

LTE Radio Analytics Made Easy and Accessible

Swarun Kumar

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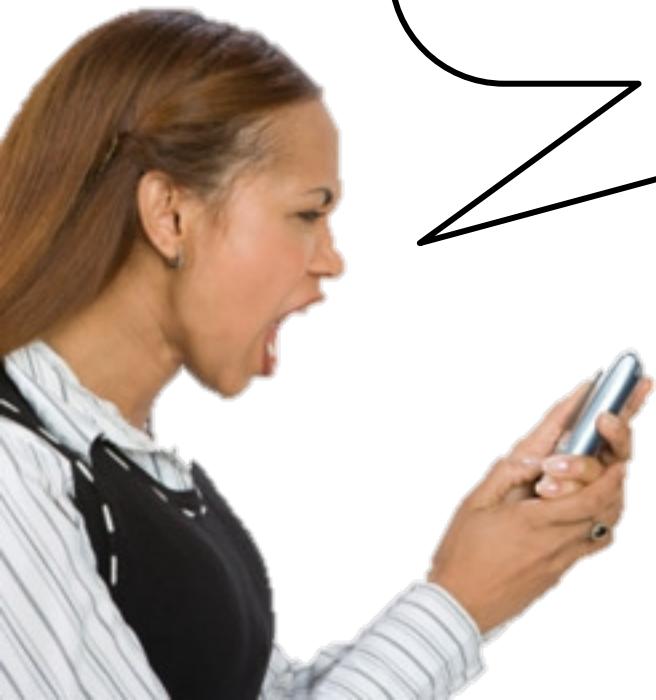


LTE – A Big Part of Our Lives

LTE is Opaque to us

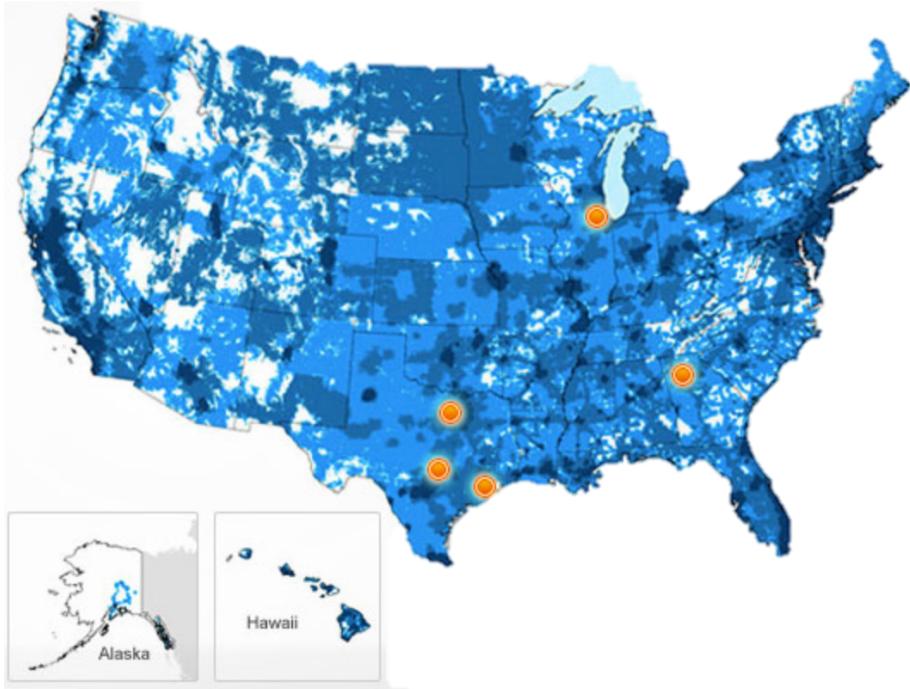
Why does my signal drop to 3G?

- Is the tower over-subscribed?
- Poor coverage?

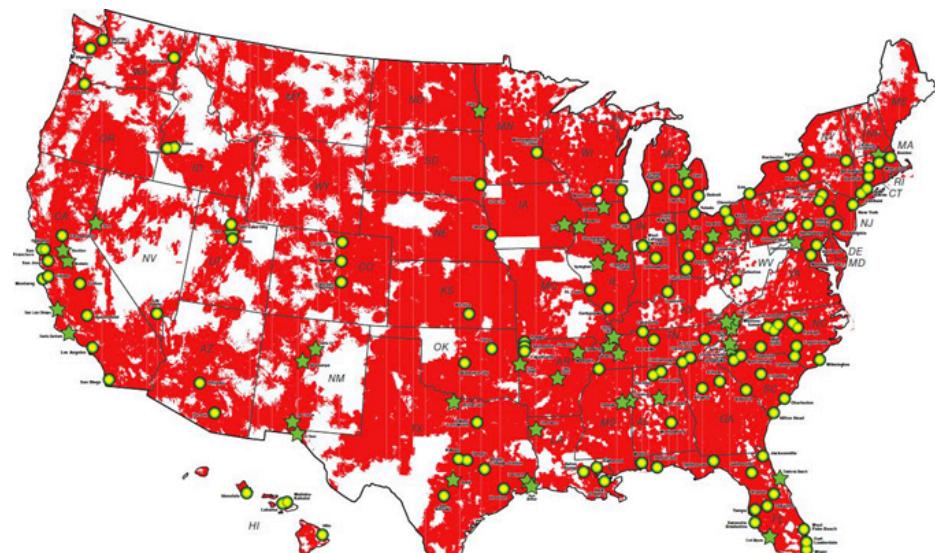


And If I Ask My Provider...

AT&T



Verizon



Even Providers struggle to keep pace!

LTE getting complex – macro, micro, femto cells



→ Complex Interference Patterns, esp. Indoors

LTE Opaque to Regulators too...

“Give us more licensed spectrum!”

“Cellular networks will collapse if you don’t!”



“Is this true?”

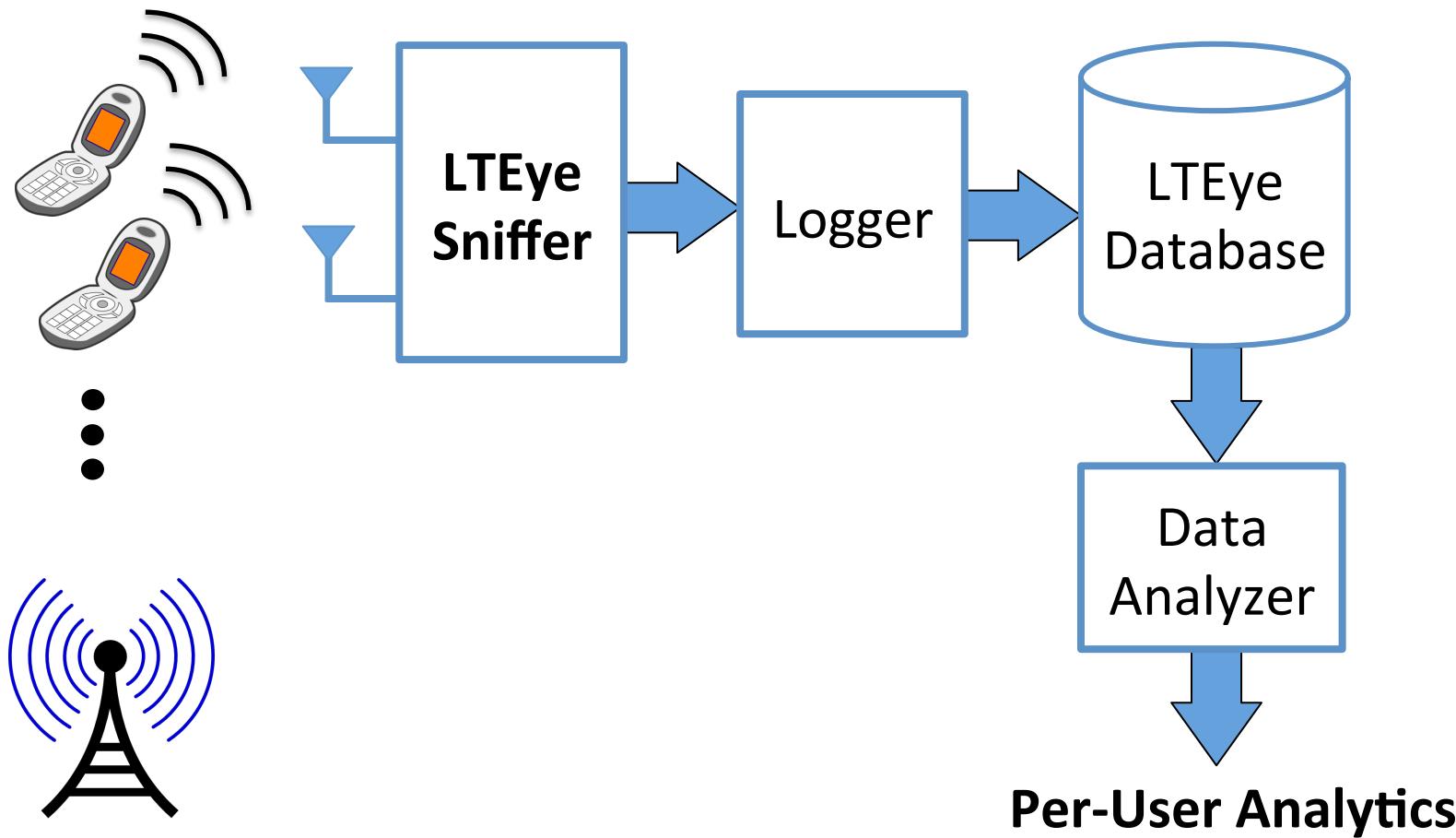
“Are they using what they have efficiently?”

Need more open access to LTE

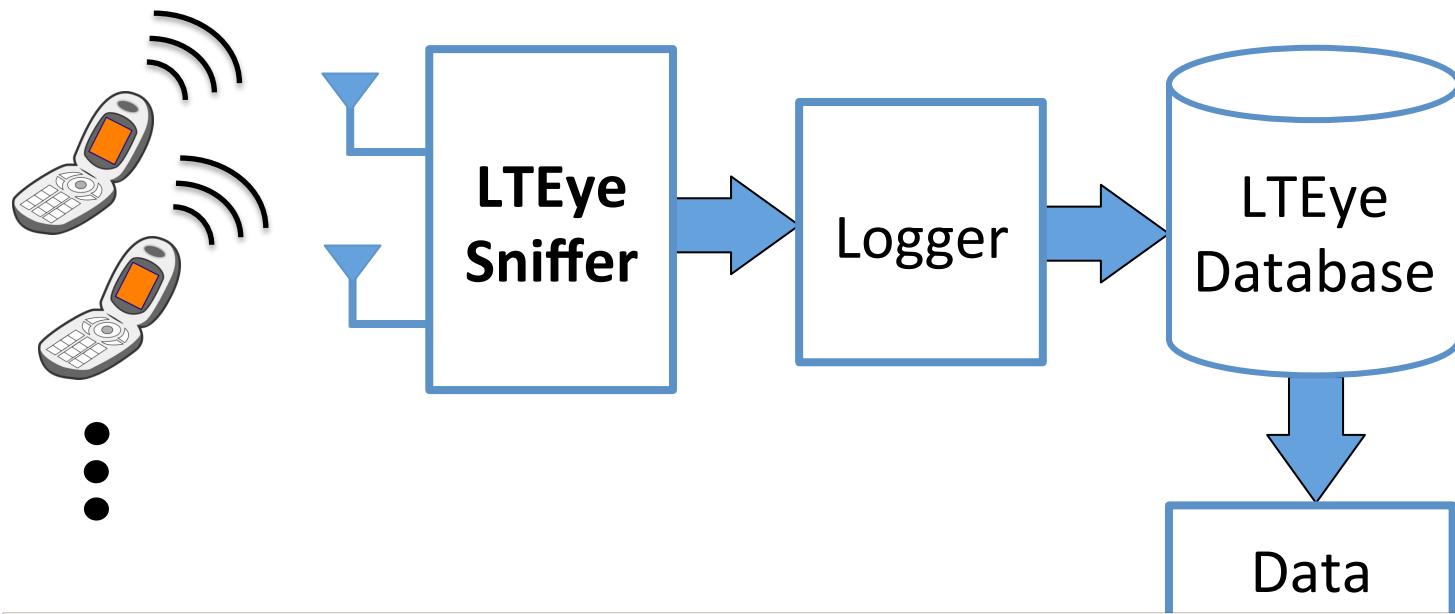
LTEye

- Open platform to monitor LTE
- Gathers per-user analytics and analyzes performance over time and space
- Does not need provider support

LTEye's Architecture



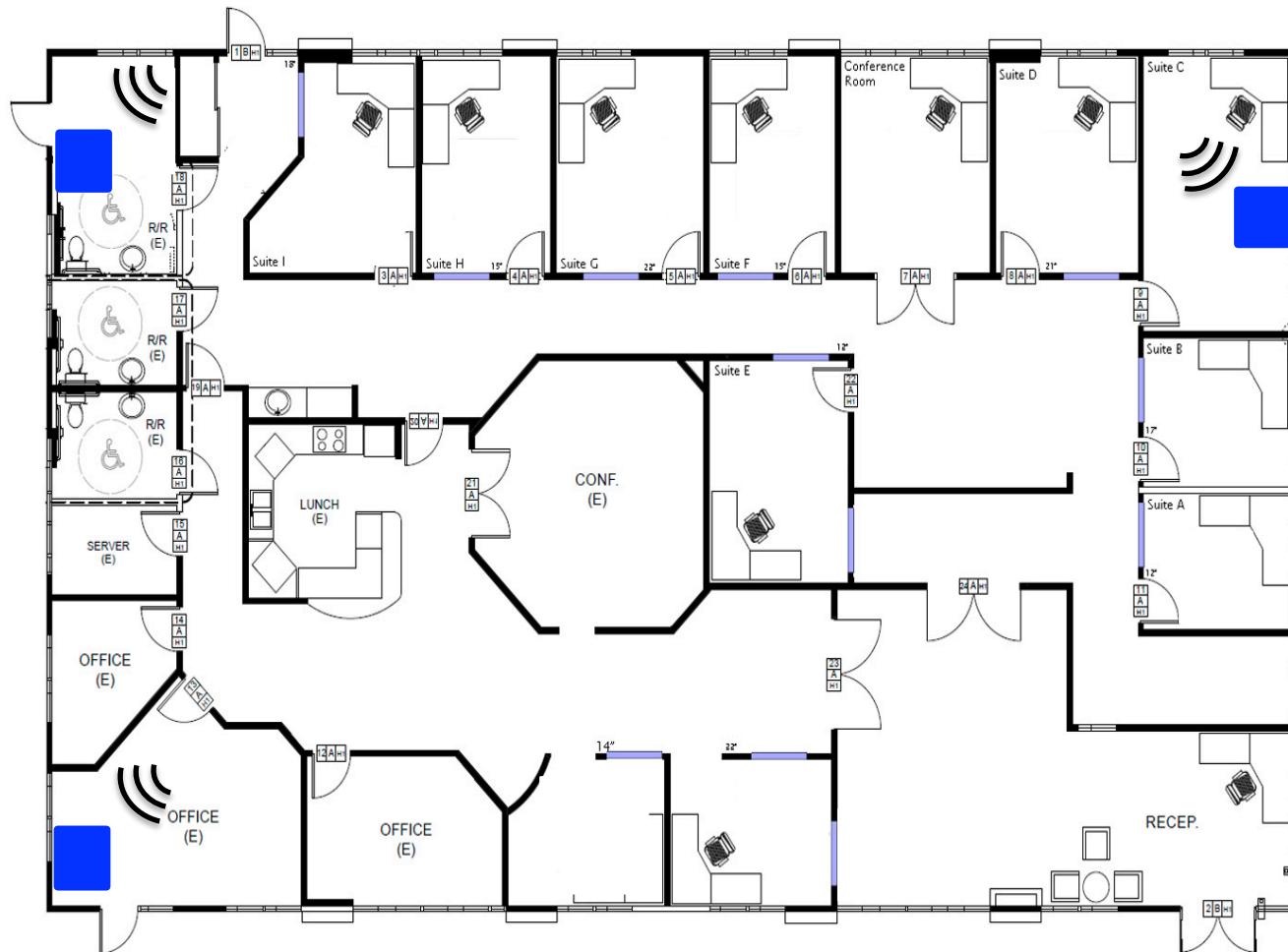
LTEye's Architecture



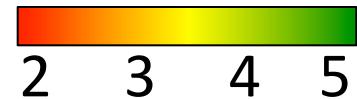
LTEye's per-user analytics preserve user privacy

- Does not access data sent/received by users
- Anonymized PHY-layer User IDs

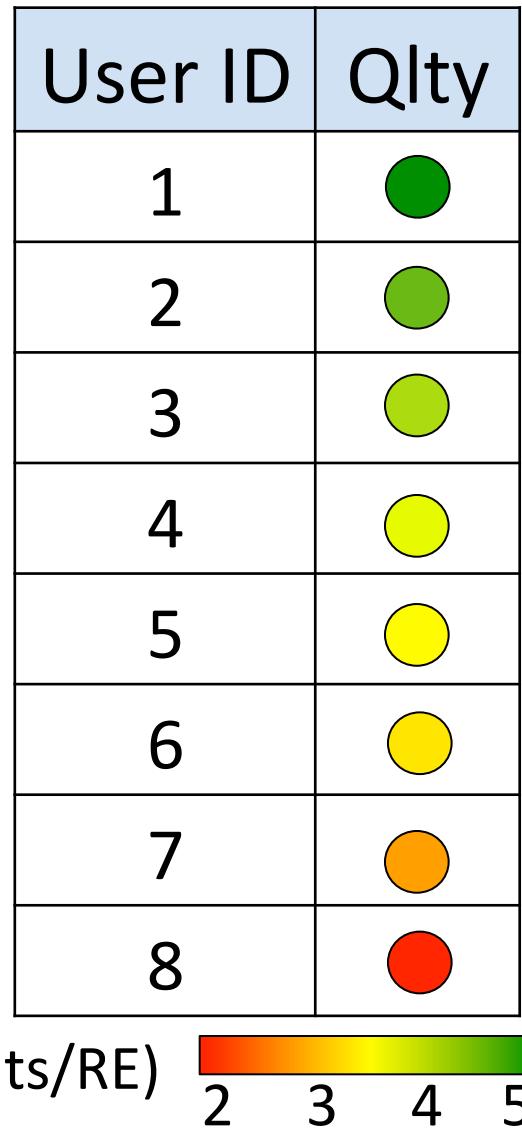
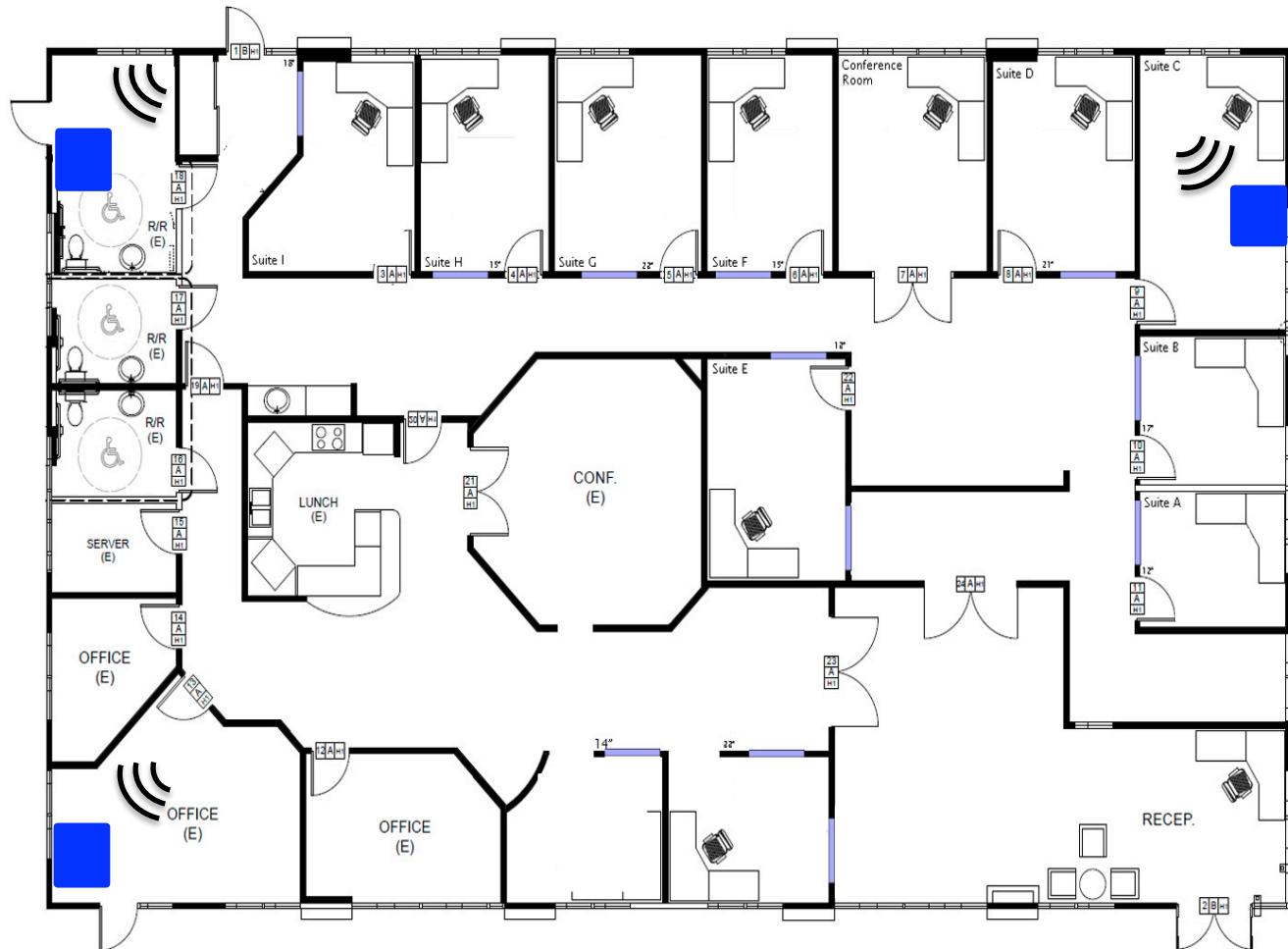
Overview of LTEye



