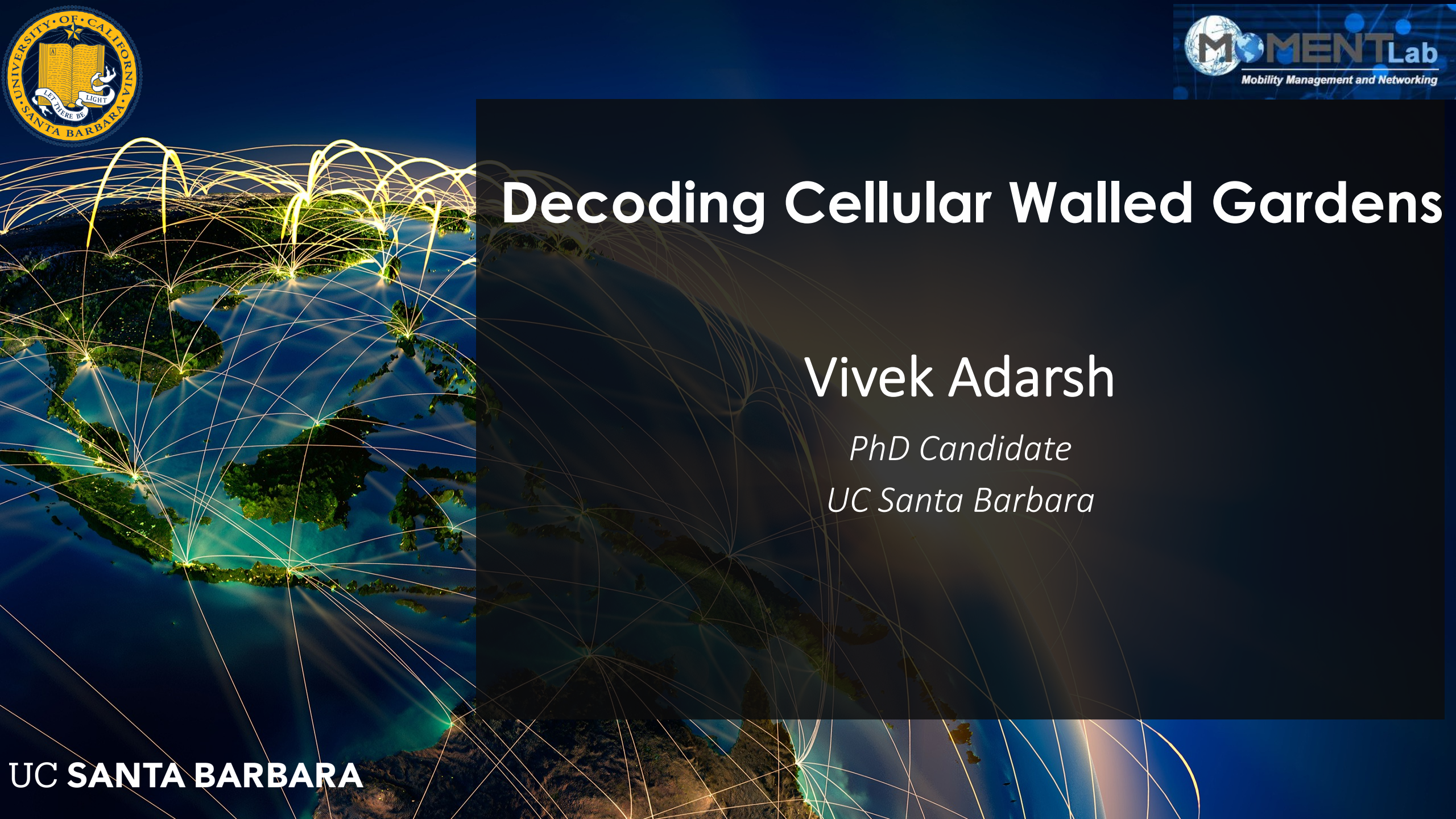


Decoding Cellular Walled Gardens

Vivek Adarsh

PhD Candidate

UC Santa Barbara

UC SANTA BARBARA

Let's start with a scenario

8:00 AM morning commute

Hwy 101

No cellular connection


TC
WSJ
Where is my internet?!

Mobile Internet

Global mobile data

~ 75 exabytes per month (2022)

Mobile traffic (last 5 years)

↑ 222%*

*STA19

Cellular Networks

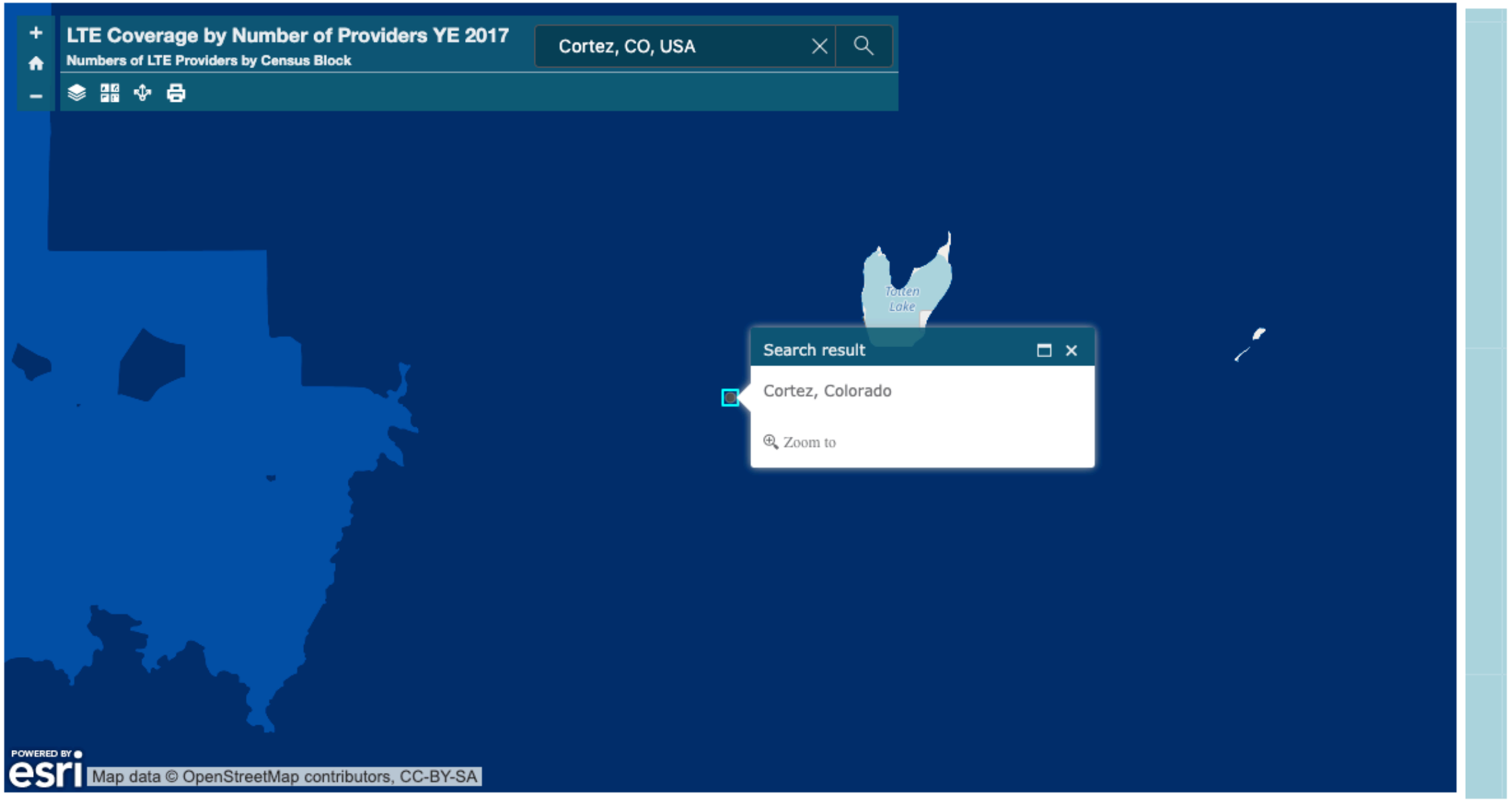
- ~4 Billion LTE users by end of 2020
- Escalating user base
  - Challenges in sustaining consistent, high-quality service
- Adequate coverage ≠ useable service
- Sudden surge in traffic demand
  - Large gatherings
  - Post-disaster scenarios

