

iCellular: Device-Customized Cellular Network Access on Commodity Smartphones

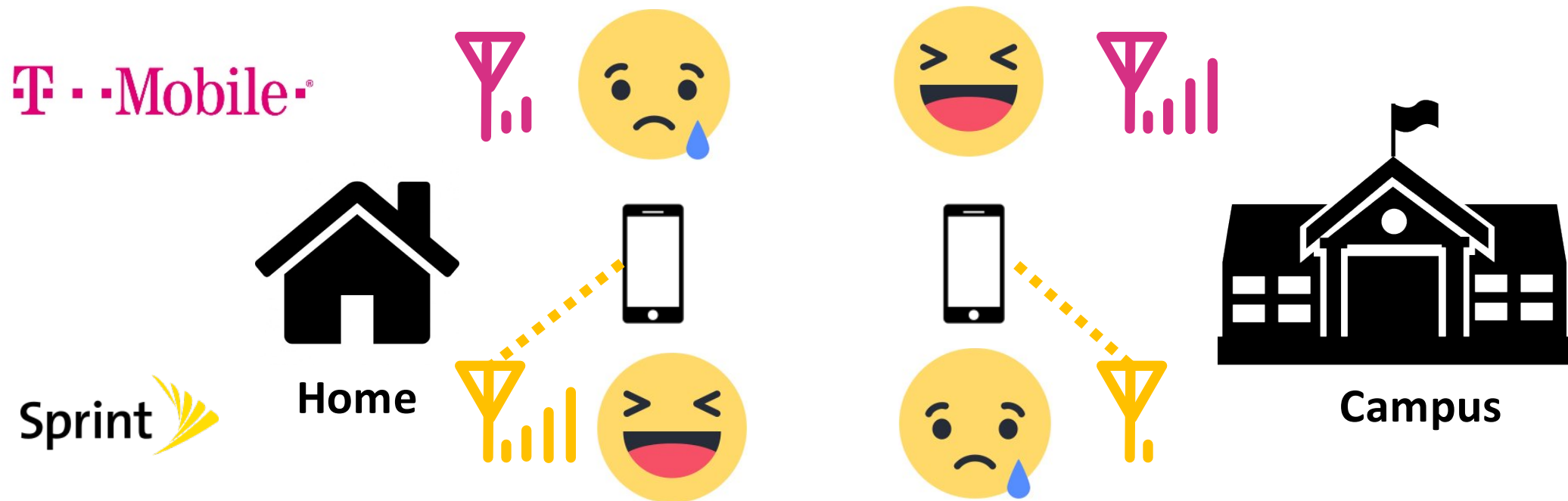
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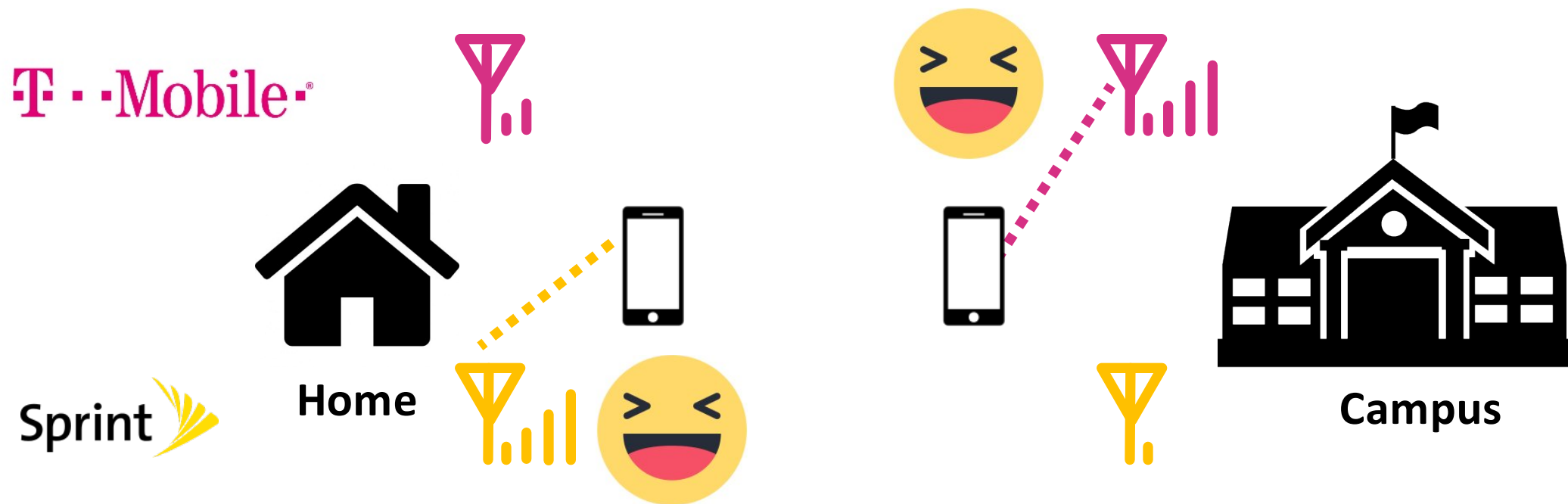
User Demands for High-Quality Cellular Access

- “We want high-quality cellular network service **anytime, anywhere**”
- No single carrier network can *always* satisfy these demands



An Alternative Approach: Multi-Carrier Access

- Let the end devices access multiple carriers and choose the best one
- Emerging efforts: Google Project Fi, Apple SIM, Samsung e-SIM, etc.



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Desired Features for Multi-Carrier Access

#1: Switch
when expected

Example:

Will my phone switch to T-Mobile when it is better than Sprint?

#2: Make a
wise decision

Example:

Will my phone select T-Mobile 4G or Sprint 3G?

