Supporting Mobile VR in LTE Networks: How Close Are We?

Demystifying five common misunderstandings, an in-device LTE booster for mobile VR

http://metro.cs.ucla.edu/mobileVR.html

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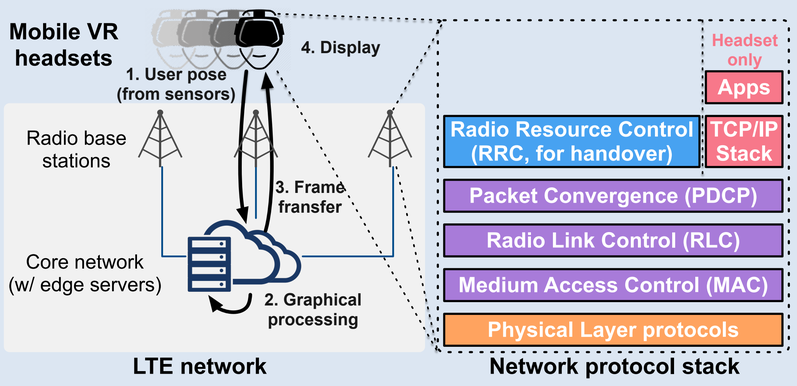
Mobile VR over LTE

Ubiquitous, high-fidelity experience

- VR powered by phones: 98% of sales
  - ✓ Low cost, excellent convenience
- Edge-based scheme over LTE network
  - ✓ Offload graphical tasks from battery-constrained mobile VR headsets



Google Cardboard

Samsung Gear VR

Latency Requirement

Human tolerance requires the overall network latency **should be ≤25ms**.

Latency Analysis Methodology

- **3GPP standard analysis**
  - ✓ Identify LTE latency deficiencies for VR
  - ✓ Derive the analytical latency equations
- **Device-side empirical study**
  - ✓ 8-month empirical study over T-Mobile, Sprint, Verizon, and AT&T
  - ✓ 3 popular VR headsets: Samsung Gear VR, Google Daydream & Cardboard
  - ✓ Diverse scenarios: Static + walking + driving under various LTE radio quality
  - ✓ 3 millions LTE signaling messages, 21 millions data packets

Dataset release

✓ All the experimental data and analysis code are publicly available

Scan QR code and explore more!

Latency Deficiencies

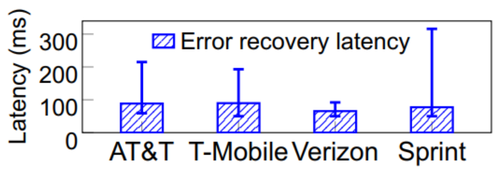
Myth1: LTE bandwidth is bottleneck

- **Reality: Sufficient bandwidth for medium-quality VR**
  - ✓ Instead, the LTE signaling operations contribute a bulk portion of latency

Inter-protocol incoordination

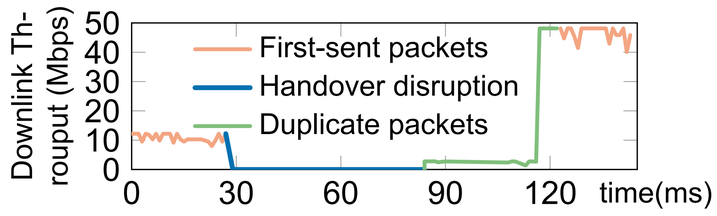
Myth 2: LTE recovers corrupted data immediately

- **Reality: Recovery is often delayed**
  - ✓ Caused by two-tier retransmission
  - ✓ Delay: ~80ms, every 1.2 s



Myth 3: The mobile device will receive new data immediately after handover

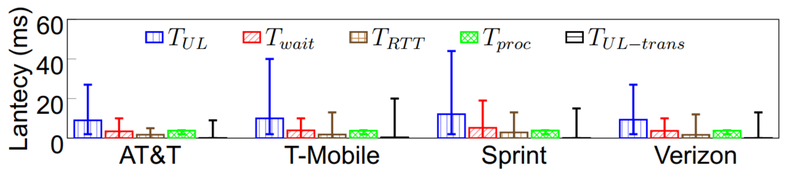
- **Reality: Head-of-line blocking**
  - ✓ New data is blocked by the duplicate received, yet unacknowledged data
  - ✓ Delay: 30.0 - 44.7ms with probability 61% - 92%