Natural Disasters

- 12 major tropical storms have hit the US in the past 4 years
- Destruction on a massive scale
- Hurricane Maria (Puerto Rico)
  - Knocked out 95% network infrastructure
- Hurricane Dorian
  - ‘Unprecedented’ devastation in Northern Bahamas[1]

[1]*Source: nbcnews*

LTE Coverage by Number of Providers - YE 2017



Source: FCC

Third Party Assessment

NETWORK QUALITY

NETWORK ACCESSIBILITY

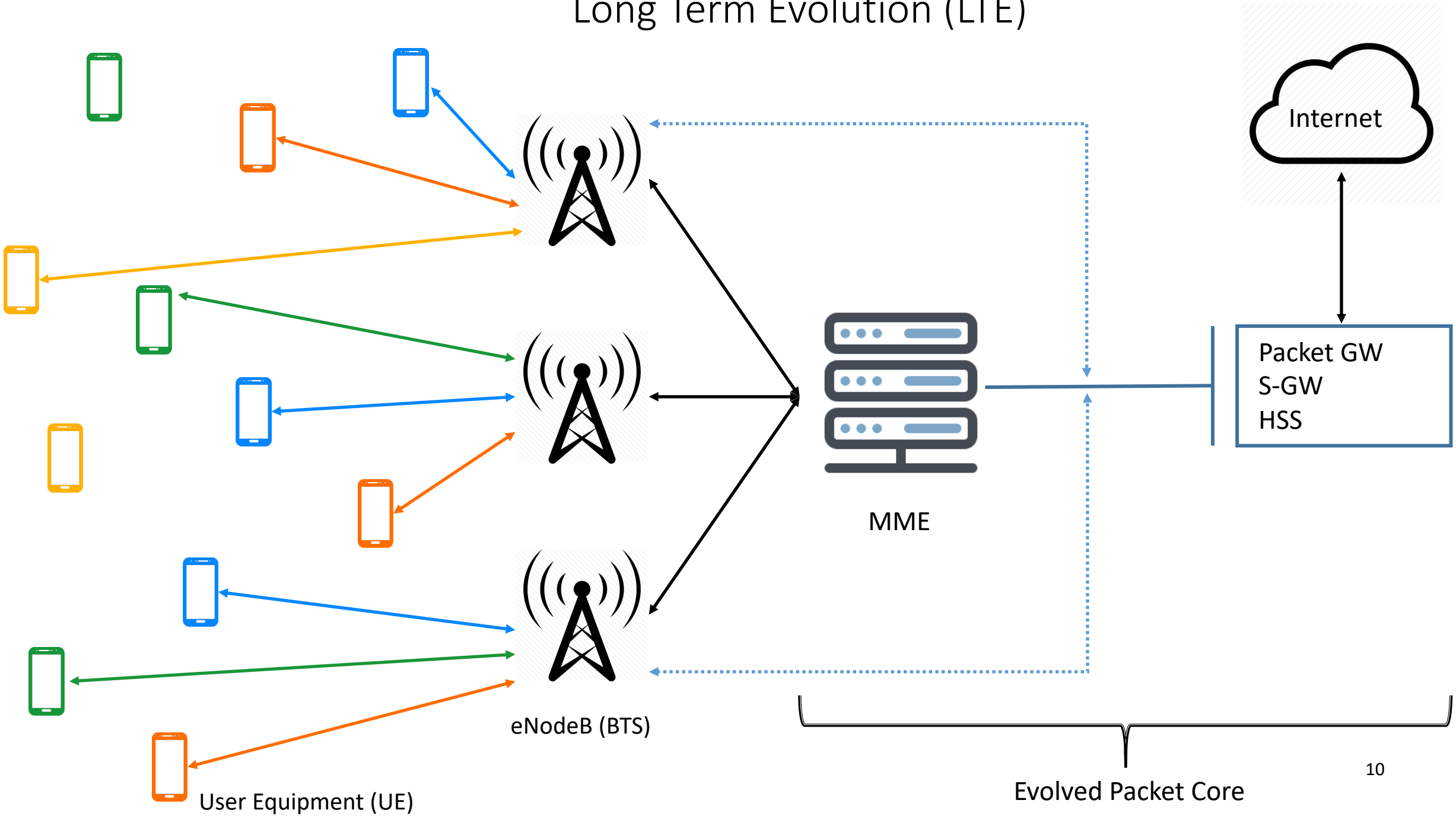
VERIFYING PROVIDERS' CLAIMS

Roadmap

- Estimating Overload in LTE Networks (IMC ‘19)
  - LTE basics
  - Motivation
  - Overload detection

- Quality of Experience on Mobile Broadband (ongoing)
  - QoE on LTE
  - Measurement campaigns

Long Term Evolution (LTE)



Third Party Assessment

Typical solutions

Cooperation of telecom providers

Active measurements through multitudes of mobile devices

Problem.

01

Existing solutions are resource and time intensive

02

May not be practical

03

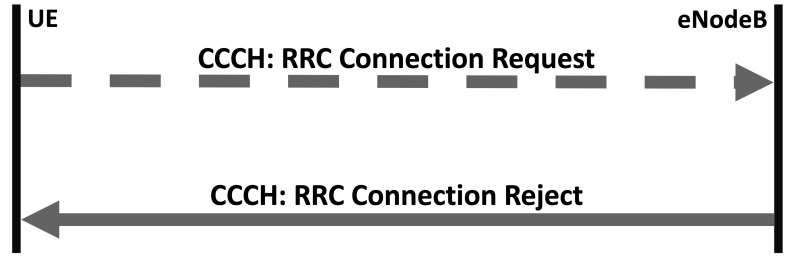
What if passive measurements could help?

Research Question

Can we use off the shelf equipment to enable third party assessment of cellular availability and network quality?

