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 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

Temporal Analytics

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

Link Quality (bits/RE)

<table>
<thead>
<tr>
<th></th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00 AM</td>
<td><img src="image" alt="Green" /></td>
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<td>1:00 PM</td>
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<td>3:00 PM</td>
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Overview of LTEye

Where are these users in the office?

<table>
<thead>
<tr>
<th>User ID</th>
<th>Qlty</th>
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<tbody>
<tr>
<td>1</td>
<td><img src="#" alt="Green" /></td>
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<td>2</td>
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<tr>
<td>5</td>
<td><img src="#" alt="Yellow" /></td>
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<tr>
<td>6</td>
<td><img src="#" alt="Yellow" /></td>
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<tr>
<td>7</td>
<td><img src="#" alt="Yellow" /></td>
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<tr>
<td>8</td>
<td><img src="#" alt="Red" /></td>
</tr>
</tbody>
</table>
Overview of LTEye

Spatial Analytics

<table>
<thead>
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<th>User ID</th>
<th>Qlty</th>
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<tbody>
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<td>2</td>
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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?

- Data Packets
  - Highly Centralized
  - Who transmits @ what time, freq?
  - Every PHY parameter under the sun!
- Downlink Control Packets
Where can we find temporal analytics?

Highly Centralized

Data Packets

Downlink Control Packets

- Packet Size → Throughput
- Modulation → Link Quality
- ACKs/Retransmits → Loss Rate

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 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
5 Bar Paradox

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

• Placed LTEye sniffers at these locations...

• Complex Deployments $\rightarrow$ 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

Control Packets

Data Packets

Flexible Size

Control Channel

Data Channel

Time
Excessive Control Overhead

- Control Packets
- Data Packets

Low Demand

- Control Channel
- Data Channel

Time
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**
• 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

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

$s(t)$

$f_1$

Time (secs)
Estimate Delay $T$ of First Path

LTE uses OFDM $\rightarrow$ Transmits at many frequencies

Both frequencies start together $\rightarrow$ Same phase

$t = 0$

$s(t)$
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 $\rightarrow$ 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

![Graph showing power versus angle with peaks at T and T']
Repeat for Each Path

![Graph showing power over angle with peaks at T, T', and 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
Measuring Spatial Analytics

Sniffer

Cellphone
Accuracy of Spatial Analytics
LTEye achieves 43 cm median accuracy in user position along each dimension.
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