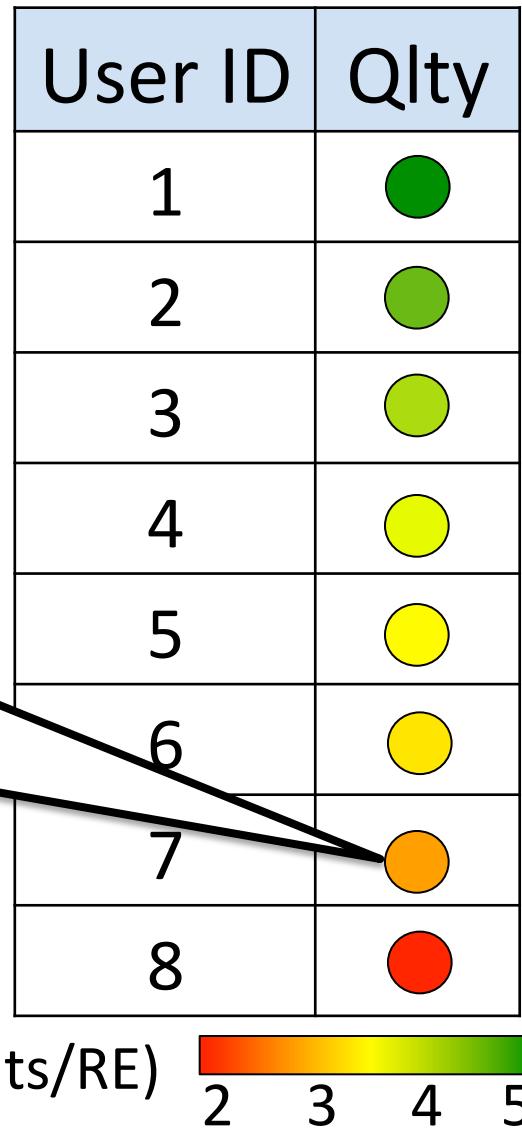
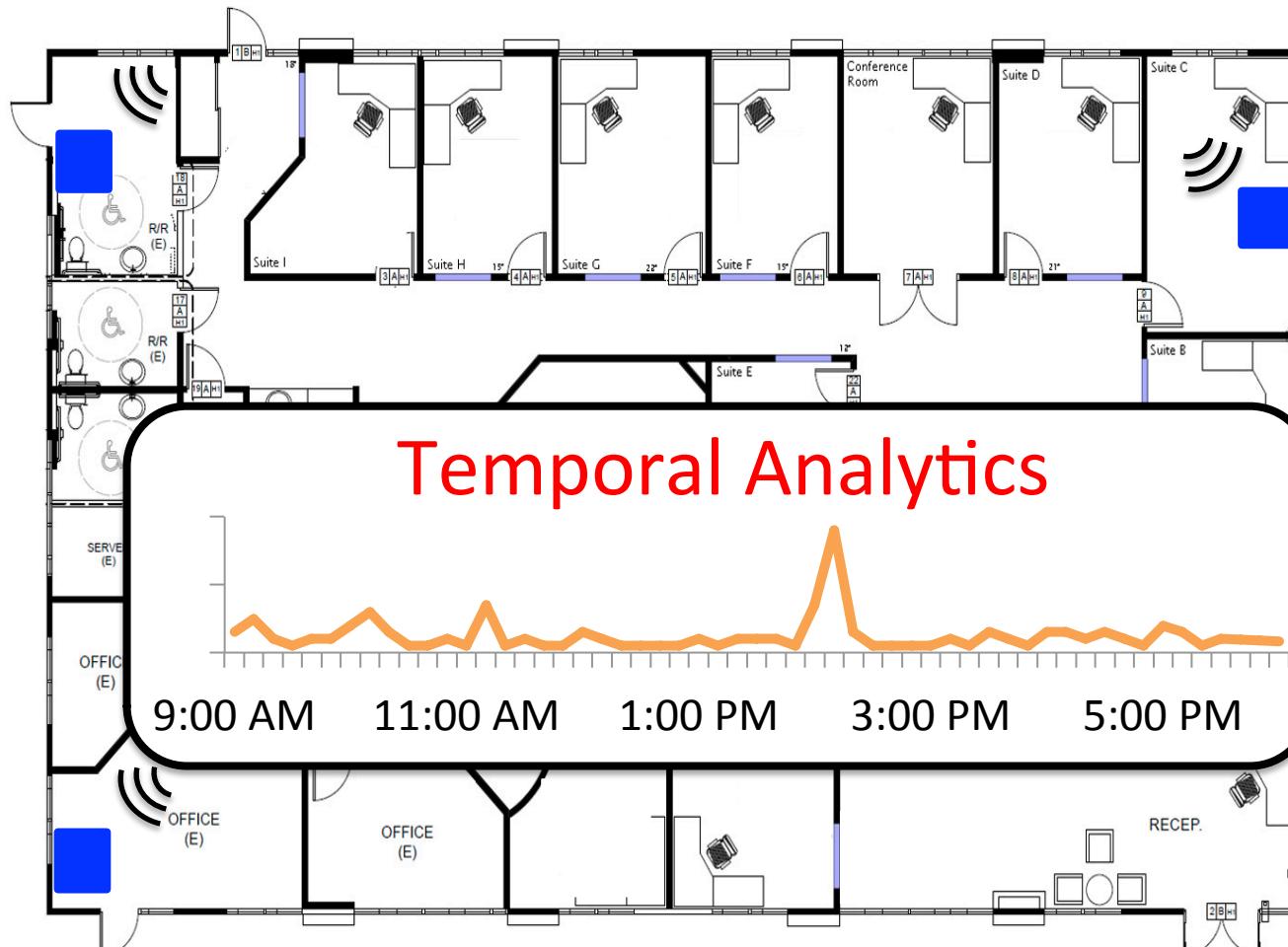
Link Quality (bits/RE)



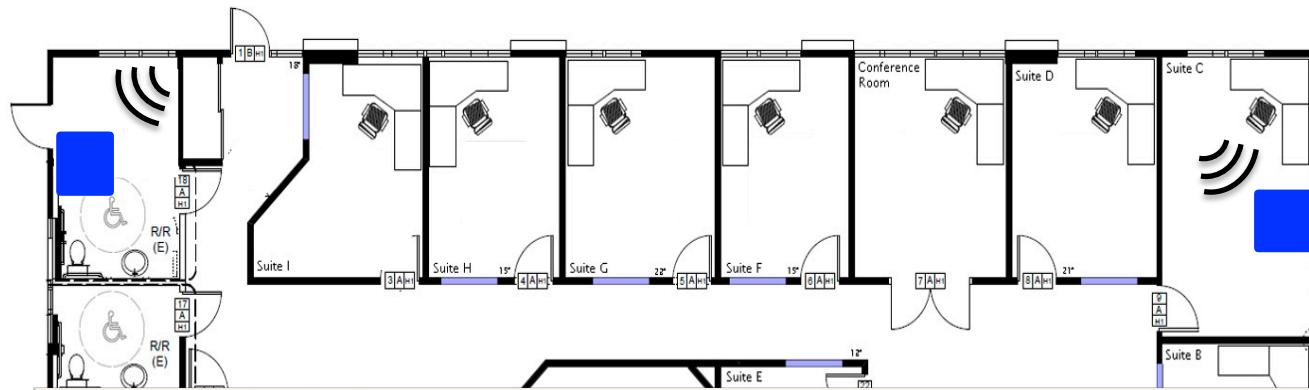
Overview of LTEye



Overview of LTEye

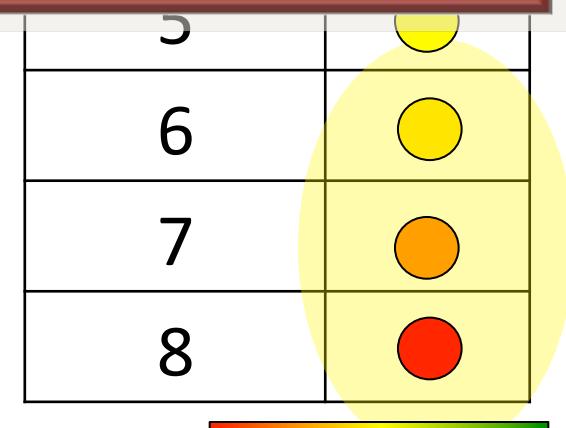
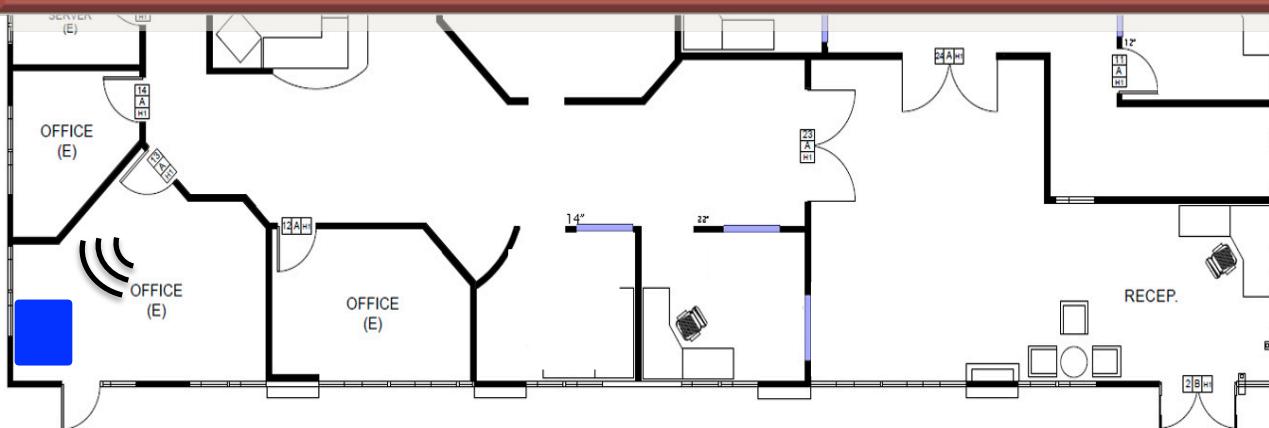


Overview of LTEye



User ID	Qlty
1	●
2	●
3	●

Where are these users in the office?

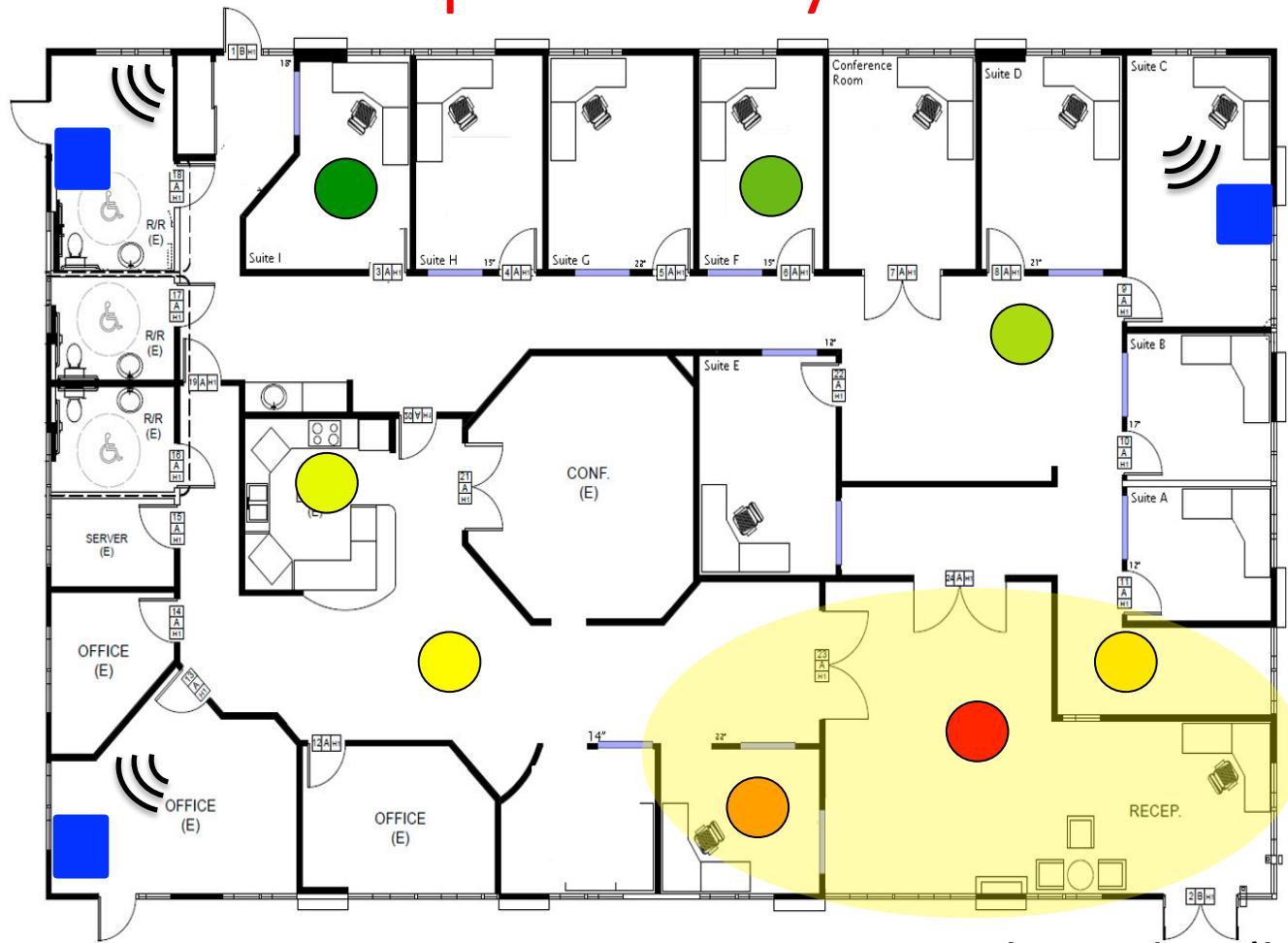


Link Quality (bits/RE)



Overview of LTEye

Spatial Analytics



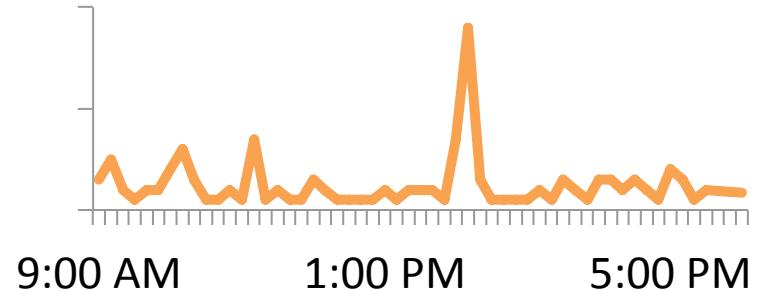
User ID	Qlty
1	
2	
3	
4	
5	
6	
7	
8	

Link Quality (bits/RE)

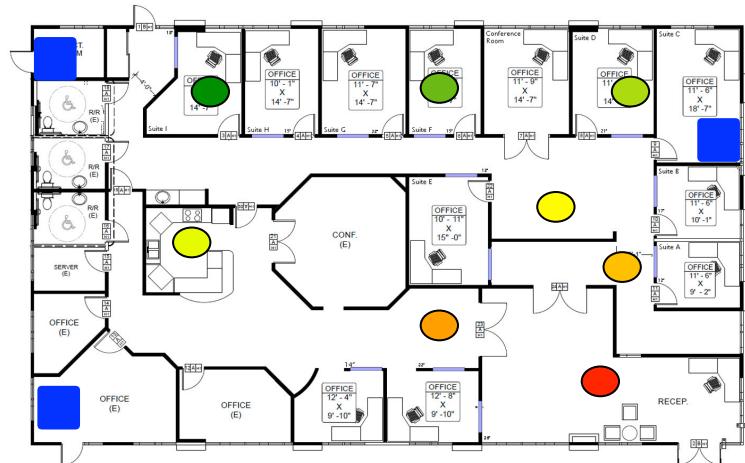


LTEye's Per-User Analytics

- Temporal Analytics

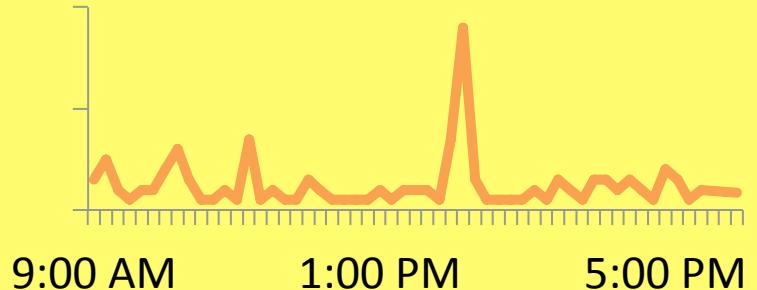


- Spatial Analytics

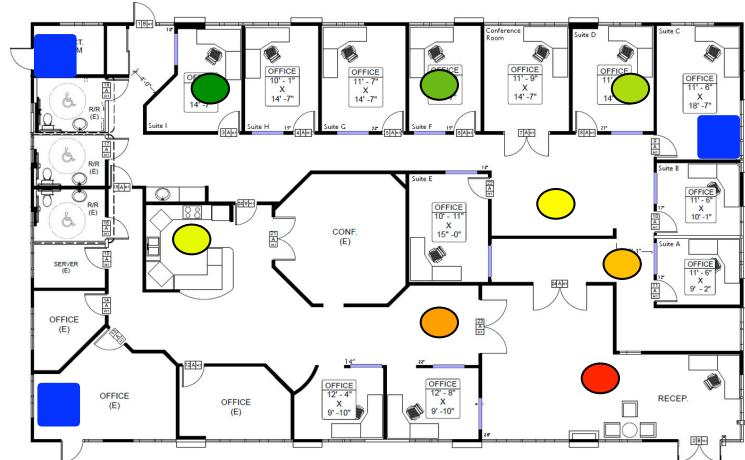


LTEye's Per-User Analytics

- Temporal Analytics



- Spatial Analytics



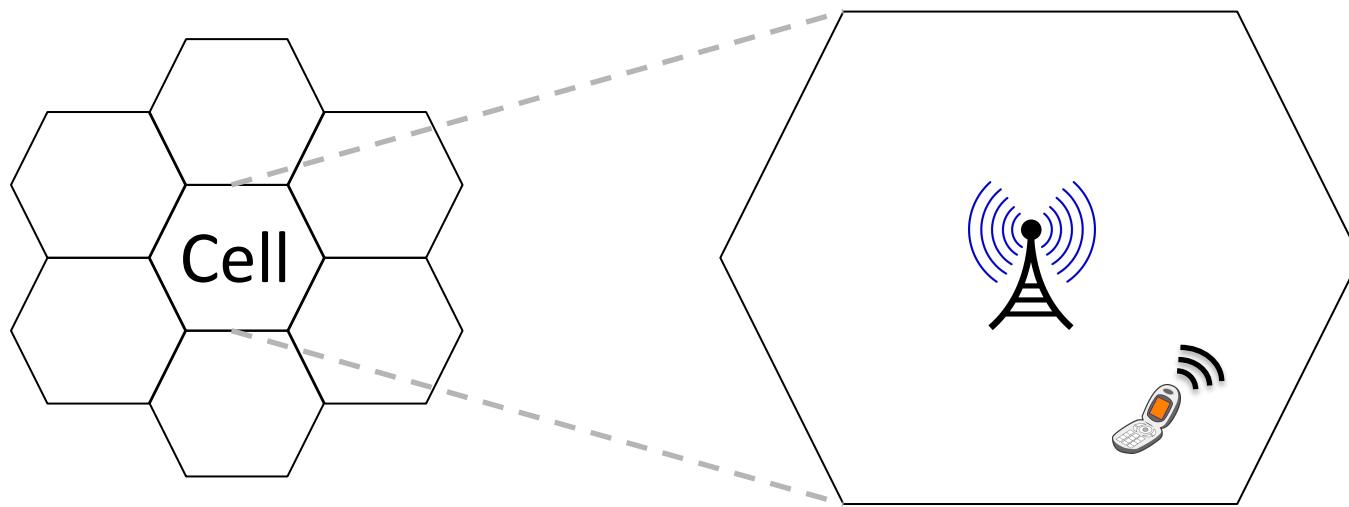
Temporal Analytics

- For each user in our cell monitor:
 - Throughput
 - Link Quality
 - Loss Rate
- Use LTEye sniffers!

Where can sniffers find these analytics?

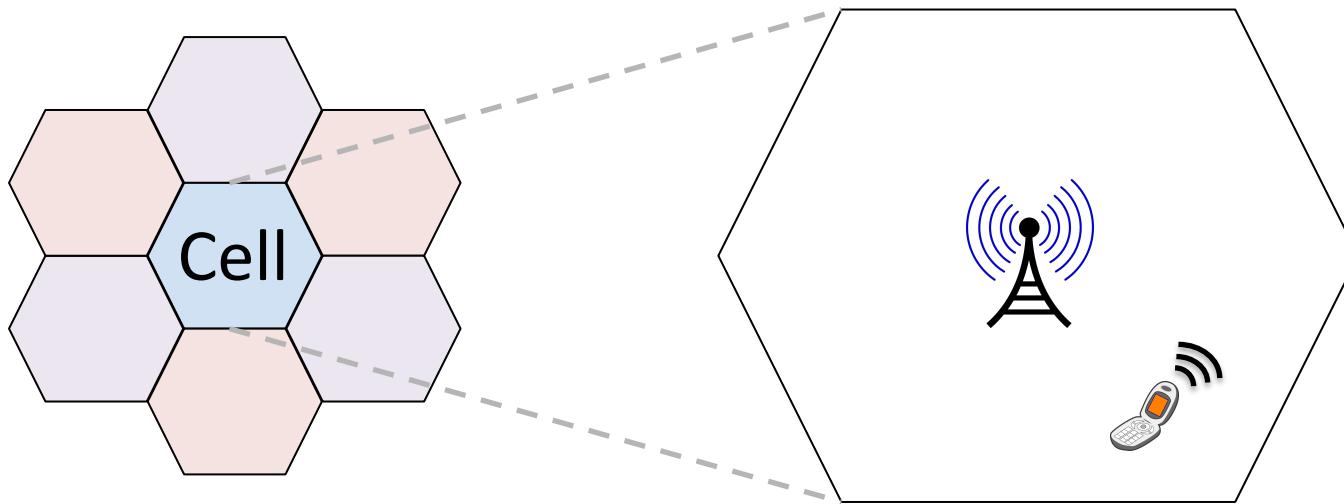
- Without provider support?
- Without expensive hardware?

