A First Look at Unstable Mobility Management in Cellular Networks

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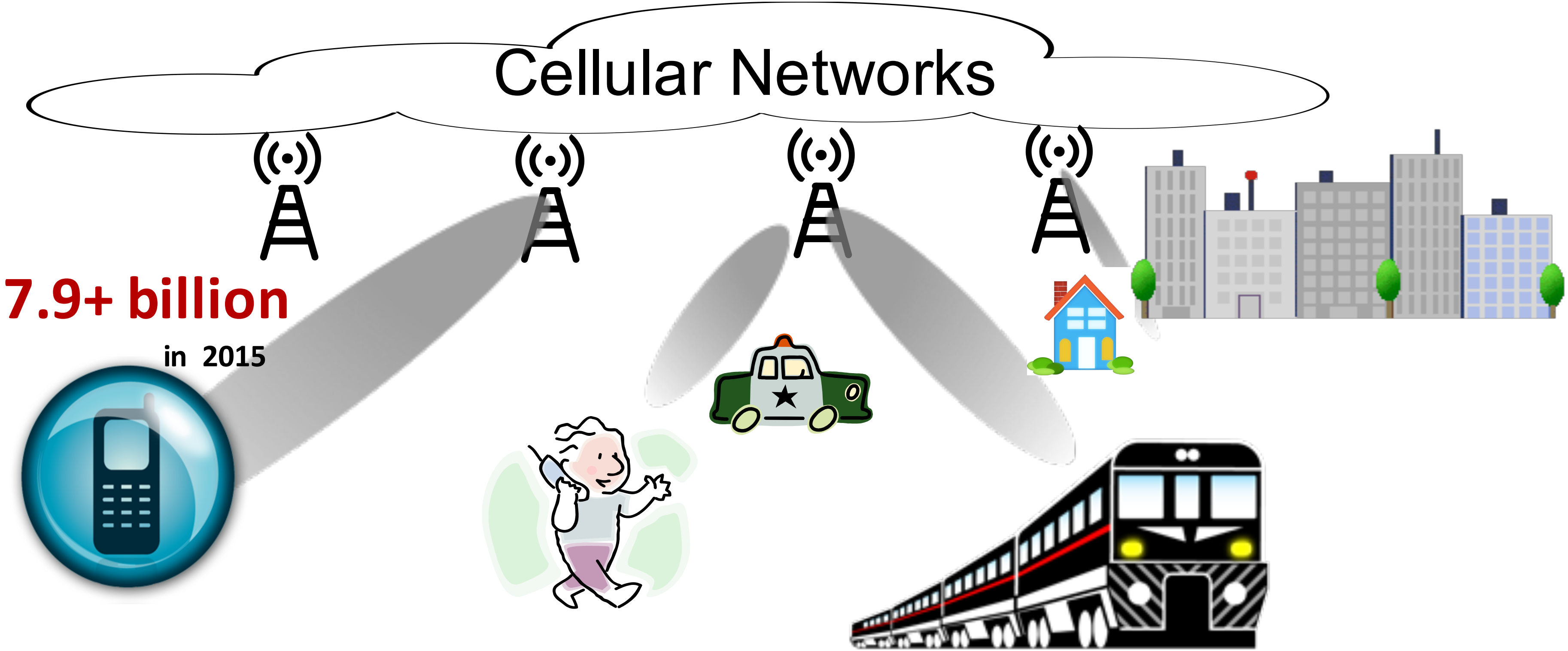
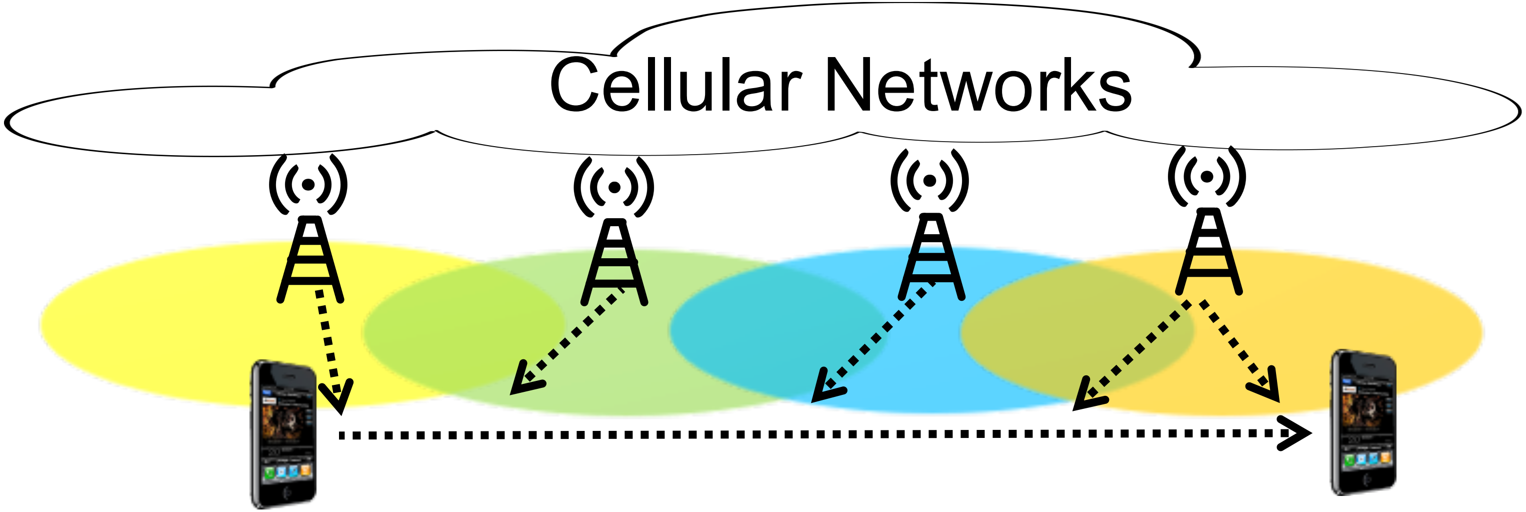
HotMobile'16

