation)
  - Data-Knowledge-Action in operation

Towards Mobile Network Intelligence



Smart End **Smart Network**

Many Benefits, e.g.,



Be Intelligently Connected!

- Performance improvement
  - E.g., network knowledge for app adaptation
- Resilience enhancement
  - E.g., failure detection & fast recovery
- Network automation (management)
- …

Orthogonal to the ongoing 5G/4G Evolution

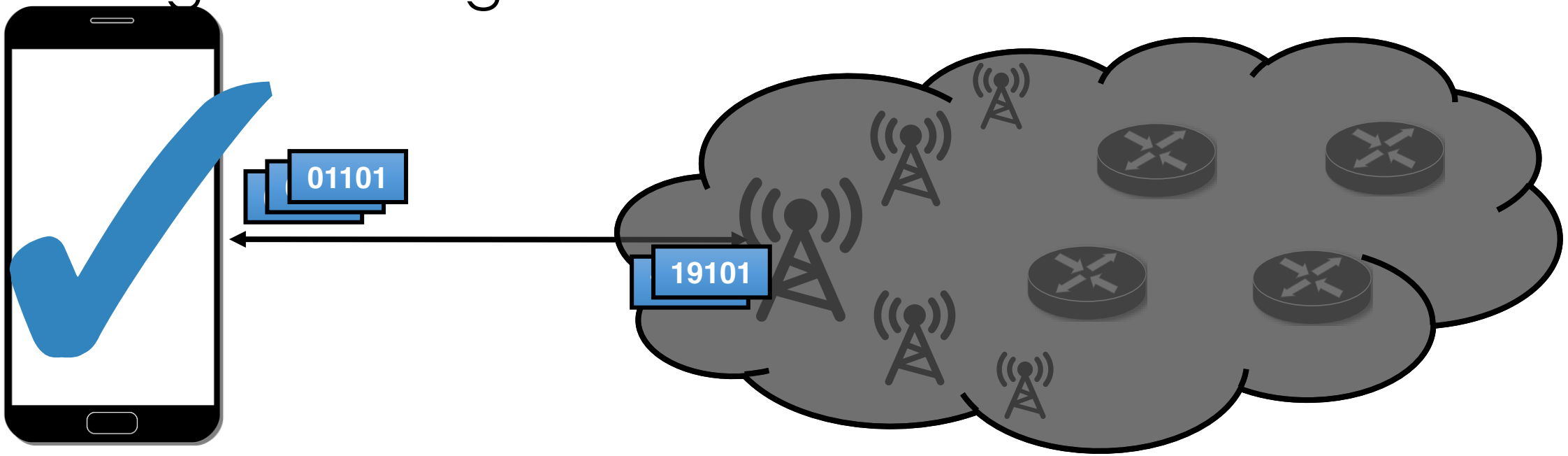
Need for Best User Experience over
5G/4G's Full Power

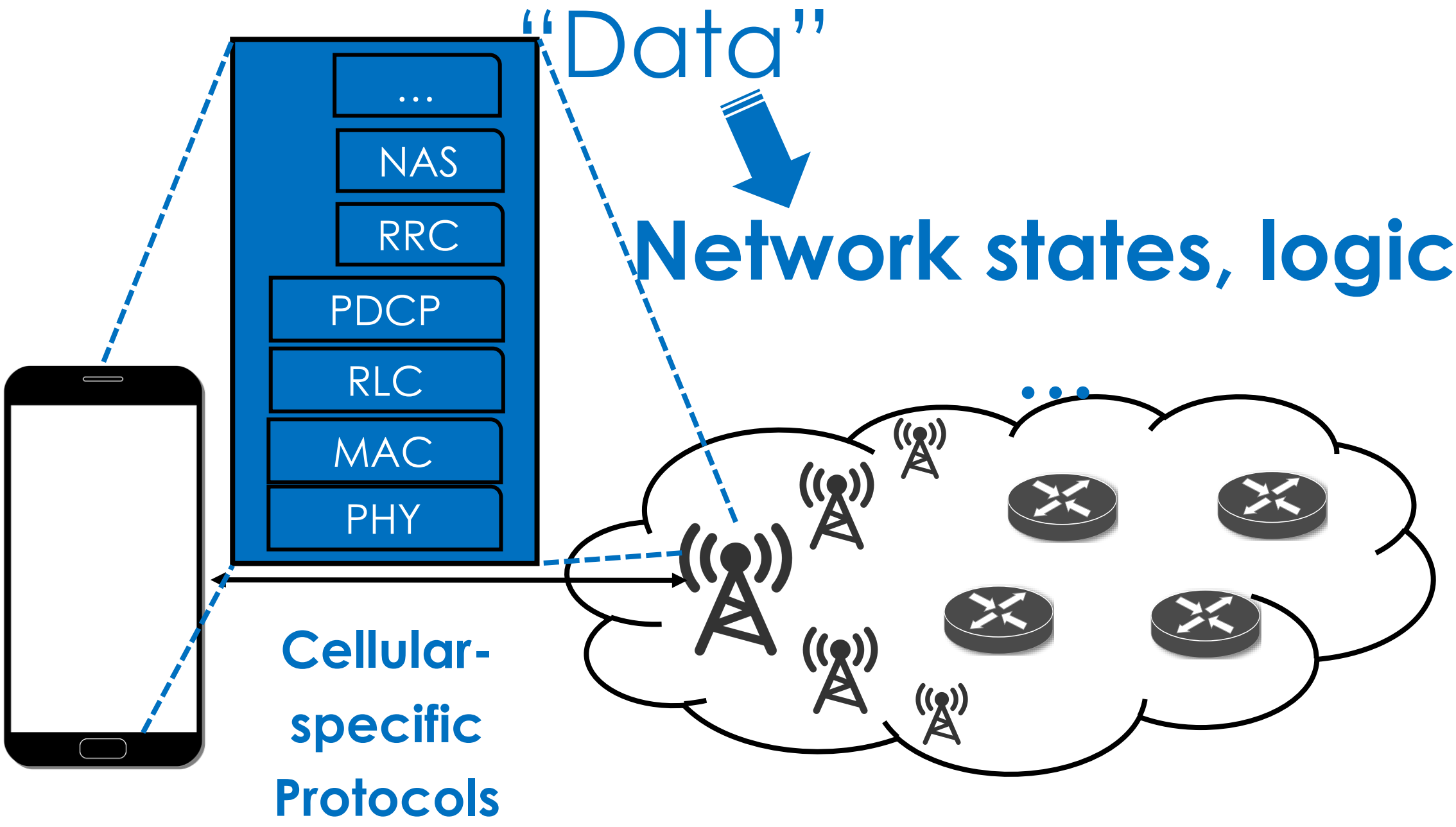
3. How to Achieve Mobile Network Intelligence?

At the very early stage

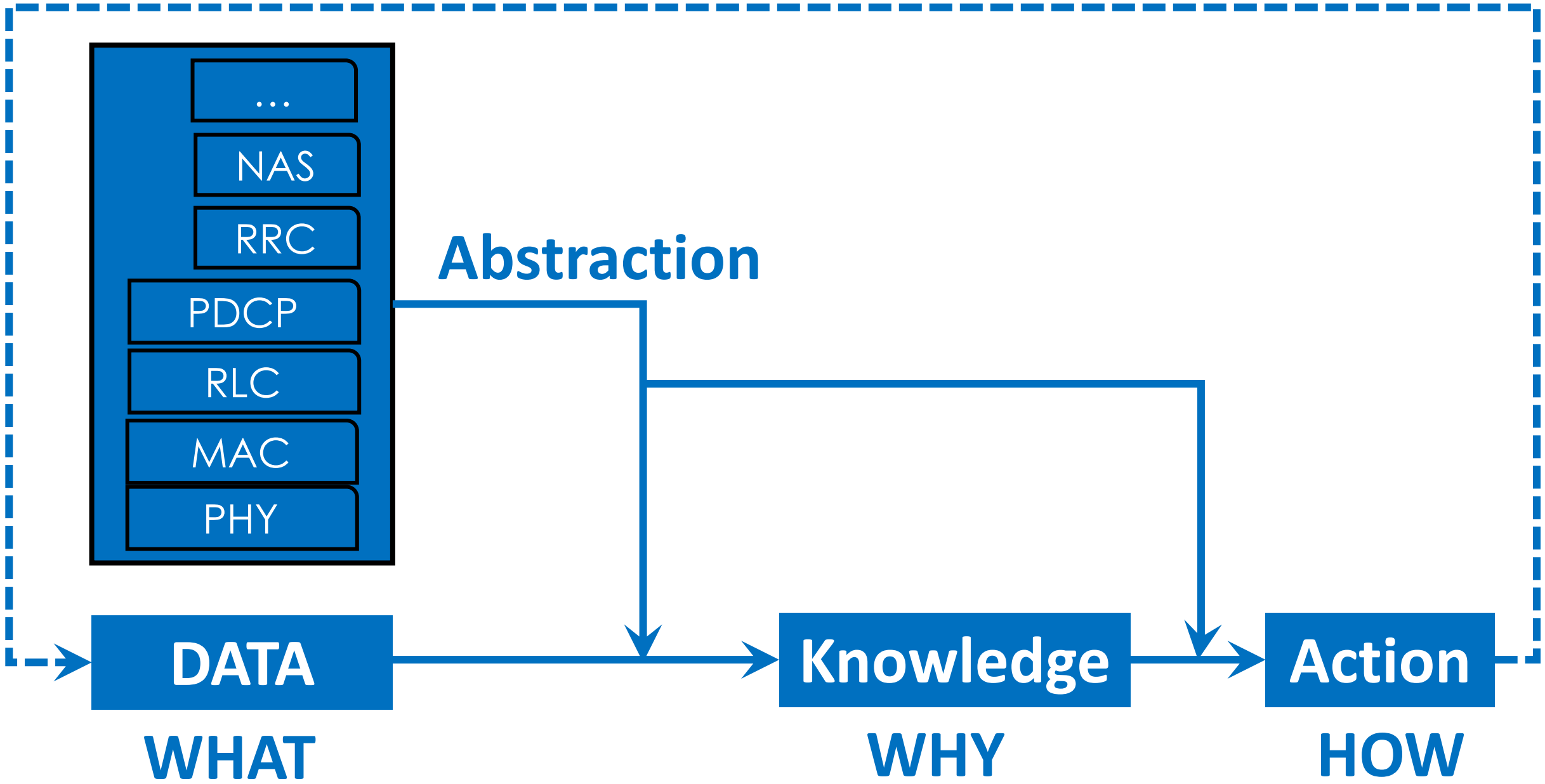
Device-side Network Intelligence

- In-Device (not at network)
- Data-driven
  - msgs exchanged betweendevice-network

