LTE Radio Analytics Made Easy and Accessible

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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 per-user analytics preserve user privacy
- Does not access data sent/received by users
- Anonymized PHY-layer User IDs
Overview of LTEye
Overview of LTEye

User ID | Qlty
---|---
1 | ![Green](#)
2 | ![Green](#)
3 | ![Light Green](#)
4 | ![Yellow](#)
5 | ![Yellow](#)
6 | ![Yellow](#)
7 | ![Orange](#)
8 | ![Red](#)

Link Quality (bits/RE)

| 2 | 3 | 4 | 5 |
Overview of LTEye

Temporal Analytics

9:00 AM 11:00 AM 1:00 PM 3:00 PM 5:00 PM

Link Quality (bits/RE)

User ID Qlty
1
2
3
4
5
6
7
8

2 3 4 5
Overview of LTEye

Where are these users in the office?

<table>
<thead>
<tr>
<th>User ID</th>
<th>Qlty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
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<td>3</td>
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<td>7</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
</tr>
</tbody>
</table>
Overview of LTEye

Spatial Analytics

User ID | Qlty
---|---
1 | 
2 | 
3 | 
4 | 
5 | 
6 | 
7 | 
8 | 

Link Quality (bits/RE)

2 3 4 5
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

A lot more complex!

- Heterogeneous cells
- All share same spectrum

Cell

Macro

Micro

Pico

705-715 MHz

735-745 MHz
Where can we find temporal analytics?
Where can we find temporal analytics?

Highly Centralized

- Who transmits @ what time, freq?
- Every PHY parameter under the sun!
Where can we find temporal analytics?

Data Packets

Downlink Control Packets

- Packet Size $\rightarrow$ Throughput
- Modulation $\rightarrow$ Link Quality
- ACKs/Retransmits $\rightarrow$ Loss Rate

No provider support
Two Important Benefits

• Uplink / Downlink

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

• PHY Layer User ID

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

- Packet Size
- Modulation
- Loss Rate
- Uplink / Downlink
- PHY User ID
LTEye Temporal Analytics
LTEye Temporal Analytics

✓ Is LTE Spectrum used Efficiently?
Network Utilization

- LTE uses equal bands for uplink and downlink
Network Utilization

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Network Utilization

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Network Utilization

- LTE uses equal bands for uplink and downlink

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

Verizon LTE  54%

Loading

www.iphonedownload...  X  Google

Cannot Open Page
Safari cannot open the page because it is not connected to the Internet.

OK
5 Bar Paradox

• Placed LTEye sniffers at these locations...
5 Bar Paradox

- Placed LTEye sniffers at these locations...

Inter-Cell Interference
5 different towers interfered!

CDF

SNR or SINR (dB)

~ 30 dB
5 Bar Paradox

- Placed LTEye sniffers at these locations...

- Complex Deployments → Complex Interference
- Providers cannot drive test indoors!

*LTEeye 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

Control Channel  Data Channel

Time
Excessive Control Overhead

Low Demand

Control Channel | Data Channel

Time

Control Packets | Data Packets
Excessive Control Overhead

Control Packets

Data Packets

High Demand

Control Channel

Data Channel

Time
This is not always followed...

- Verizon stations always use maximum size
This is not always followed...

- Verizon stations always use maximum size
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?
1. Identify peaks

\[ r(t) = s(t) + s'(t) + s''(t) \]
Our Solution

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

$$r(t) = s(t) + s'(t) + s''(t)$$

Delay = $T$
Estimate Delay $T$ of First Path

LTE uses OFDM $\rightarrow$ 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 \( \rightarrow \) 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

Power

0°  Angle  360°

T  T'  T''
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