Estimating Overload

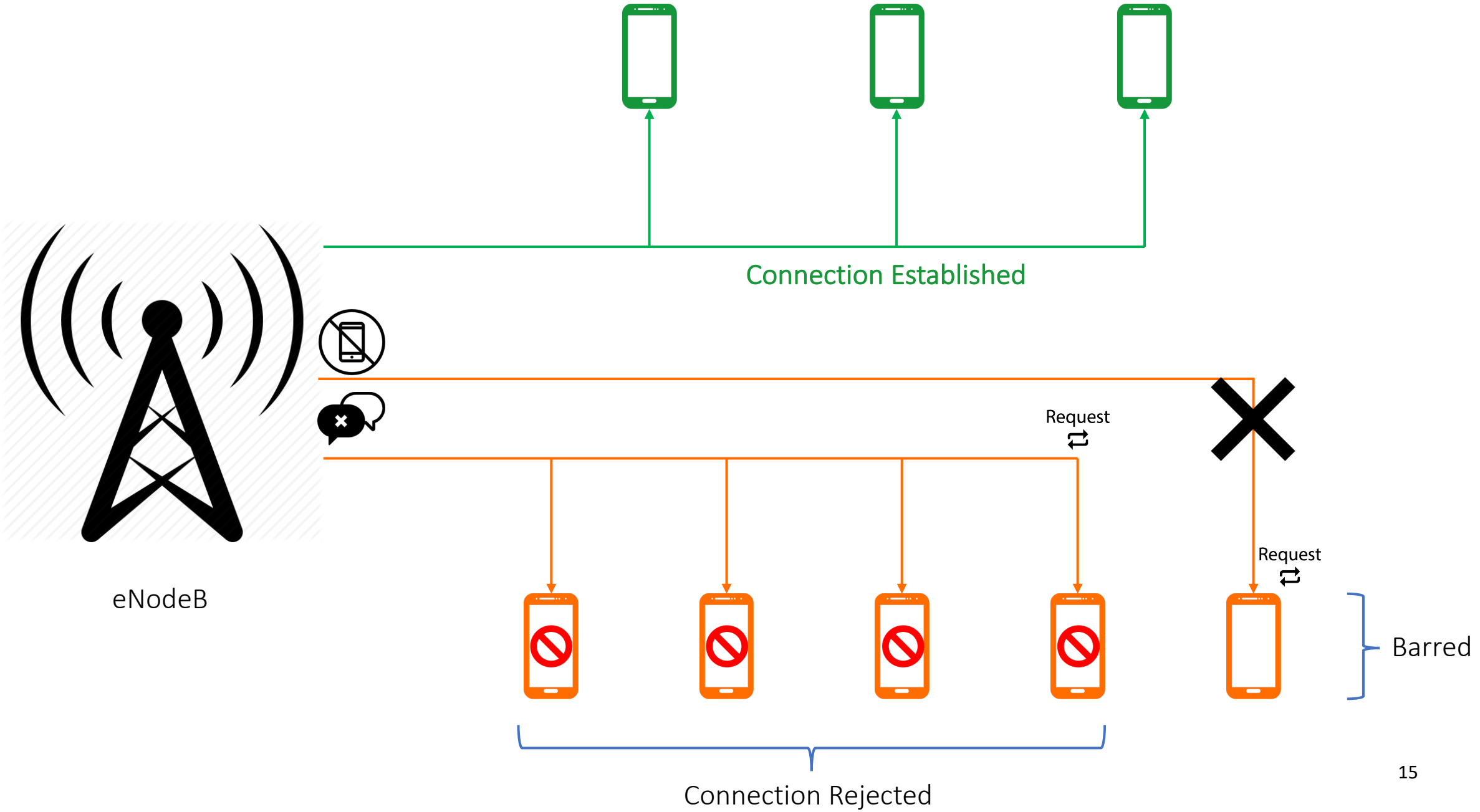
- Connection request:
  - ✓ Connection Accept
  - ⊘ Connection Reject



- Key to reducing overload = Deny access
- eNodeBs (BS) broadcast “rejects”

Channel Type	RLC Mode
CCCH	Transparent (Decodable from passive capture)
Direction	**RRC Message**
Downlink	Connection Setup Connection Reject
Uplink	Connection Request

Signaling Radio Bearers (SRB0)


Connection Established
Request
Request
eNodeB
Barred
Connection Rejected

- Quantify the number of reject and request messages
- Non-intrusive, federally compliant
- Off-the-shelf equipment

Linux box

USRP

LTE antenna

Datasets

Dataset	Location	Date	# LTE frames	Capture duration
St. Patrick's day parade (**SPD**)	Balboa Park, SD	3/16/2019	1.1 Million	76 minutes
Concert shamrock (**CSR**)	Downtown SD	3/16/2019	1.7 Million	113 minutes
St. Patrick's day parade baseline (**SPD_base**)	Balboa Park, SD	3/26/2019	275K	65 minutes
Concert shamrock baseline (**CSR_base**)	Downtown SD	3/26/2019	135K	60 minutes

T-Mobile

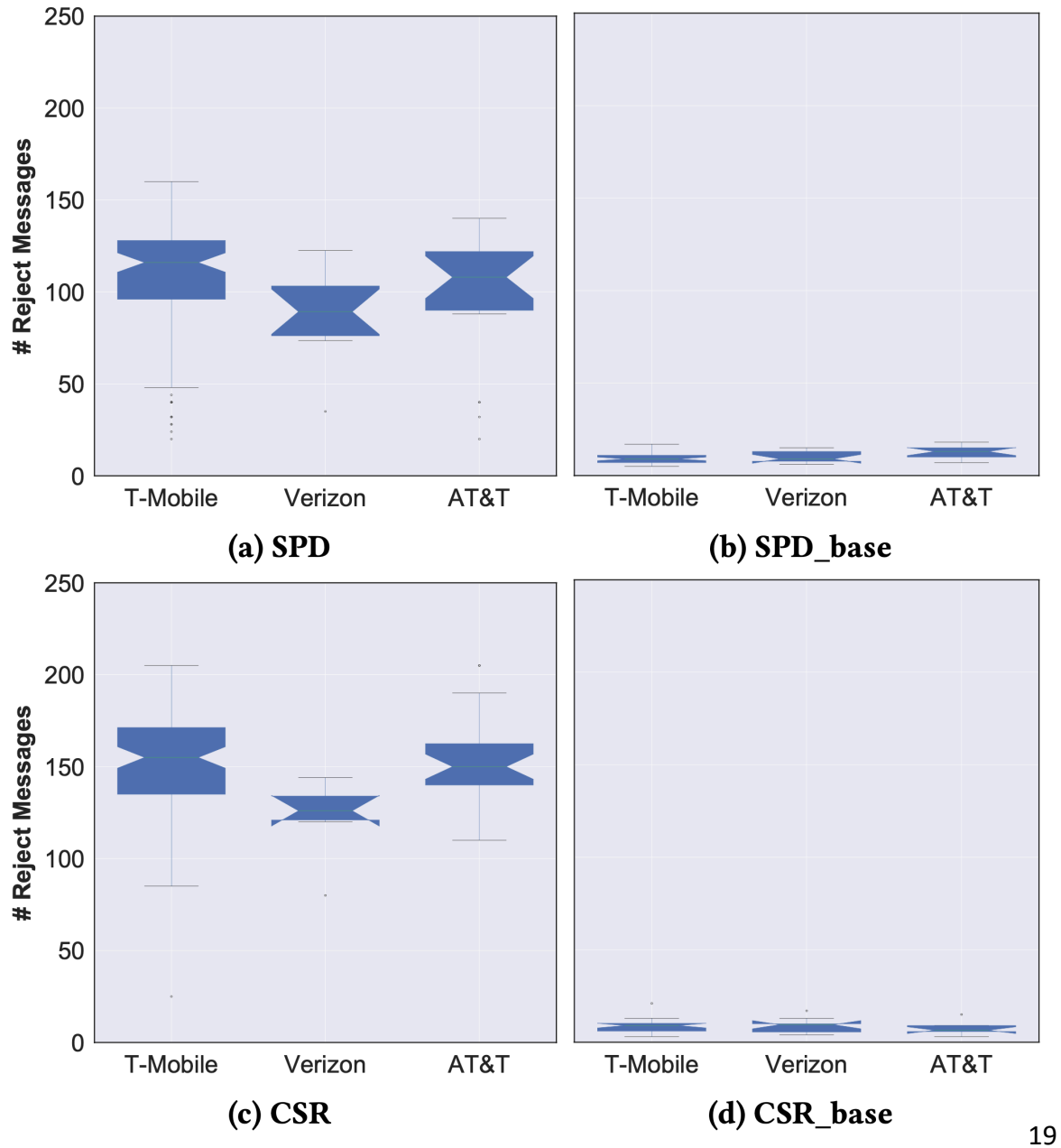
verizon

AT&T

Evaluation

of Connection Rejects

- Significantly more rejects in SPD and CSR
  - 8X in SPD
  - 15X in CSR
- Bin size: 30 seconds