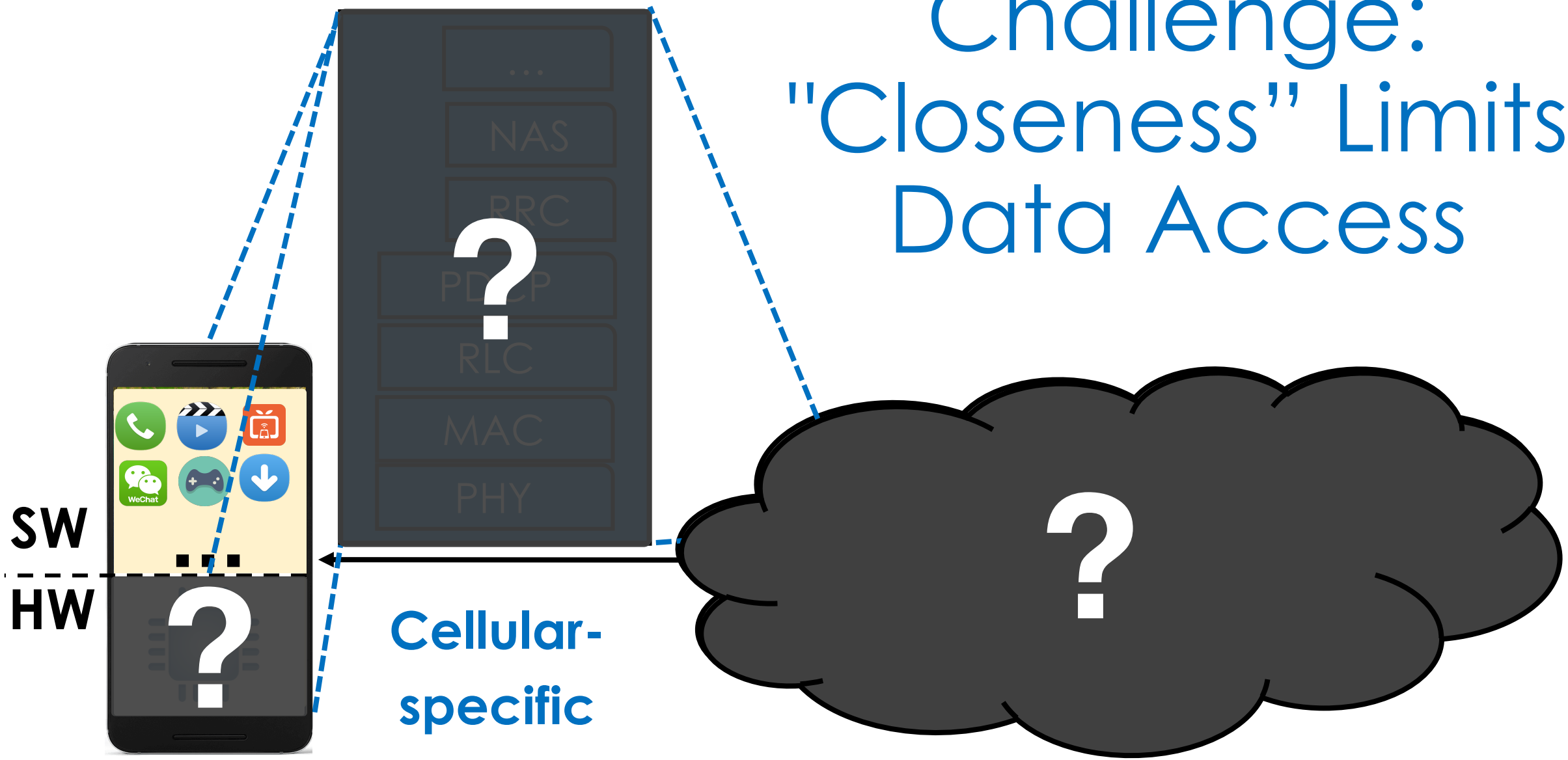



"Data"
Network states, logic,
...
NAS
RRC
PDCP
RLC
MAC
PHY
Cellular-specific Protocols