Today's LTE Networks



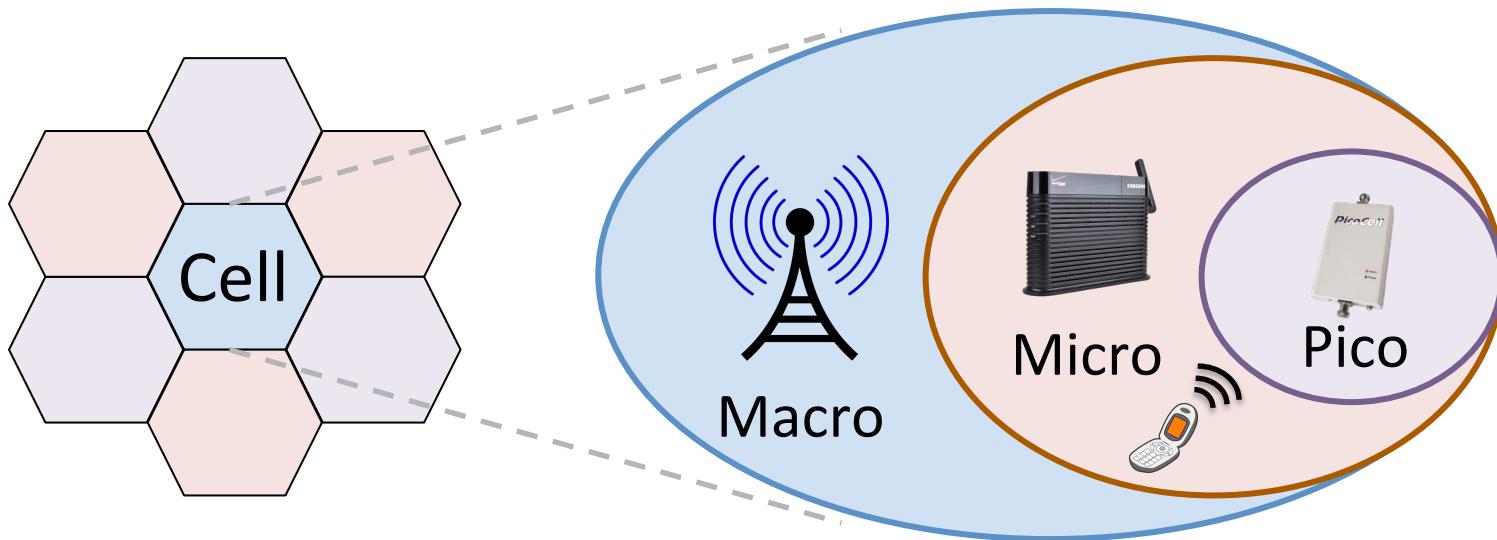
Today's LTE Networks

A lot more complex!



Today's LTE Networks

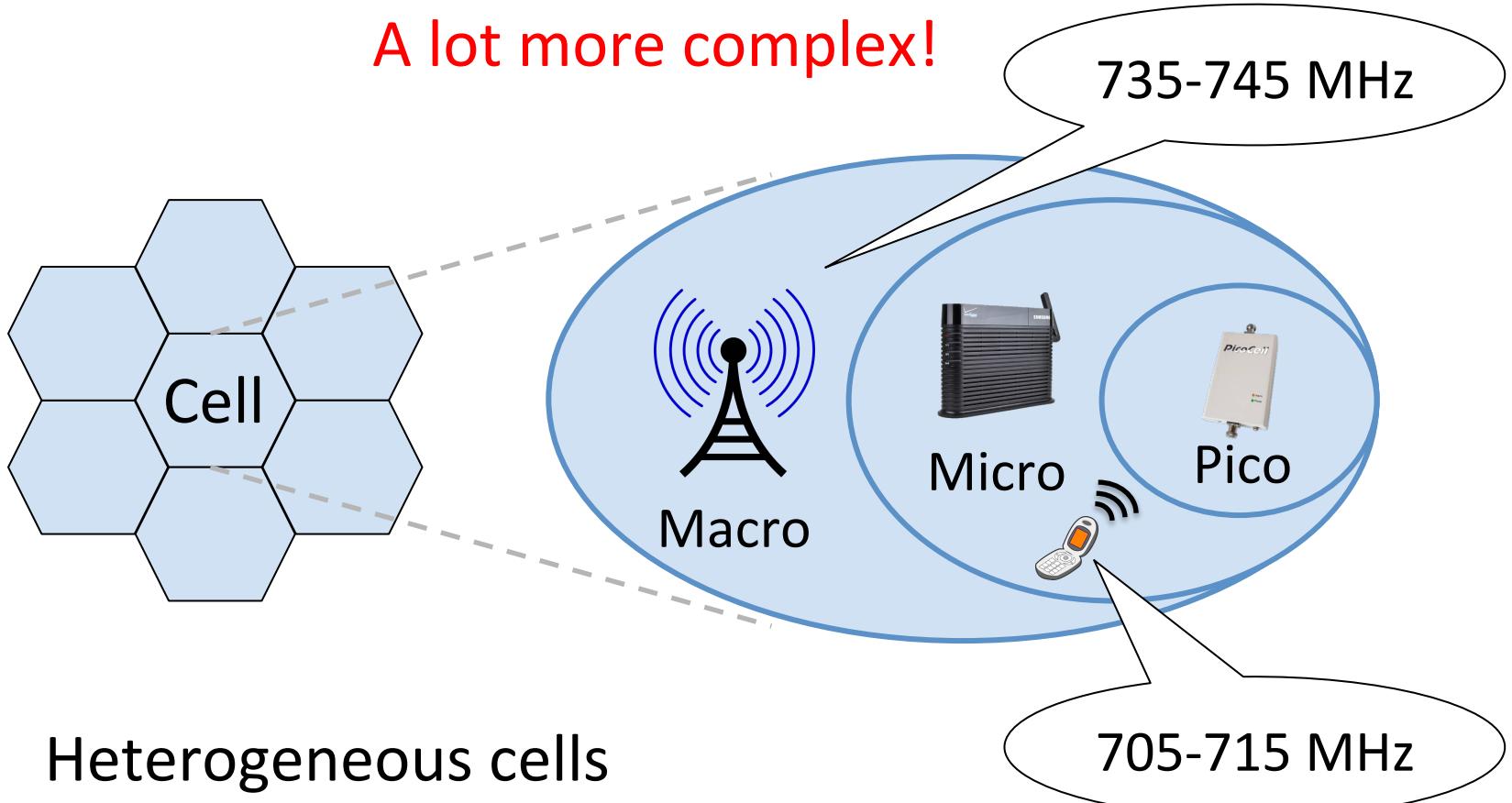
A lot more complex!



- Heterogeneous cells

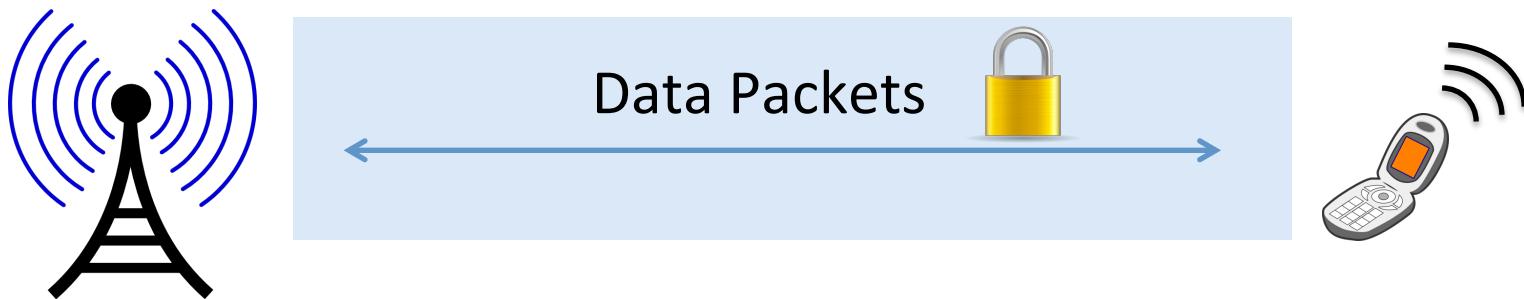
Today's LTE Networks

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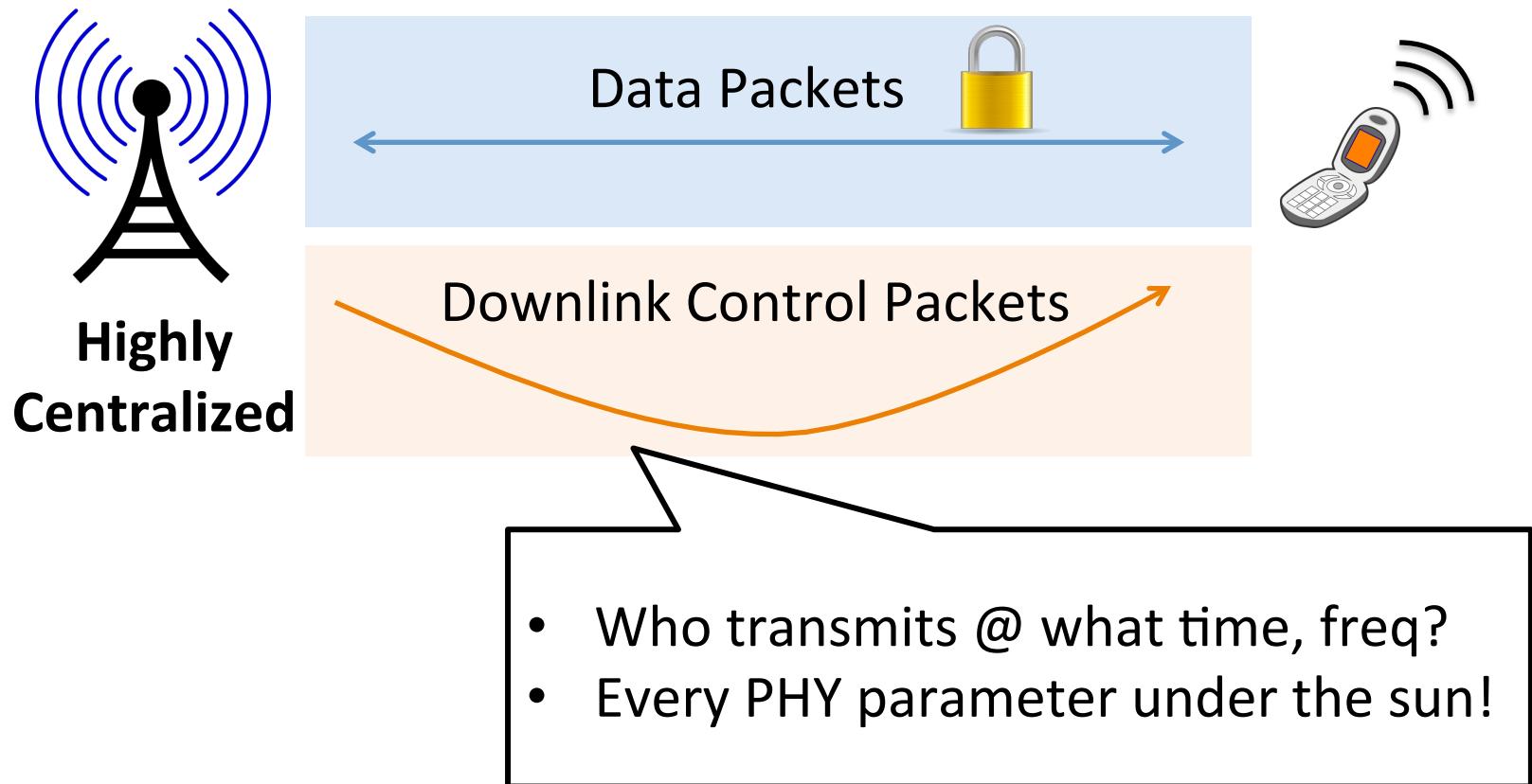


- Heterogeneous cells
- All share same spectrum

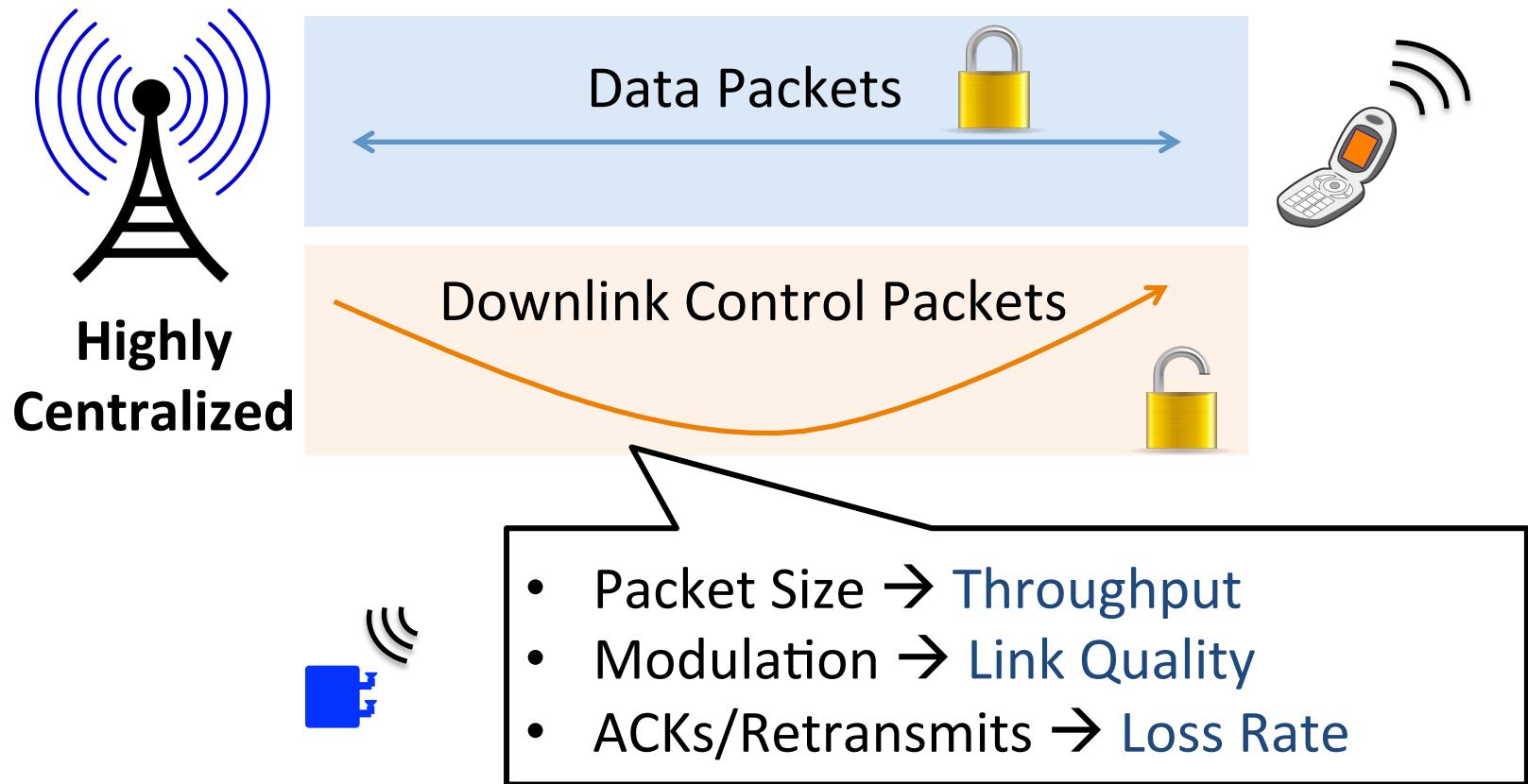
Where can we find temporal analytics?



Where can we find temporal analytics?



Where can we find temporal analytics?



No provider support

Two Important Benefits

- Uplink / Downlink



20-60 W



< 250 mW

Cheap hardware can listen to nearby towers
LTEye can get analytics on phones it can't even hear

Two Important Benefits

- Uplink / Downlink



20-60 W

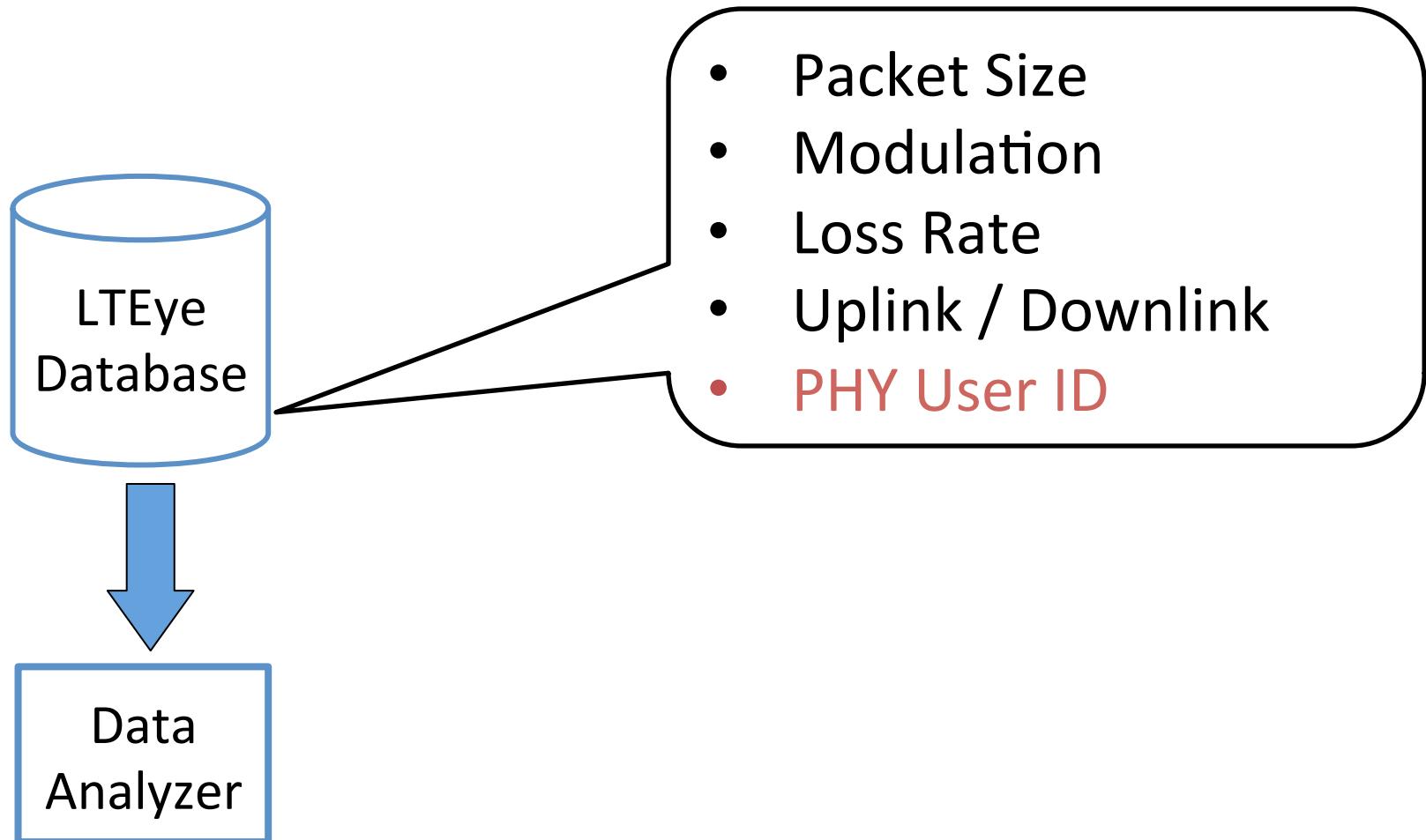


< 250 mW

- PHY Layer User ID

User IDs change over time; Must ensure consistency
→ Details in our paper

LTEye Database



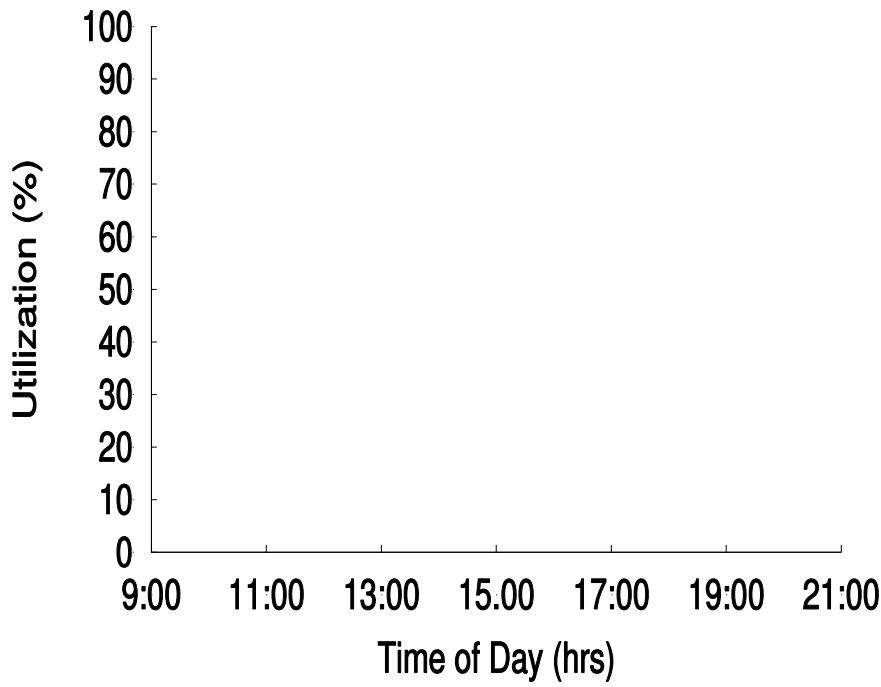
LTEye Temporal Analytics

LTEye Temporal Analytics

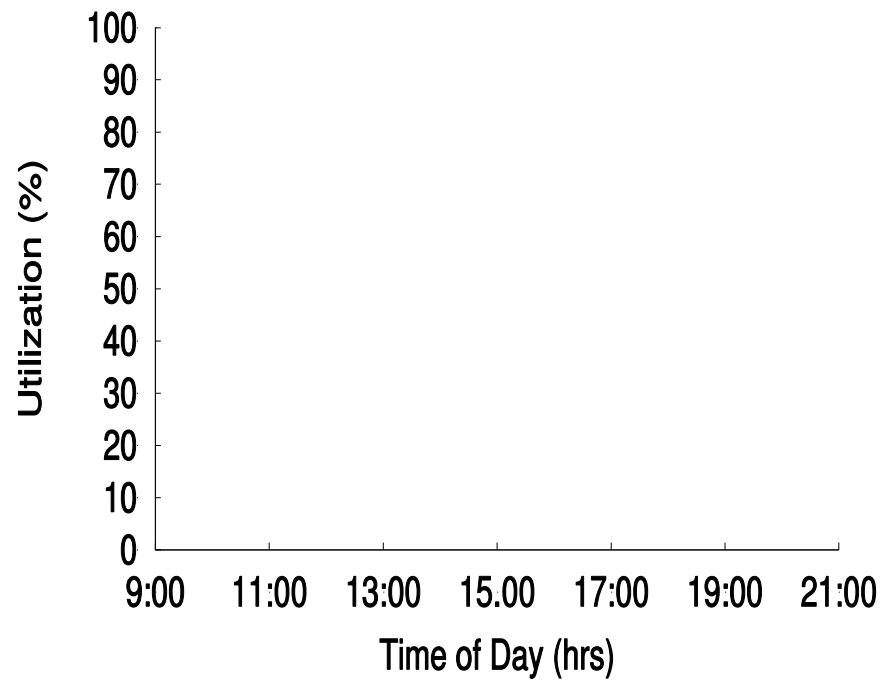
- ✓ Is LTE Spectrum used Efficiently?