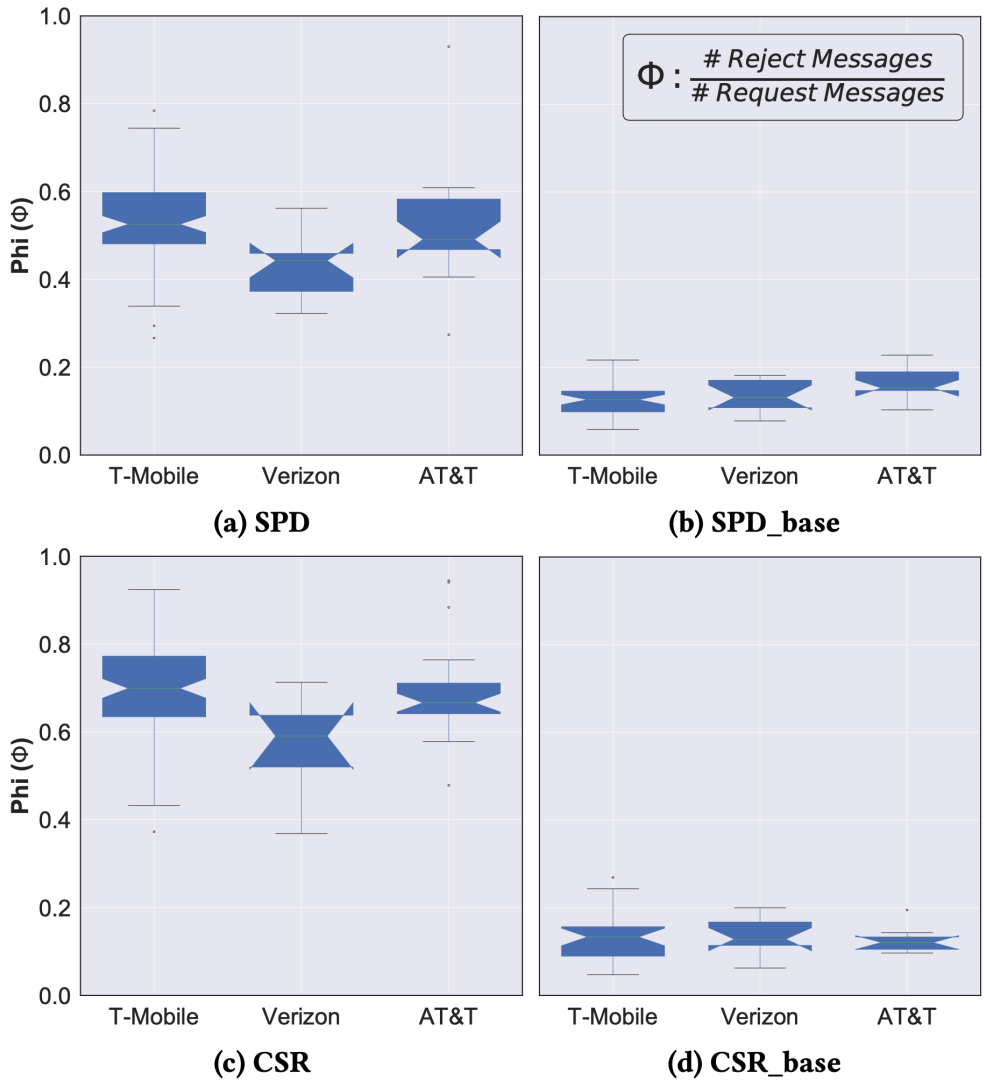


Phi = Rejects/Requests

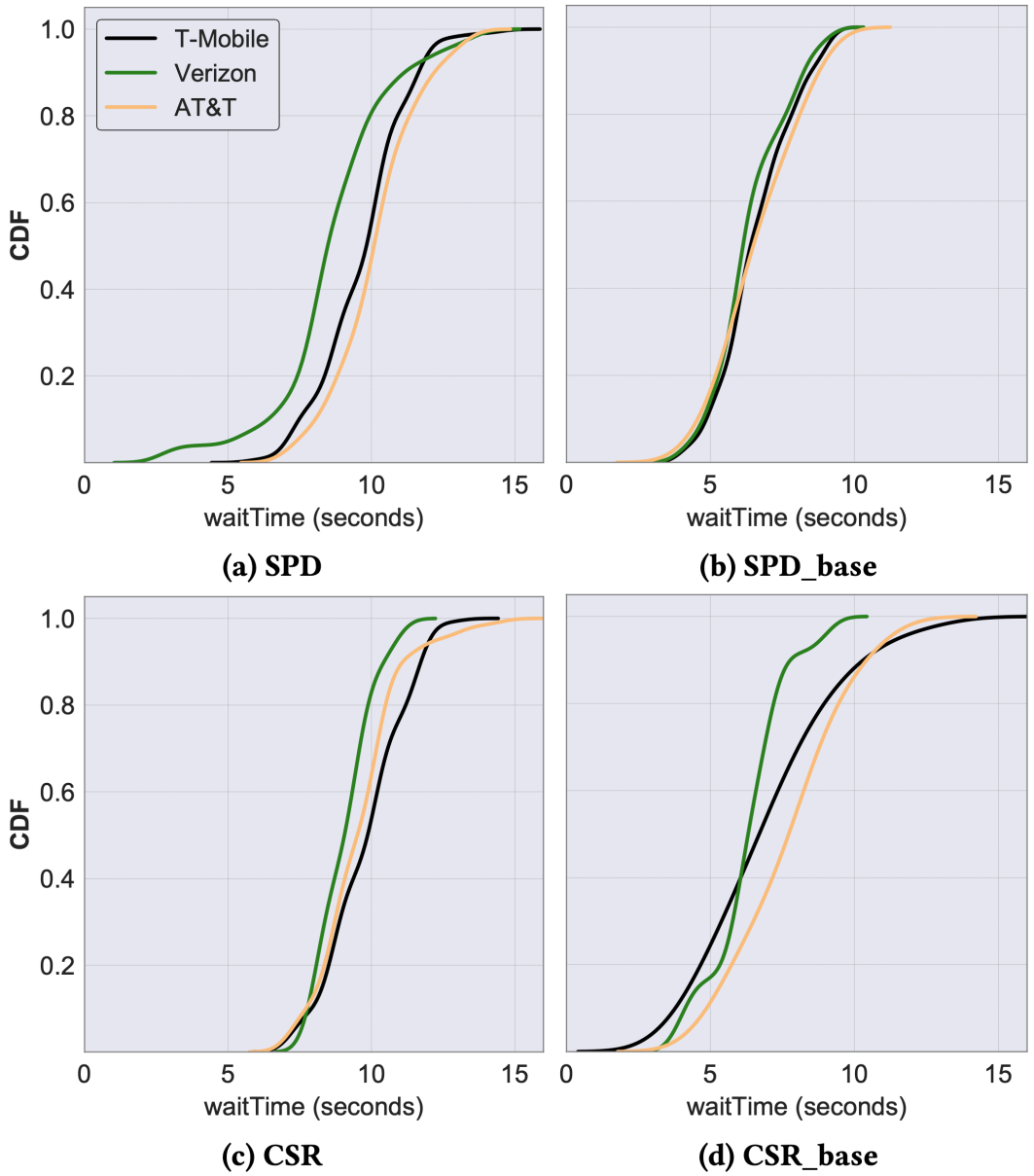
Indicates the severity of overload

Bin size: 30 seconds

Phi (SPD, CSR) is consistently higher



Phi Measure



waitTime

- waitTime: Back-off time before reconnection attempt
- Contained within every reject message
- Part of overload mitigation scheme
- Longer waitTime in SPD, CSR