#3: Fast and
seamless switch

Example:

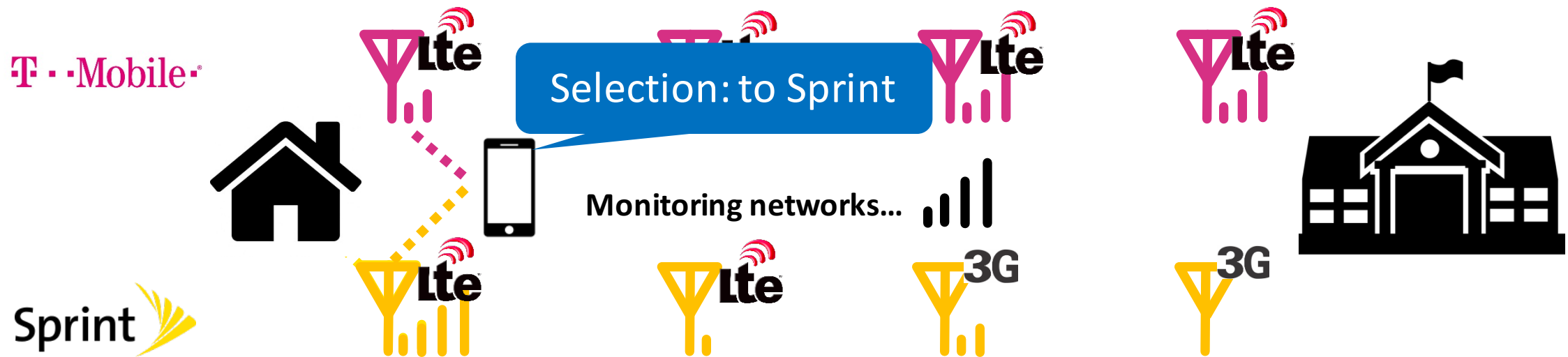
Will my phone quickly switch to Sprint 4G with minimal data disruption?

Outline

- Multi-carrier access today: three issues
 - Root cause analysis
- iCellular design
- Evaluation

Multi-Carrier Access Primer

- Rich coverage at each location (3G/4G, multi-carriers)
- Inter-carrier switch: monitoring → selection → switch

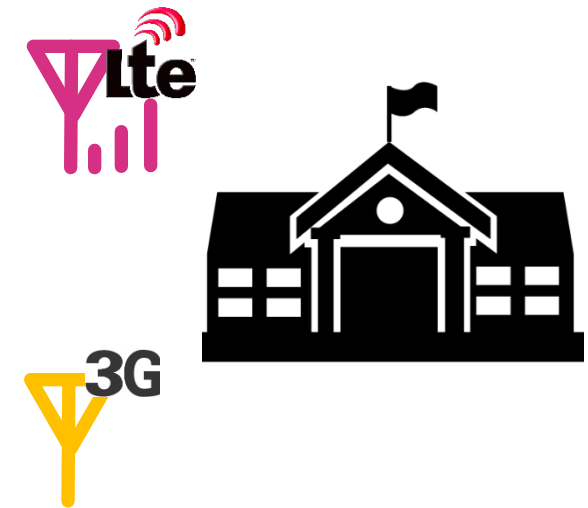
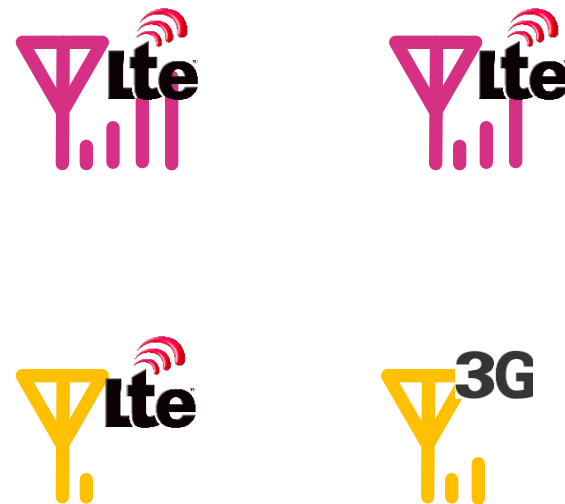


Issue 1: Passive Monitor Misses Better Network

#1: Switch when expected

#2: Make a wise decision

#3: Fast and seamless switch



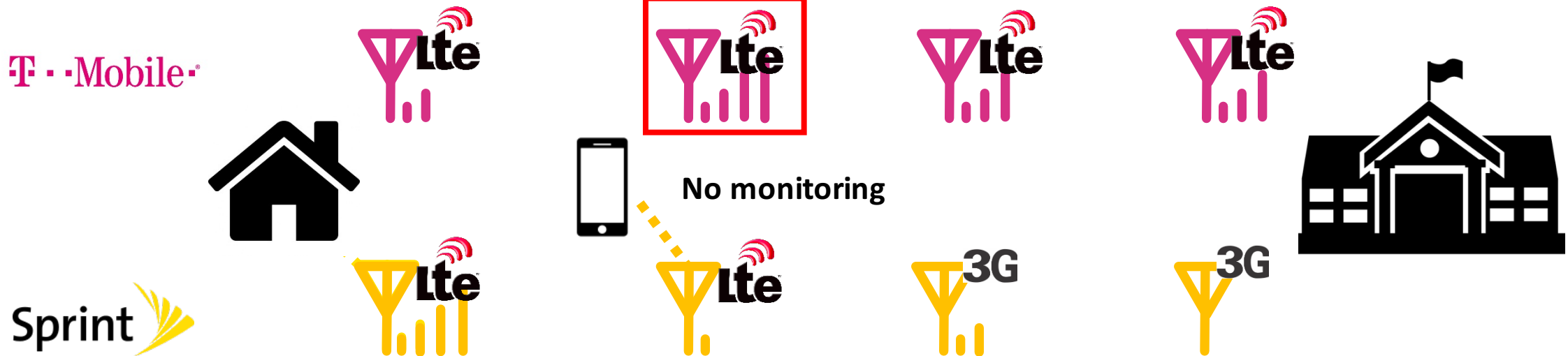
Issue 1: Passive Monitor Misses Better Network

- Monitoring is triggered when the serving carrier network fails
 - Optimized for single-carrier access: roaming to other carriers was not preferred