Single protocol deficiency

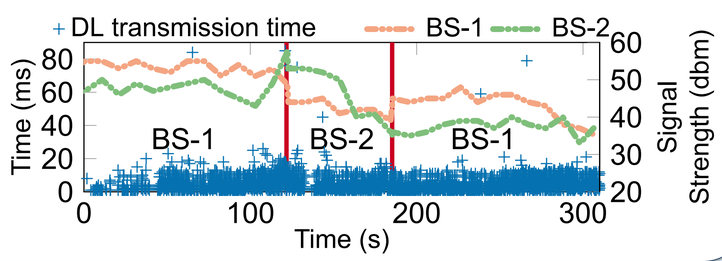
Myth 4: Uplink motions are quickly sent to the base station

- **Reality: Latency-unfriendly LTE control channel design**
  - ✓ Unnecessary waiting delay for regular VR uplink traffic
  - ✓ Delay: 6.3~9 ms for 81.5% packets



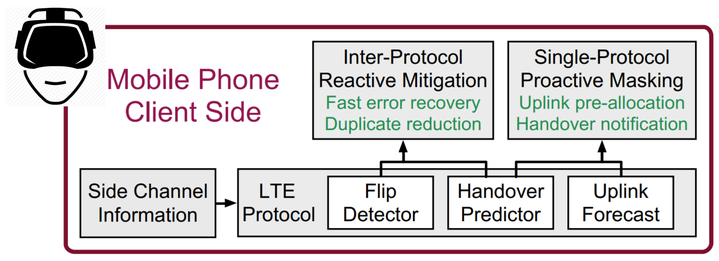
Myth 5: LTE mobility is seamless

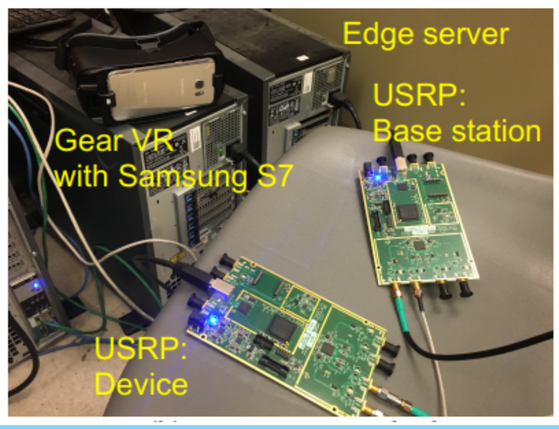
- **Reality: LTE handover incurs long service disruption**
  - ✓ Hard handover: "Break before Make"
  - ✓ Disruption time: 67.4 ~ 83.7ms
  - ✓ Some handovers are unnecessary



Our solution: LTE-VR

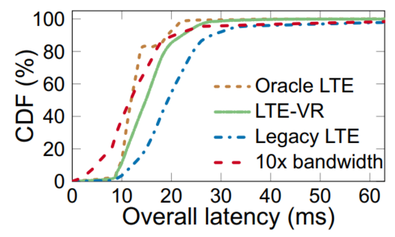
- **An in-device LTE booster for VR**
  - ✓ Only the end device has sufficient info to mitigate VR-perceived latency
  - ✓ Readily available without any network infrastructure changes
  - ✓ Compliant to LTE standards
- **Cross-layer adaptation + rich side-channel information**
  - ✓ Inter-protocol incoordination: Reactively mitigate unnecessary latency from protocol interplays
  - ✓ Single-protocol deficiency: Proactively mask the unavoidable latency





How Well LTE-VR Performs

- **Satisfy VR's latency demands with 95% probability**
  - ✓ Latency outlier reduced by 3.7X
  - ✓ Approximate oracle LTE
  - ✓ Comparable to LTE with 10X bandwidth expansion



- **Negligible overhead**
  - ✓ 4%-8% signaling overhead
  - ✓ 2.3% extra uplink grants
  - ✓ 0.1% extra downlink bandwidth

Projecting LTE-VR to 5G

- **Complementary to 5G radio**
  - ✓ LTE-VR can work directly with 5G radio technologies for further latency reduction (up to 31x)
- **Insights for 5G signaling design**
  - ✓ Link-layer protocol refinement
  - ✓ Complement 5G handover re-design

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