Ubiquitous Cellular Network Access

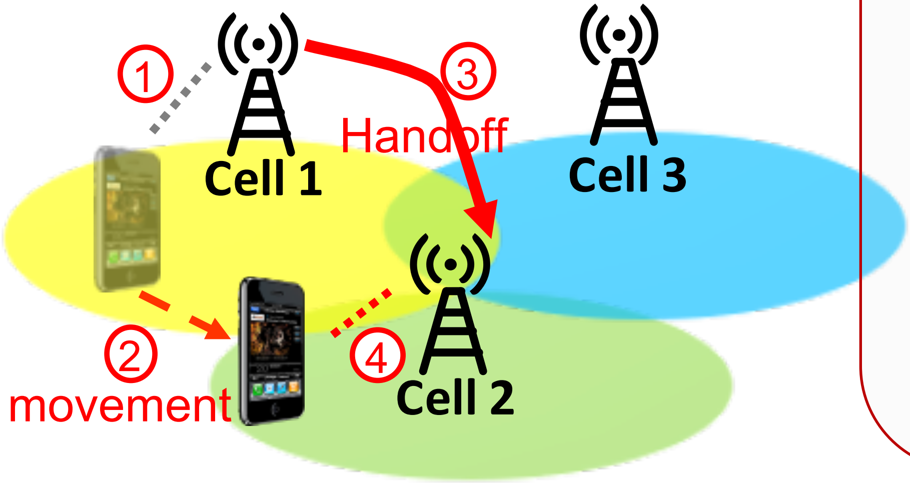


Mobility Management (MM) via Handoff



- Seamless connectivity (via switching the serving cell)
  - Each cell: limited radio coverage

Desirable Handoff: Stability

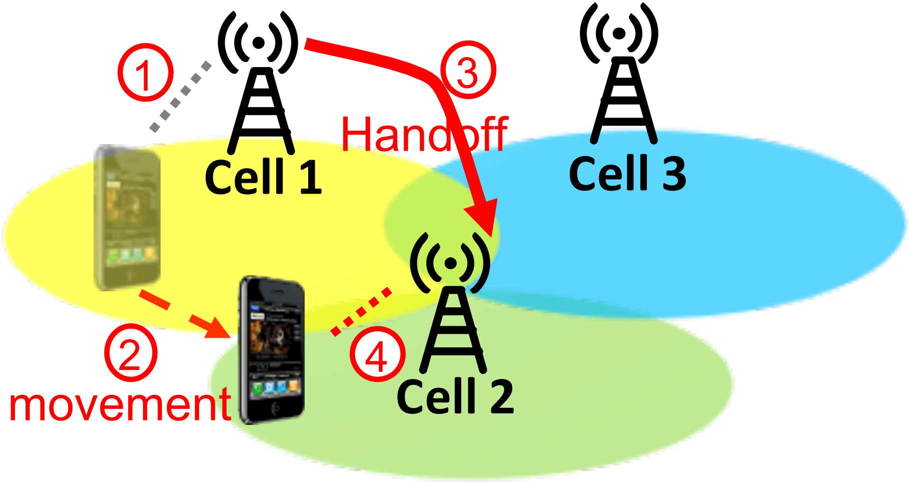


Why desirable?

- Handoff comes at a cost
  - Multi-round signaling exchange
  - Service disruption/degradation

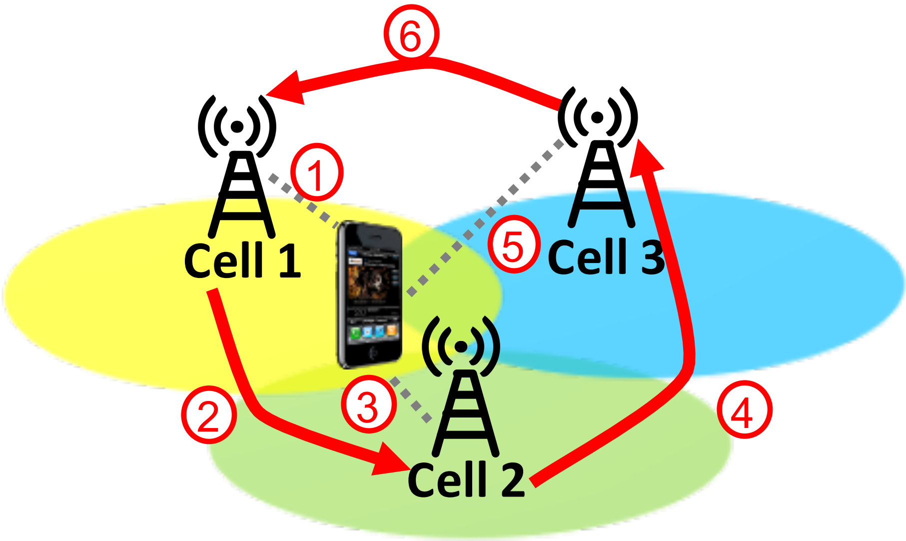
- Converge to certain cell given an invariant setting

Desirable Handoff



- Stability
  - Converge to certain cell

Problematic Handoff



- Instability (persistent loop):
  - C1->C2->C3->C1->C2->C3…

This Work: Instability in Mobility Management

- Q1: Does it exist in real networks?
- Q2: Why unstable?
- Q3: How to identify such risk?

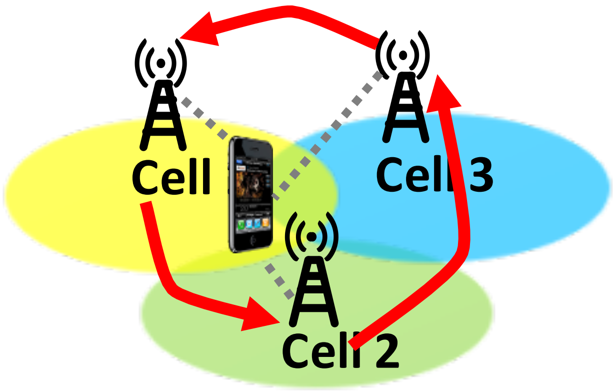
Caused by fundamental (persistent) conflicts in policy
not by transient factors (radio dynamics etc)

Q1: Does unstable MM exist in reality?