~~#1: Switch when expected~~

#2: Make a wise decision

#3: Fast and seamless switch

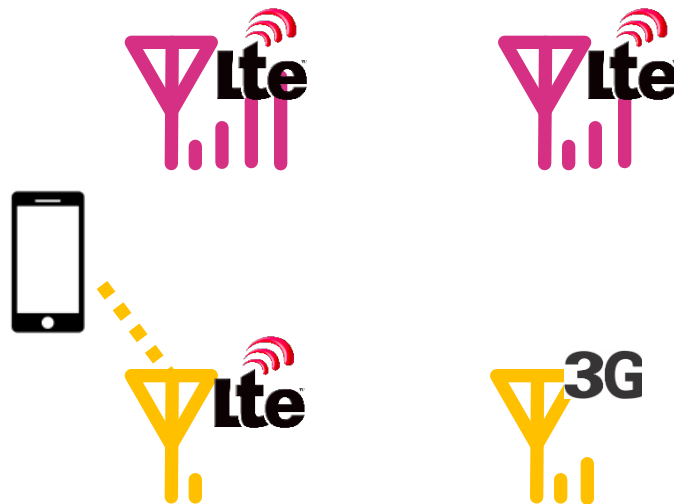


Issue 2: Unwise Network Selection

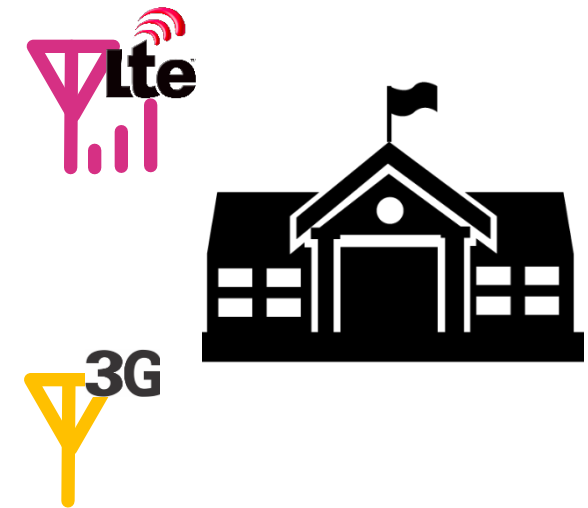
~~#1: Switch when expected~~



#2: Make a wise decision



#3: Fast and seamless switch



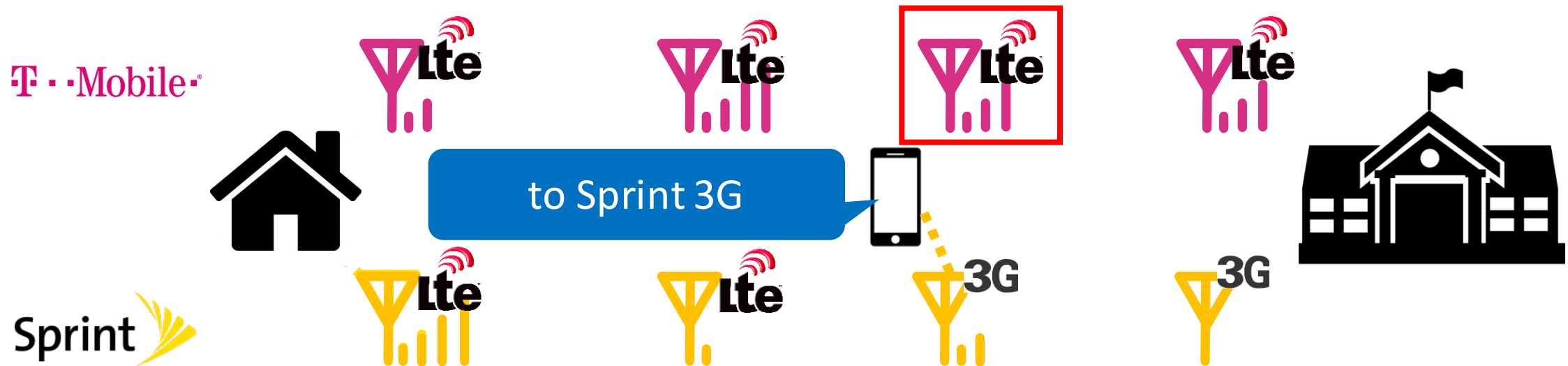
Issue 2: Unwise Network Selection

- Intra-carrier handoff is still preferred, although other carriers are better
 - Serving carrier network affects the mobility decision

~~#1: Switch when expected~~

~~#2: Make a wise decision~~

#3: Fast and seamless switch

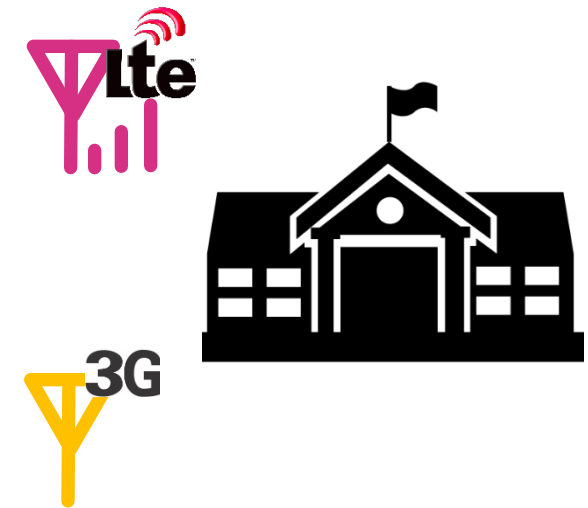
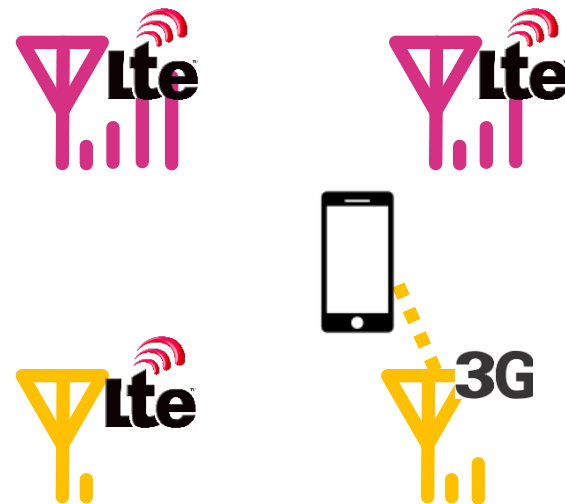