Omega Measure

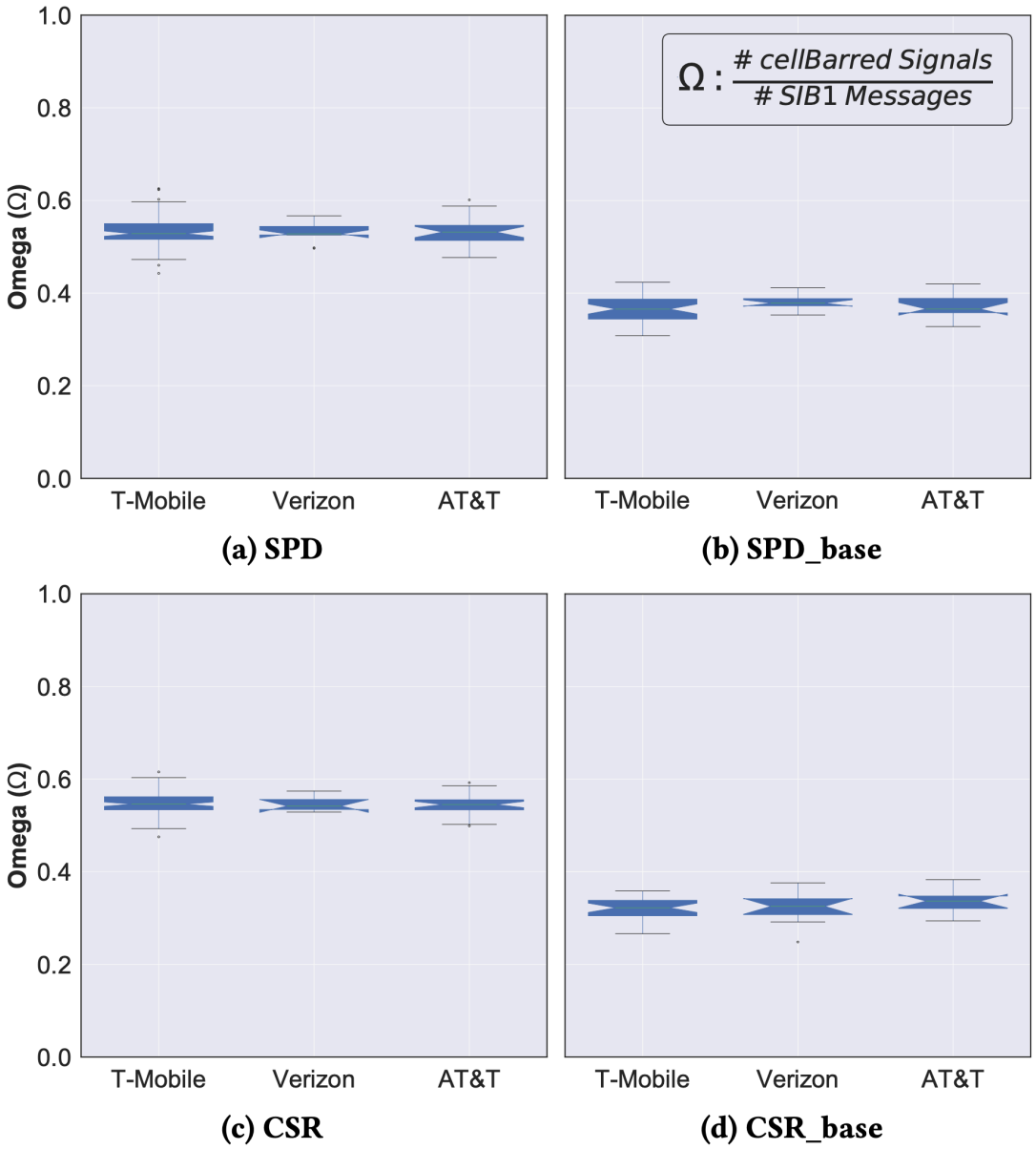
cellBarred flag: Contained in SIB1 messages

UE is not allowed to camp on a particular cell

Ω Omega $= \frac{\#\ \text{cellBarred signals}}{\#\ \text{SIB1 messages}}$

20% increase in SPD, CSR

Positive correlation between Omega and overload



Takeaway

We develop a third-party network assessment system to estimate overload that is:

- Operator agnostic
- Scalable
- Uses low-cost, off-the-shelf equipment

Roadmap

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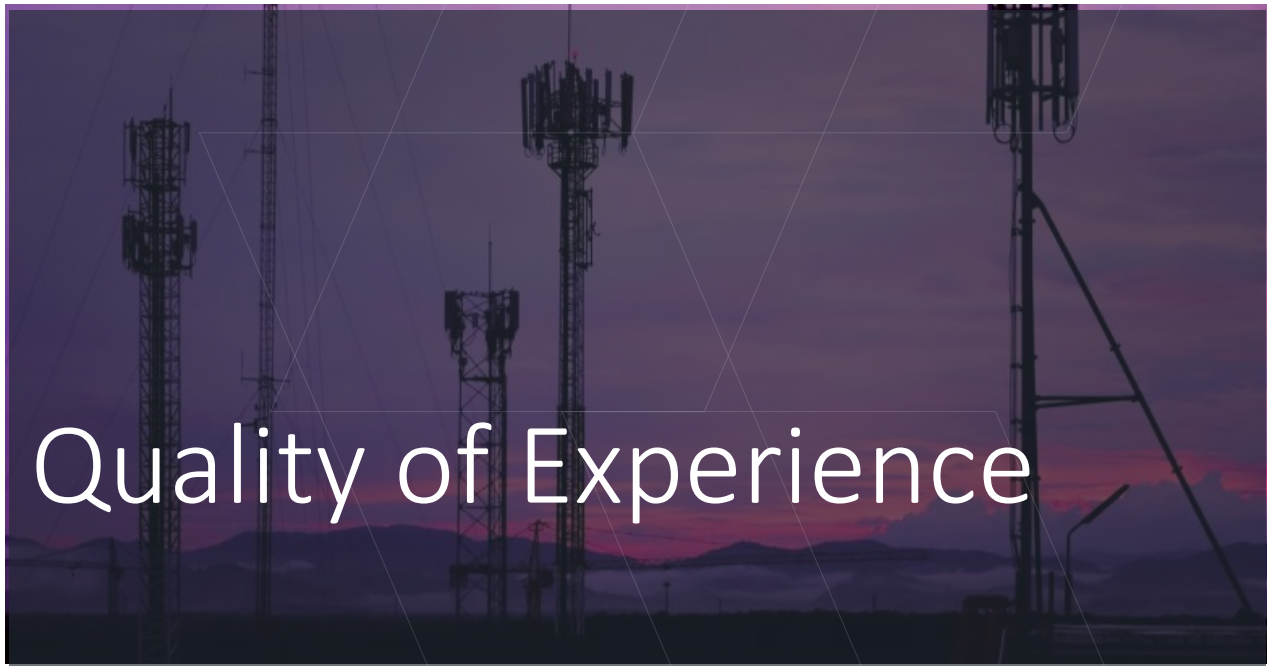


