Discovering Fine-grained RRC State Dynamics and Performance Impacts in Cellular Networks

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¹The views presented here are as individuals and do not necessarily reflect any position of T-Mobile.
Why RRC states?

- Radio Resource Control (RRC) states balance **performance** and **power consumption**
- Carriers: How do RRC transitions affect users?
- Mobile systems/apps: How to account for RRC transitions in scheduling traffic? ¹

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Contributions

- Methodology for crowdsourcing RRC measurements
  - Impact of *demotions/promotions* on latency
- Perform a worldwide study of RRC performance
  - Previously unknown latency problems
- Cross-layer analysis from link layer to application layer
  - Through crowdsourcing and controlled experiments
Related work

- RRC states impact performance (controlled experiments)\(^1,2\)
  - We characterize the performance impact globally
- Bad interactions between applications and RRC state timers \(^3\) and how to avoid them \(^4\)
  - We focus on state transition problems
- Client measurements to understand networks \(^5\)
  - Large-scale RRC measurements not yet addressed

\(^1\) Qian et. al, MobiSys 2011 \(^2\) Huang et. al, MobiSys 2012 \(^3\) Vallina-Rodriguez et. al, IMC 2013
\(^4\) Liu et. al, MobiArch 2011 \(^5\) Shepard Hotmetrics 2010 and many others
RRC state background

High power, low latency

DCH

FACH (small transmissions)

PCH

Low power, high latency

DCH

PCH

3G UMTS Implementation Examples
Crowdsourcing RRC measurements

- Android application runs on unmodified user devices to collect network measurements
- As part of Mobiperf (U of M/Northeastern joint project)
- Application, source code, data: www.mobiperf.com
- Data is anonymized
- App respects user data/battery constraints
How to infer RRC states

Adapted from Qian et al, IMC 2010
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Data collection

- Use `/proc/net` to observe and avoid interfering traffic
- Long-term data collection to deal with noisy data
- Similar technique to measure higher level protocols
- Validated results with Qualcomm’s QxDM
  - Reveals radio link layer messages

![Graph showing normalized RTT and inter-packet timing](image)
The deployment

Using Mobiperf, a popular mobile app for measuring mobile network performance¹:

650 000 sets of tests, 7 distinct network technologies

Demotion delays: a previously unknown problem

Expected results:

- Small packets
- Large packets
- Inter-packet time interval
- Round-trip time
- Network delay
- Promotion delay
- State demotion

Actual results:

![Graph showing normalized RTT vs. inter-packet timing with empty packets and 1 KB packets highlighted.](image-url)
How to infer RRC states

through cross-layer analysis with Qualcomm’s QxDM
Prevalence of demotion delays

Distribution of additional delays seen across carriers

- 3G, FACH, median
- LTE, median
- LTE, 95th %

Extra delay during state demotions (ms)

Fraction of carriers
Application impact

Using a custom application controller to simulate web browsing

Measurements of page loading times for two major carriers
Takeaways

For carriers:
- Client-based performance measurements are critical
- We have identified several RRC implementation pitfalls
- Simpler state machines may perform better than complex ones

For mobile system developers:
- Systems exist for scheduling traffic around RRC states
- Adapt to carrier RRC state characteristics?
Conclusion

- Methodology to accurately measure RRC transitions on uncontrolled user devices
  - Measures user-perceived performance directly
  - Collect data accurately and efficiently by intelligently scheduling measurements
- Allowed creation of largest RRC performance data set to date
  - Revealed previously unknown performance problems
  - Essential as networks continue to evolve
- Cross-layer analysis with a custom application controller tool
  - Confirm, analyze in depth problems detected in the wild
Thank you!