Issue 3: Long Switch Time and Service Disruption

~~#1: Switch when expected~~

~~#2: Make a wise decision~~

#3: Fast and seamless switch



Issue 3: Long Switch Time and Service Disruption

- Exhaustive search for all possible carrier networks

~~#1: Switch when expected~~

~~#2: Make a wise decision~~

~~#3: Fast and seamless switch~~

Time	Event
11:19:57.414	Out-of-service. Start network search
11:19:57.628	Scanning AT&T 4G cell 1, unavailable
11:19:57.748	Scanning AT&T 4G cell 2, unavailable
...	...
11:20:11.788	Scanning Verizon 4G cell 1, unavailable
...	...
11:20:12.188	Scanning T-Mobile 4G cell 1, available
11:20:12.771	Attach request (to T-Mobile 4G)
11:20:14.788	Attach accept

RF band scanning:
14.7s

Network registration:
2.6s



Reality of Multi-Carrier Access

~~#1: Switch
when expected~~

~~#2: Make a
wise decision~~

~~#3: Fast and
seamless switch~~

Reality of Multi-Carrier Access

P1:
Passive
monitor

P2:
Unwise
selection

P3:
Long switch and
disruption

Can we solve these problems
without changing 3G/4G design?

Empower the end device with low-level cellular info!

iCellular Overview

P1:
Passive
monitor

P2:
Unwise
selection

P3:
Long switch and
disruption



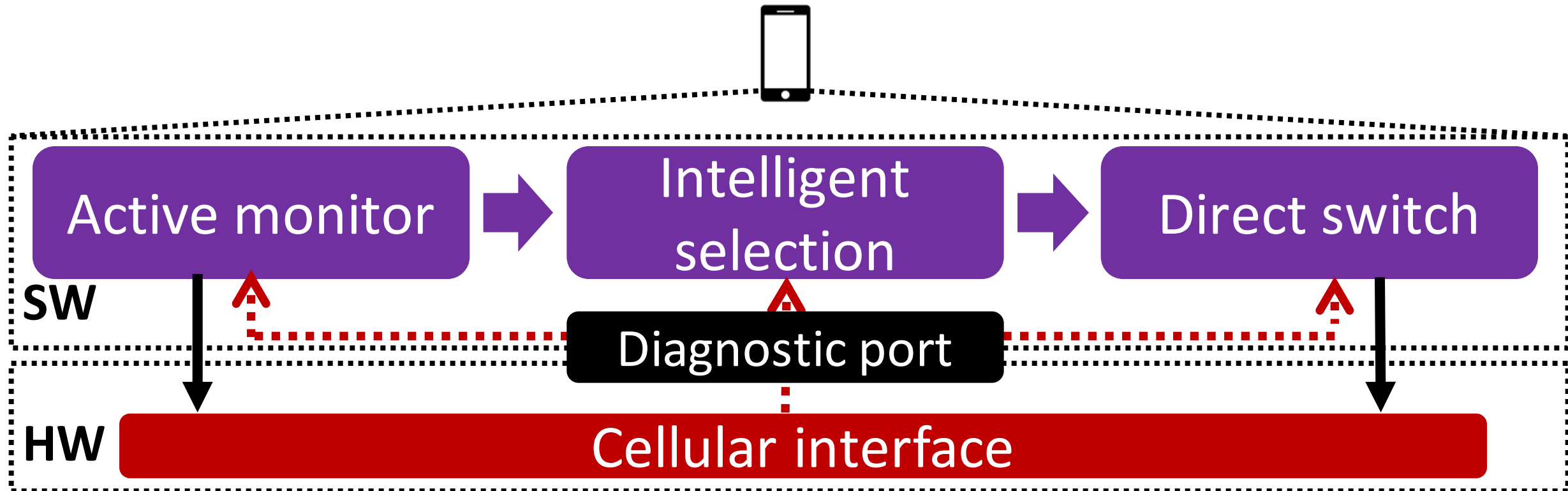
Active monitor

Intelligent
selection

Direct switch

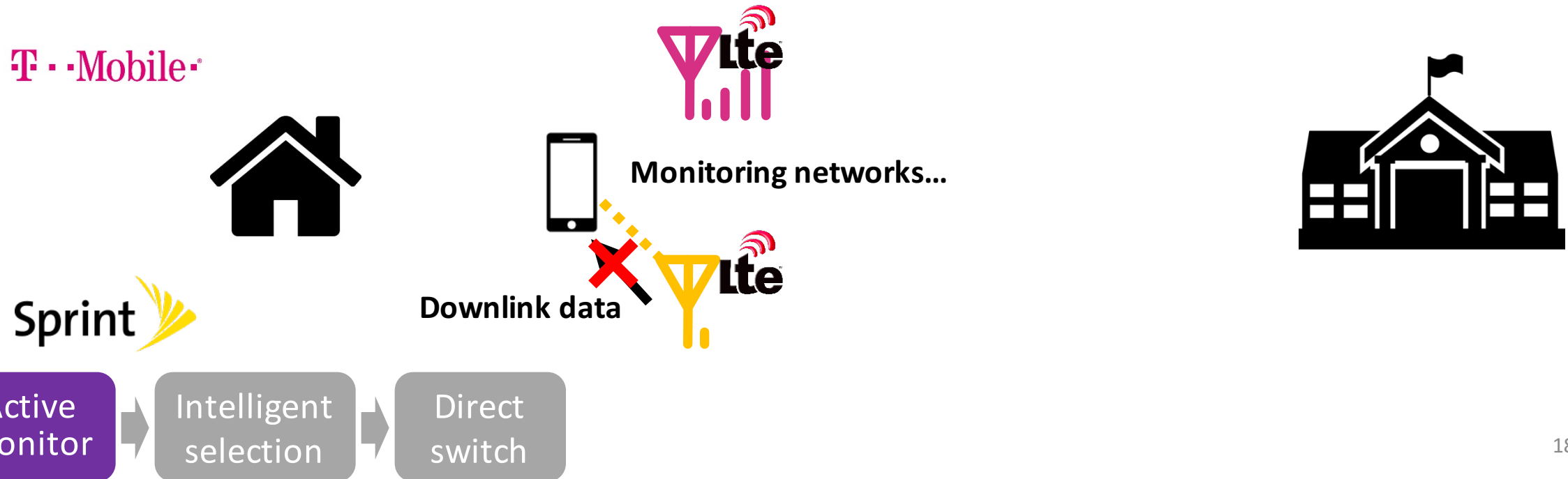
iCellular Architecture

- A in-phone software service
- Leverage low-level mechanism and info
 - Runtime cellular info (knowing more for a wiser decision)
 - Ability for adaptation in existing mechanisms (action ready now)



Active Monitor

- **Goal:** proactively detect other available carrier networks
- **Mechanism:** manual network search
- **Challenge:** searching other carriers may disrupt data service!