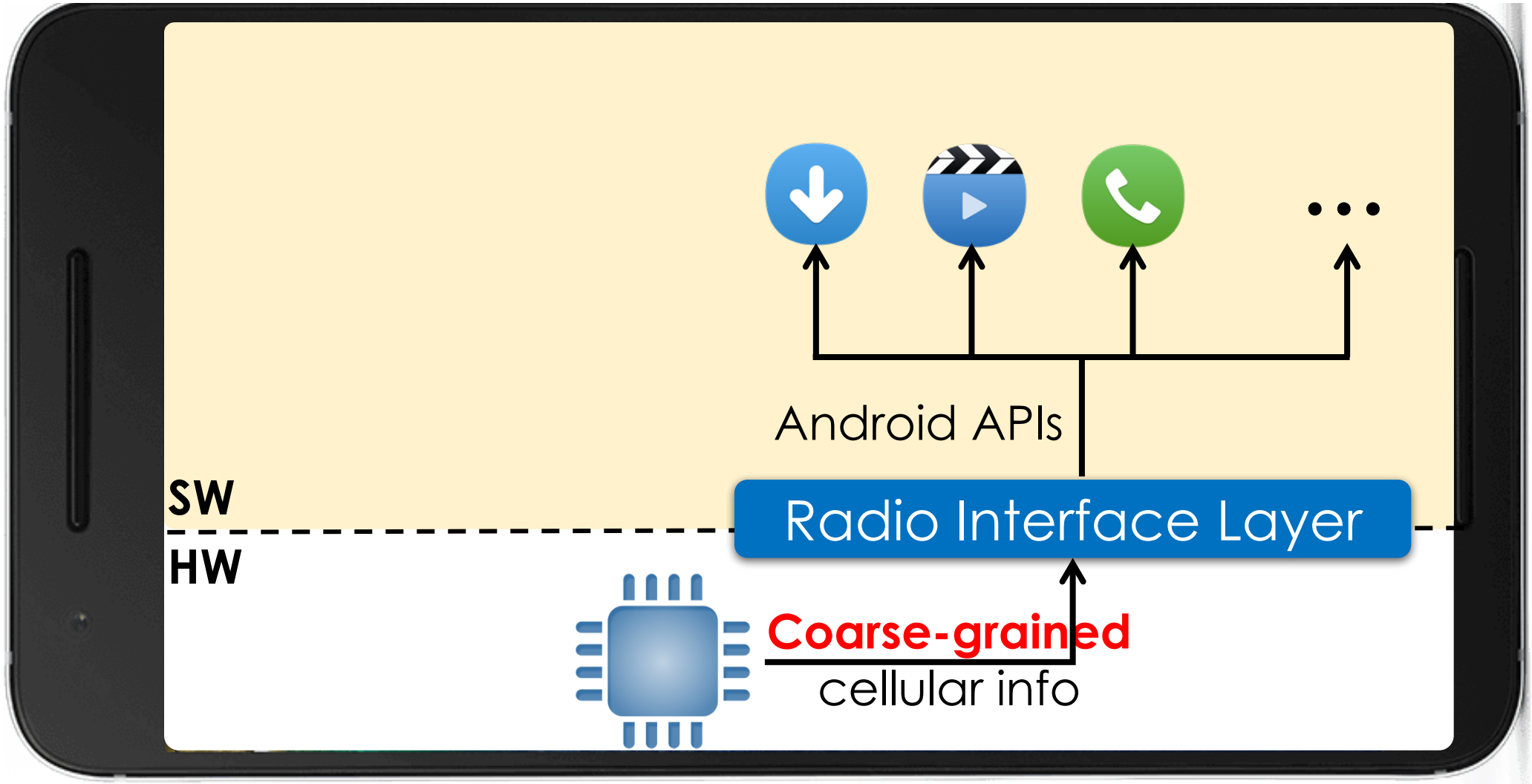
Data-Knowledge-Action Cycle



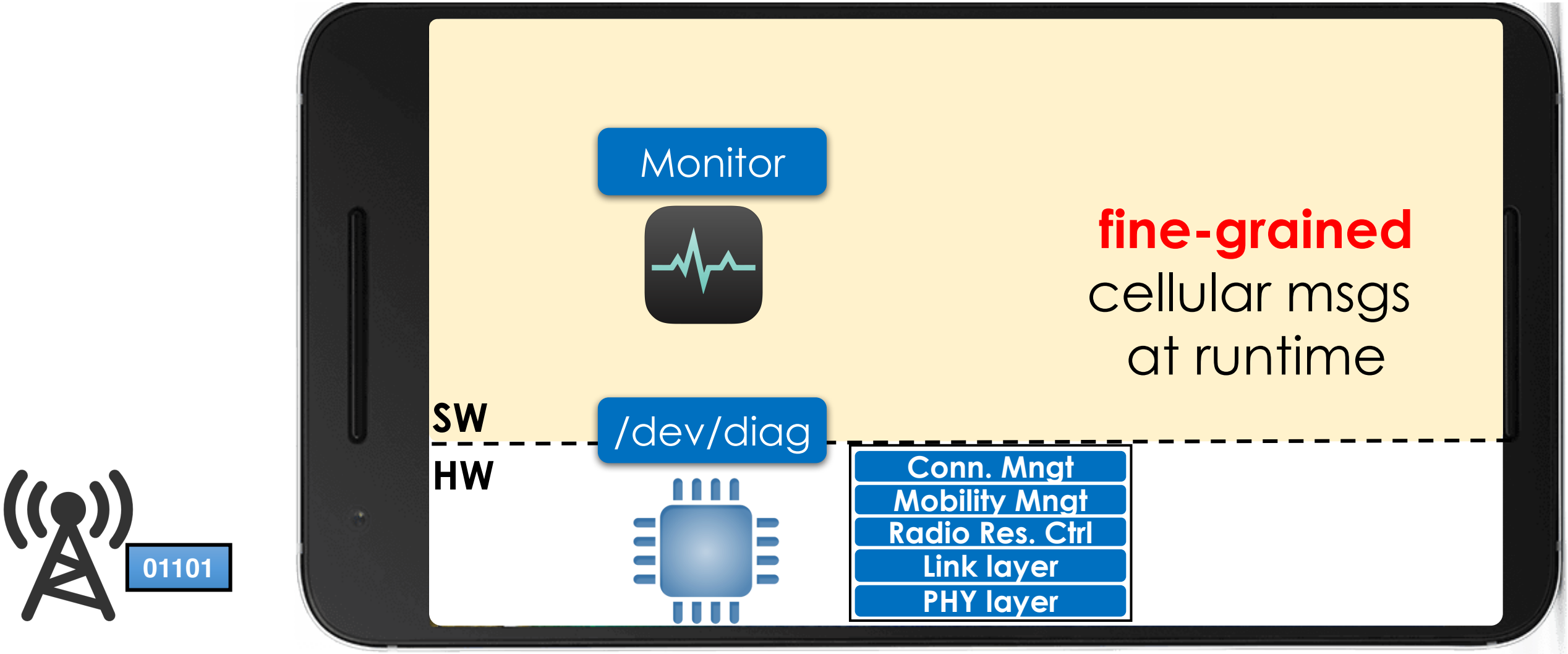
Challenge: "Closeness" Limits Data Access