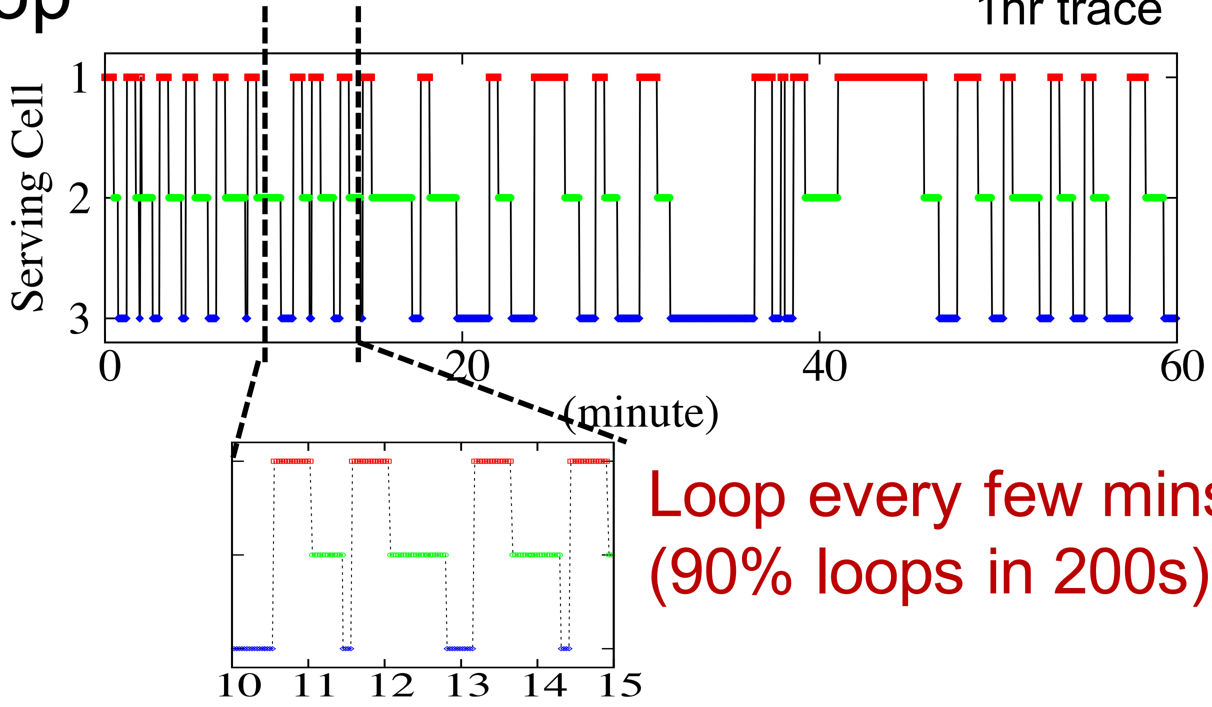
- Unfortunately, Yes!

3-Cell Loop Example

- Static, 40hr-loop



Cell1: 4G
Cell2: Femtocell (3G)
Cell3: 3G

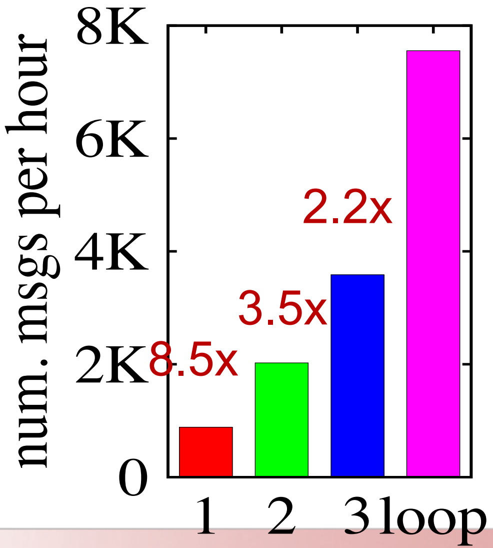


Loop every few mins
(90% loops in 200s)

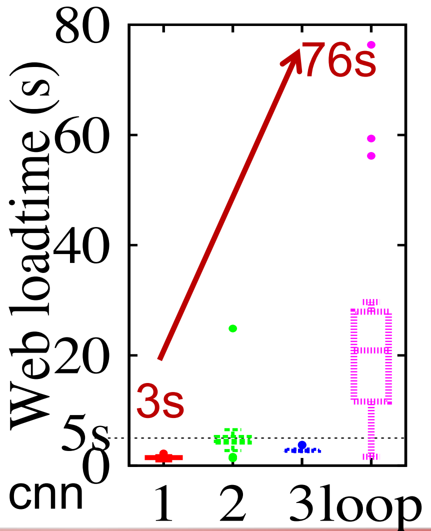
Negative Impacts in Real-world

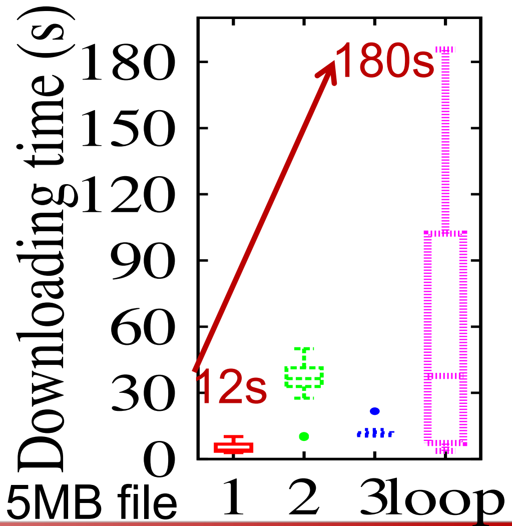
- Hurt both carriers and users

- Excessive signaling overhead (2-8x)



- Performance degradation (10+ fold slowdown)