Network Utilization

- LTE uses equal bands for uplink and downlink



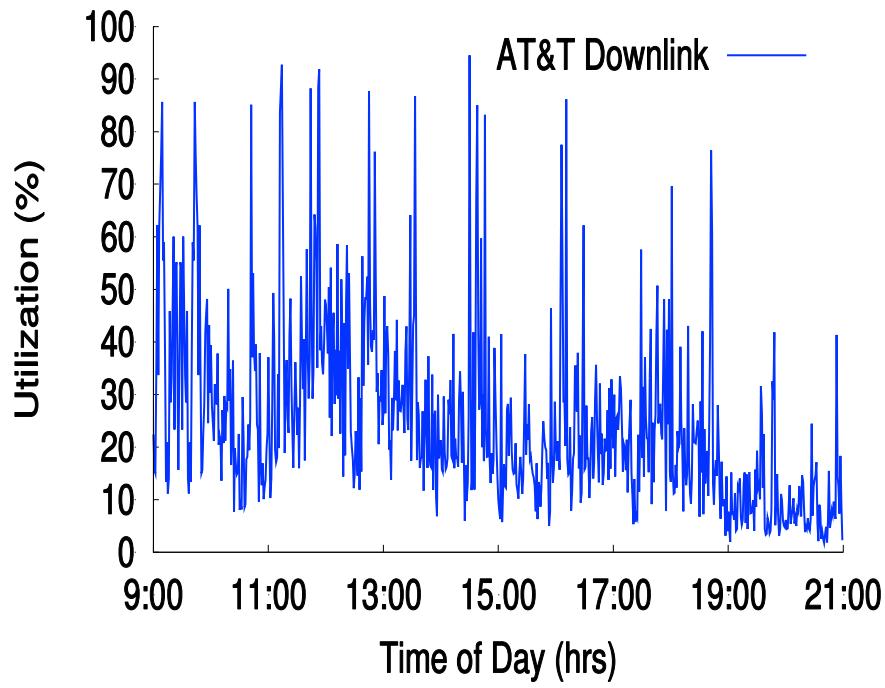
AT&T



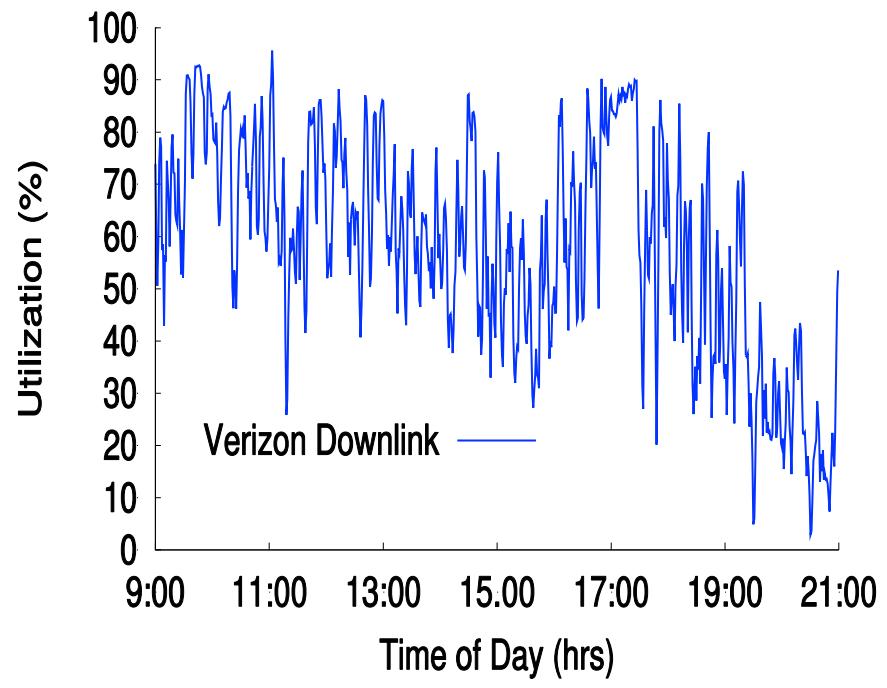
Verizon

Network Utilization

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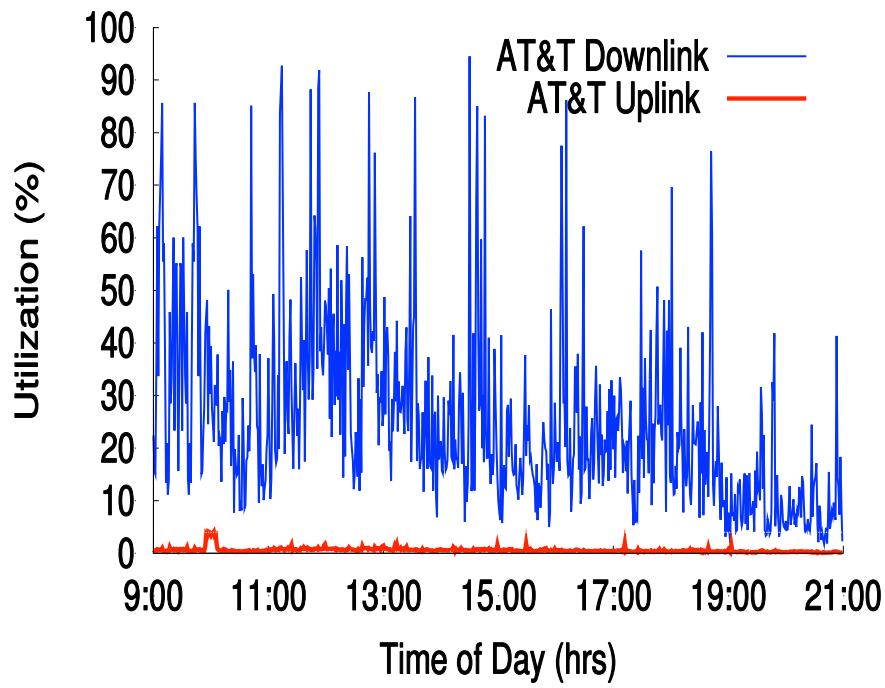
AT&T



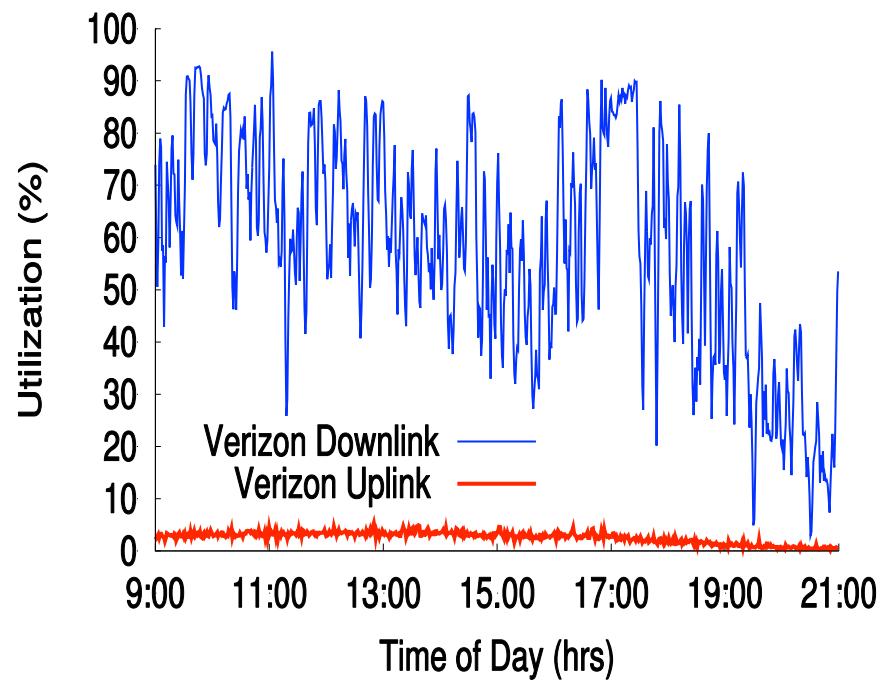
Verizon

Network Utilization

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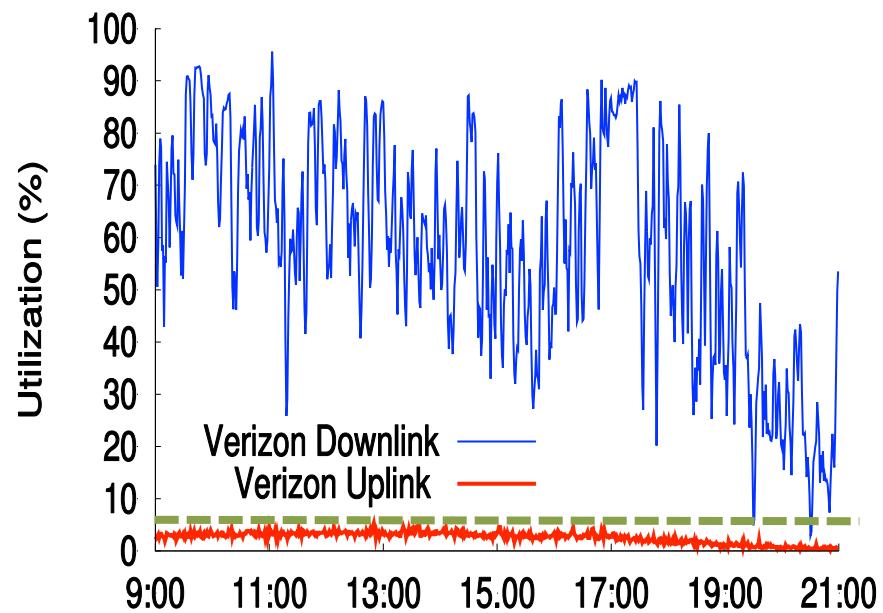
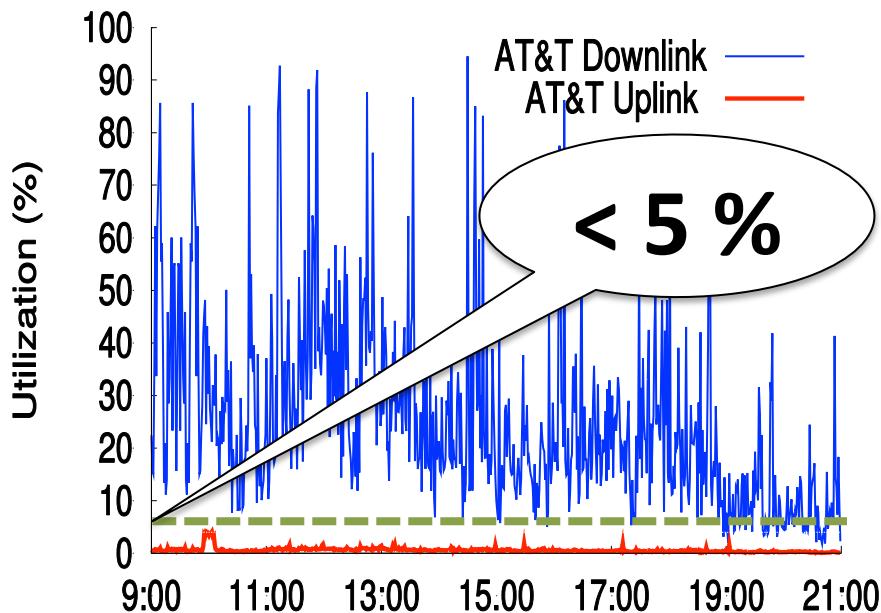
AT&T



Verizon

Network Utilization

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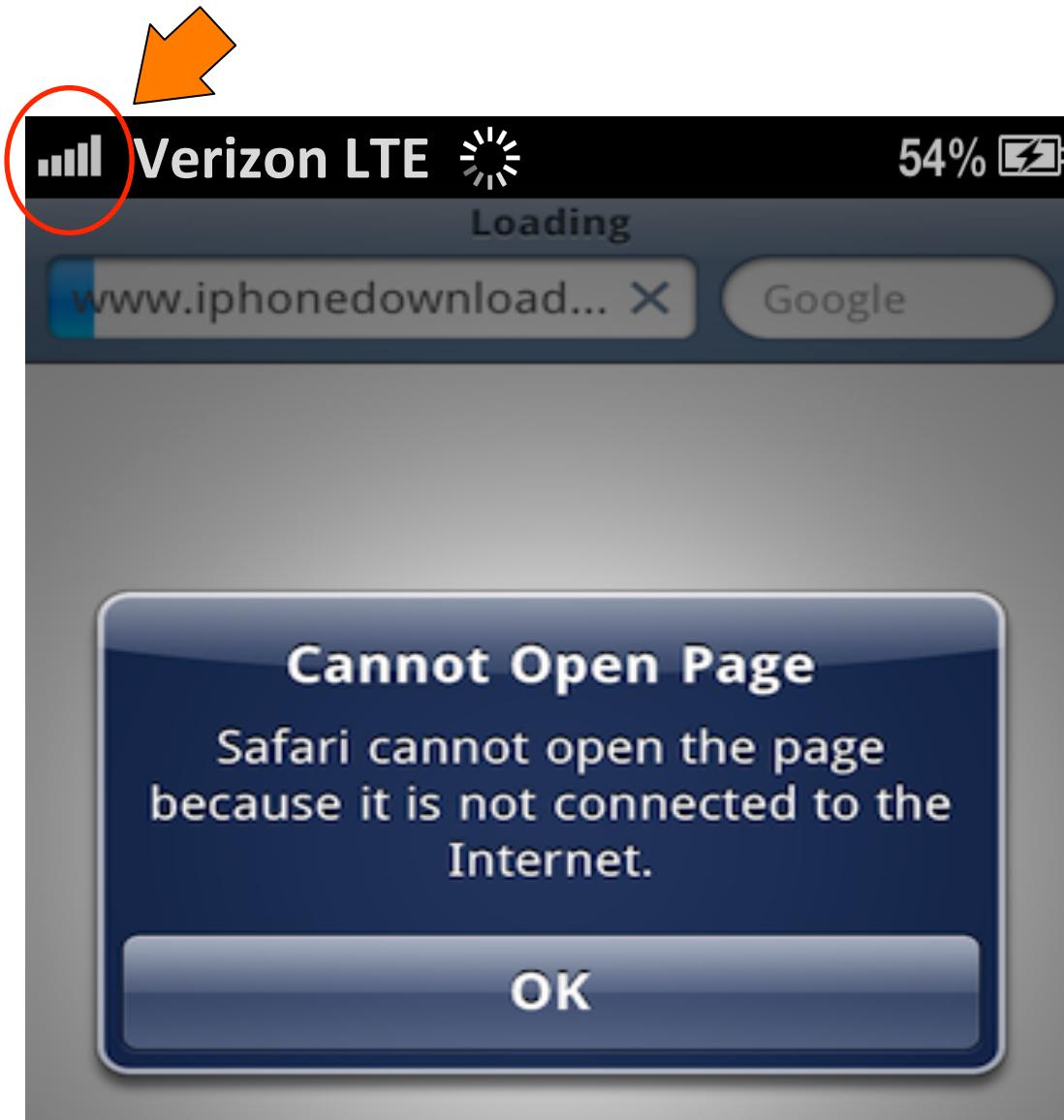
Nearly 2 x resources for high-demand downlink
using vacant uplink spectrum!

LTEye Temporal Analytics

✓ Is LTE Spectrum used Efficiently?

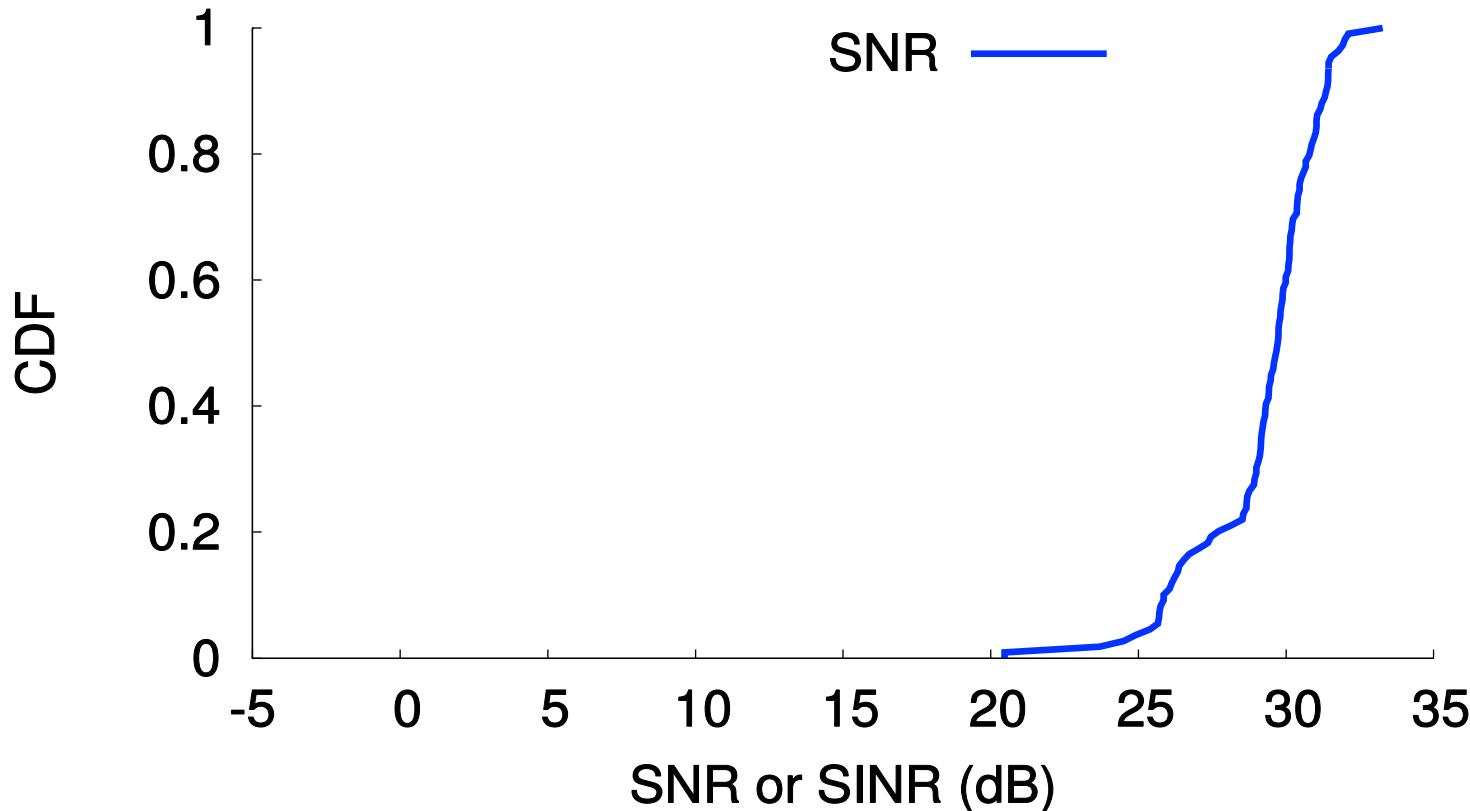
✓ Why is LTE poor in some spots
of my building?

5 Bar Paradox



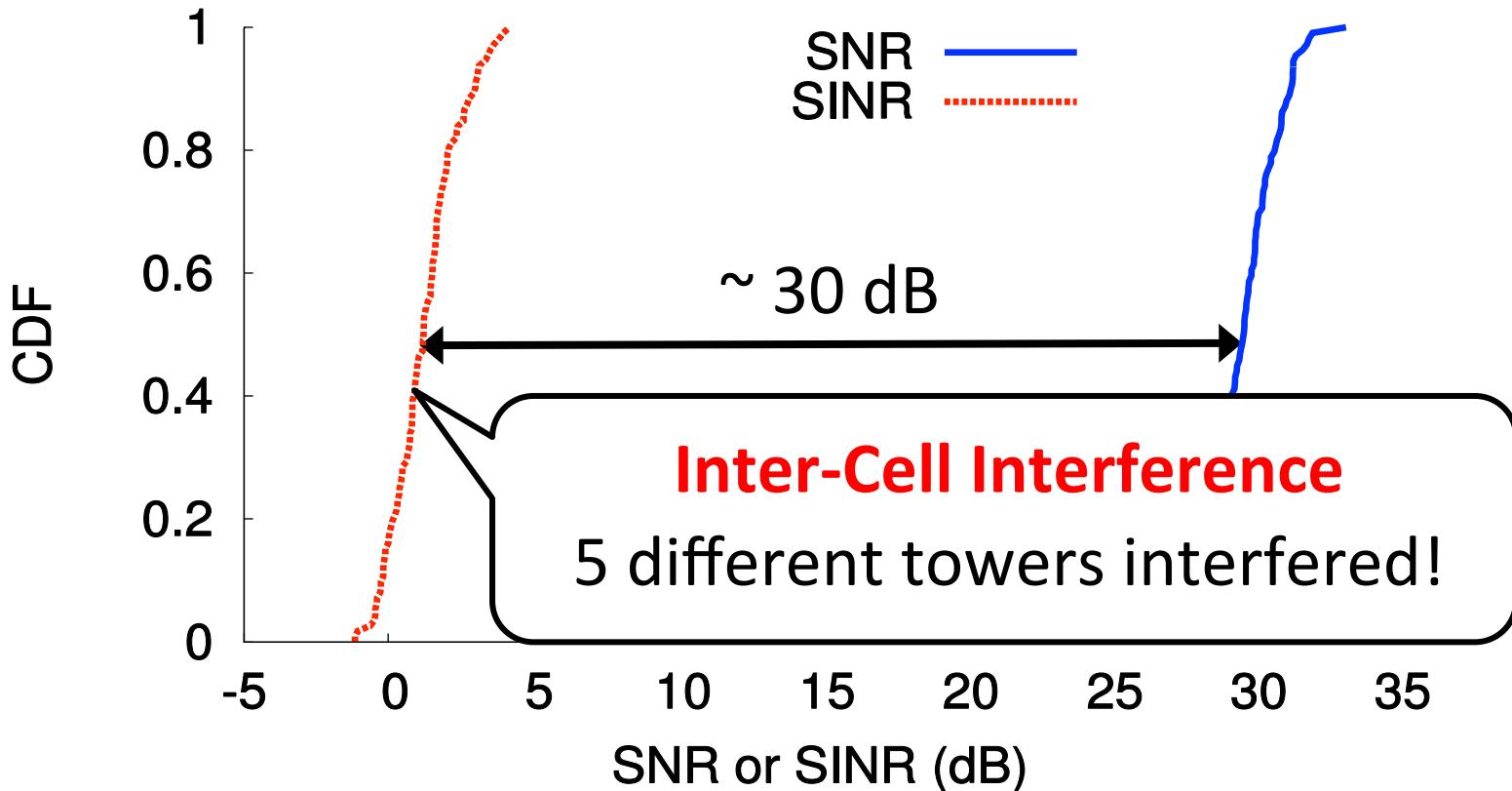
5 Bar Paradox

- Placed LTEye sniffers at these locations...