Quality of Experience

Three quarters of global traffic is video

Domain filled with prior work

Drawbacks:
Limited scope
Platform dependency

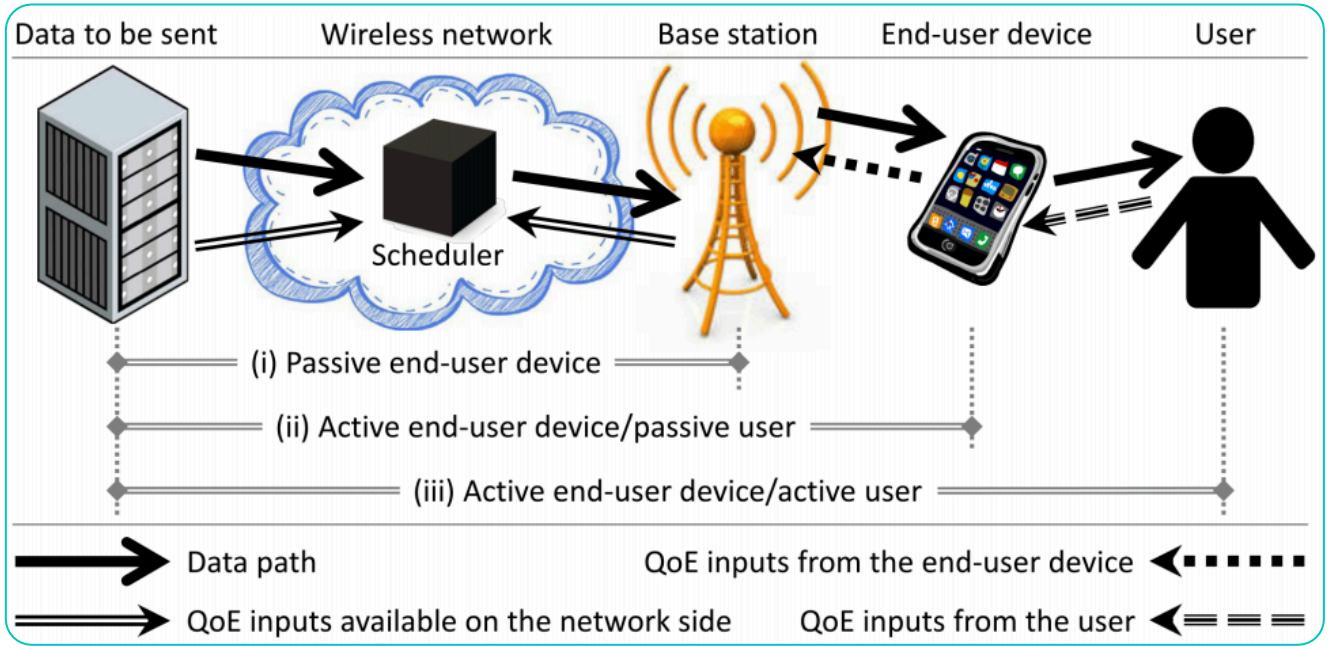
Scalability

[SST17]
[Gup+19]
[MNA17]

Vantage Points

- Perspective from within the network
- Discernable insights about the network state

But which one to choose?



Taken from Sousa et al. *[SQR19]*

Is that enough…?

Not always.

Accuracy

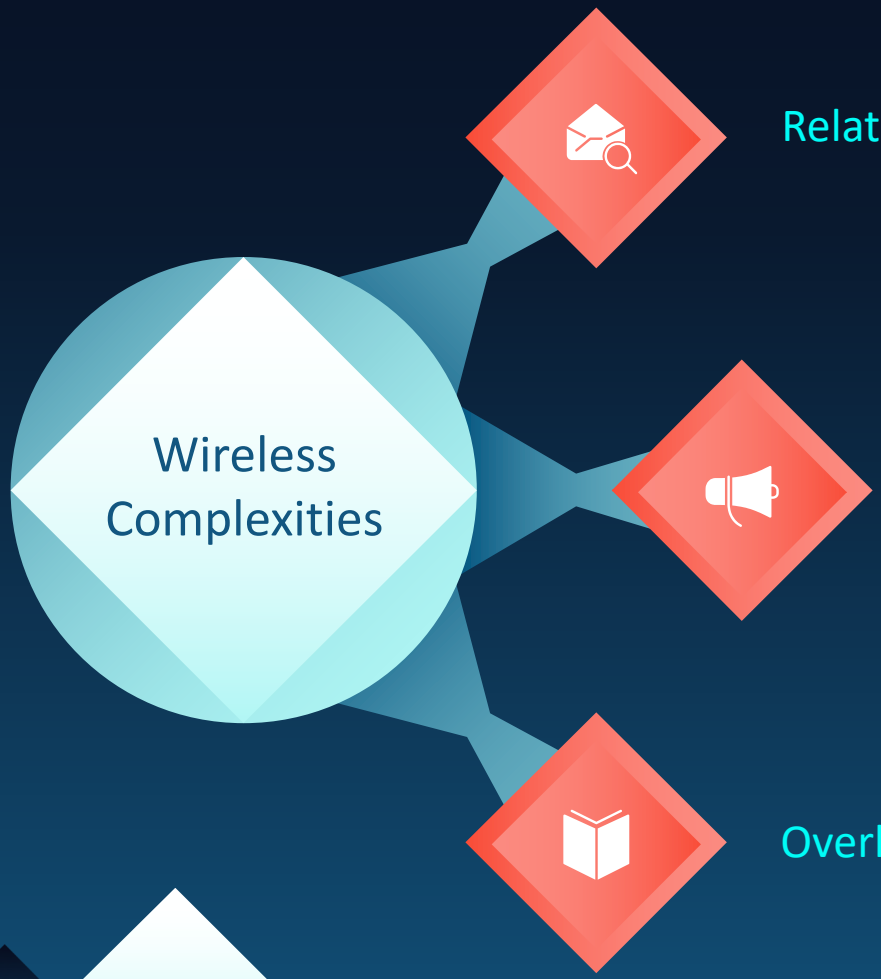
How representative the metrics are

Responsiveness

Delay in system's reaction

Design Philosophy

Minimize $\frac{Responsiveness}{Accuracy}$



Relatively less exploration of vantage points in cellular networks

Peeking over cellular *“walled garden”* is difficult

Overload -> Congestion -> QoE degradation: Passive measurements!

Research Question

Can over the air passive measurements be used to estimate the quality of experience at the user end?