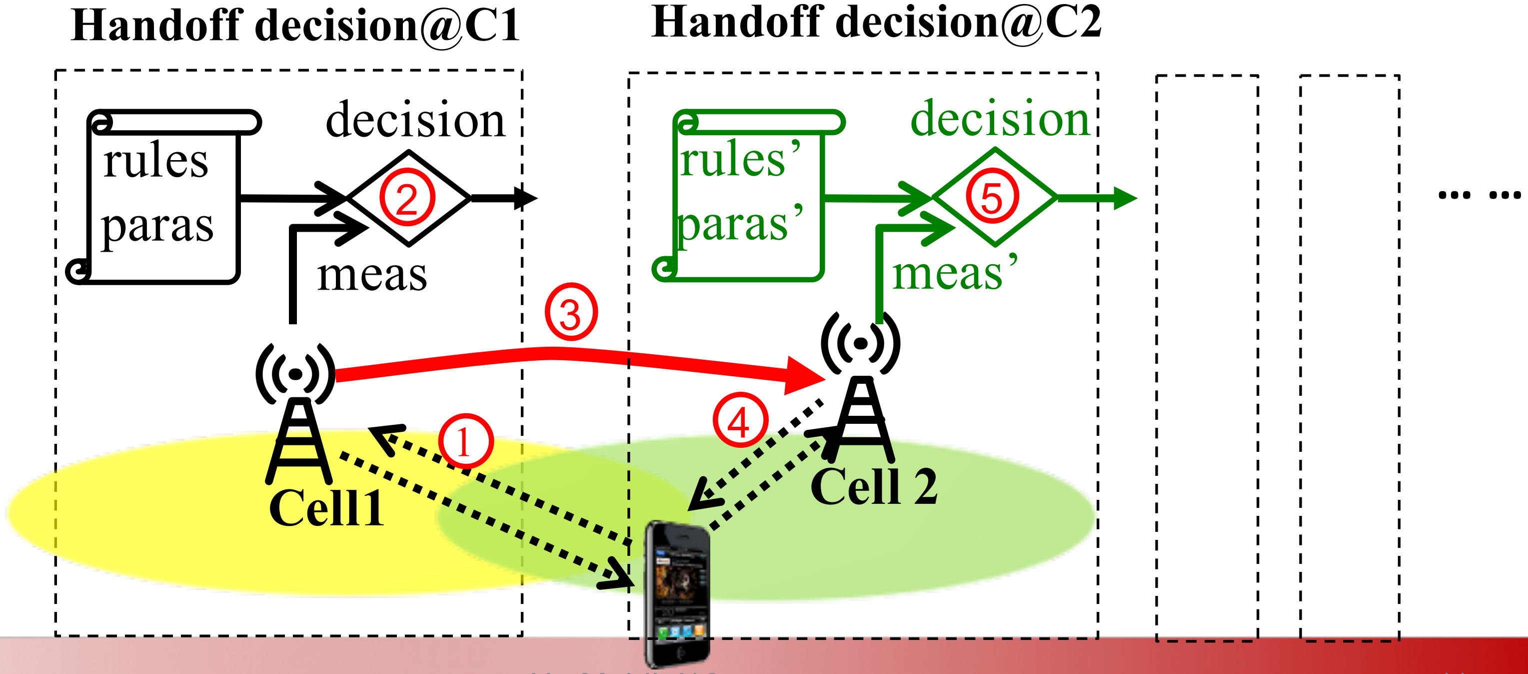




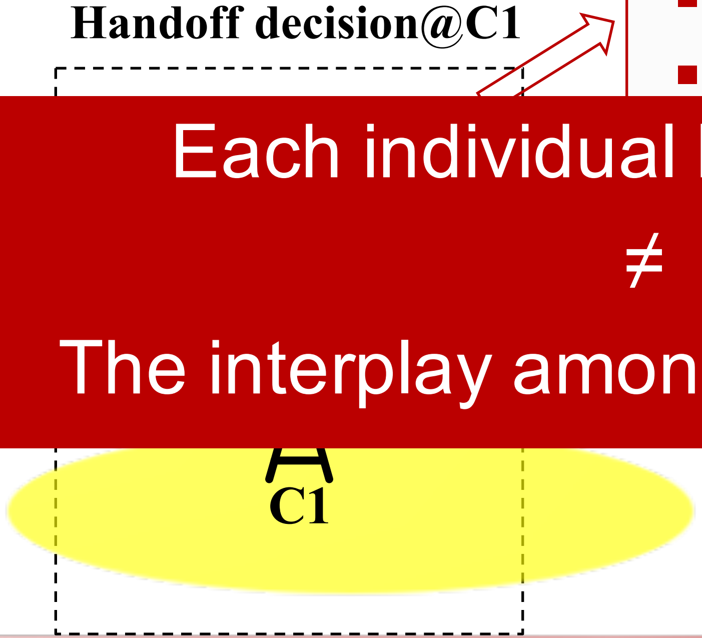
Q2: Why is MM unstable?

Distributed Nature of Handoff

- Each handoff: trigger-decision-execution phases
- Sequence of handoffs



Handoff for Versatile Demands



- Seamless connectivity
- Voice/data support
- Performance

Each individual handoff: OK

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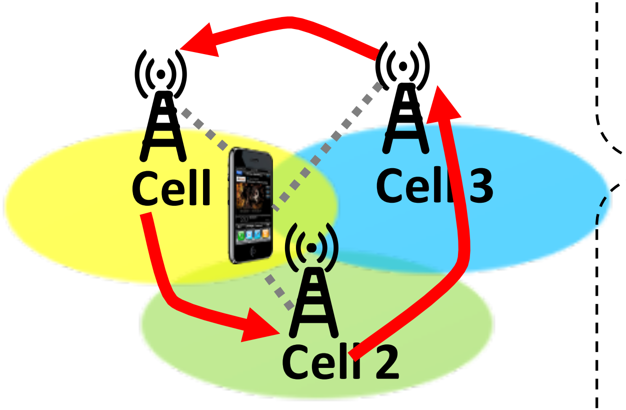
The interplay among multiples: OK

3-Cell Loop Example



Cell1: 4G
Cell2: Femtocell (3G)
Cell3: 3G

Rule/preference configuration@C1 (4G)

- C2 (Femto) > C1 (4G) for offloading
- C1 (4G) > C3 (3G) for higher-speed

C1: C1→ C2

@C2 (3G Femto)