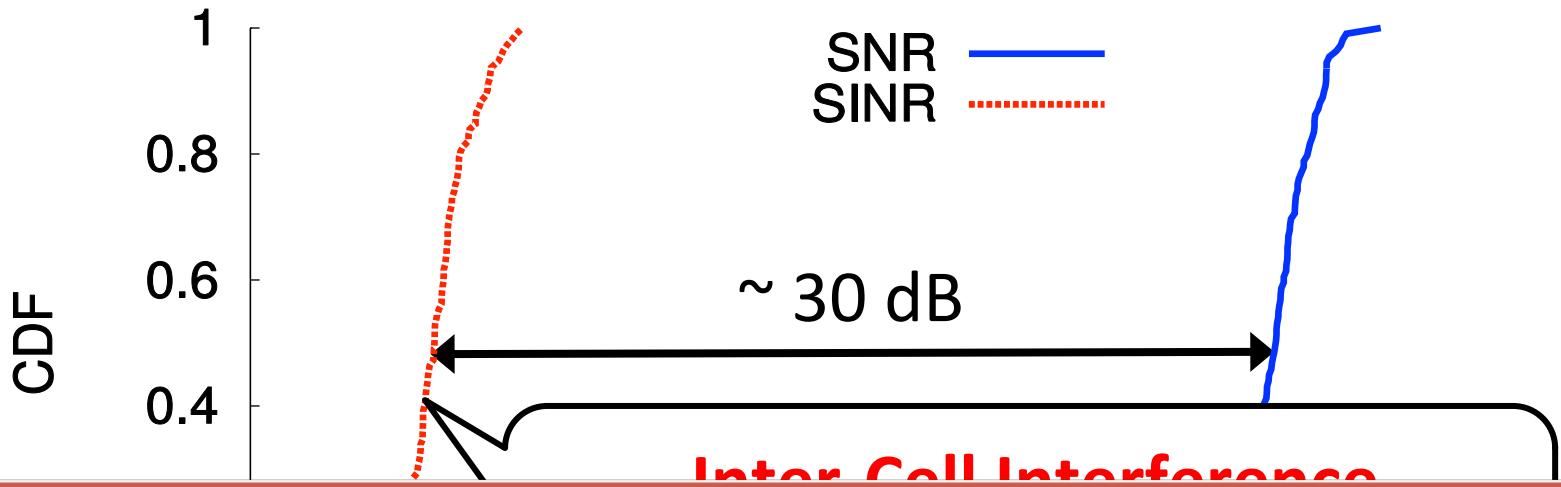
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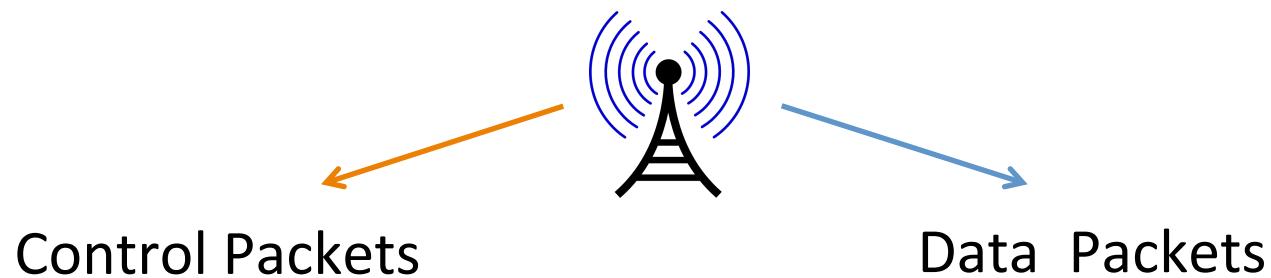


- Complex Deployments → Complex Interference
 - Providers cannot drive test indoors!
- LTEye can help providers learn indoor performance

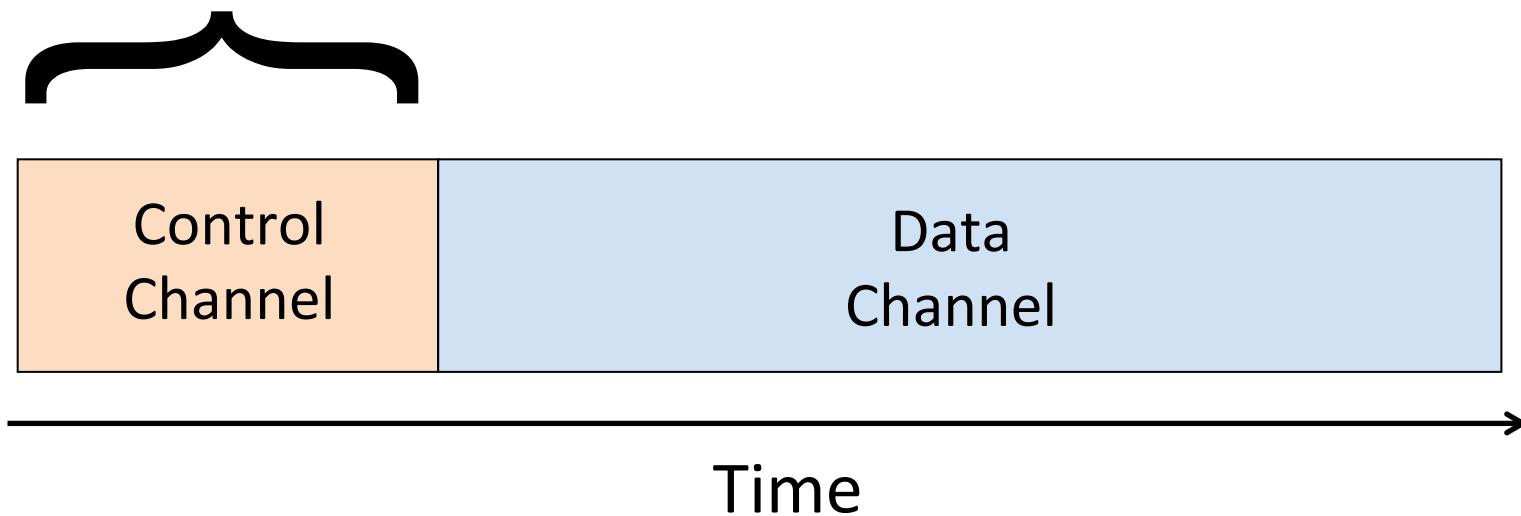
LTE Insights

- ✓ Is LTE Spectrum used Efficiently?
- ✓ Why is LTE poor in some spots of my building?
- ✓ Is LTE network configured efficiently?

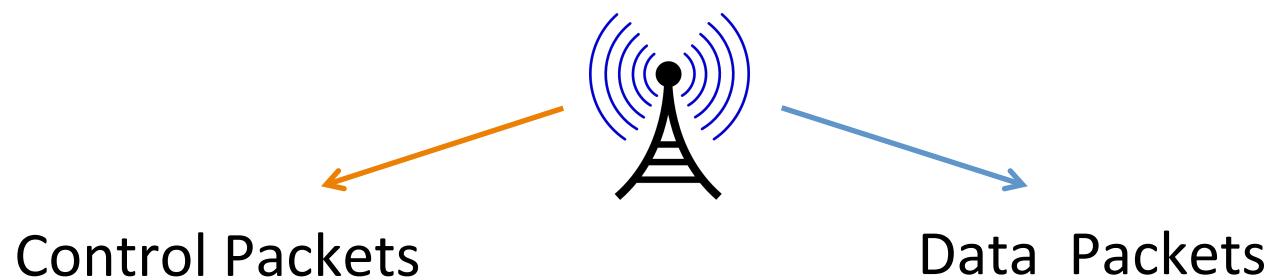
Excessive Control Overhead



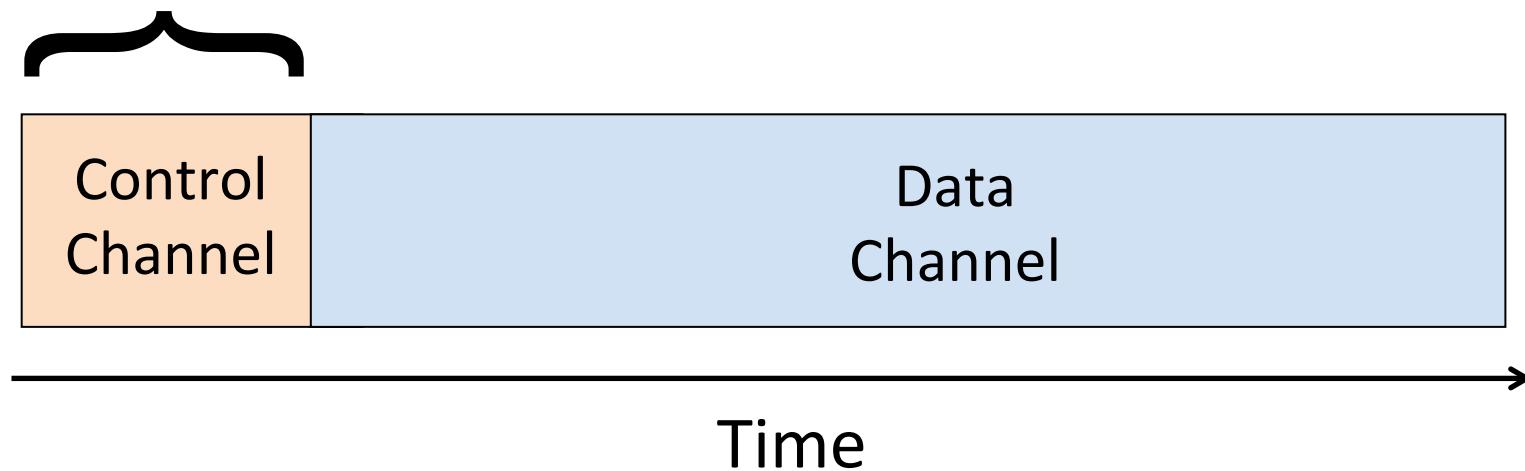
Flexible Size



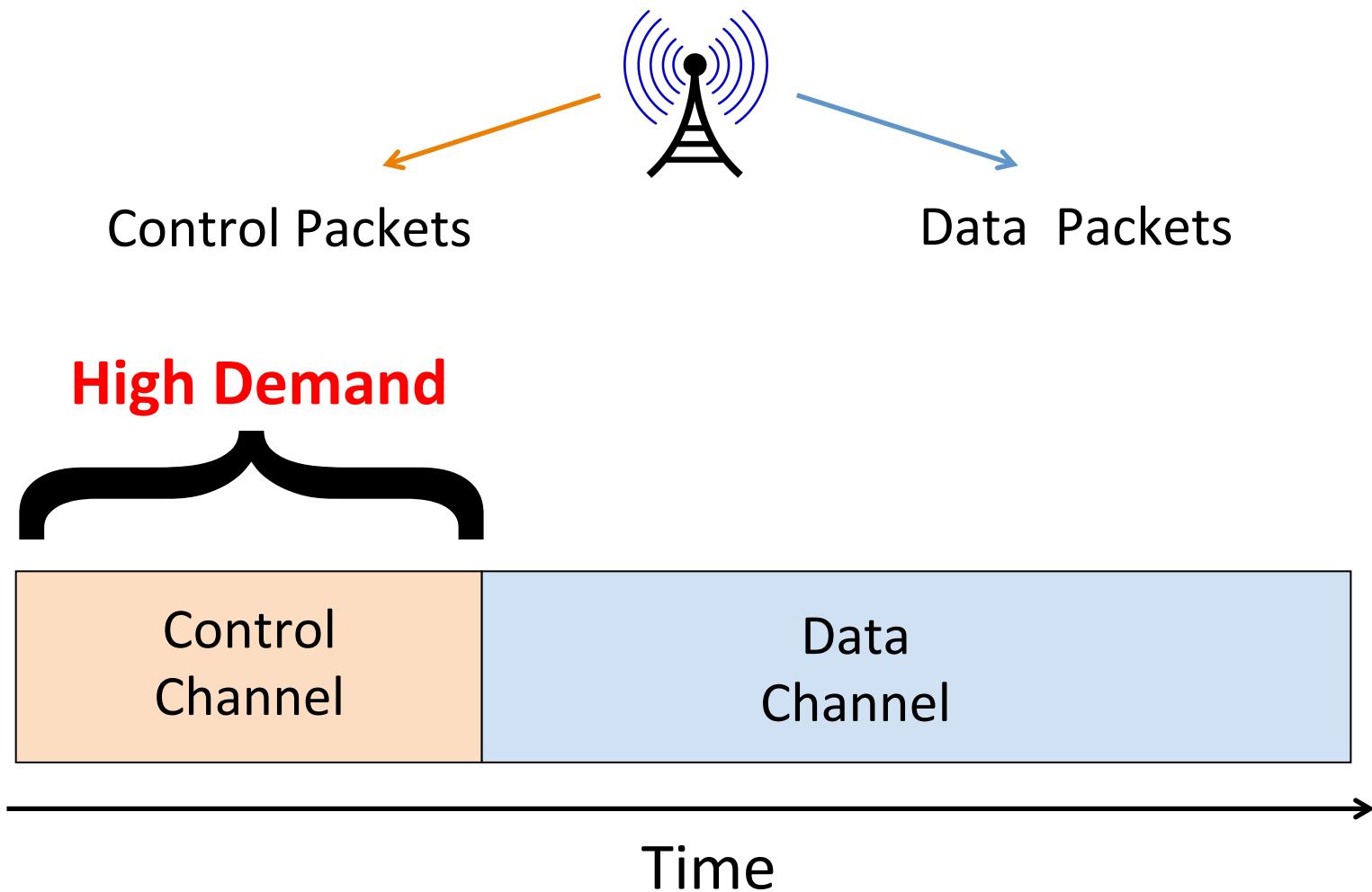
Excessive Control Overhead



Low Demand

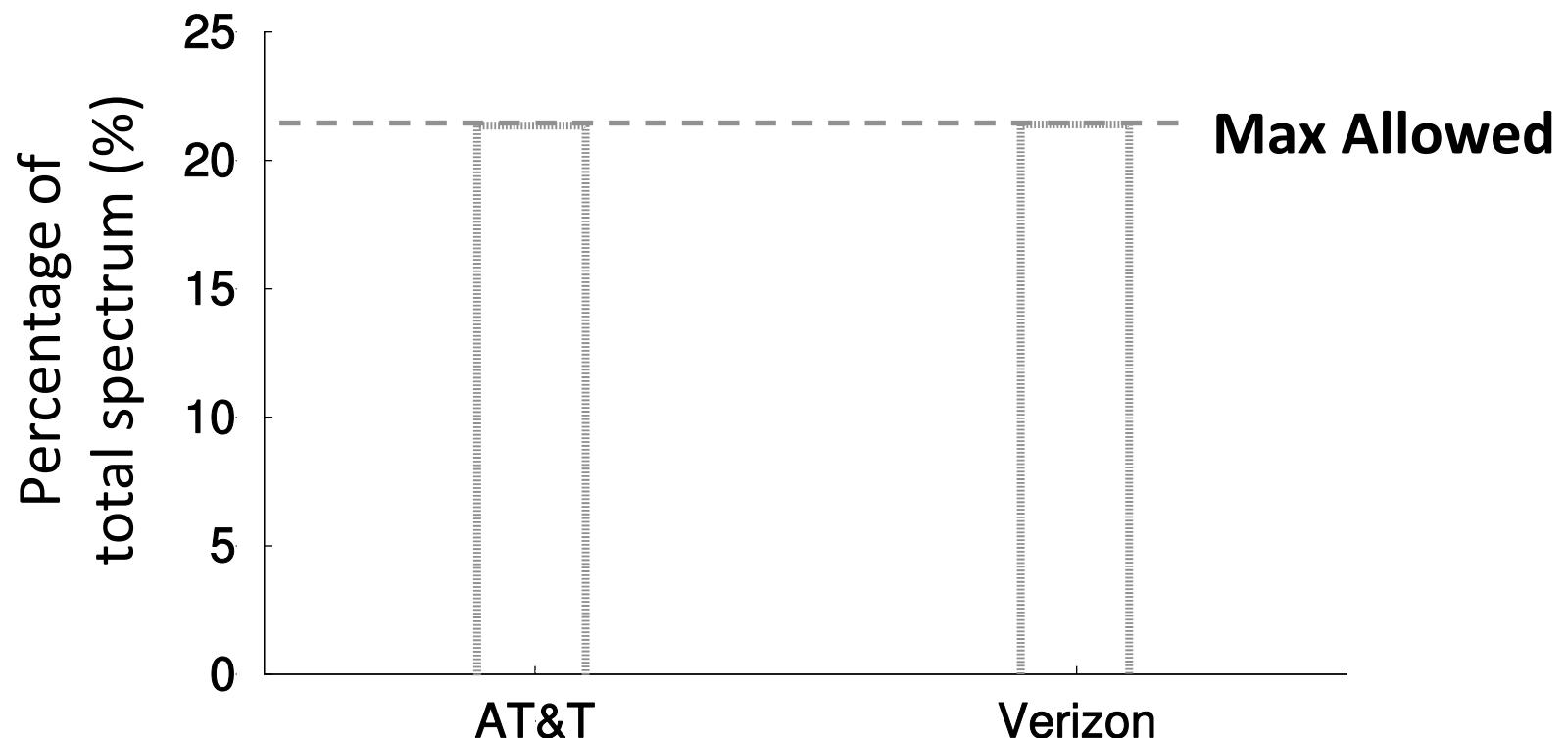


Excessive Control Overhead



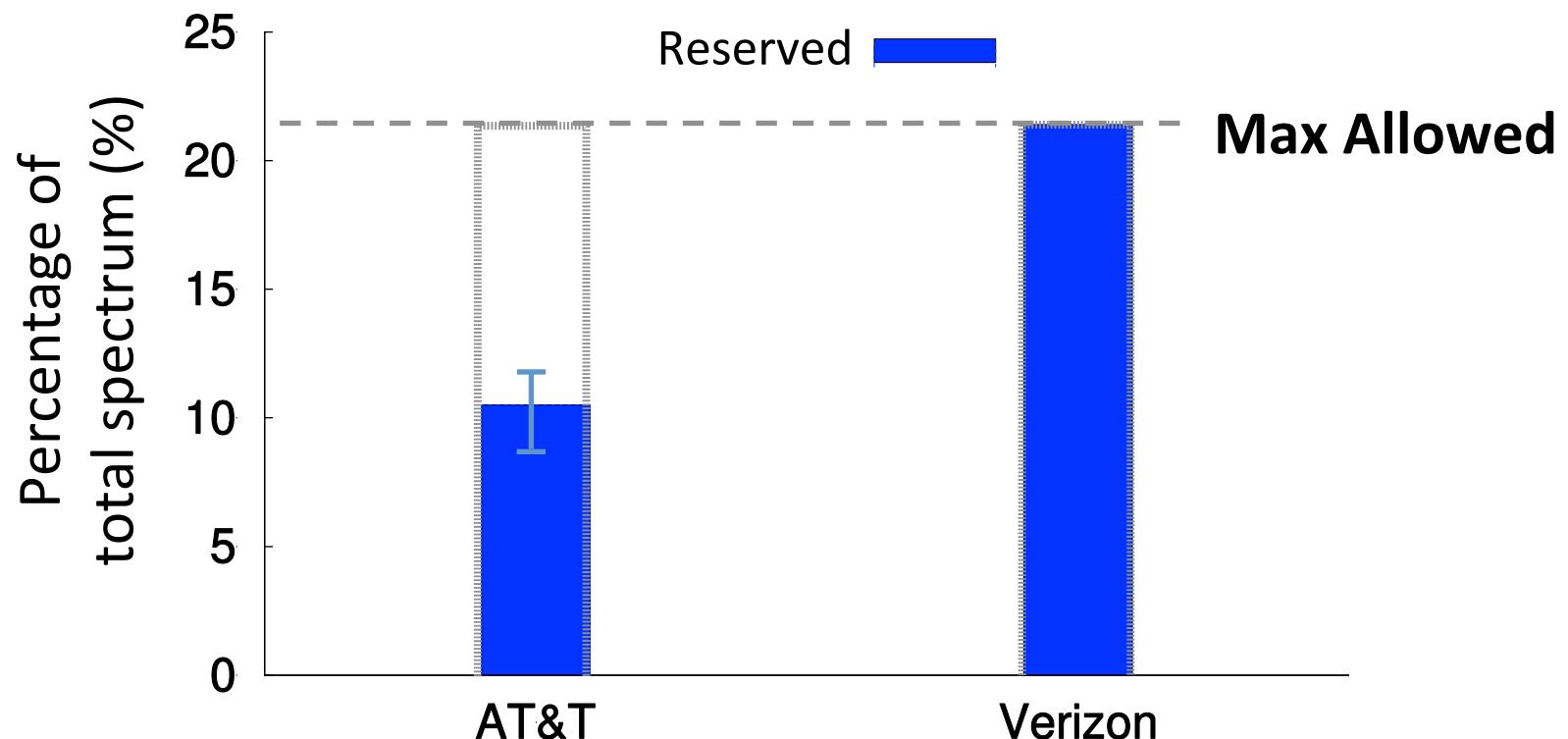
This is not always followed...