Active Monitor

- **Key insight:** data reception is regulated by paging cycle
- Schedule the manual network search with low-level cellular feedback

T-Mobile



Monitoring networks...

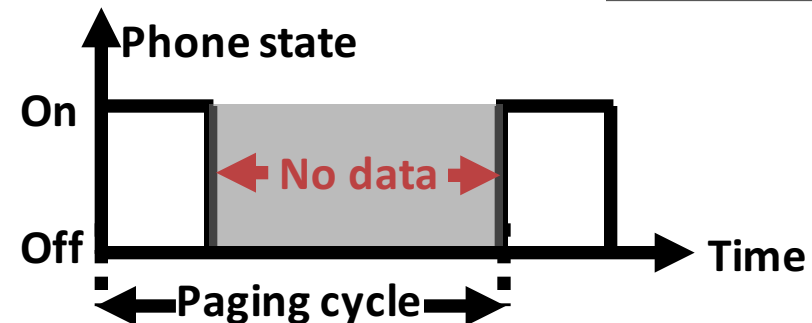


Sprint

Active monitor

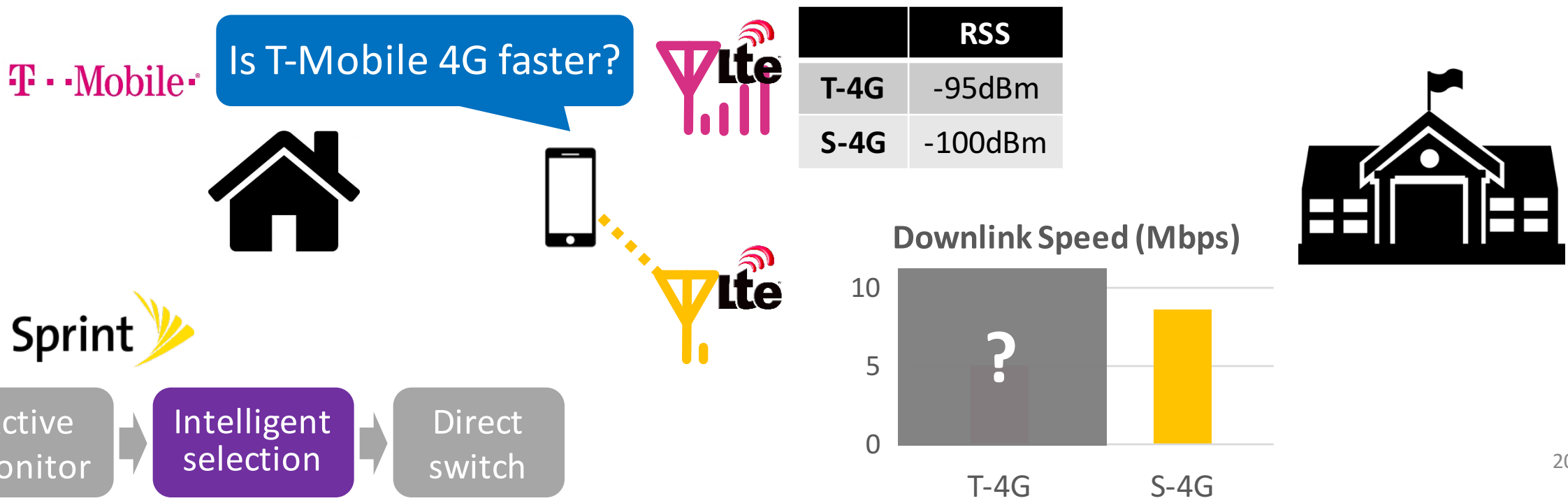
Intelligent selection

Direct switch



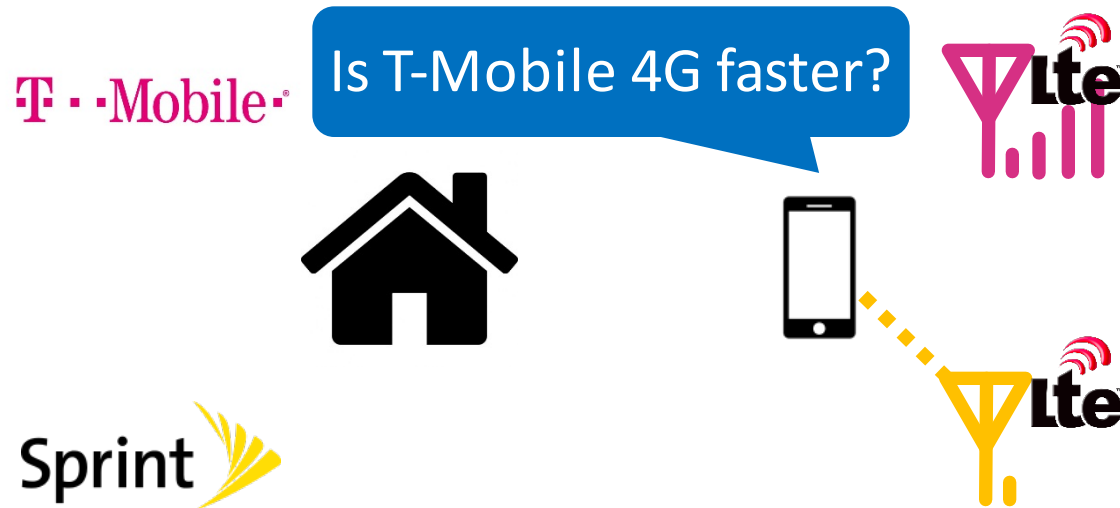
Intelligent Selection

- Without registration, data performance cannot be measured ...
- Better signal strength \neq Faster speed!
 - Heterogeneous carrier networks