- Best radio strength with same preferences for all cells

C2: C2→ C3

@C3 (3G)

- C1 (4G) > C3 (3G) for higher-speed

C3: C3→ C1

From Example to Generalization

- Each handoff decision: $t = Fs(s, C)$
  - s: serving cell
  - C: set of candidate cells
  - *Fs*: decision function for serving cell s
  - t: target cell

- The sequence of handoff decisions

$$s \rightarrow Fs(s) \rightarrow \cdots c_i \rightarrow [c_{i+1} = Fc_i\,(c_i)] \rightarrow \cdots, ci \in C.$$

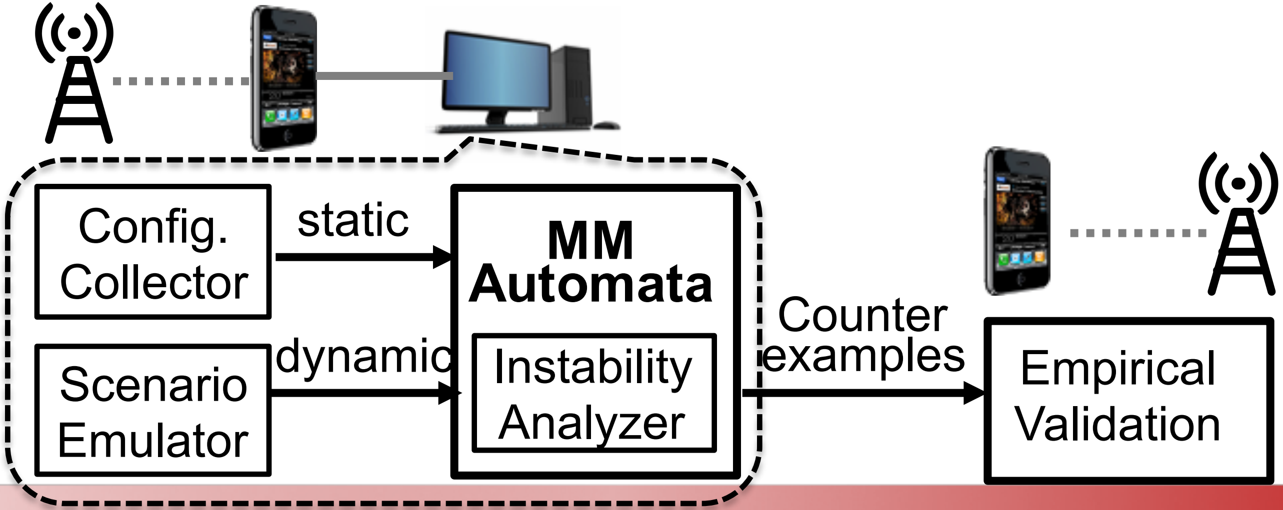
From Example to Generalization

- Instability = No convergence
  - e.g., persistent loop: $c \rightarrow \cdots c_i \rightarrow c_{i+1} \rightarrow \cdots\ c.$
- **[Necessary stability condition]** there exists at least one t, s.t. $\exists t \in C, t = Ft(t, C)$
- **[Necessary and sufficient condition]** (1) $\exists t \in C$, $t = Ft(t, C)$; (2) there exists a handoff path from the initial cell s to the desirable t

Q3: How to detect possible instability?

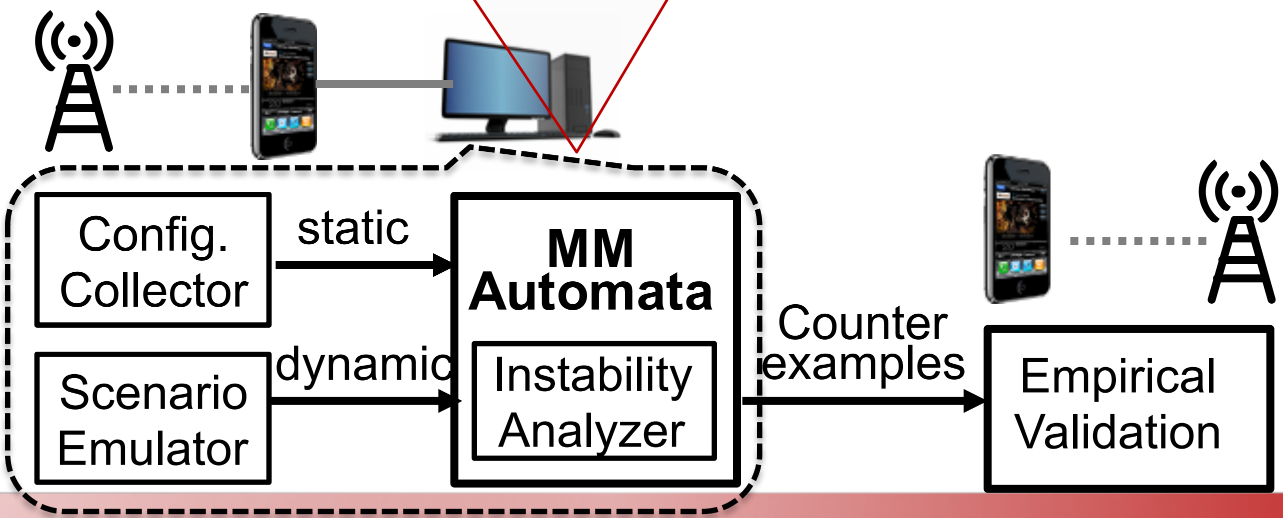
MMDIAG

- In-device diagnosis
  - Carriers: reluctant to provide network-side MM info
- Two-phase: analyzer and validation