- Verizon stations always use maximum size



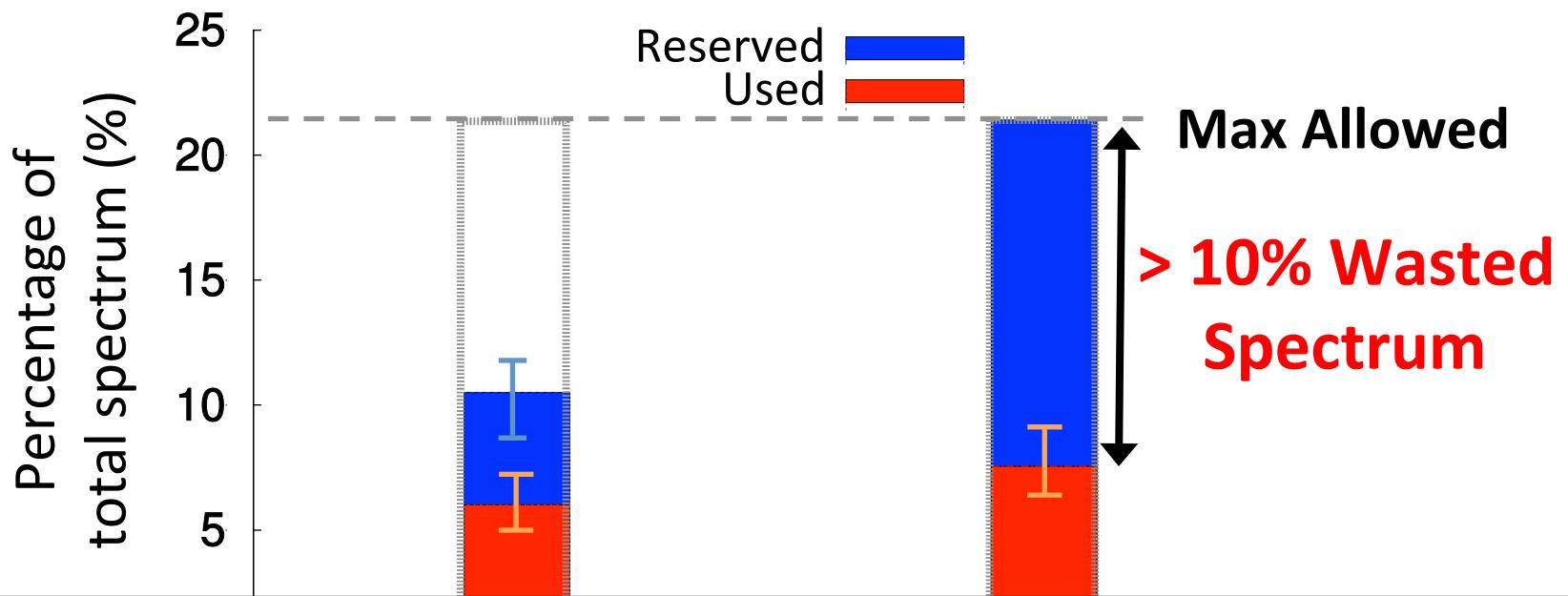
This is not always followed...

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This is not always followed...

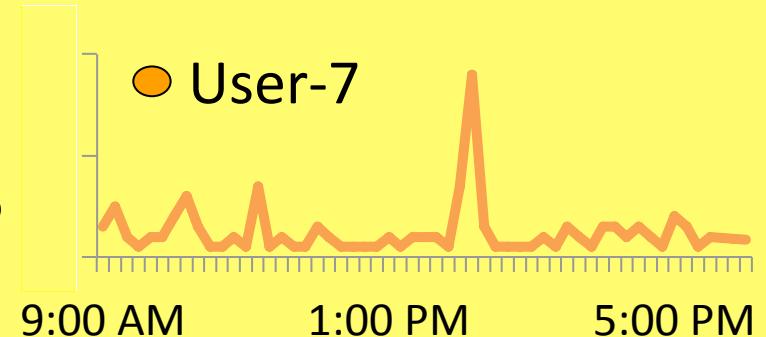
- Verizon stations always use maximum size



10% of spectrum waste = nearly \$500 Million!

LTEye's Per-User Analytics

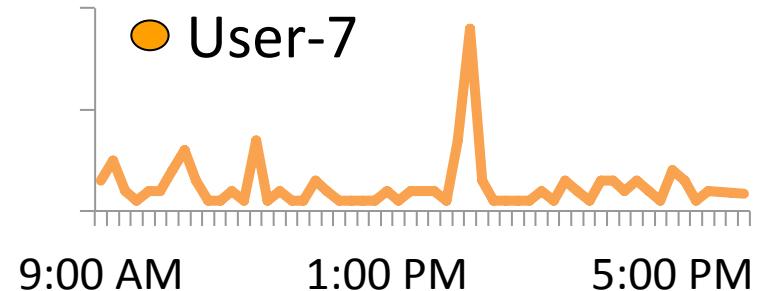
- Temporal Analytics



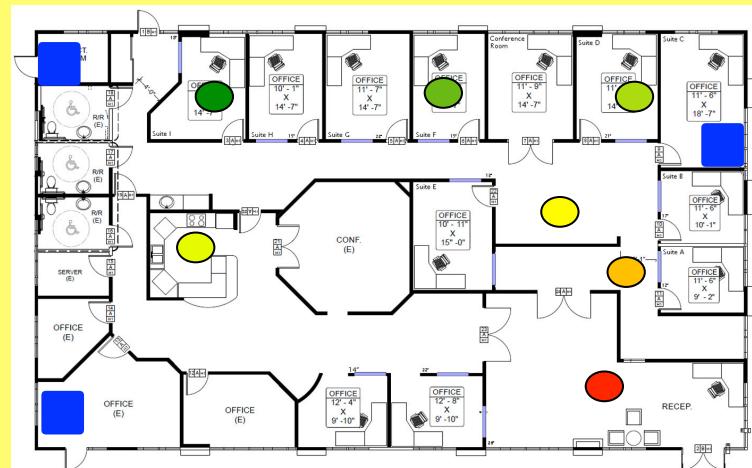
- Spatial Analytics

LTEye's Per-User Analytics

- Temporal Analytics



- ## • Spatial Analytics

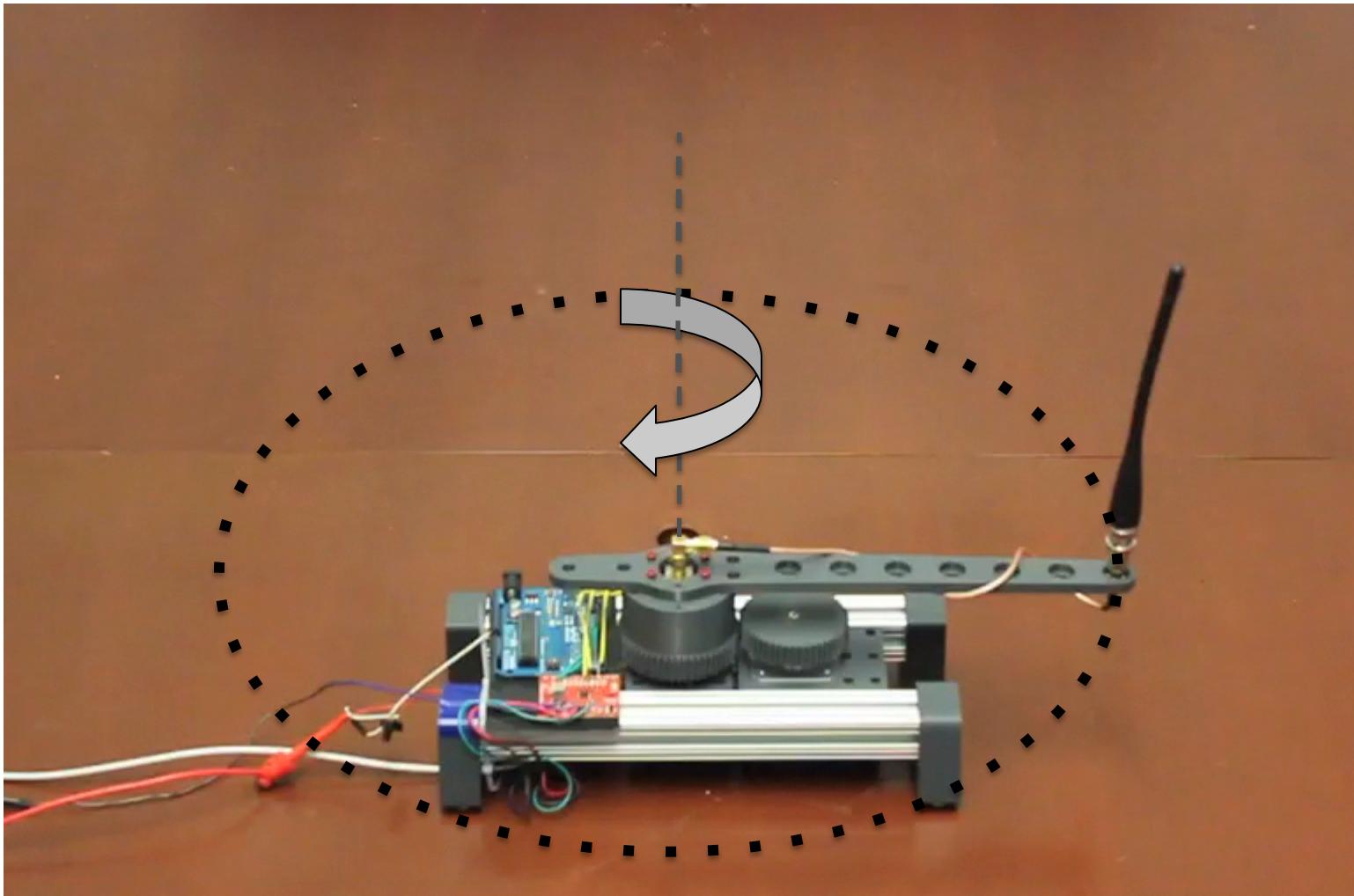


Spatial Analytics

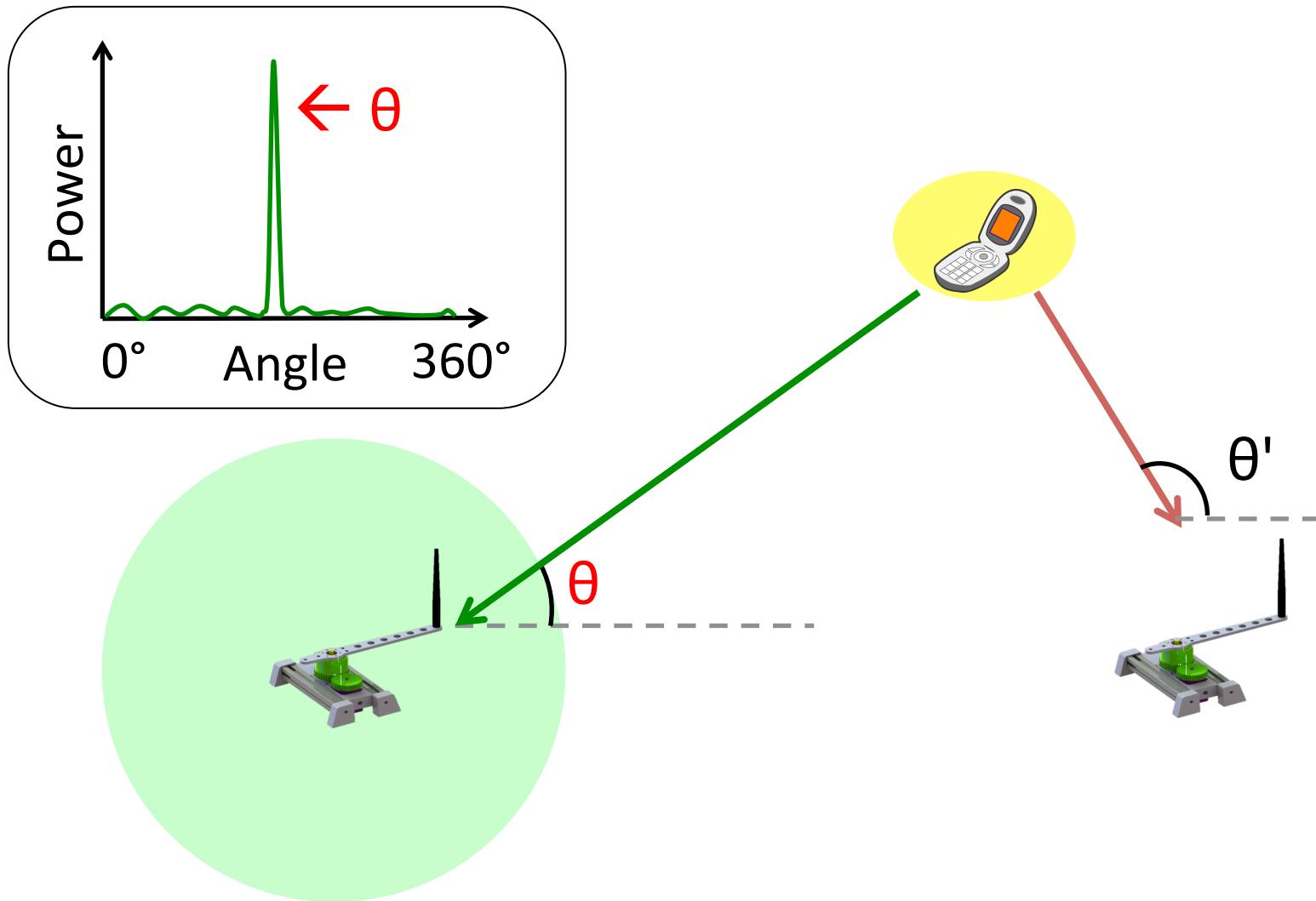
“Localize LTE Users”

Antenna arrays with good accuracy needs
very many antennas

Synthetic Aperture Radar (SAR)

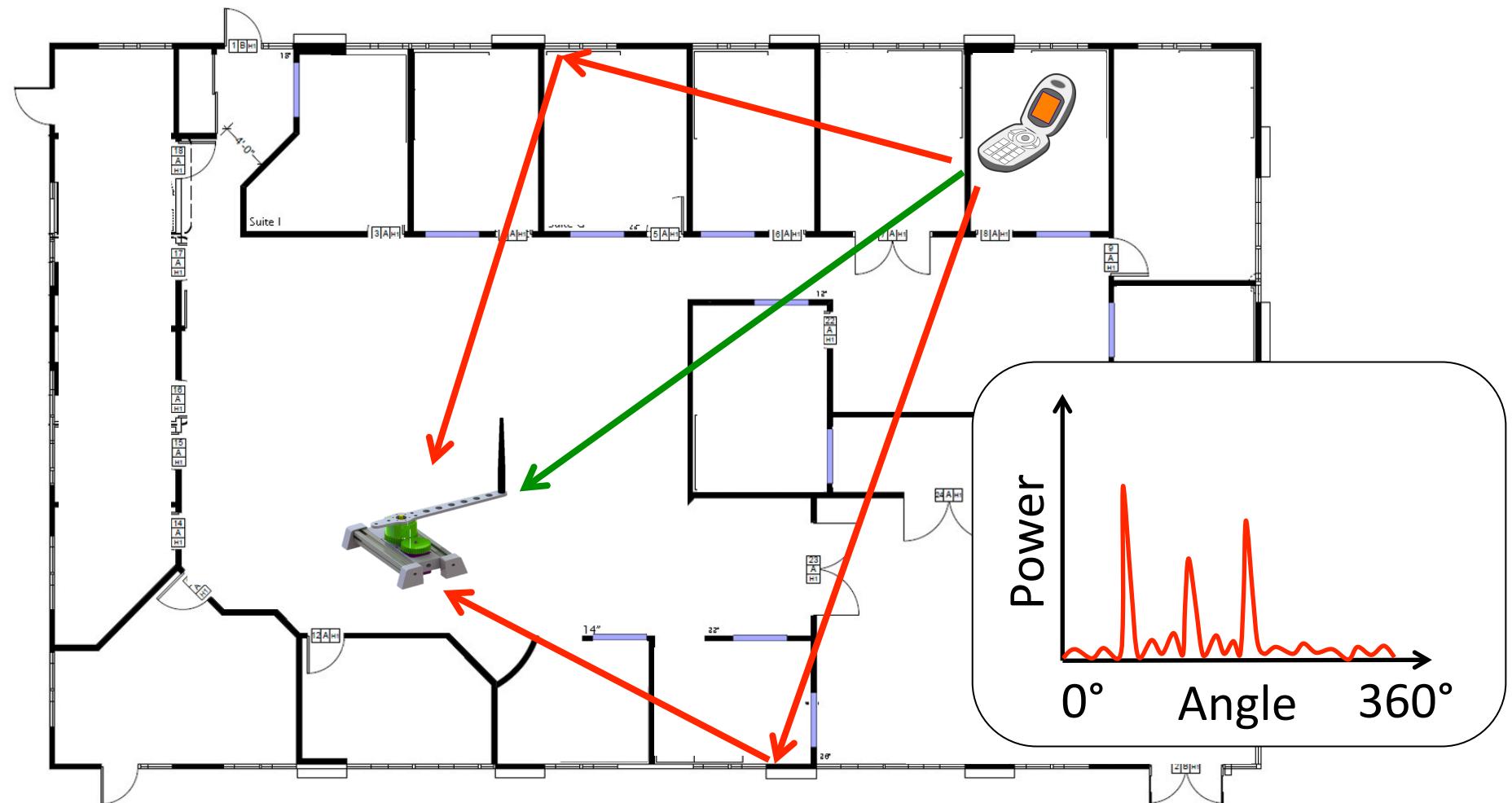


Synthetic Aperture Radar (SAR)



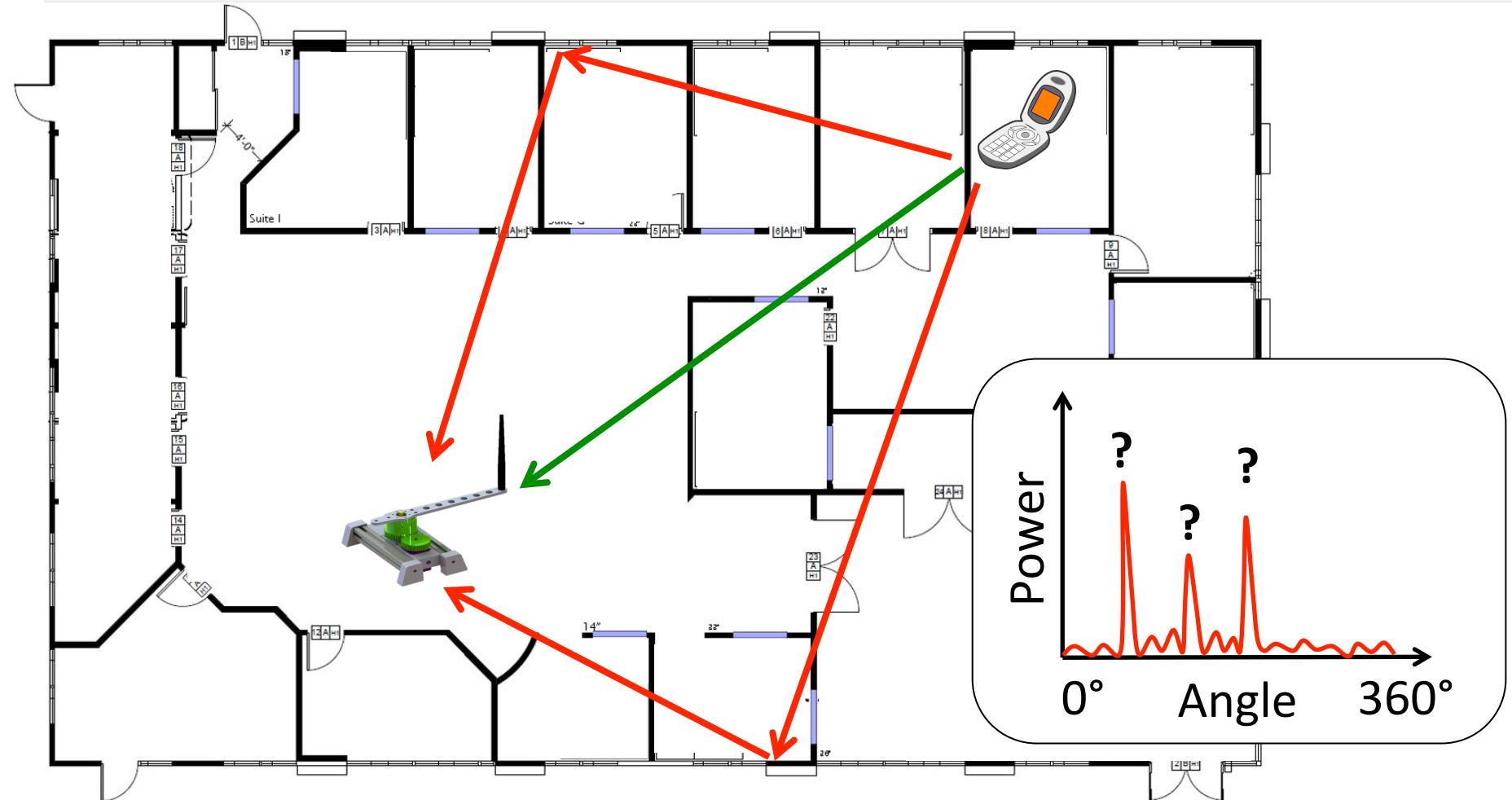
Challenge: Multipath

LTE penetrates walls better



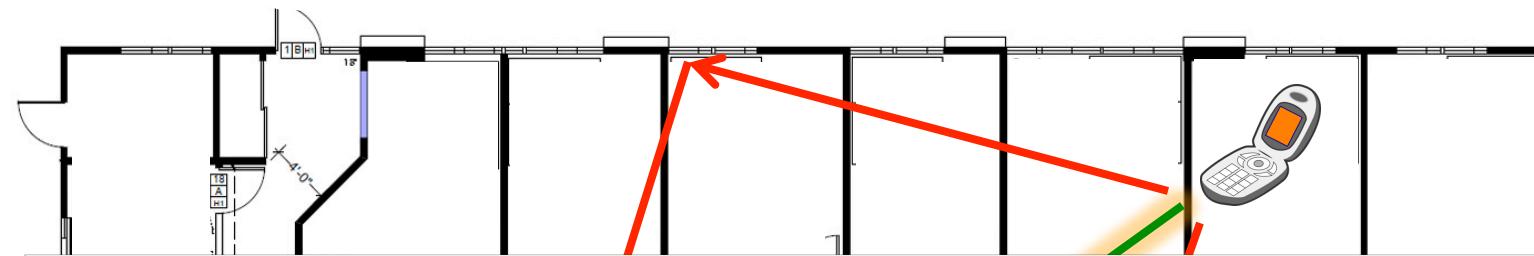
Challenge: Multipath

Which peak corresponds to direct path?