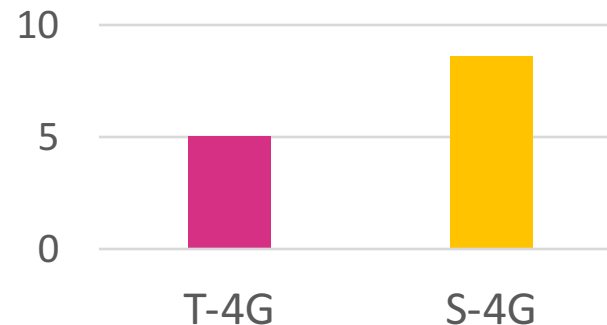
Intelligent Selection with Prediction

- Collect each carrier network's profile: QoS + radio parameters
- Predict carrier performance with radio measurements + cellular profile



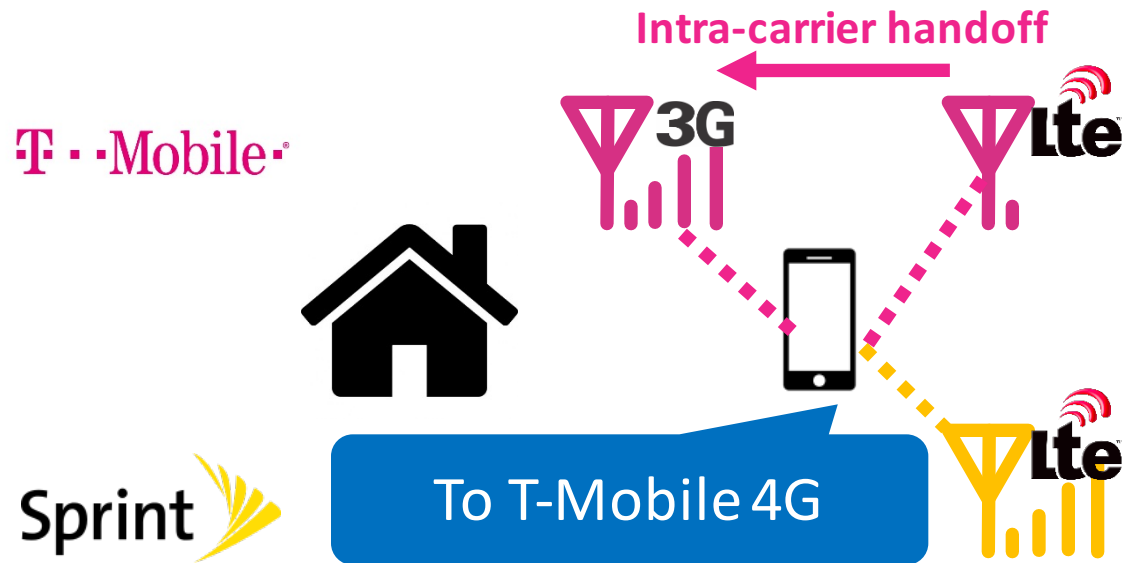
	RSS	QoS class
T-4G	-95dBm	Background
S-4G	-100dBm	Interactive

Downlink Speed (Mbps)



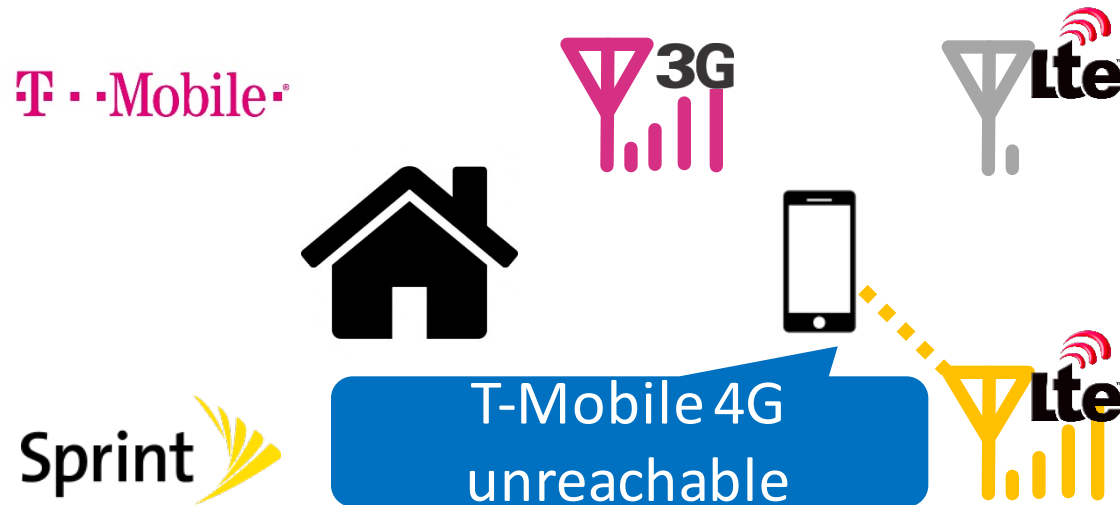
Decision Faults Prevention

- Conflicts with network-side mobility rules



Decision Faults Prevention

- Conflicts with network-side mobility rules
- Safeguard device selection by predicting decision faults



Intra-carrier handoff profile	
T-4G	Handoff to 3G if $RSS_{T-4G} < -120\text{dBm}$, and $RSS_{T-3G} > -90\text{dBm}$