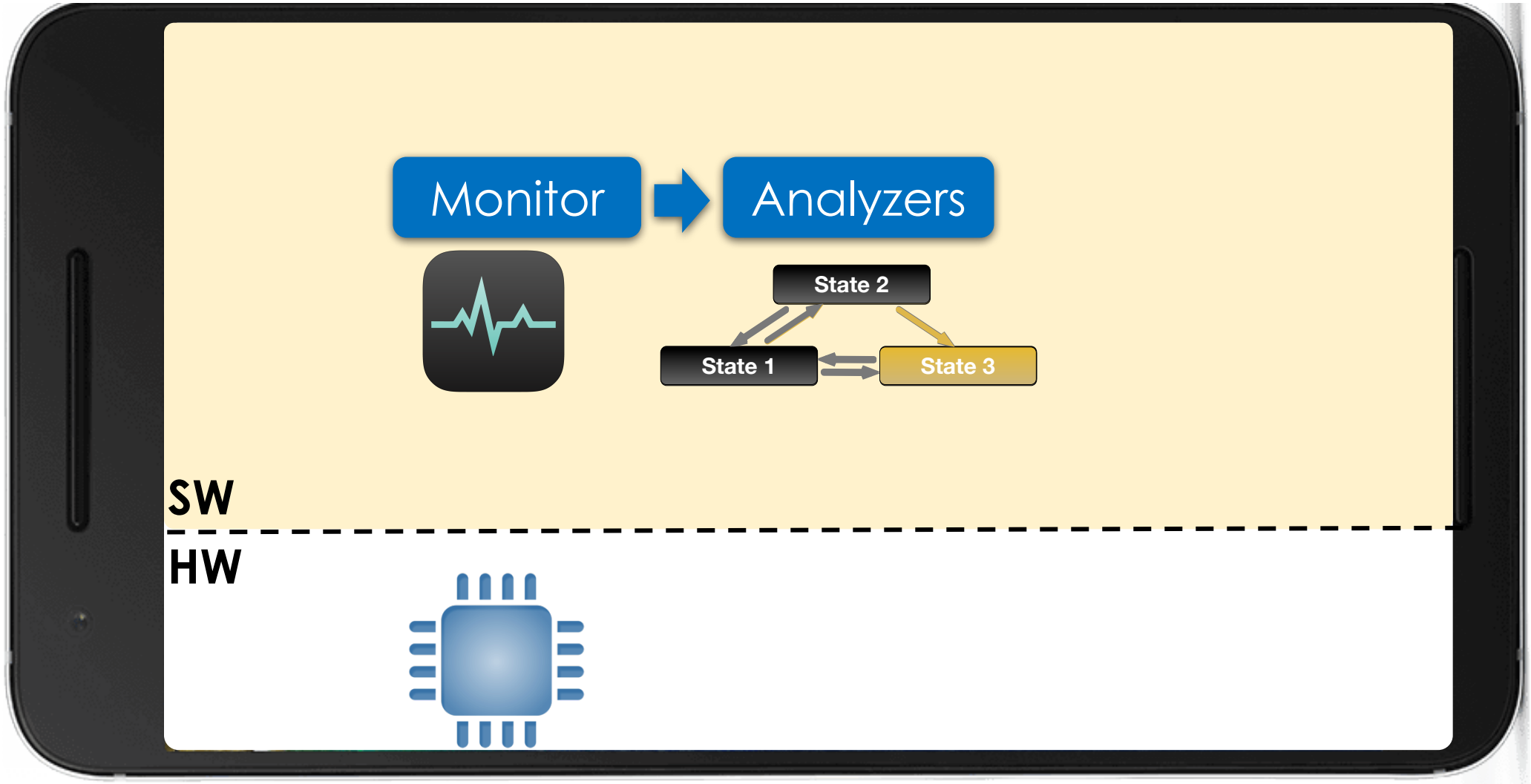
No Ordinary Interface @ Device



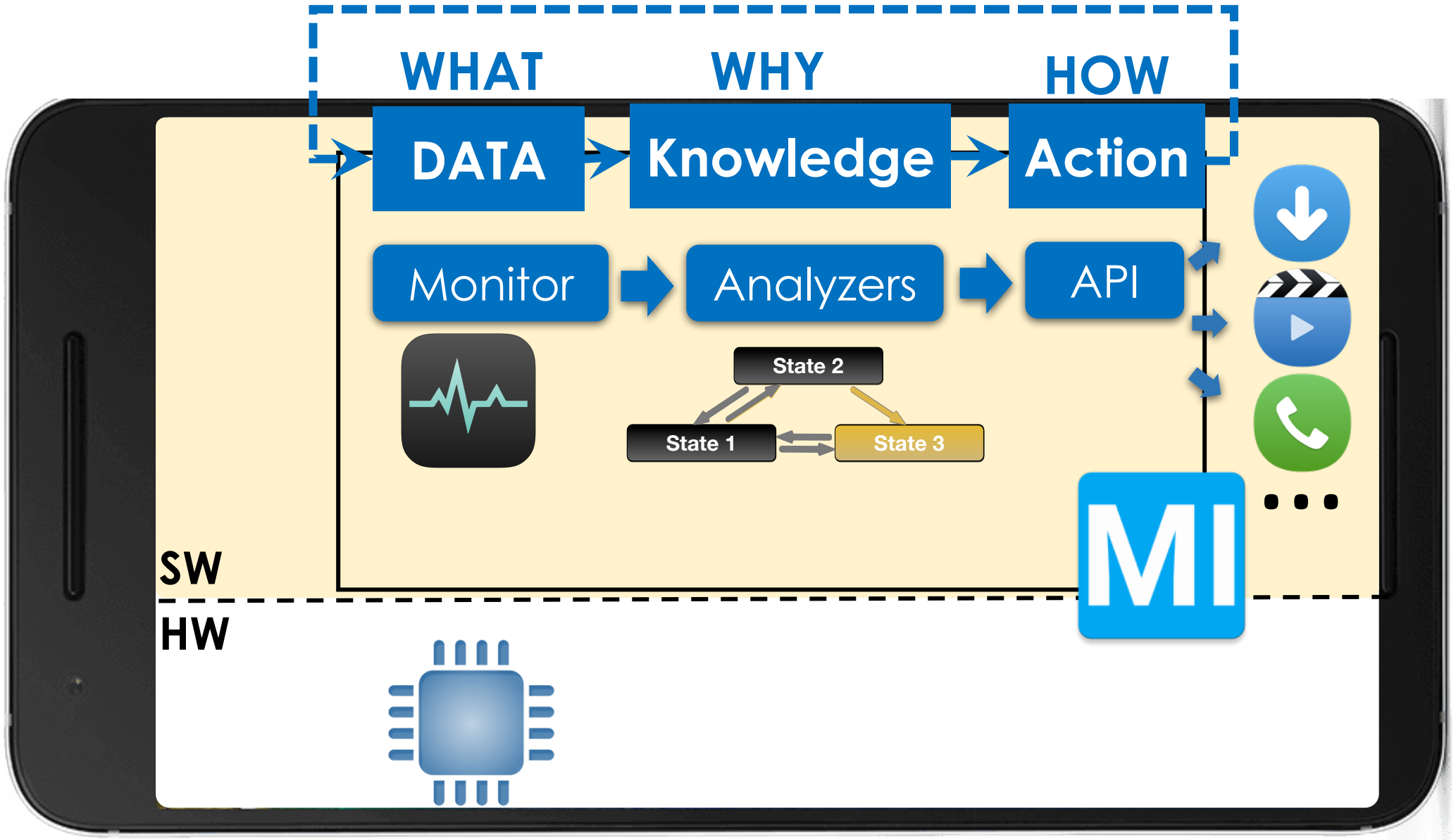
MobileInsight: Open Data Access



MobileInsight: Build Protocol Analytics



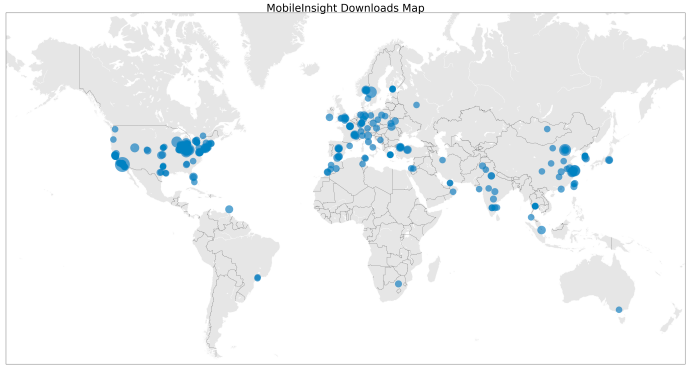
MobileInsight: Expose Inference to App



MobileInsight: Many Benefits

	Full msg coverage	Fine grained	Analysis	At scale	In-phone
MI	✔	✔	✔	✔	✔
Android APIs	✘	✘	✘	✔	✔
External Tools (e.g., QXDM)	✔	✔	✘	✘	✘
Operator-side cellular analytics	✔	✔	✔	✘	✘

What MobileInsight Has Done?



http://mobileinsight.net/

- ❑ Monitor + Analyzer
  - Wide coverage of protocols/msgs
  - A variety of devices supported
  - Responsive and effective
  - Acceptable overhead
- ❑ Release 3.3 (12/05/2017)
  - First public release (06/2016)
- ❑ Download by 170+ org
- ❑ Open source codes
- ❑ Open datasets

Smartphones Connect "**Smart**"

Unveil & understand real problems

Sample projects:

- Network diagnosis
- Network verification
- Mobile big data analytics
- …

Improve performance , efficiency, reliability

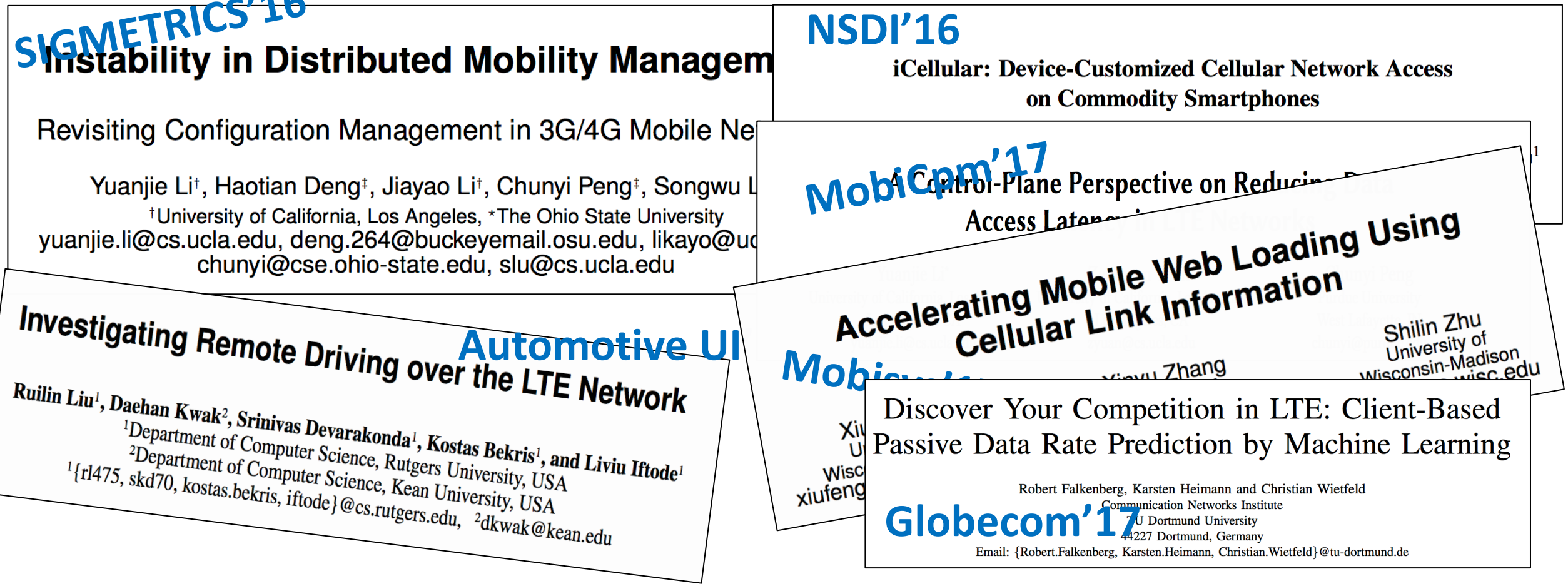
Sample projects:

- Cross-layer optimization
- Security enhancement
- Protocol optimization
- …

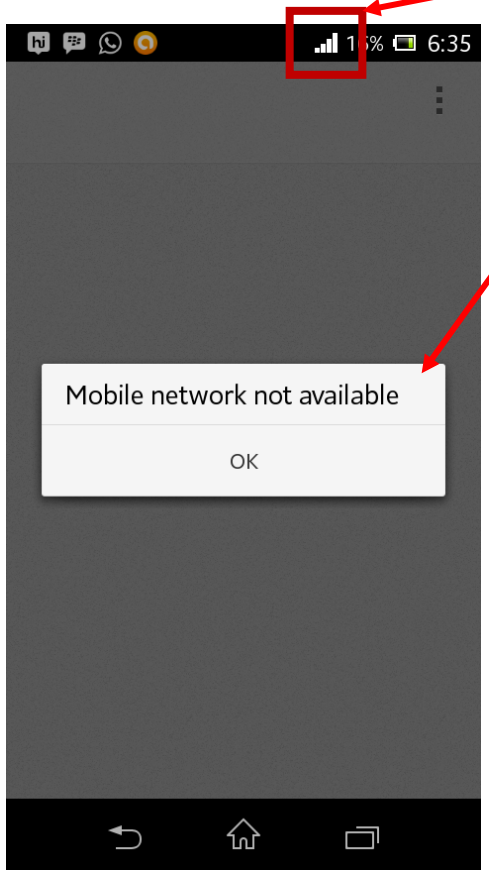
Selective Publications

Unveil & understand real problems

Improve performance , efficiency, reliability



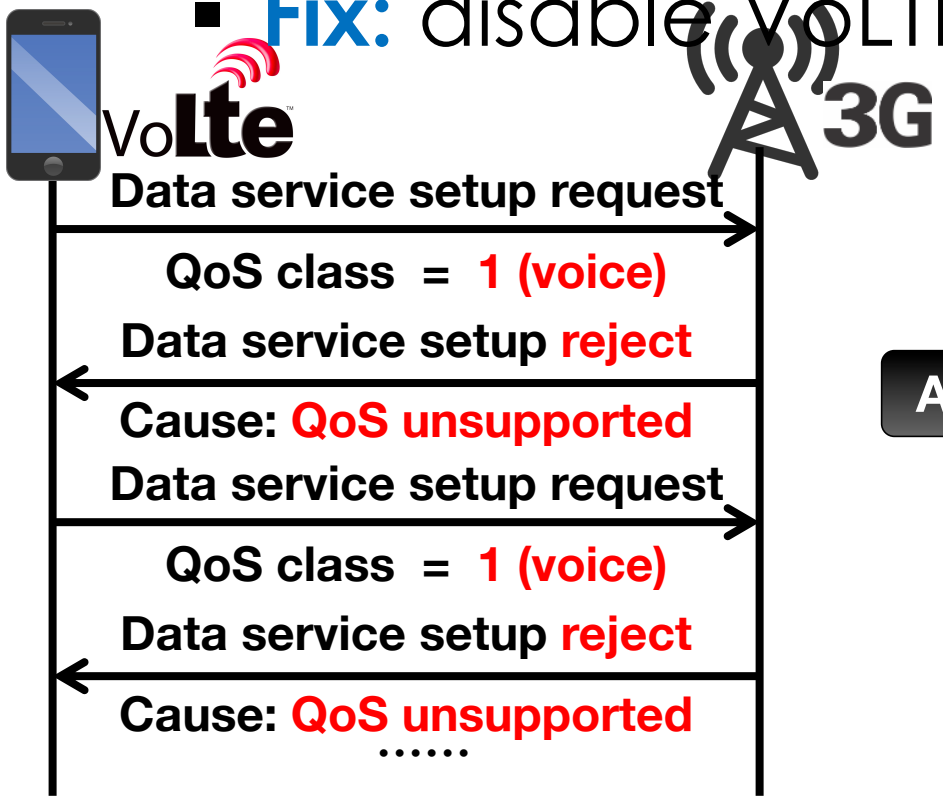
A Simple Example

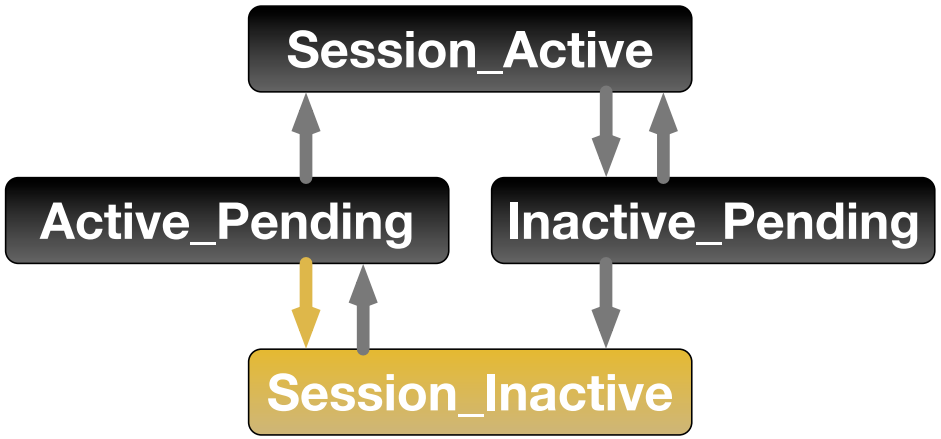


Good radio quality,
Why no data?

