Demystify Undesired Handoff in Cellular Networks

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Mobile Era: "Always Connected"



In-building



Outdoor



Walking







On the subway



On the high-speed train₂

"Always Connected" via Cellular Networks



"Always Connected" via Mobility Support (Handoff)



Desired Handoffs: "Always Well Connected"



- Multiple choices
 - □ RAT: 4G, 3G, 2G
 - Freq bands: 700MHz, 1900MHz, etc.
- Desired handoff:
 - Better RAT (4G> 3G)
 - Stronger signal coverage

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Undesired Handoffs: "Not Well Connected"

- Not a nice or wise handoff choice
 - □ Ex1: in 2G when 4G/3G is available
 - Ex2: even out of service when 4G/3G is available
- Questions in this work
 - Q1: Do they happen in reality? (Yes)
 - Q2: How to detect them?
 - Q3: Why do they occur?
 - Q4: What lessons learnt?

Q2: How to Detect?

From theory to practice

Background: Handoff Procedure

• 3 steps: trigger-**decision**-execution



Background: Handoff Procedure

3 steps: trigger-decision-execution



Our Methodology: Formulation

Step 1: Build a handoff model

■ Each iteration: one atomic handoff decision: $s \rightarrow t = \Omega_s(G_s, O_s), t \in C_s$

- s, t: serving/target cell
- C: set of candidate cells
- Ω: decision logic
- G: configuration (tunable parameters)
- O: measurement (runtime observation)
- □ Handoff sequences: $s \rightarrow c_1 \rightarrow ... \rightarrow c_i \rightarrow [c_{i+1} = \Omega_{ci}(c_i)] \rightarrow ...$

Our Methodology: Analysis

Step 2: Undesired reachability analysis ---- Possible path



► Handoff path

Our Methodology: Two cases

Possible path Step 2: Undesired reachability analysis Handoff path Class I: convergence split iopt

Our Methodology: Two cases

Step 2: Undesired reachability analysis ---- Possible path

Handoff path

- Class I: convergence split
- Class II: premature convergence



From Theory to Practice



¹MobileInsight (Mobicom'16): http://metro.cs.ucla.edu/mobile_insight ²MMDIAG (SIGMetrics'16)

Q1: Do they exist in reality? Q3: And why?

Reality-check and root-cause analysis

Reality Check

- Experiment settings
 - Two US carriers
 - In two cities (Los Angeles, CA and Columbus, OH)
 - 50 outdoor locations, 63 indoor locations,
 - Macrocells plus femtocells (self-deployed)
 - Collected handoff profiles (logic, config., meas.)
- Four instances identified
 - In both categories
 - Three causes

Category I.A: Unaccessible intermedite cells (1/5)

Instance #1: Fail to reach 4G from 2G



- Cause: missing configuration for 2G→ 4G
 Likely no update in 2G
- More real cases in the paper

Category I.A: Unaccessible intermedite cells (2/5)



- Reality check:
 - □ US-I: missing $2G \rightarrow 4G$ configuration during idle and active
 - □ US-II: missing $2G \rightarrow 4G$ configuration during active
 - □ 5 out 63 locations: 3G is not accessible (< -105dBm)

Category I.A: Unaccessible intermedite cells (3/5)

- Performance impact: much smaller
 - Web browsing (cnn.com): every 1 min



Category I.A: Unaccessible intermedite cells (4/5)

Instance #2: Out of service from Femto to 4G



Cause: missing configuration from Femto→ 4G
 Improper configurations in 3G Femtocells

Category I.A: Unaccessible intermedite cells (5/5)

- Reality check
 - □ US-I (only): all femtocells (No femtocells in US-II)
 - 5 out of 63 locations: 4G but no/weak 3G

Category I.A: Unaccessible intermedite cells (5/5)

- Reality check
- Performance impact:
 - Exp: out-of-service duration w/wo 3G



Category II.B: Blocked Decision (1/2)

- Instance #3: 3G blocked by 2G
 - Scenario: both 3G and 2G available when leaving 4G;
 - During active
- Causes:
 - Device: 2G meas. comes first
 - Serving cell:
 - first-come-first-serve
 - improper device-network
 coordination



Category II.B: Blocked Decision (2/2)

- Reality check on measurement criteria satisfied
 - OP-I: 60 out of 63 locations (95.2%)
 - □ OP-II: 100% locations
- Reality check on actual handoff results
 - OP-I: 100% to 2G (all serving cells use FCFS)
 - □ OP-II: 5.7% to 2G (not all serving cells use FCFS)

Category II.B: Blocked Decision (2/2)

- Reality check on measurement criteria satisfied
 Reality check on actual handoff results
- Performance impact: handoff latency

10.8% call drop in US-II (when 2G+3G available) 100 100US-I áuug' US-I 80 80 CDF (%) CDF(%)60 60 40 40 2G+3G20 2G+3G20 3G 3G 0 0 30 15 2010 25 20 30 25 15 () 25 Handoff latency (s) Handover latency (s)

Category II.C: Problematic Device-Network coordination

Instance #4: Out of service when 3G band unsupported
 Scenario: moving into 3G area after leaving Femtocells

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Cause:
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- Serving cell: measuring all 3G bands
- Device's 3G capability not compatible
- Device rejection (halt)

Device capability query Device capability response **3G Measurement** Config (Event, TTT, etc.) **Reject: Unsupported bands** ve coverage

Category II.C: Problematic Device-Network coordination

- Reality-check
 - When moving out of 3G femtocells (US-I only)
 - All test phones: 100% failur

Device capability query

Device capability response

3G Measurement

Config (Event, TTT, etc.)

Reject: Unsupported bands

→Leave coverage

Q4: Lessons Learnt

Blame Whom?

- Operator: Practical challenges
 - Many reasons for today's choices
- Device (chipset vendors): Freedom
 Nothing wrong from its perspective
- Lessons:
 - Verification required (@operator, @device-operator)
 - Easy fix should be made possible (NFV, easy configuration updates)

Blame Whom?

- Operator: Practical challenges
 - □ 2G cells: expensive upgrade (No direct 2G→4G path)
 - Full 3G deployment not guaranteed
 - Seemingly reasonable strategies
 - FCFS (handoff upon first meas): reduce latency but miss better choices
 - Measure all 3G bands: don't miss handoff without prior knowledge
- Device (chipset vendors): Freedom
 - Freedom: conduct meas in any order; reject once failure
- Lessons:
 - Verification required (@operator, @device-operator)
 - Easy fix should be possible (NFV, configuration updates made easy)

Possible Fixes

- Device-side: Be a more proactive local controller
 - Self-check and correct if improper handoffs
 - Lesson: devices should not simply follow

- Network-side: a centralized controller
 - Self-check and coordinate handoff configurations among cells
 - Make configuration updates easy (NFV, ongoing 5G)

Summary

First work to study undesired handoff reachability

- Overlooked in the past
- Real-world cases reported
- Root causes in mobility management misconfigurations explored

 Make a call for attention from research and industry community