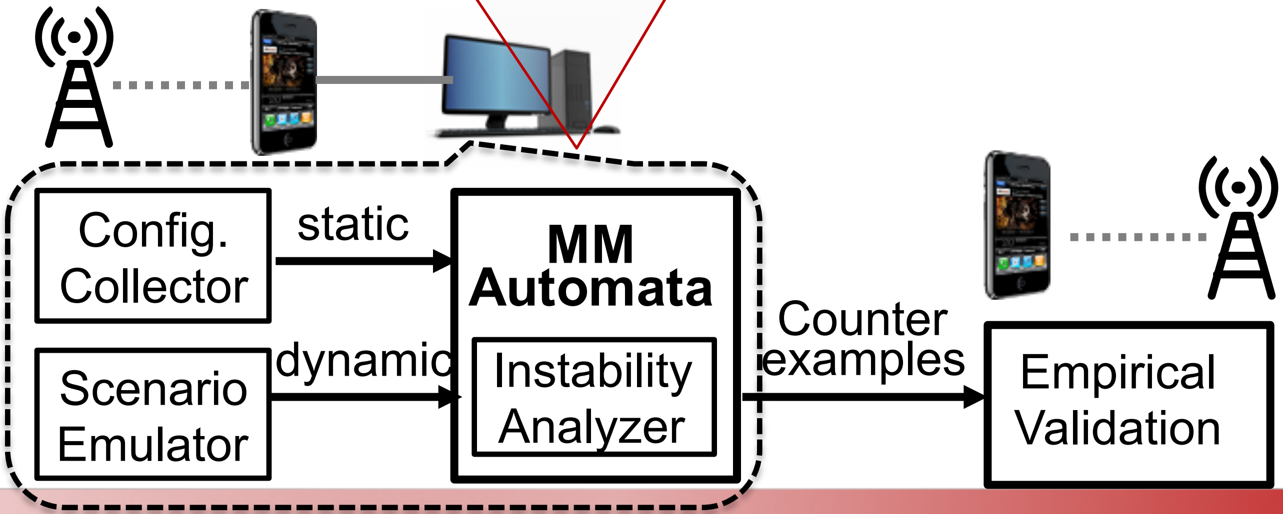
MMDIAG

- Model based on 3GPP spec
- Decision logic, configuration parameters and runtime observation (scenario)



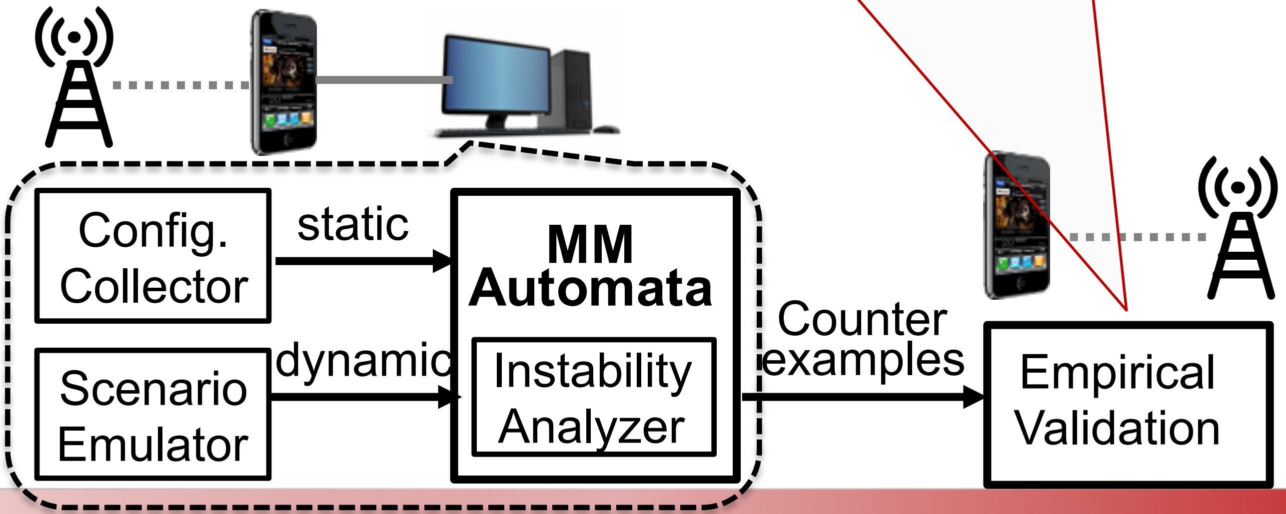
MMDIAG

- Model based on 3GPP spec
- Decision logic, configuration parameters and runtime observation (scenario)
- Violation check



MMDIAG

- Scenario reconstruction and experiments
  - Configurations and observations in counterexample
  - Trace collection and comparison