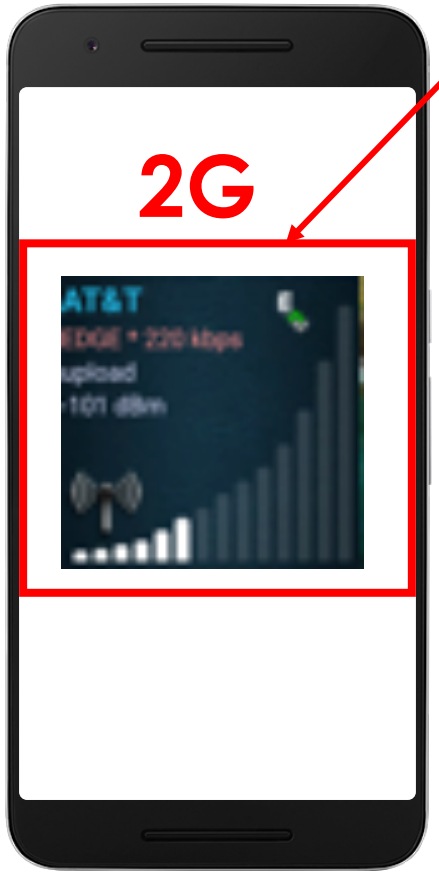
When Smartphones Connect "**Smart**"

- Analyze cellular messages exchanged
  - Track protocol state dynamics
- **Cause:** device-side misconfiguration
  - **Fix:** disable VoLTE when the device in 3G





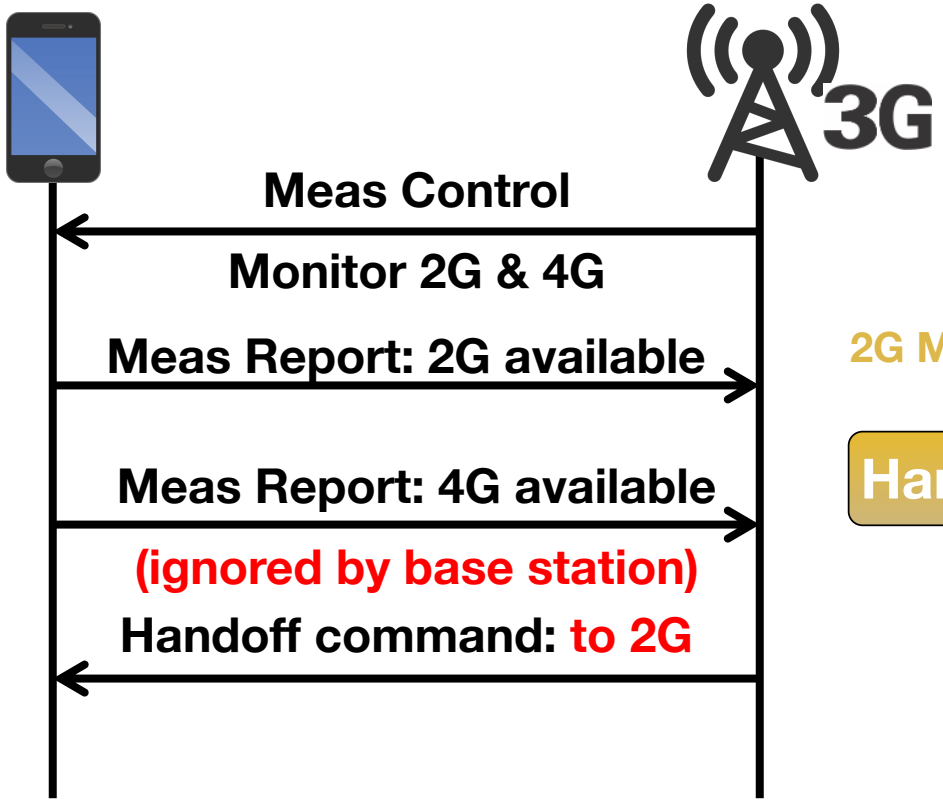
Another Example

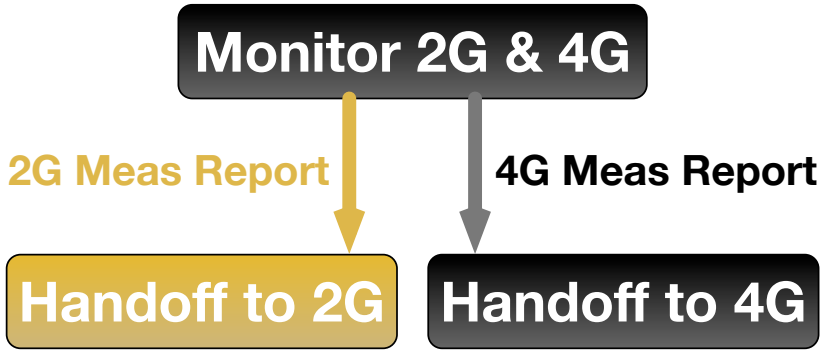


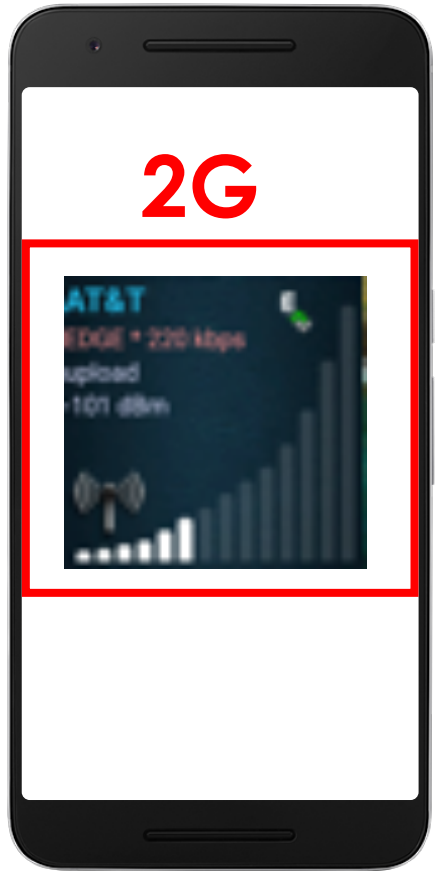
Why 2G, not 4G when 4G available?

When Smartphones Connect "**Smart**"