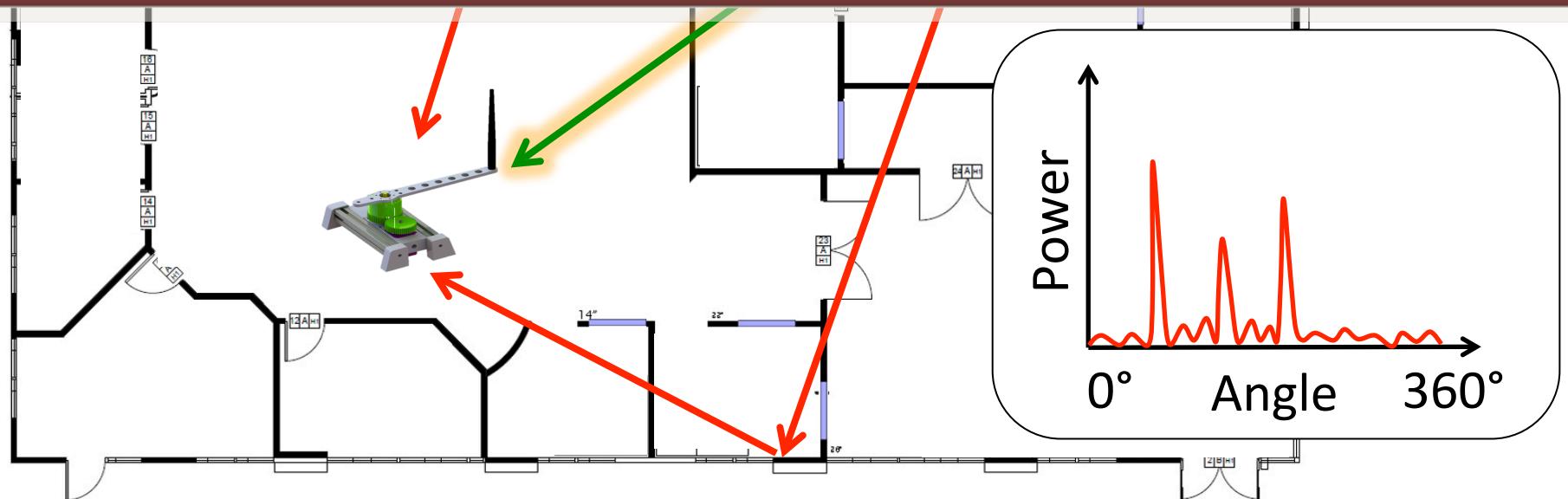


Key Observation

Direct path is shortest
→ Path with least delay

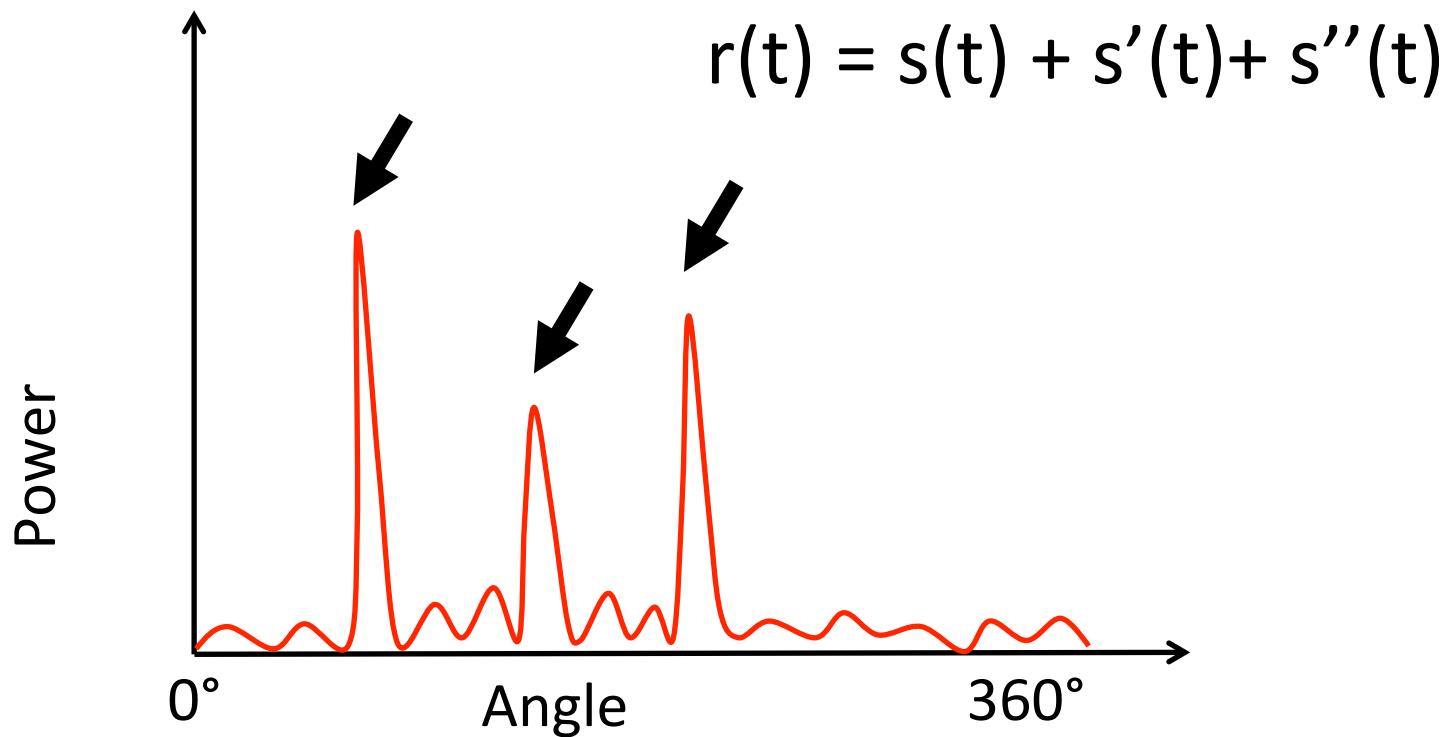


But, which path has the shortest delay?



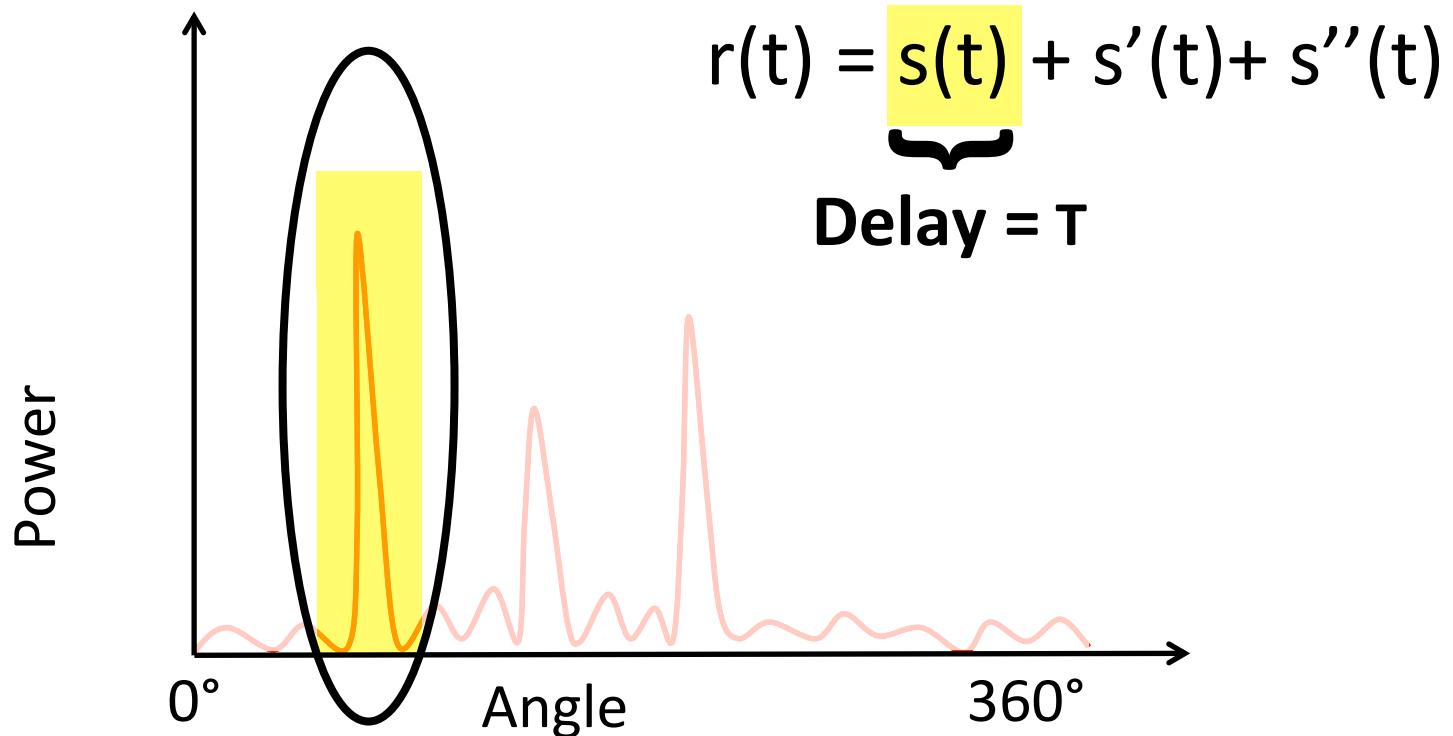
Our Solution

1. Identify peaks



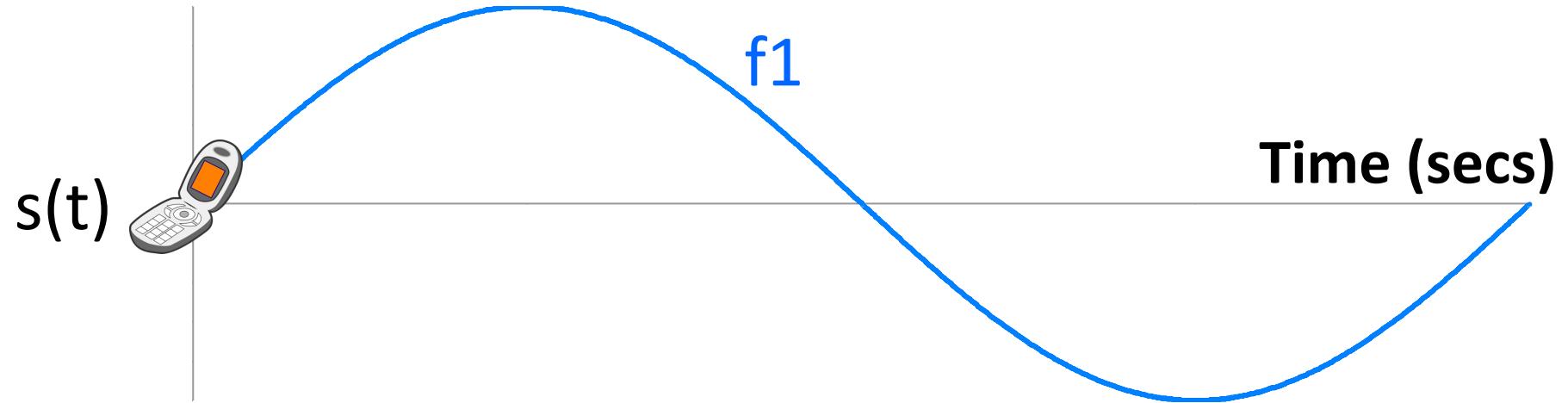
Our Solution

1. Identify peaks
2. Apply filter around each peak
3. Compute delay T of the path



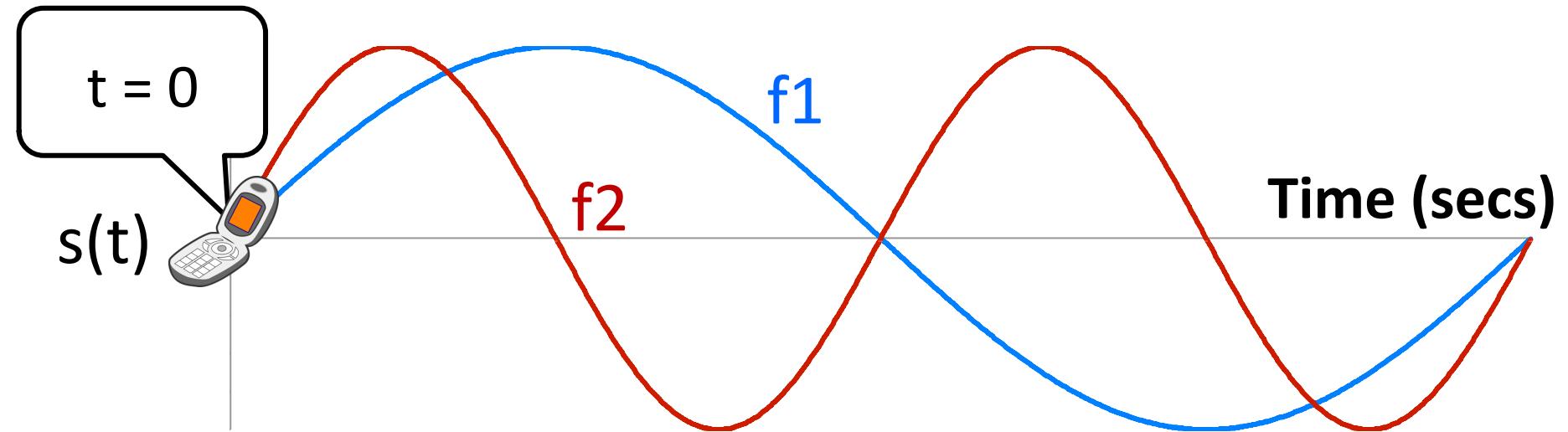
Estimate Delay T of First Path

LTE uses OFDM → Transmits at many frequencies



Estimate Delay T of First Path

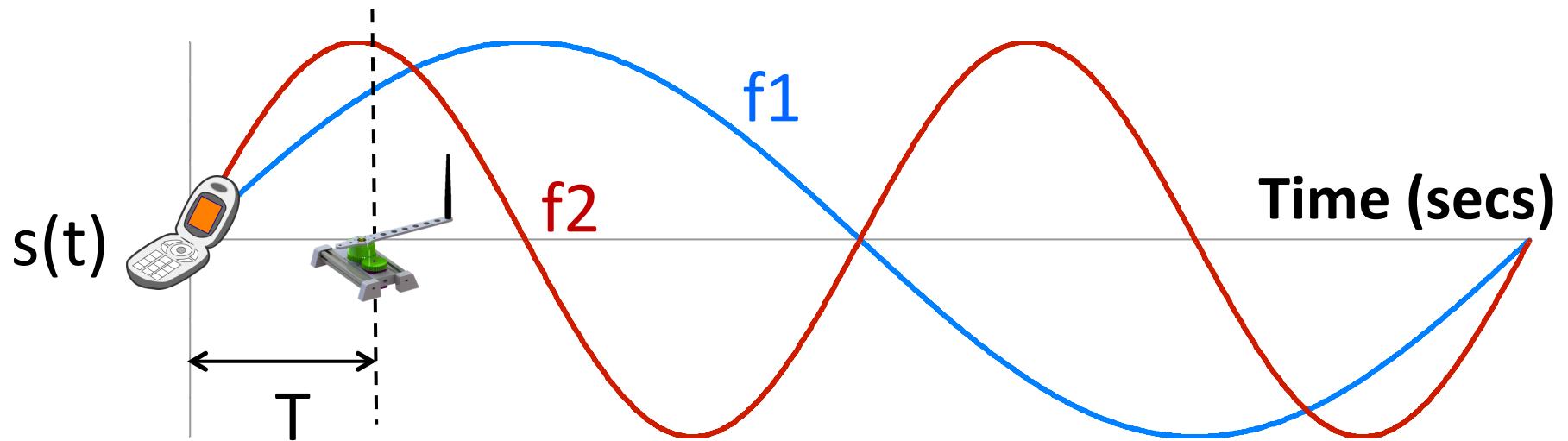
LTE uses OFDM → Transmits at many frequencies



Both frequencies start together → Same phase

Estimate Delay T of First Path

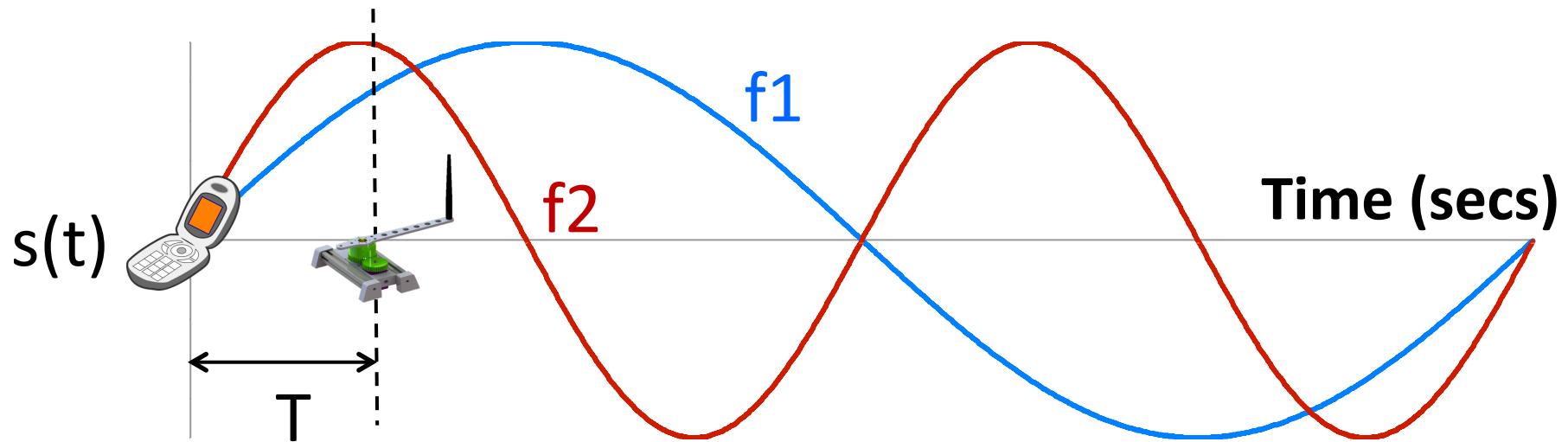
LTE uses OFDM → Transmits at many frequencies



Frequencies rotate at different speeds

Estimate Delay T of First Path

LTE uses OFDM → Transmits at many frequencies



Different frequencies exhibit different phases

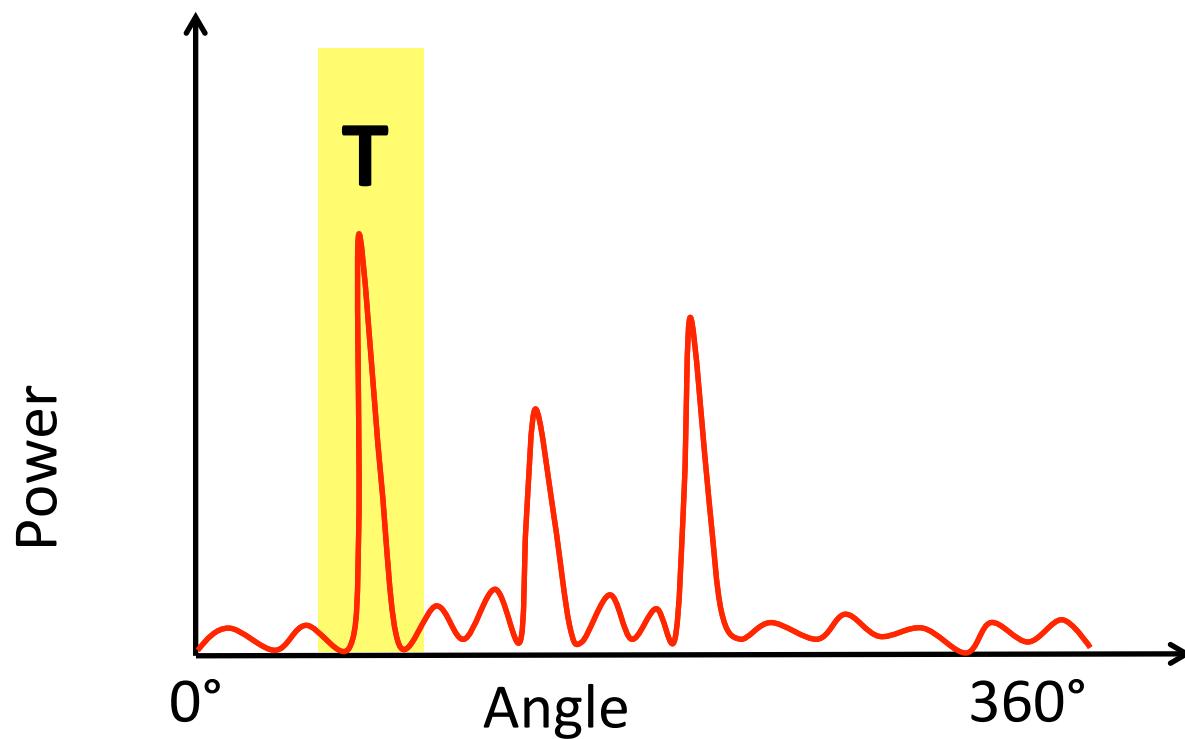
$$\phi_1 = 2\pi f_1 T$$

$$\phi_2 = 2\pi f_2 T$$

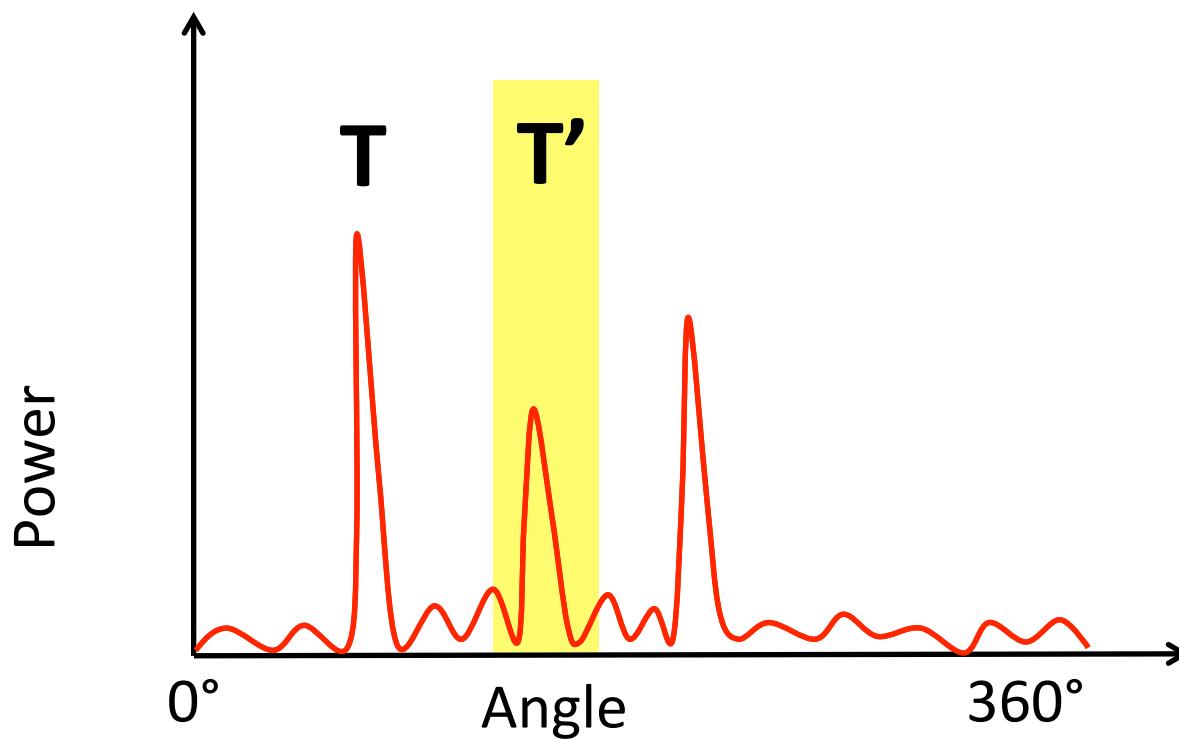
✓ ✓?