Measurement Campaigns

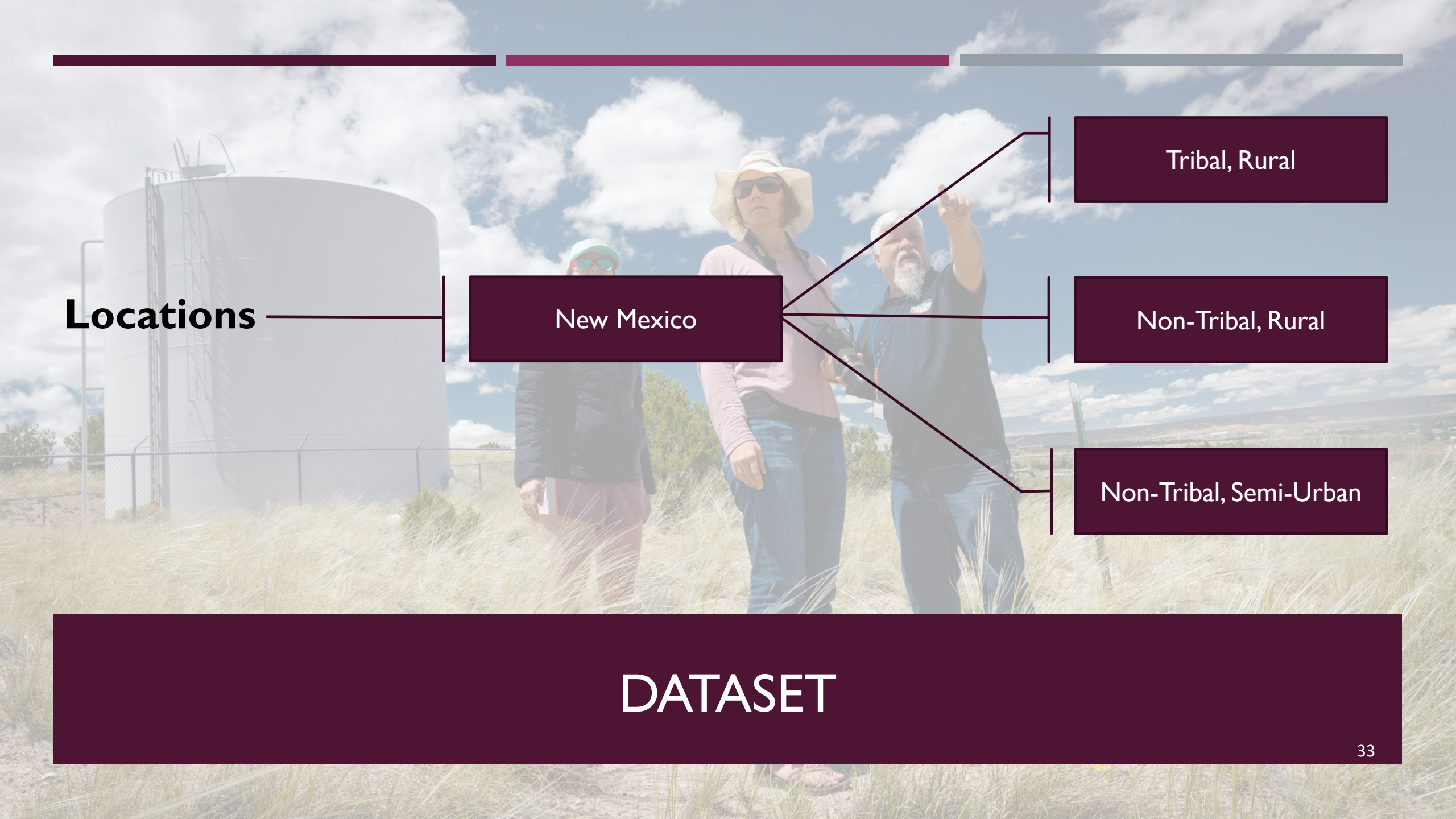
Tribal Lands – Southern California

Northwestern New Mexico

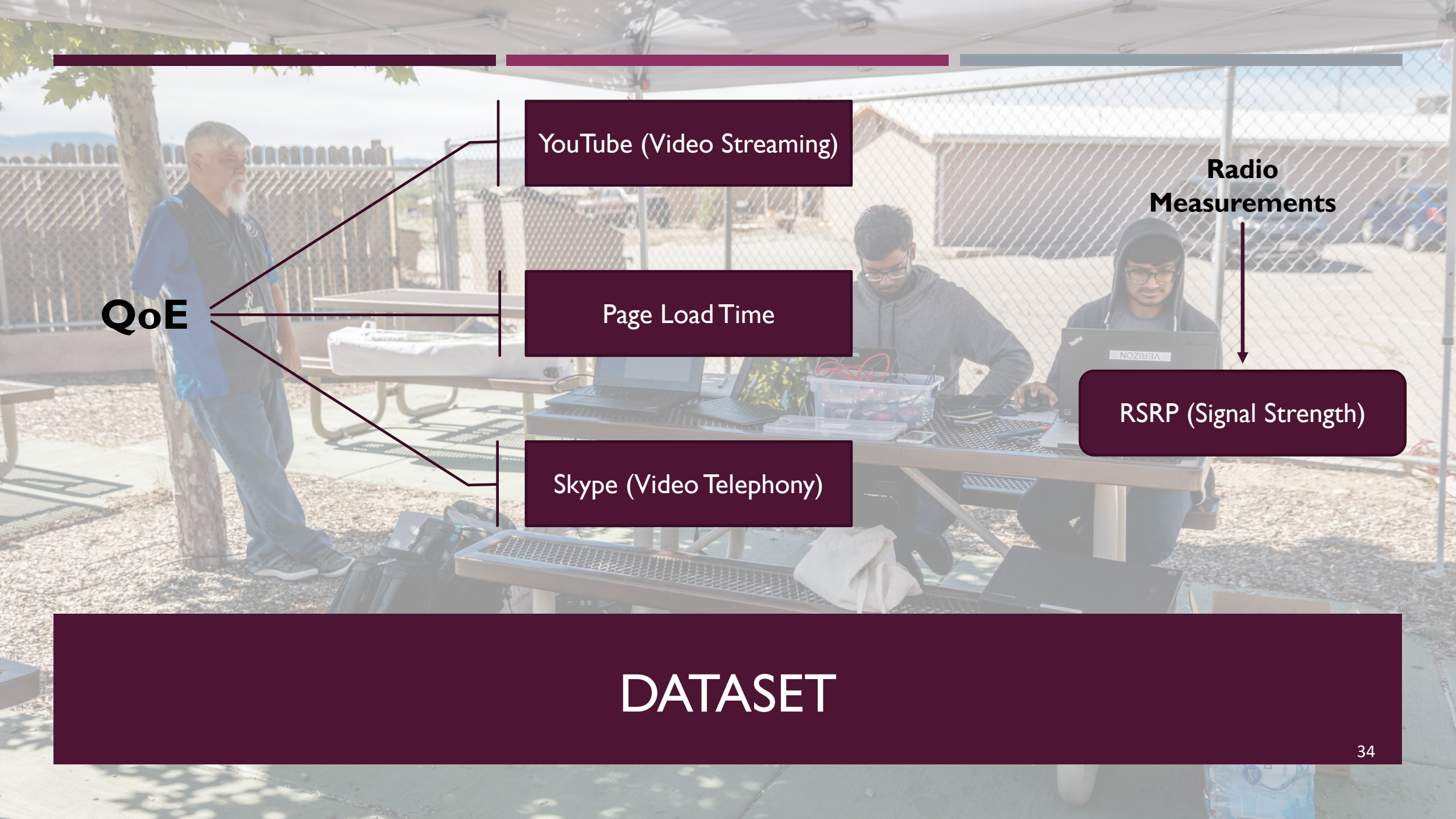
- Extensive measurement campaign
- Team of 4 PhD students
- Weeklong measurement drive