- **How:** Analyze inferred handoff decision logic



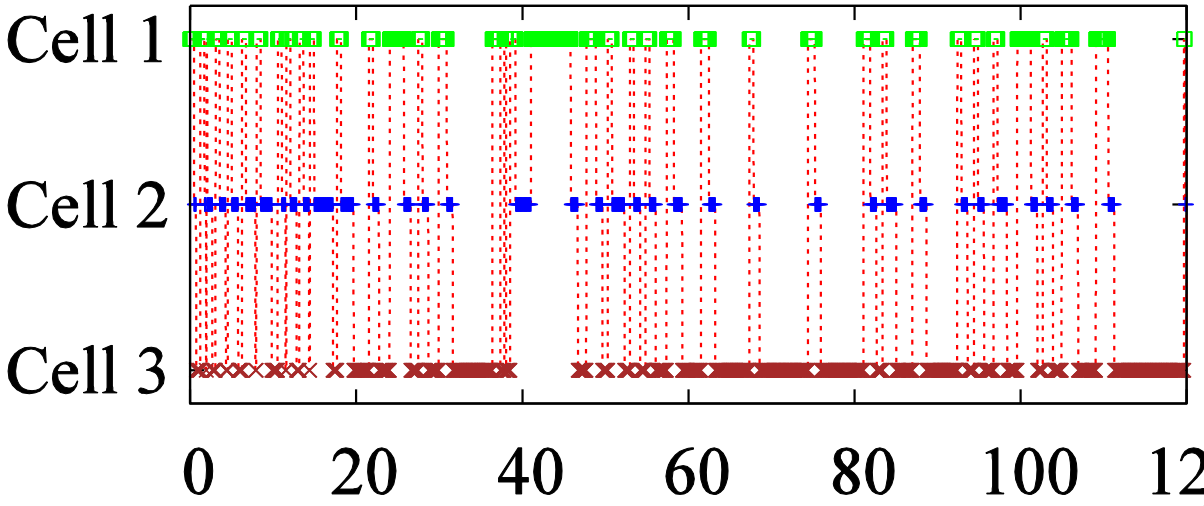


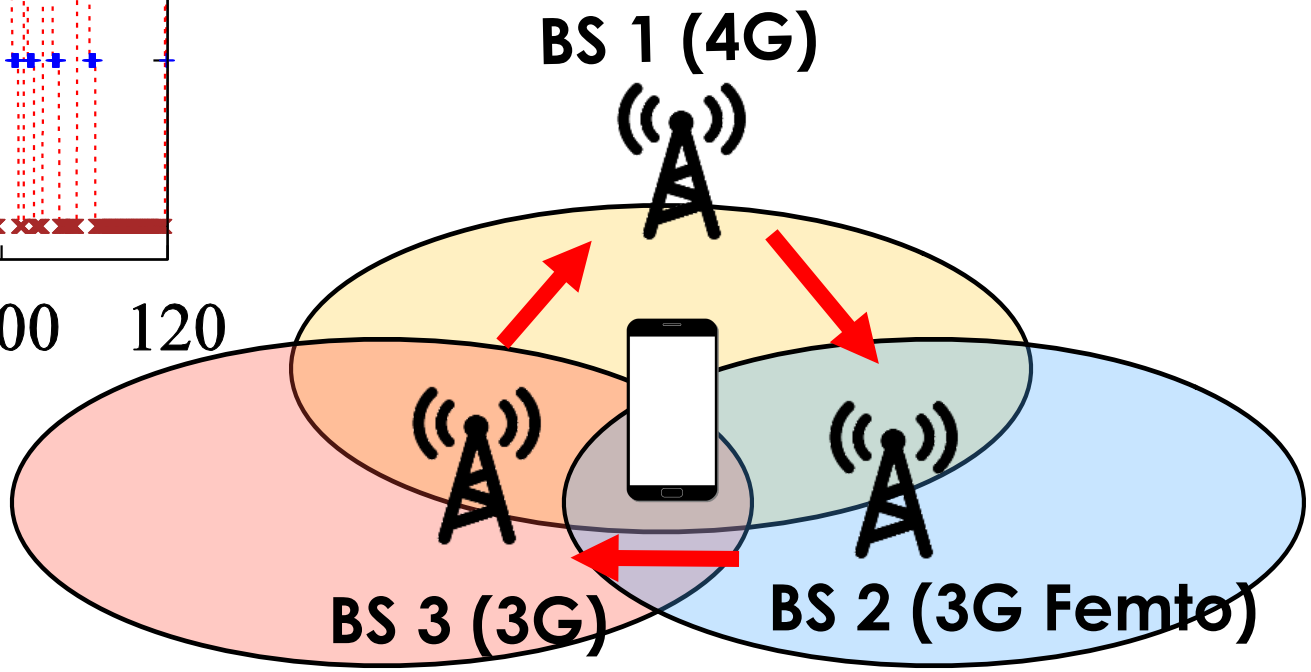


Reference: Mobicom'16

A Formal Verification on Mobility

- Handoff stability [sigmetrics'16]





A Formal Verification on Mobility

- Handoff: configuration at the serving cell
  - Handoff: distributed process
  - Configuration: diverse (not conflict-free)
- Theoretic results: handoff stability
  - Necessary/sufficient conditions for stability
- Real-world measurement and assessment
  - MobileInsight → collect and analyze configurations
  - 21 instances in two US carriers(2016) ; 30+ (2017)
- Solution: device-side fix

Reference: Mobicom'16

Open Research Opportunities

Unveil & understand real problems

Sample projects:

- ✓ Network diagnosis
- ✓ Network verification
- • Mobile big data analytics
- • …

Improve performance , efficiency, reliability

Sample projects:

- • **Cross-layer optimization**
- • Security enhancement
- • Protocol optimization
- • …

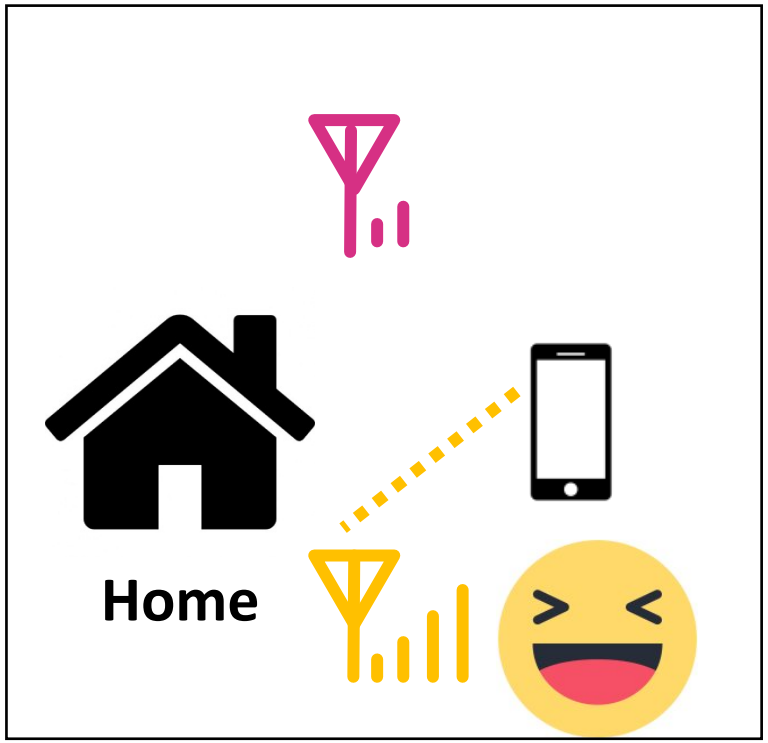
iCellular for Google Fi [NSDI'16]

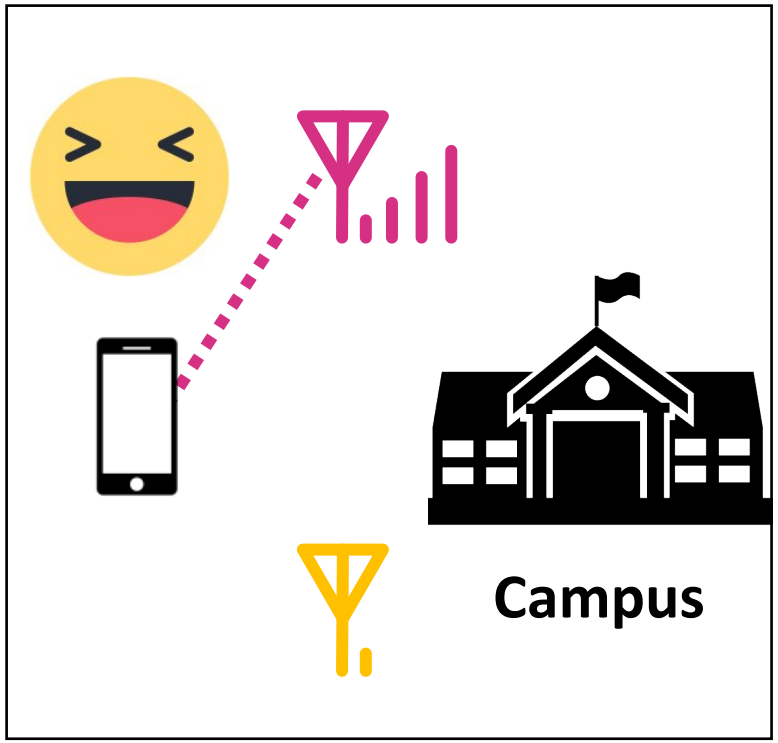
- boost wireless via multi-carrier access