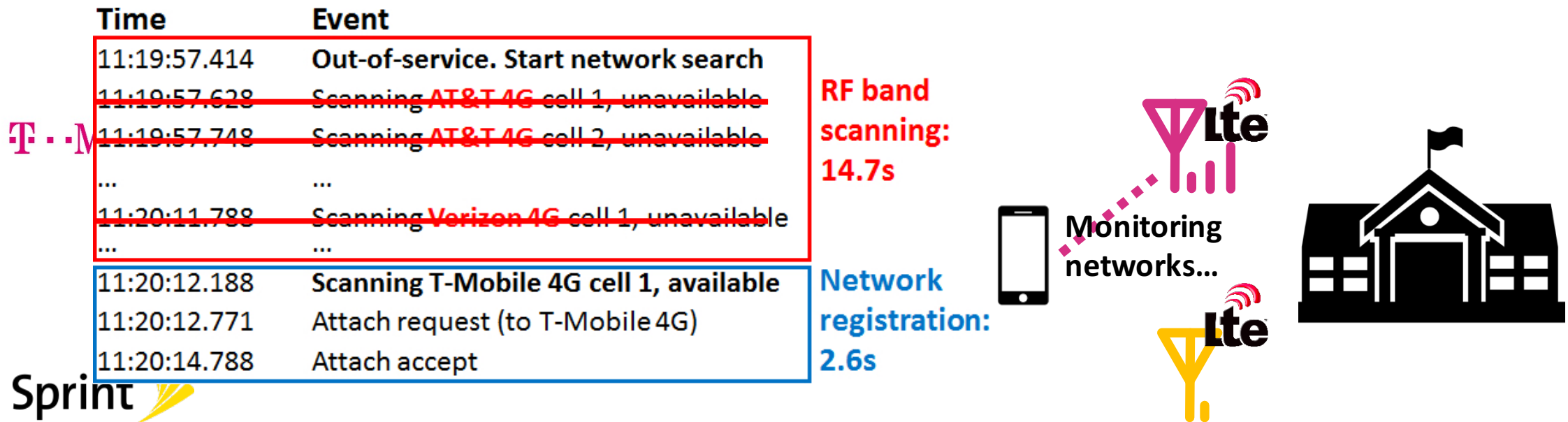
RSS	
T-4G	-123dBm
T-3G	-85dBm

T-4G → T-3G handoff would be triggered!



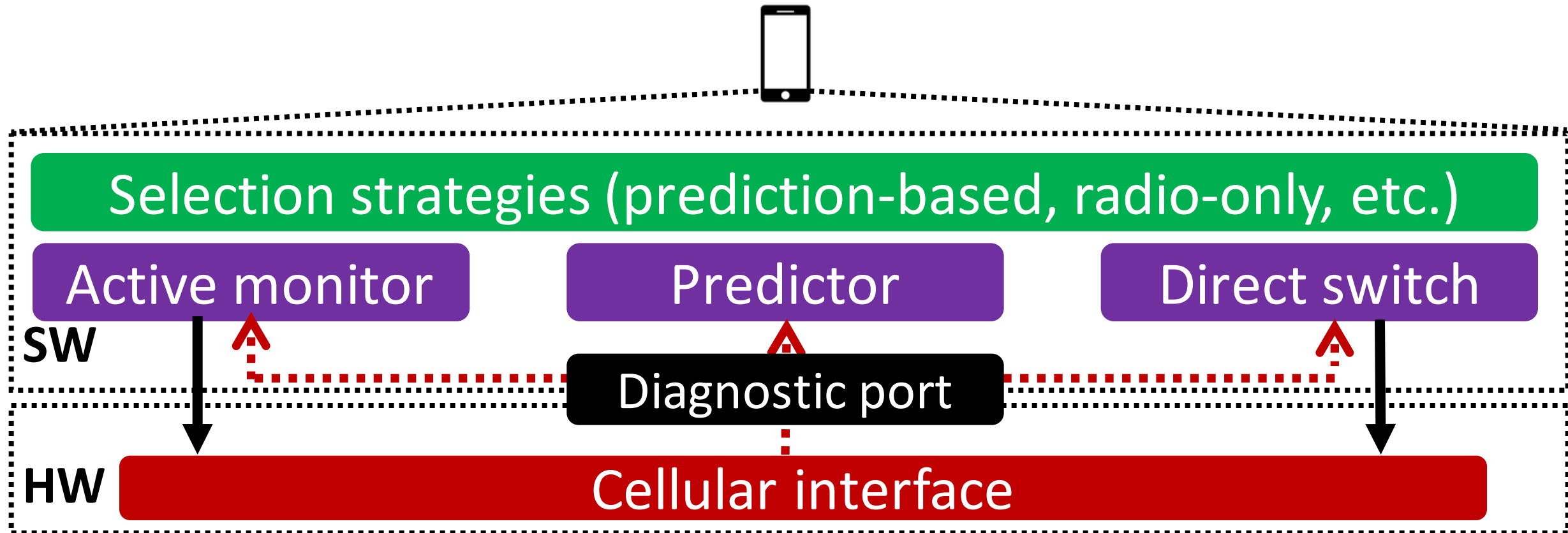
Adaptive Direct Switch

- **Goal:** minimize switch time and service disruption
- **Key insight:** most switch time is spent on exhaustive search
- **Solution:** cross-layer adaptation for PLMN preference



Implementation

- In-phone daemon service on Nexus 6/6P
- Leverage Project Fi SIM card for multi-carrier access
- Built-in strategies for better usability

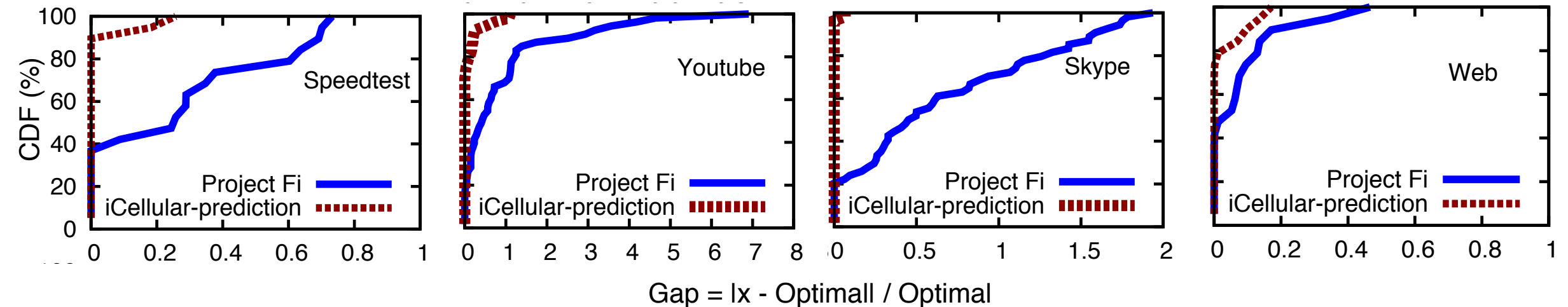


Evaluation Setup

- Comparison between iCellular and Project Fi
- Pedestrian mobility and static experiments at campus
- Four representative applications:
 - **Bulk file transfer:** SpeedTest
 - **Web:** Firefox
 - **Video streaming:** Youtube
 - **VoIP:** Skype

