Virtual Coverage In Rural Environments

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Background

- Many people don’t have access to service for mobile phones
- Rural Stations have three components
  - BTS (Base Transceiver Station)
  - Backhaul Network
  - Grid
- 95% of people in rural areas don’t have that service
- Why?
  - Cost of power for base stations (500,000-1 million USD)
  - Cannot reduce power much more despite tech advancements
Solution!

- Virtual Coverage
  - Turns off network for periods of time, e.g. at night ("idle" times)
  - Turns on when user sends a "burst" signal
  - Utilizes existing handheld and radio equipment

Base Design

- Examined two areas for inspiration
  - Alaska: Need wide coverage within mountainous areas
  - Uganda: No coverage in rural areas, users wanted emergency services most
- Goals
  - Support wide area, solar powered infrastructure
  - Low power, continuous service for emergencies
  - Reduce infrastructure cost, build off existing GSM infrastructure
    - Build off of a BTS
System Implementation

- 2G implementation using OpenBTS
  - Used Range Networks 5120 2G GSM BTS
  - 3G/4G more prone to errors
  - OpenBTS open source, 2G GSM
- Modify an existing base station
  - After 10W, can increase comm. capacity
  - Requires a lot of energy (65% of power for 10W, 84% for 50W)

<table>
<thead>
<tr>
<th></th>
<th>Range (km)</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2W Tower</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>10W Tower</td>
<td>35</td>
<td>7</td>
</tr>
<tr>
<td>50W Tower</td>
<td>35</td>
<td>35</td>
</tr>
</tbody>
</table>

System Implementation: Modifications

- Need to have low power mode in base station for “idle” times
- Hardware Changes:
  - Added switch for the Power Amplifier to turn off when idle
- Software Changes:
  - Switch controls PA for entering idle mode
  - Stays on for min. 90 s after calls completed
  - Disables radio while in idle mode
  - Detects mobile-terminated (incoming) and mobile-originated (outgoing) calls
  - Transceiver detects burst packet on Absolute Radio Frequency Channel Number (ARFCN)
Hardware

“Wake Up” A Tower

- Cellphones
  - Used osmocomBB mobile phone, called “Wake-Up Phone”
  - Sends burst packet to BTS on its ARFCN, which exits idle state
  - It broadcasts its ARFCN number of beacon channel, handsets store that number to wake up BTS in the future or search for currently available BTS’s

- Radio
  - “Wake-Up Radio”
  - Similar to cellphone, but is cheap and lower power
  - Only used for mobile-originated comm., tower can handle mobile-terminated
  - Has onboard battery pack, interfaces for other forms of energy
## Technical Evaluation

<table>
<thead>
<tr>
<th>Component</th>
<th>Draw (W)</th>
<th>% (10W)</th>
<th>% (50W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer</td>
<td>12</td>
<td>17.4</td>
<td>7.8</td>
</tr>
<tr>
<td>Radio</td>
<td>12</td>
<td>17.4</td>
<td>7.8</td>
</tr>
<tr>
<td>10W Amp</td>
<td>45</td>
<td>65.2</td>
<td></td>
</tr>
<tr>
<td>50W Amp</td>
<td>130</td>
<td></td>
<td>84.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Time (Avg s)</th>
<th>Time (Max s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WUP (2G) (MT)</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>WUP (2G) (MO)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>HTC Dream (3G)</td>
<td>12.1</td>
<td>41.8</td>
</tr>
<tr>
<td>Samsung Nexus S (3G)</td>
<td>23.6</td>
<td>37.6</td>
</tr>
<tr>
<td>Nokia 1202 (2G)</td>
<td>10.8</td>
<td>14.6</td>
</tr>
</tbody>
</table>
Deployment Example

- Estimate cost of deployment in a South Asian country
  - 5 hours of usable sunlight during winter
  - Operating costs of 442 USD for 200 AMP-Hours for 24V battery
  - Solar panels 1.07 USD/W
  - BTS uses 155W full power, 25W idle

- Results
  - Idle tower requires $\frac{1}{6}$th of batteries, solar panels, infrastructure
  - Scales linearly (more idle = less energy requirements)
  - 80% idle station needs 300W solar panel, 6 batteries
    - Traditional requires 1kW solar panel, 17 batteries

Real World Evaluation

- Look at “worst case” of virtual coverage benefits.
- Used log data of two mobile telecom firms in Sub-Saharan Africa and South Asia
- Following methods used for analysis:
  - Compute results from 6am-6pm and 6pm-6am separately
  - Allow towers remain active for 30 seconds after user-initiated action
  - Allow min. 90 seconds availability at a time for additional connections
  - Remove any towers that are idle > 24 hours
Real World Evaluation: Idleness

- Scale is sublinear w/ total amount of calls for logarithmic trend line
  - SSA: $y = -0.077 \ln(x) + 1$
  - SA: $y = -2.04 \ln(x) + 2.8$
- Outcome? Infrastructure cost can scale sublinearly for number of users and number of serviced calls
- Idle time
  - 98% towers more idle at night in SSA, 89% more idle in SA
  - 53% of towers in SSA, 86% in SA are over 20% idle at night

Calls Per BTS

SSA Calls/BTS  SA Calls/BTS
Real World Evaluation: Power Savings

- Uses estimates of power consumption of towers
  - Large Capacity: 155W full power, 25W idle (84% savings)
  - Small Capacity: 70W full power, 25W idle (65% savings)
- Overall, user experience is barely impacted

<table>
<thead>
<tr>
<th></th>
<th>Power Draw</th>
<th>Savings %</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSA Original</td>
<td>45.6 kW</td>
<td>0</td>
</tr>
<tr>
<td>SSA Day</td>
<td>21 kW</td>
<td>7.2</td>
</tr>
<tr>
<td>SSA Night</td>
<td>18 kW</td>
<td>20.7</td>
</tr>
<tr>
<td>SSA Total</td>
<td>38 kW</td>
<td>13.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Power Draw</th>
<th>Savings %</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA Original</td>
<td>1483 kW</td>
<td>0</td>
</tr>
<tr>
<td>SA Day</td>
<td>584 kW</td>
<td>21.3</td>
</tr>
<tr>
<td>SA Night</td>
<td>488 kW</td>
<td>34.3</td>
</tr>
<tr>
<td>SA Total</td>
<td>1071 kW</td>
<td>27.7</td>
</tr>
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</table>

Power Savings

SSA Power Savings

SA Power Savings
Discussion

- Positives
  - Significant power savings -> cost savings, environmental benefits
  - Incentivizes increased coverage in rural areas
- Negatives
  - Does not support SMS
  - Susceptible to DOS attacks
  - Not implemented in reality
  - Will this enhance problems of the poor?

Additional Resources

- NSDI Presentation
- All images used in this presentation are from the “Expanding Rural Networks with Virtual Coverage” paper and presentation