Project Fi

T-Mobile

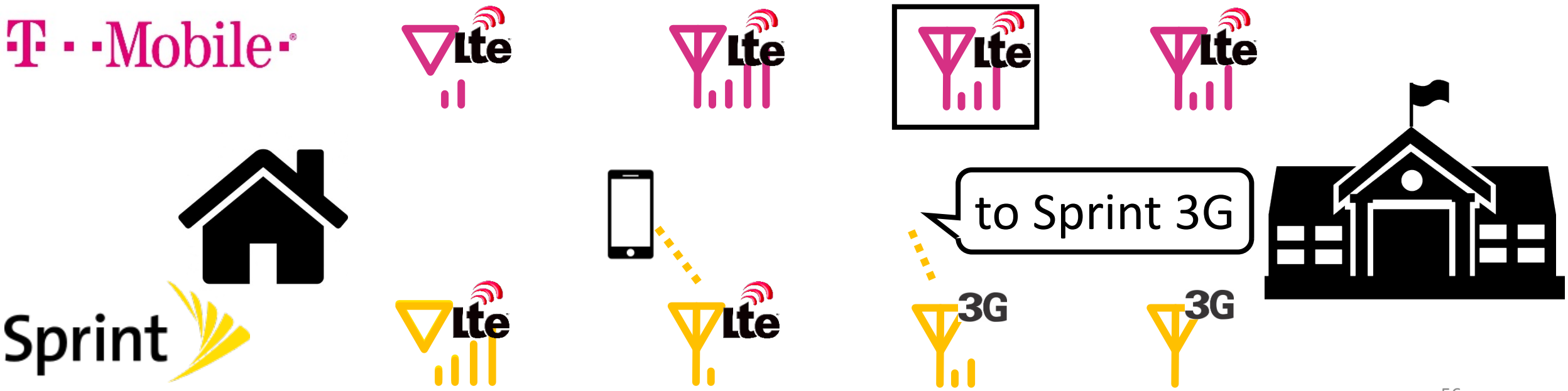
Sprint





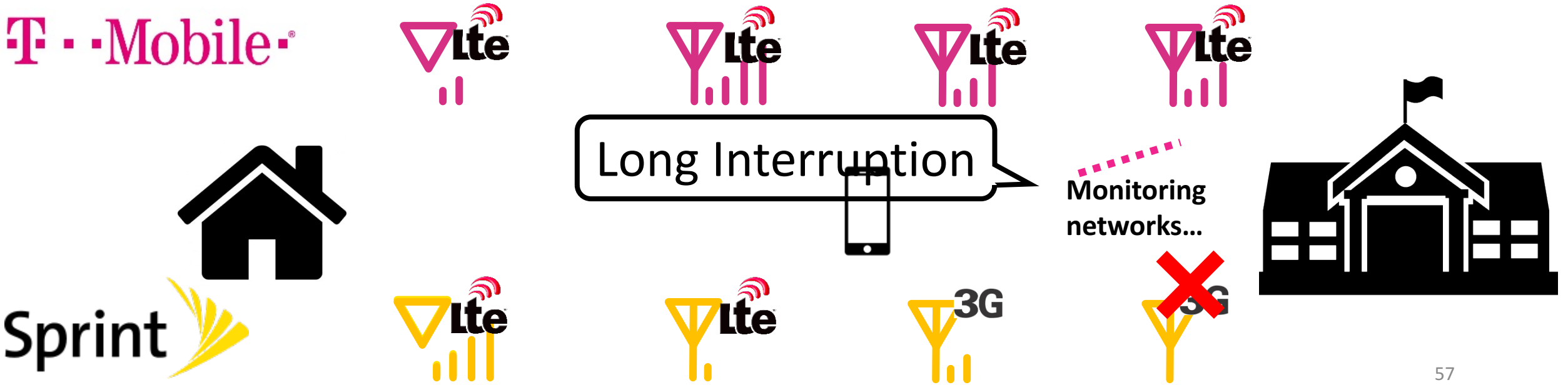
However, Two Downsides

- Make a worse choice



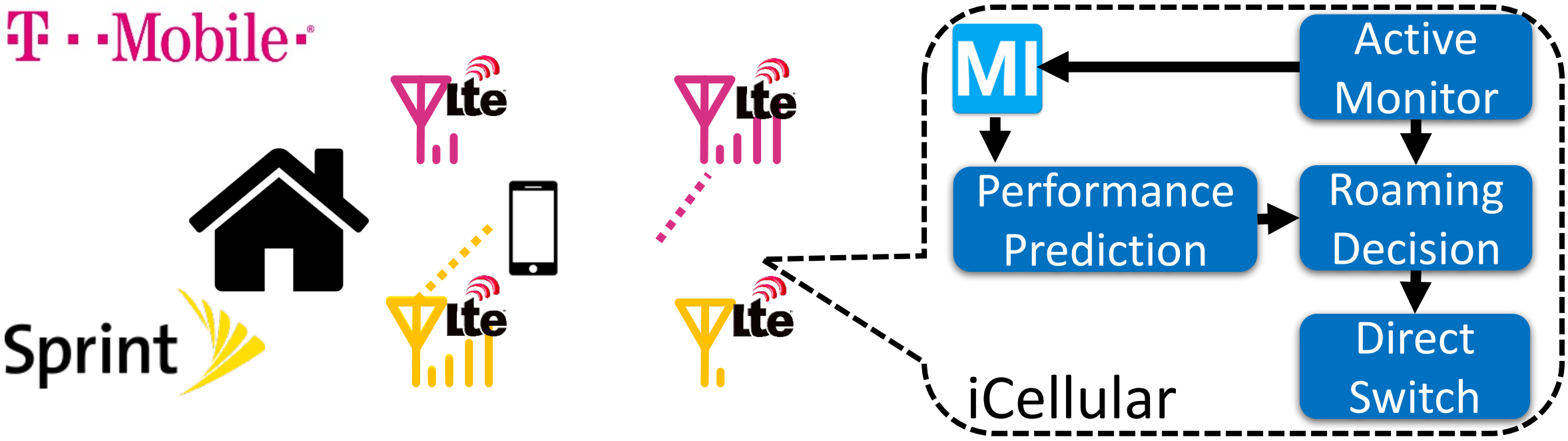
However, Two Downsides

- Make a worse choice
- Long disruption during the switch
- **Cause**: no cellular information @device
  - Passively follows whatever the networks asks it to do



iCellular: A Client-side Solution

- **Proactive** selection with runtime net. info
  - Throughput: 23.8% on average, 3.74x at max
  - Latency: 60.4% on average, 1.9x at max



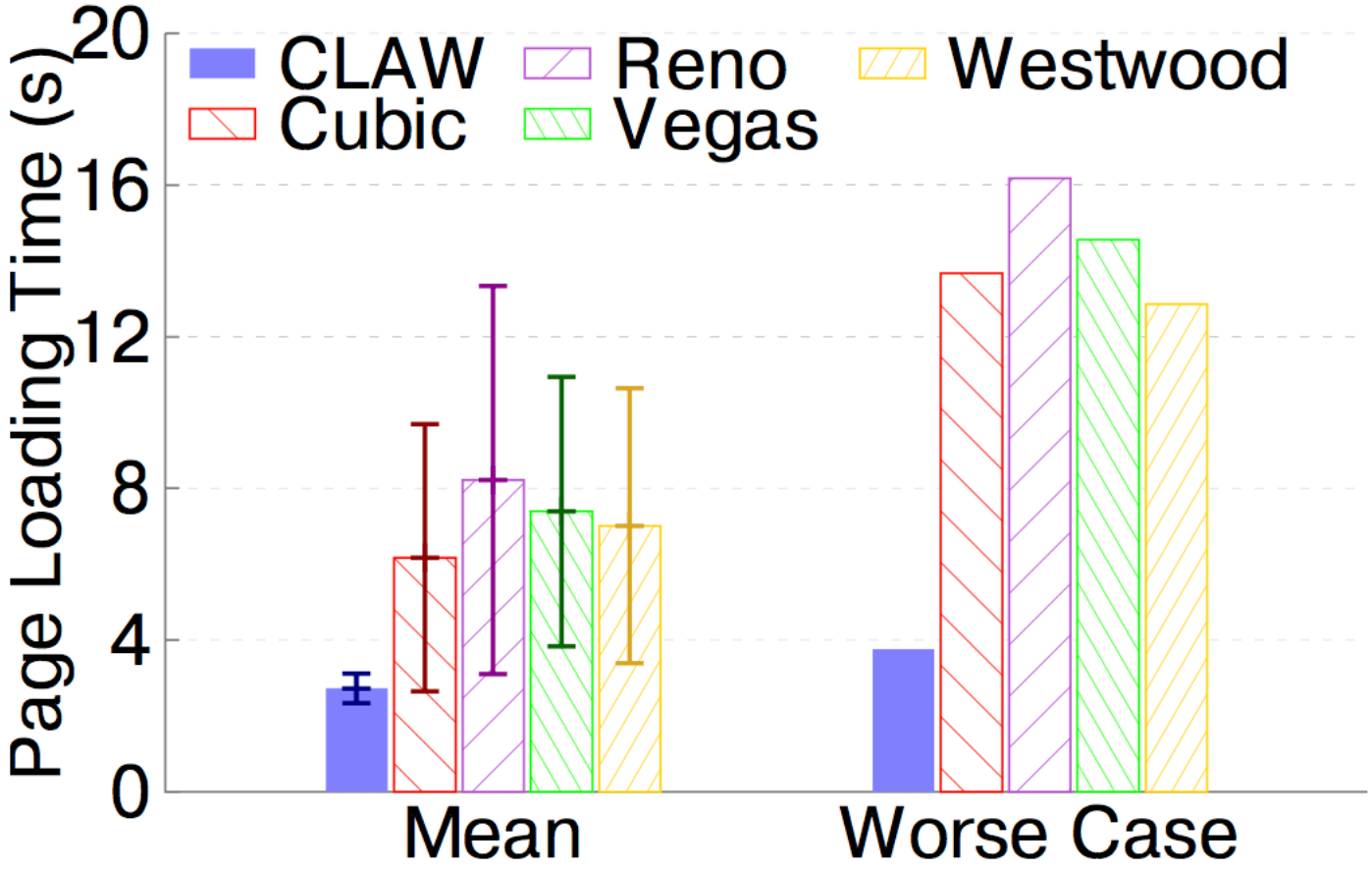
Mobile Web Loading Acceleration

- Xie et.al. (3rd-party) [Mobysys'17]
- Problem: Long delay (3 ~ 12+s over LTE)
- Cause: TCP doesn't adapt to real network conditions
  - TCP adaptation misled by large and unstable RTT
  - TCP overreacts to LTE link losses
  - Short web flows hinders the sending rate from quick convergence to the network bandwidth
- Core idea: using cellular link information to predict runtime bandwidth

Their Solution: CLAW

- CLAW (Cellular-Link-Aware Web-loading)
- TCP converges to net.bandwidth within one RTT
  - Estimate available resource
  - By harnessing LTE's PHY-layer statistics, including signal energy, packet loss and modulation scheme
  - Using what is available through the diagnostic interface (MobileInsight) at smartphones
- Details referred to their paper
  - RSRQ → cell load estimation → available resource for one client → real-time bandwidth estimation → combined with TCP adaptation → CLAW

CLAW Outperforms Existing TCP



Smartphones Connect "**Smart**"

Unveil & understand real problems

Improve performance , efficiency, reliability

Network Intelligence **@Device**

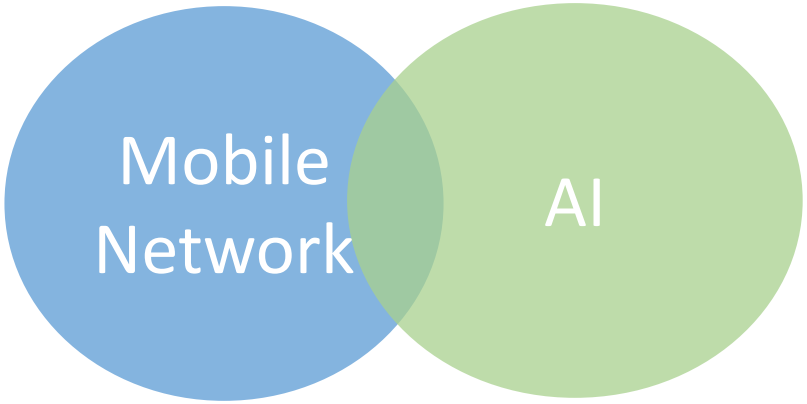
Remark:

These examples
can't cover many possibilities
newly exposed.