$$\Delta\phi = 2\pi \Delta f T$$

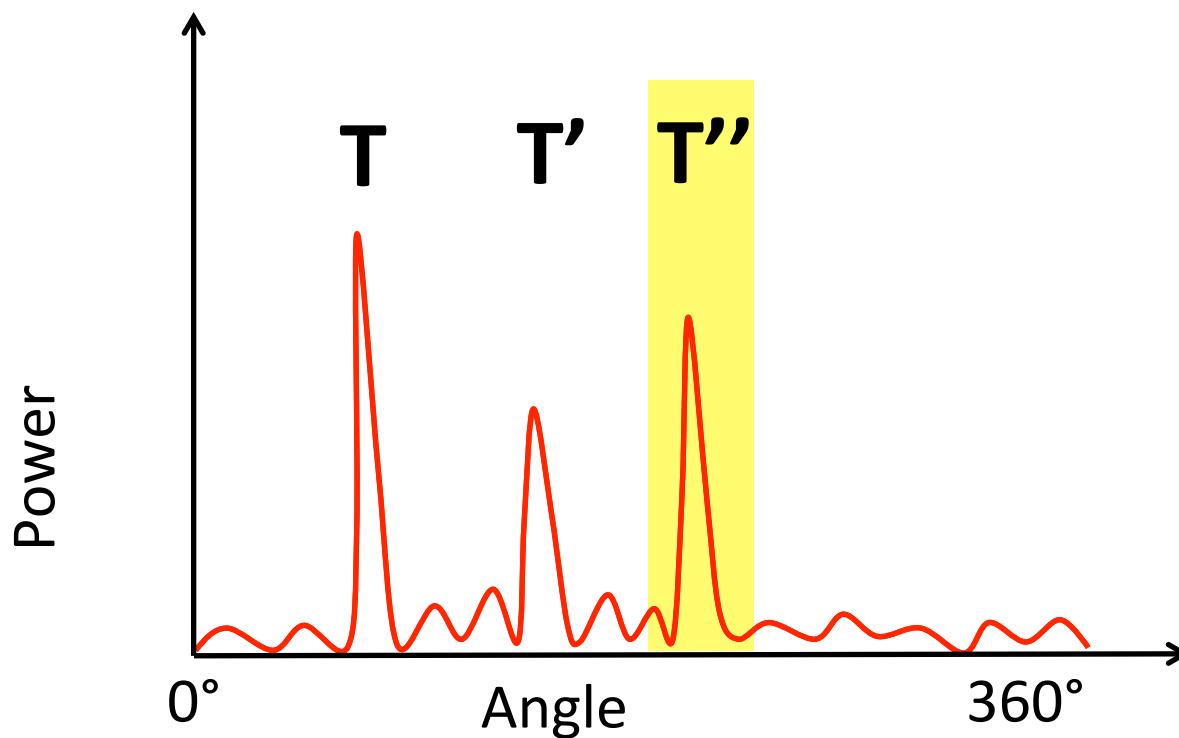
Estimate Delay T of First Path



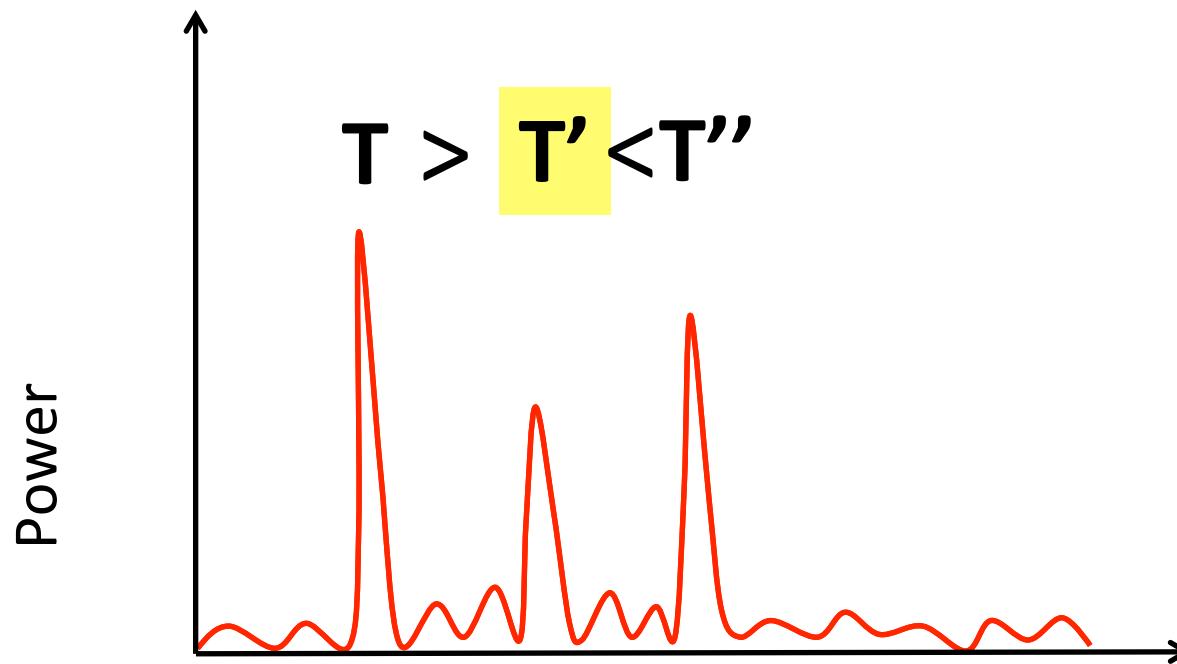
Repeat for Each Path



Repeat for Each Path

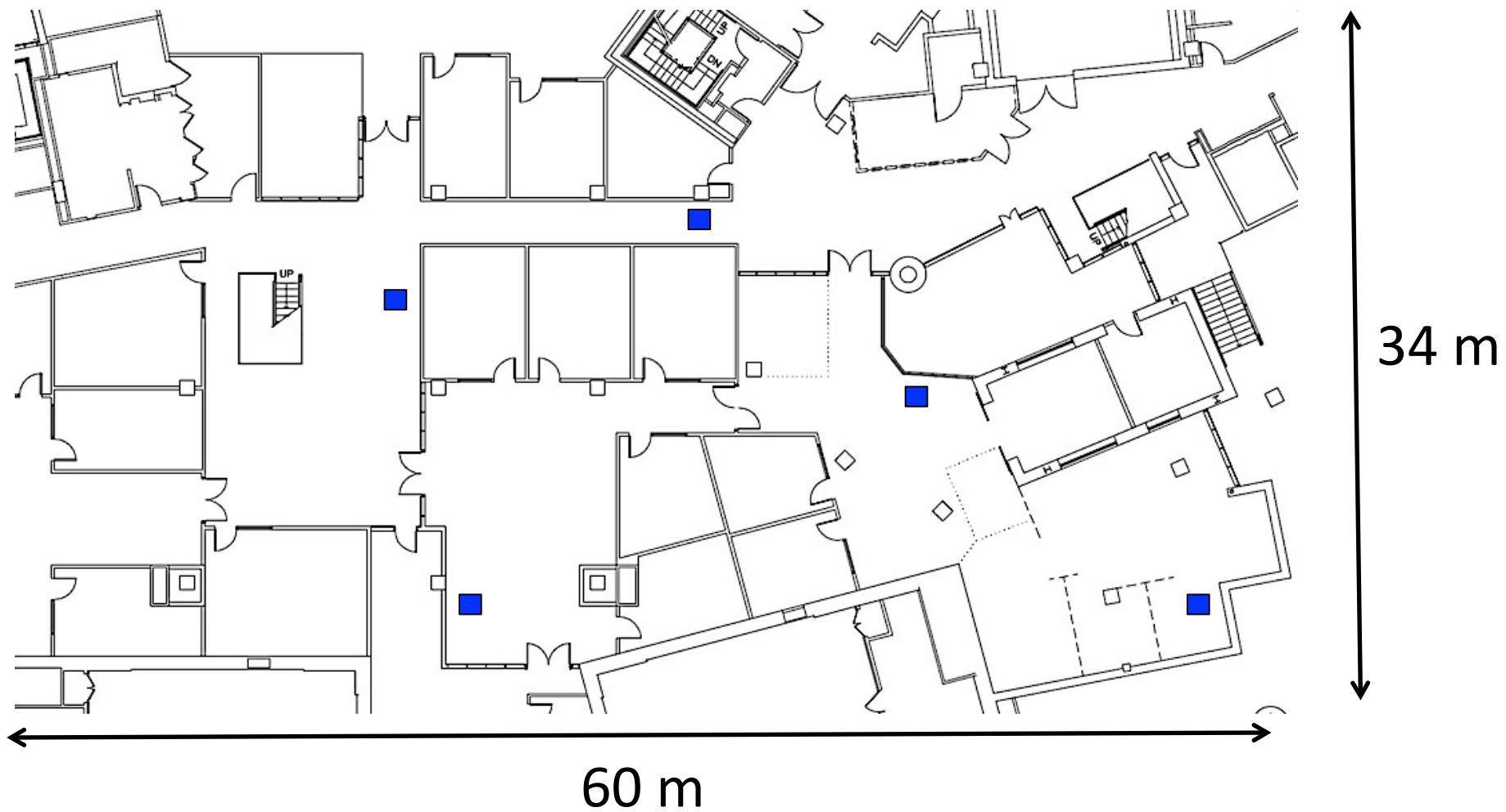


Repeat for Each Path

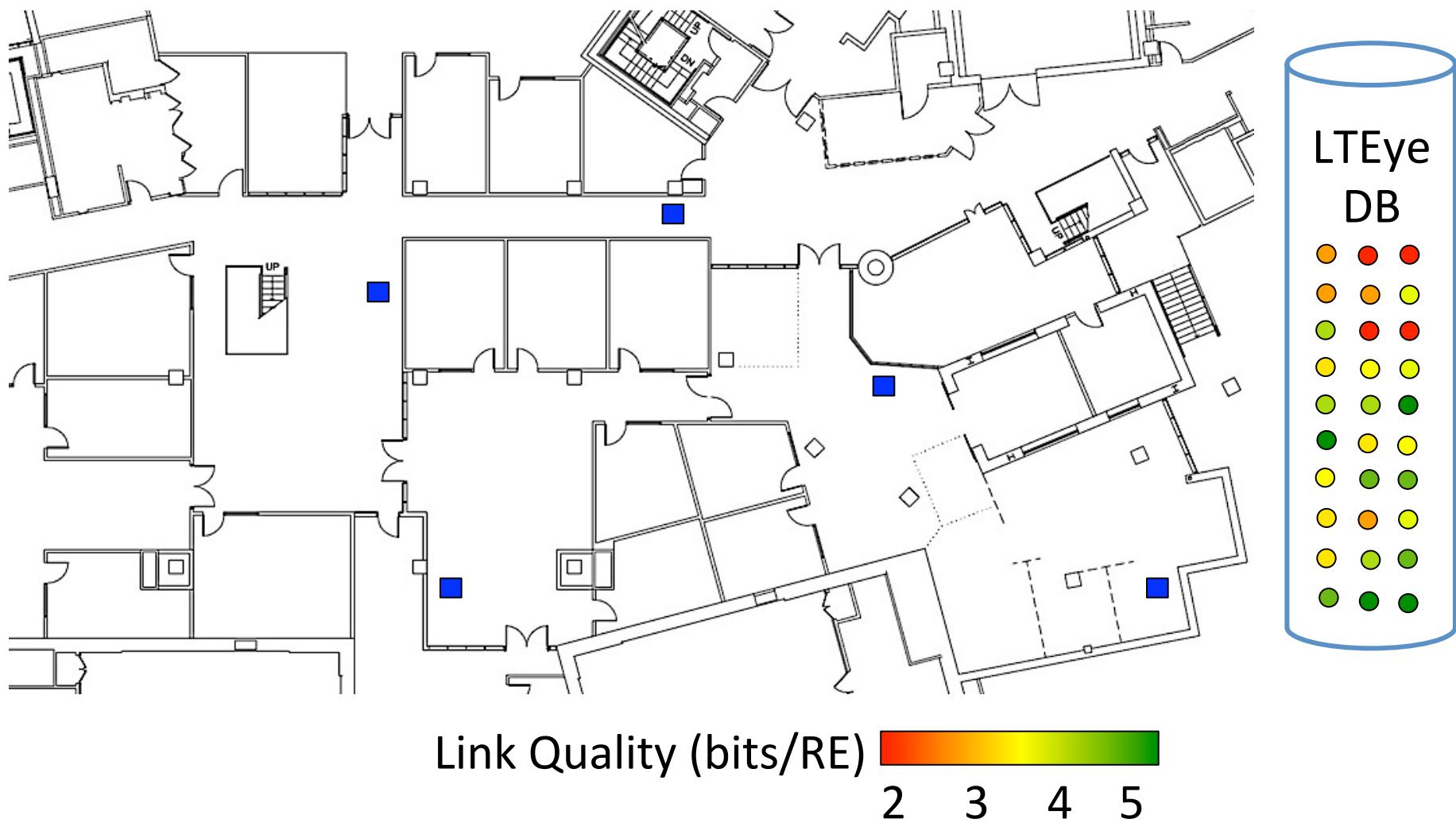


- Find which path is the least delayed LOS path
 - LTEye knows correct direction of cellphone
- LTEye can obtain Spatial Analytics despite multipath

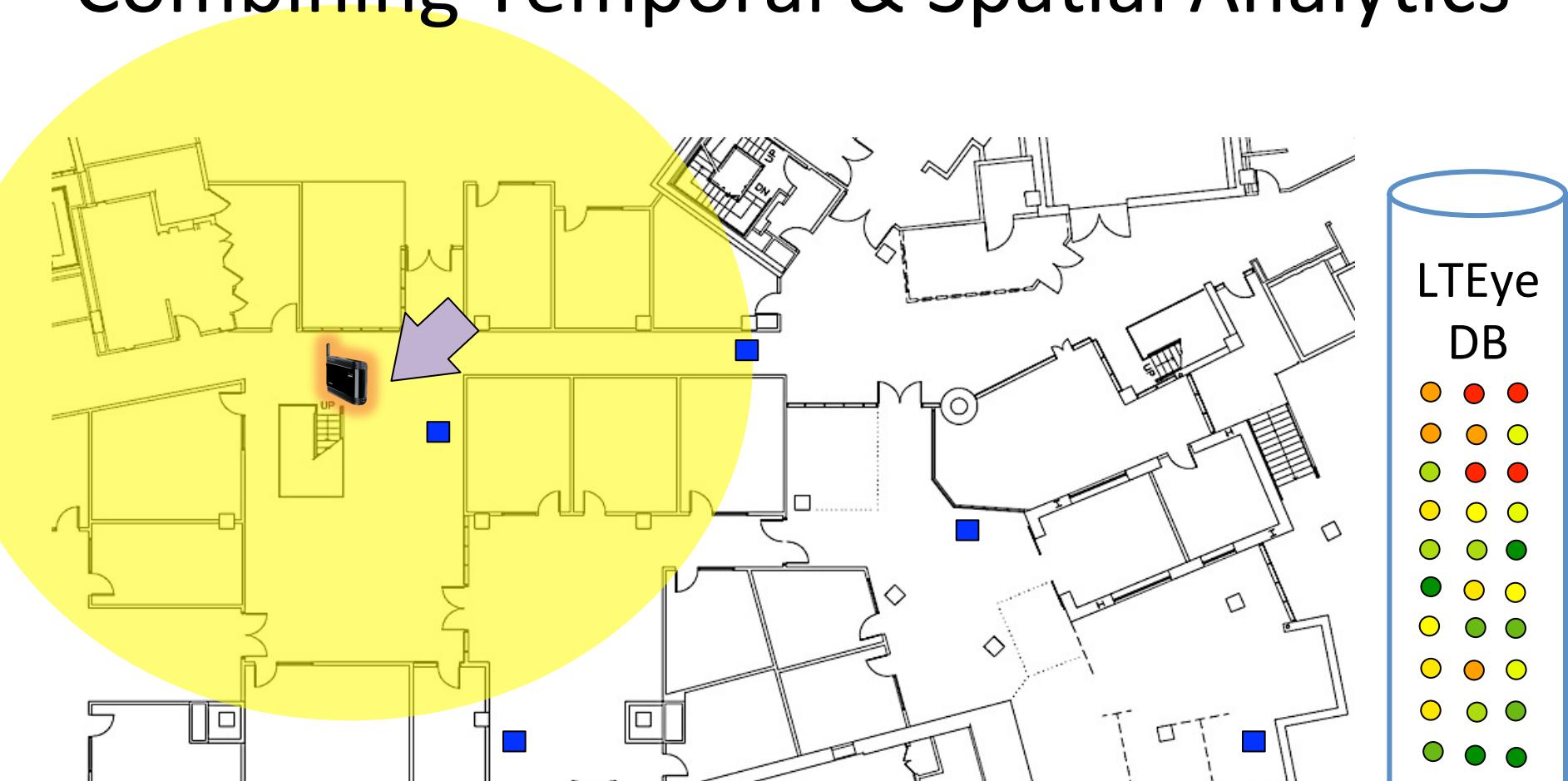
Combining Temporal & Spatial Analytics



Combining Temporal & Spatial Analytics

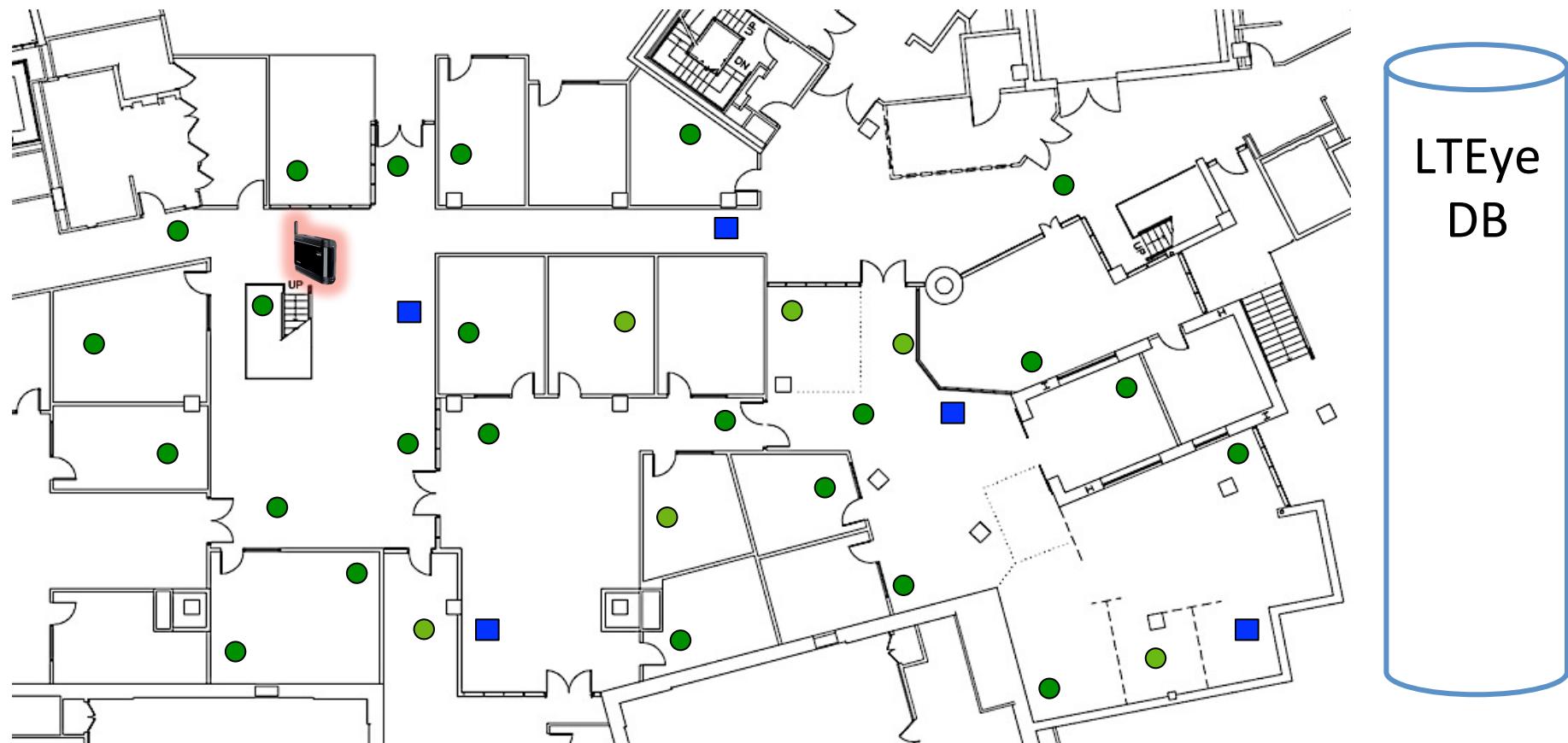


Combining Temporal & Spatial Analytics



LTEye achieves 43 cm median accuracy in cellphone position along each of x, y, z

Combining Temporal & Spatial Analytics



LTEye – A versatile tool to debug LTE performance

Conclusion

- Open platform to monitor LTE without provider support
- Gathers per-user spatial and temporal analytics
- Insights on performance, problems, e.g. inter-cell interference and inefficient spectrum usage