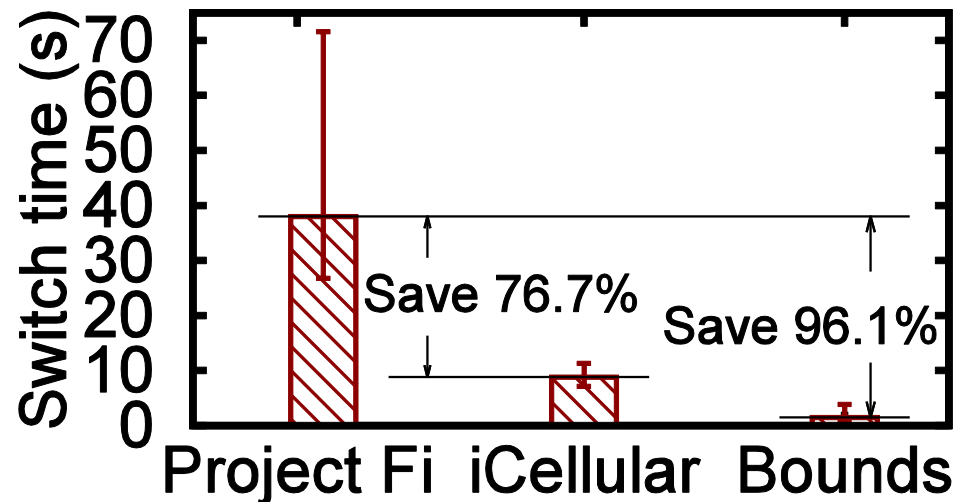
Data Performance Improvement

- **Downlink speed increment: 23.8%** on average, **3.74x** at maximum
- **Video suspension reduction: 37%** on average, **6.9x** at maximum
- **VoIP latency reduction: 60.4%** on average, **1.9x** at maximum
- **Web loading time reduction: 7.3%** on average, **46.5%** at maximum



Inter-carrier Switch Time Reduction

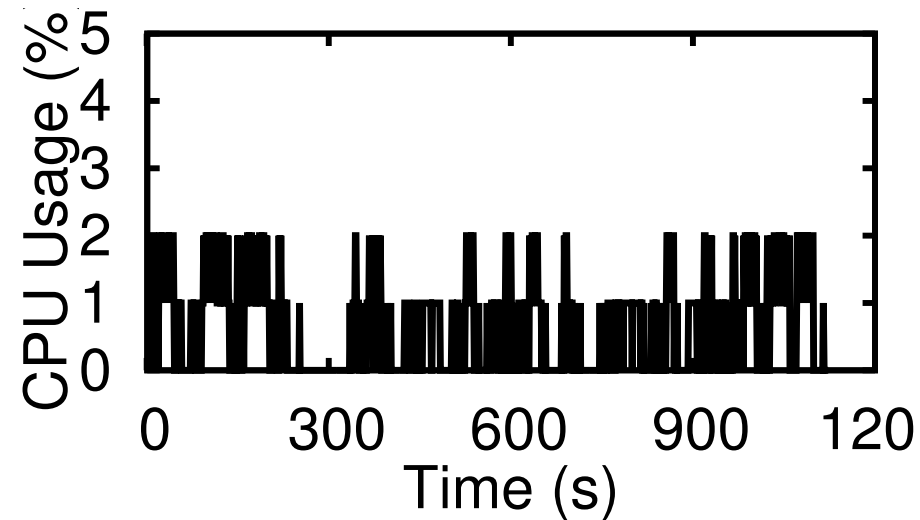
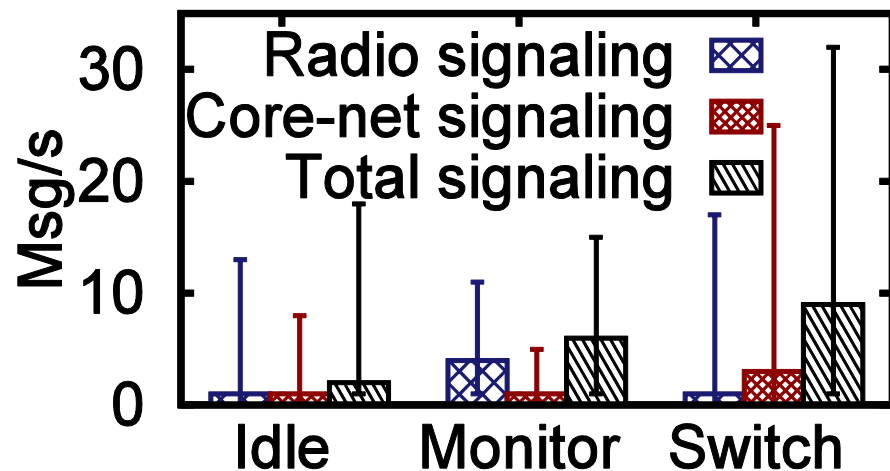
- Average saving: **37.7s** → **8.8s** (**76%** reduction)
- Further improvement is possible with better SIM implementation



Time	Event
16:40:36.756	Deregister from Sprint 4G SIM card
16:40:36.890	Invalidate SIM data request Reconfig:
16:40:36.892	Reconfiguring SIM card... 6.4s
...	...
16:40:43.100	SIM card configuration done
16:40:44.501	Scanning T-Mobile 4G cell 1, available
16:40:44.709	Attach request (to T-Mobile 4G)
16:40:45.471	Attach accept Network registration: 2.3s

iCellular's Overhead

- **Signaling overhead: 32 msg/s** at maximum
- **CPU/Memory: below 2%/16.5MB**
- **Energy consumption: 4.75%** battery usage in 24-hr normal usage test
 - Comparable to normal mobile apps: e.g., 4.54% for Skype in same test



Conclusion

- Multi-carrier access is promising, but its full benefits are constrained
 - Legacy 3G/4G was designed for single-carrier access
- The end device can take a more active role in multi-carrier access
- Leveraging runtime cellular information is an alternative dimension to enhance device-side inter-carrier switch

Thank you!