4. What Remain Open Questions?

Many Opportunities Ahead

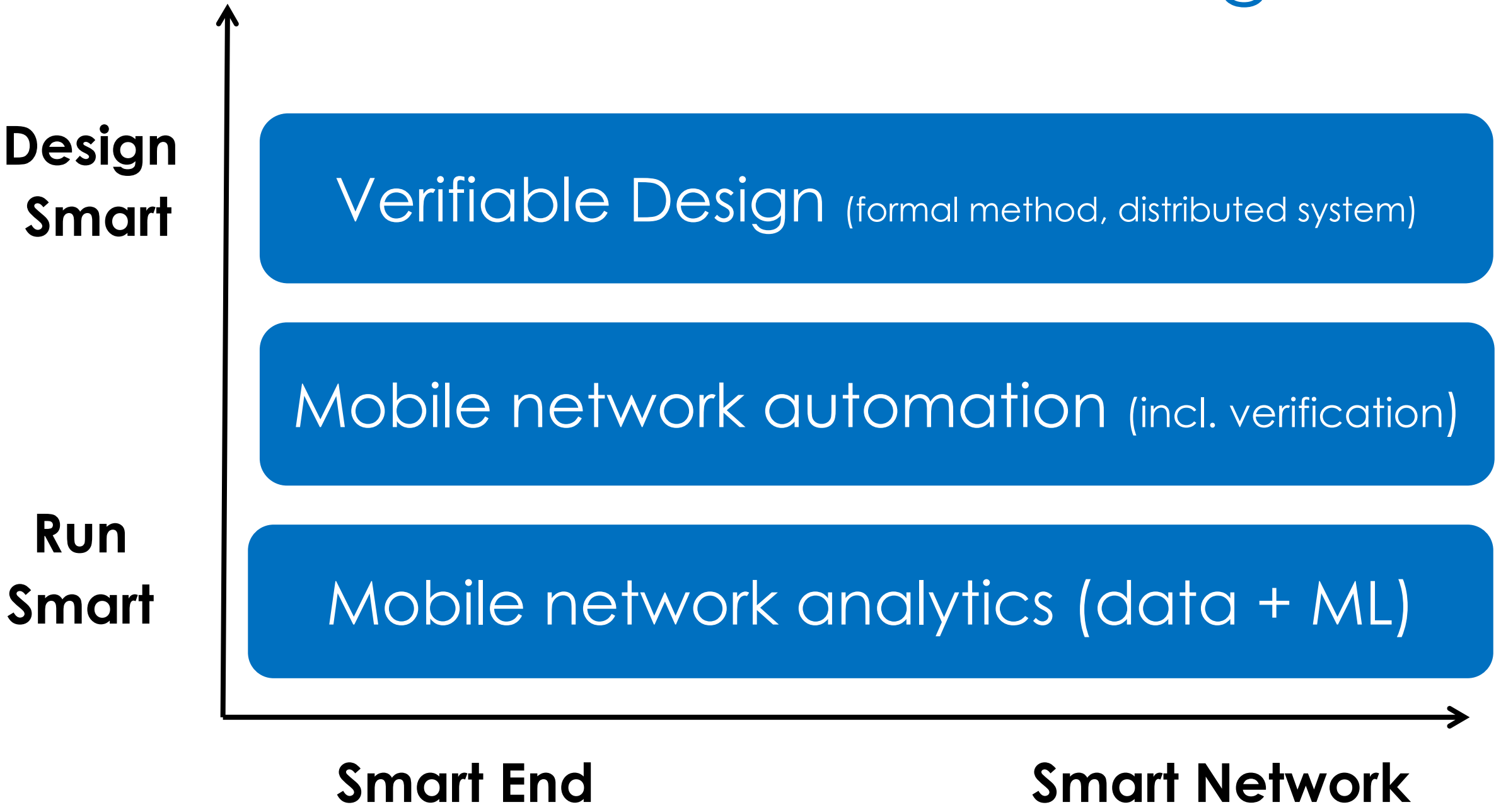
Towards Mobile Network Intelligence



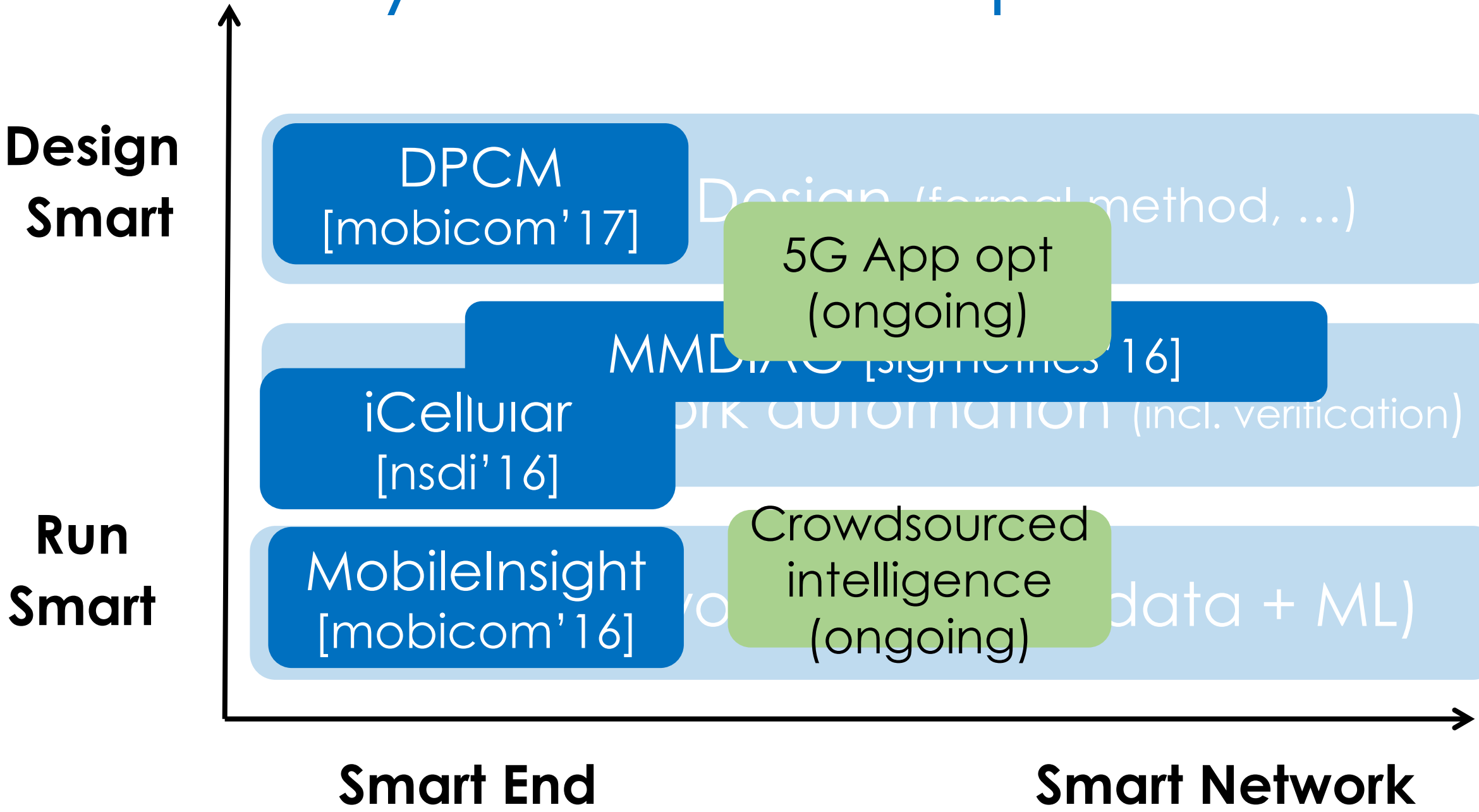
Be Intelligently Connected!

- Run smart (in operation)
  - Data-Knowledge-Action in operation
- Design smart
  - Provable correctness & property by design

Towards Mobile Network Intelligence



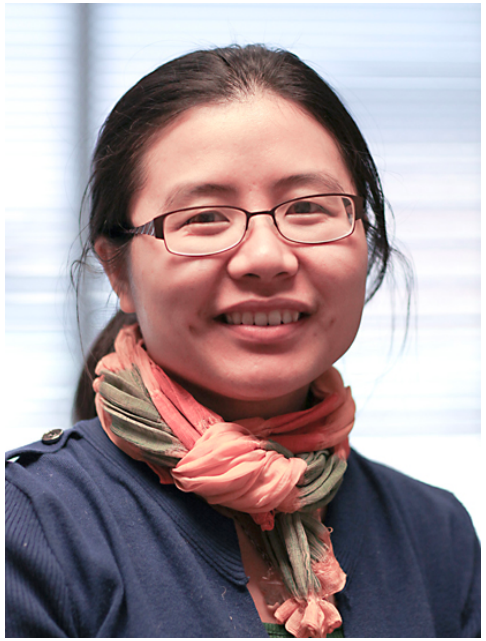
My Recent Footprints



Takeaways

- **Towards mobile network intelligence**
  - Cognitive network management (5G)
  - Exploit data-knowledge-action cycle with ML
  - Formal approach for provable correctness
- **MobileInsight: In-device network intelligence**
  - Our first-step: ready-to-use
  - Category: smart end, run smart
  - Conduct research of your own interests
- **Many new opportunities exposed**
  - **Join us! Make a difference**

Many Thanks to



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NSF

http://mobileinsight.net
https://github.com/mobile-insight
http://mssn.cs.purdue.edu/mobileinsight_lab/milab
Technical support: support@mobileinsight.net

Demos

- MobileInsight 3.3
  - Youtube video: http://mobileinsight.net/news-3.3.html
- MiLAB – MMDIAG
  - Contact chunyi@purdue.edu

Reference: Our Publications (1/2)

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Reference: Our Publications (2/2)

[nsdi16] Yuanjie Li, Haotian Deng, Chunyi Peng, Zengwen Yuan, Guan-Hua Tu, Jiayao Li and Songwu Lu, *iCellular: Device-Customized Cellular Network Access on Commodity Smartphones*, NSDI'16, Santa Clara, CA, March 2016.

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