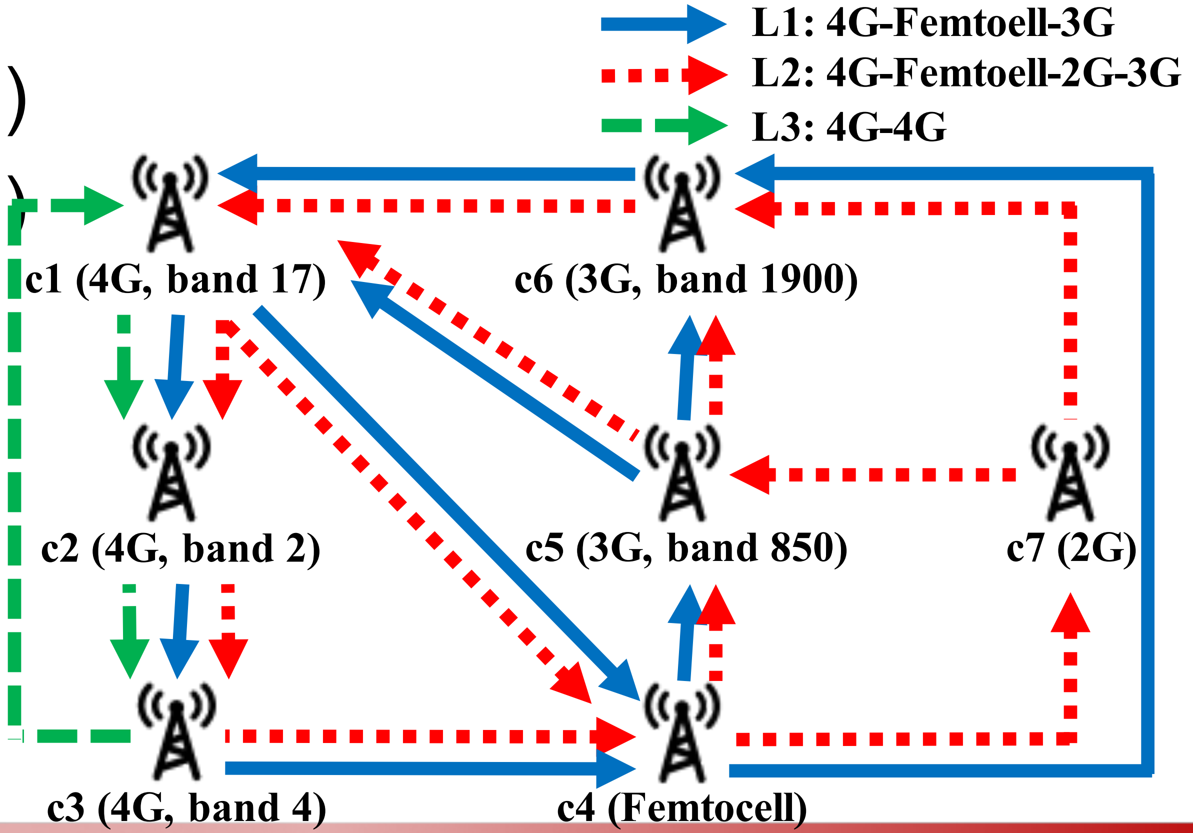


Real-World Findings

- One top-tier US carrier
- Los Angeles and Columbus
    - 63 locations (outdoor)
    - 50 spots (indoor)

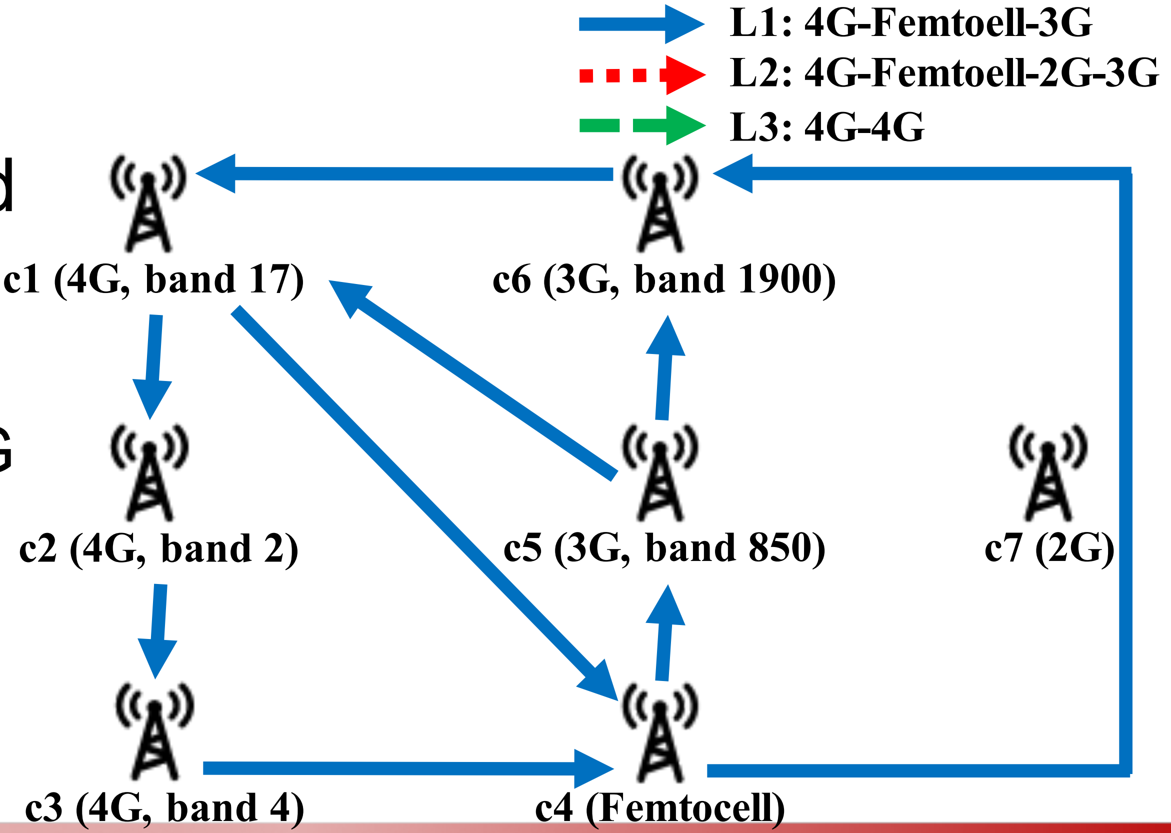
Preliminary Results

- 17 loops (idle)
- 1 loop (active)