Dataset

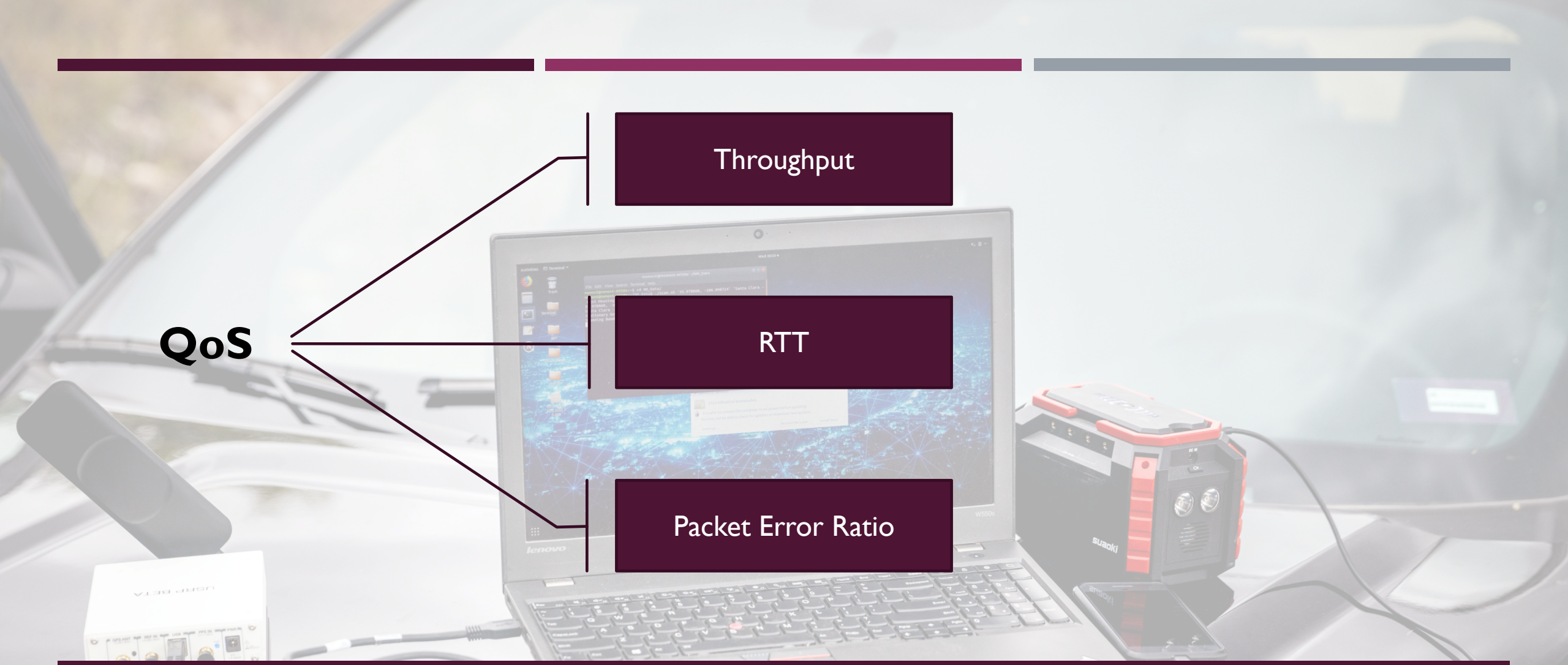
- Over 200 GB of packet traces
- ~ 1 million temporally varying radio measurements


Locations
New Mexico
Tribal, Rural
Non-Tribal, Rural
Non-Tribal, Semi-Urban

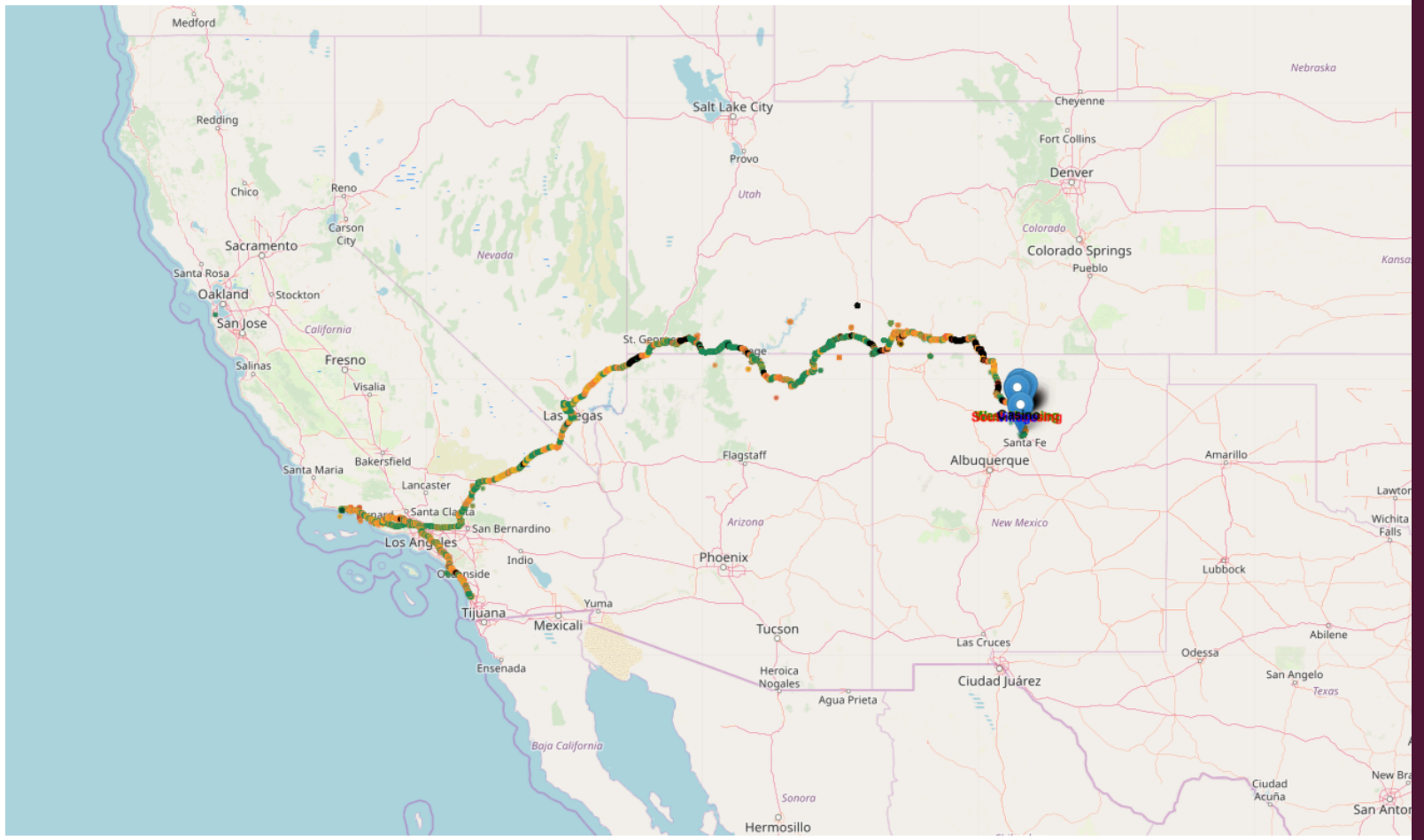
DATASET


QoE
YouTube (Video Streaming)
Page Load Time
Skype (Video Telephony)
Radio Measurements
RSRP (Signal Strength)

DATASET



DATASET



LTE COVERAGE MAP

- 6 states
- 2665 miles driven
- 4 major telecom operators
- Over 200,000 ***"ground truth"*** datapoints

Field work is challenging but quite rewarding.

This work would not have been possible without my collaborators.

Prof. Elizabeth Belding (UCSB)
Prof. Ellen Zegura (GaTech)
Prof. Arpit Gupta (UCSB)

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https://vivekadarsh.com

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- **[MNA17]:** "Neural adaptive video streaming with Pensieve." *Conference of the ACM Special Interest Group on Data Communication* 2017.
- **[SQR19]:** "A survey on QoE-oriented wireless resources scheduling." *arXiv preprint arXiv:1705.07839* (2017).
- **[STA19]:** https://www.statista.com/statistics/277125/share-of-website-traffic-coming-from-mobile-devices/

Thank you