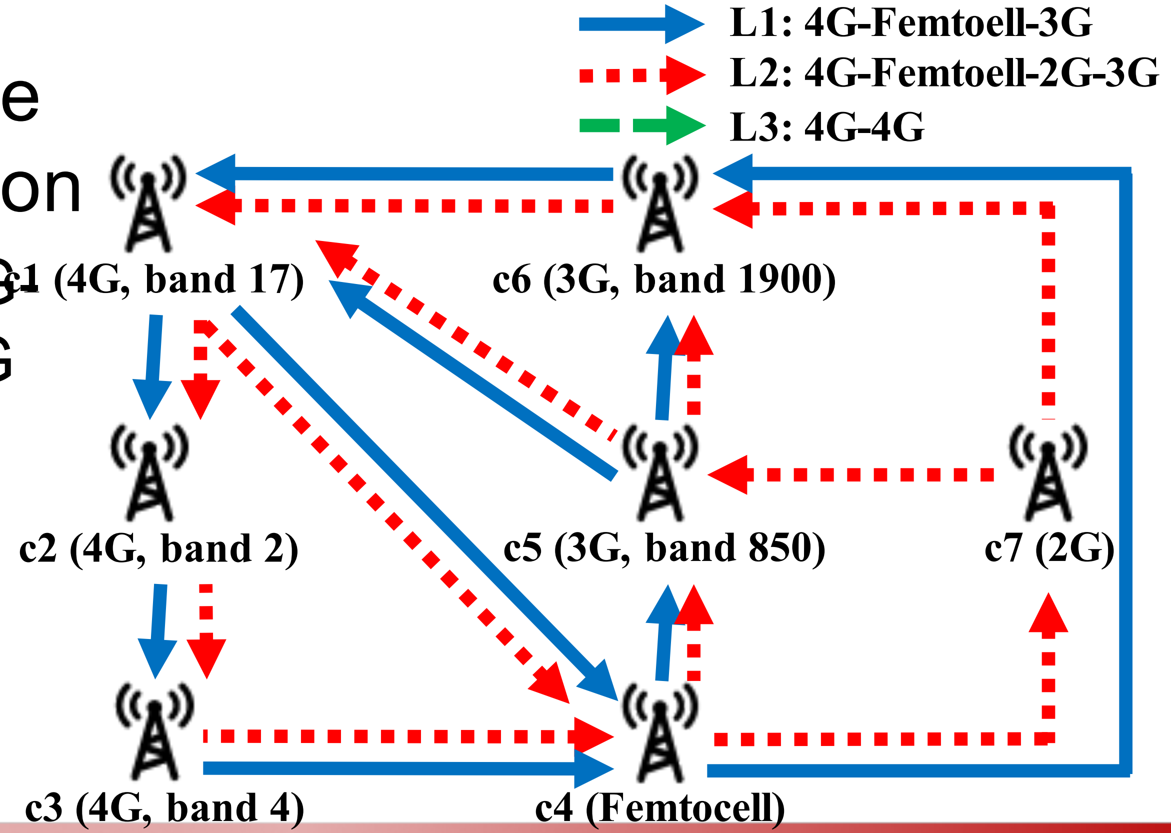
Four Classes (Root Causes)

- #1: uncoordinated handoff goals
  - 8 variants, 4G-Femto-3G



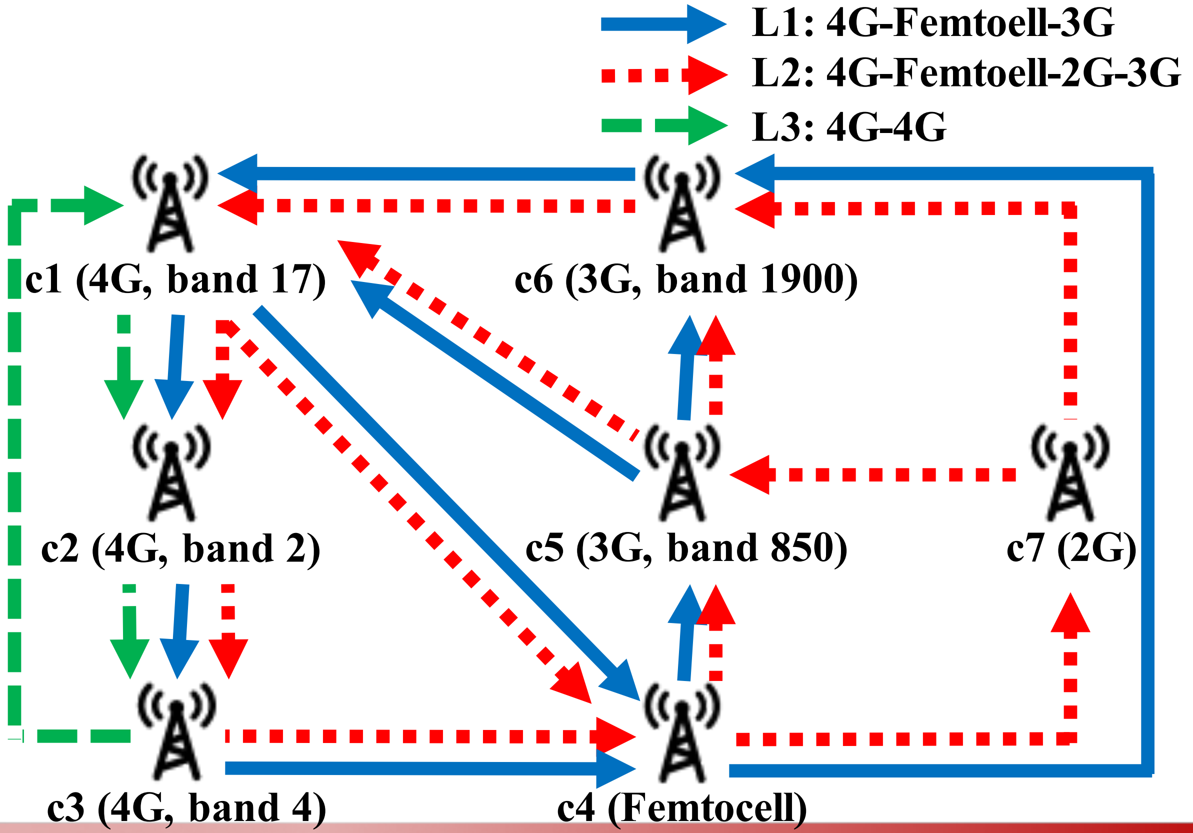
Four Classes

- #2: device-side misconfiguration
  - 8 variants, 4G-Femto-2G-3G



Four Classes

- #3: Imprudent 4G upgrade
  - One 4G-only loop
- #4: uncoordinated load balancing
  - One 4G-only loop (active)



Takeaway

- Largely stable in practice
  - Instability mainly caused by Femtocells or incompatible upgrades

- But in principle, instability likely exists
  - Distributed nature
  - Diversity and external (non-carrier) factors in case of heterogeneous networks (femtocells, small cells, WiFi, etc)

Open Issues

- Non-stability properties
  - Handoff converges to an undesirable choice (3G/2G when 4G available)
- Cooperate with network-side efforts
- From detection to fix
  - Report identified problems to carriers
  - Assist end-devices to intervene the loop

Summary

- A first look at instability in mobility management over cellular network
- Disclose real-world persistent loops caused by misconfigurations and policy conflicts
- Propose MMDIAG to detect unstable MM
- Call for more attention and efforts

Thank you! Questions?