Expanding Rural Cellular Networks with Virtual Coverage

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Cellular Telephony

- **Highest adoption since lightbulb**
  - ~5B users in ~25 years
    - More users than IPv4 addresses!
  - Numerous studies showing user benefits
    - Jensen showed benefits from installation (8% profit increase, 4% price fall)
    - Waverman et al showed benefits of adoption (+.1 phones per capita = + .59% GDP growth)

Cellular Telephony

- Highest adoption since lightbulb
- **Billions currently not on network**
  - Some luddites, sure…
  - But at least 1B outside of coverage

Why no coverage?

Why no coverage?

1. **Cost**
   - Personal reports of order 500K-1M USD to do an install in rural Indonesia
   - Requires dense population for install

Why no coverage?

1. Cost
2. **Power**
   - GSMA: 95% of people lacking cellular coverage live in areas without grid power. (1)
   - ITU: 50% of rural tower operational expenses (OPEX) are power-related. (2)

1)Powering Telecoms: East Africa Market Analysis Sizing the Potential for Green Telecoms in Kenya, Tanzania and Uganda

2) Green Solutions to Power Problems (Solar & Solar-Wind Hybrid Systems) for Telecom Infrastructure.

Goal:
Reduce the cost of rural cell installations by reducing cell tower power draw

Plan:
Find the part drawing the most power and reduce its energy consumption

So what’s in a rural tower?

Rural Cellular Tower

- A Rural Cellular Tower contains 3 parts:


Base Transceiver Station (BTS)


Backhaul Network


Power

Rural Cellular Tower

- A Rural Cellular Tower contains 3 parts:
  1. **Base Transceiver Station (BTS)**
     - **Traditional Vendor: Siemens BS-240**
       – 50-100K USD
       – 1K+ Watts

Rural Cellular Tower

- A Rural Cellular Tower contains 3 parts:
  1. **Base Transceiver Station (BTS)**
     - Traditional Vendor
     - **Build yourself: Ettus B100**
       - 2000USD
       - 150W
       - Low Quality

Rural Cellular Tower

- A Rural Cellular Tower contains 3 parts:
  1. **Base Transceiver Station (BTS)**
     - Traditional Vendor
     - Build yourself: Ettus B100
     - **Small Vendor: Range Networks 5150**
       - 15K USD
       - 150 Watts
       - Full disclosure: I work for them

Rural Cellular Tower

- A Rural Cellular Tower contains 3 parts:
  1. Base Transceiver Station (BTS)
  2. **Backhaul Network**
     - **Wired**
       - Negligible power draw
       - Very expensive to install in rural areas

Rural Cellular Tower

- A Rural Cellular Tower contains 3 parts:
  1. Base Transceiver Station (BTS)
  2. **Backhaul Network**
     - Wired
     - **Microwave: Alcatel-Lucent MDR-8000**
       – High bandwidth (300 Mb/s)
       – 25K USD
       – 70 Watts
       – Requires spectrum license

Rural Cellular Tower

- A Rural Cellular Tower contains 3 parts:
  1. Base Transceiver Station (BTS)
  2. **Backhaul Network**
     - Wired
     - Microwave
     - **Long Distance Wifi: Ubiquiti NanoBridge M2**
       - Low bandwidth (80 Mb/s)
       - 100 USD
       - 5.5 Watts

Rural Cellular Tower

- A Rural Cellular Tower contains 3 parts:
  1. Base Transceiver Station (BTS)
  2. Backhaul Network
  3. **Power Infrastructure**
     - **Grid Power**
       - Literally just plugging in
       - Only available near urban areas

Rural Cellular Tower

- A Rural Cellular Tower contains 3 parts:
  1. Base Transceiver Station (BTS)
  2. Backhaul Network
  3. **Power Infrastructure**
     - Grid Power
     - **Diesel Generator/Batteries**
       - Requires road for trucking diesel in
       - Requires fence for protecting diesel
       - Also in urban areas if power unreliable
       - 50-100K USD

Rural Cellular Tower

- A Rural Cellular Tower contains 3 parts:
  1. Base Transceiver Station (BTS)
  2. Backhaul Network
  3. **Power Infrastructure**
     - Grid Power
     - Diesel Generator/Batteries
     - **Solar/Renewables**
       – Less "related" infrastructure
       – Cost depends on power draw…

Example: Solar Power

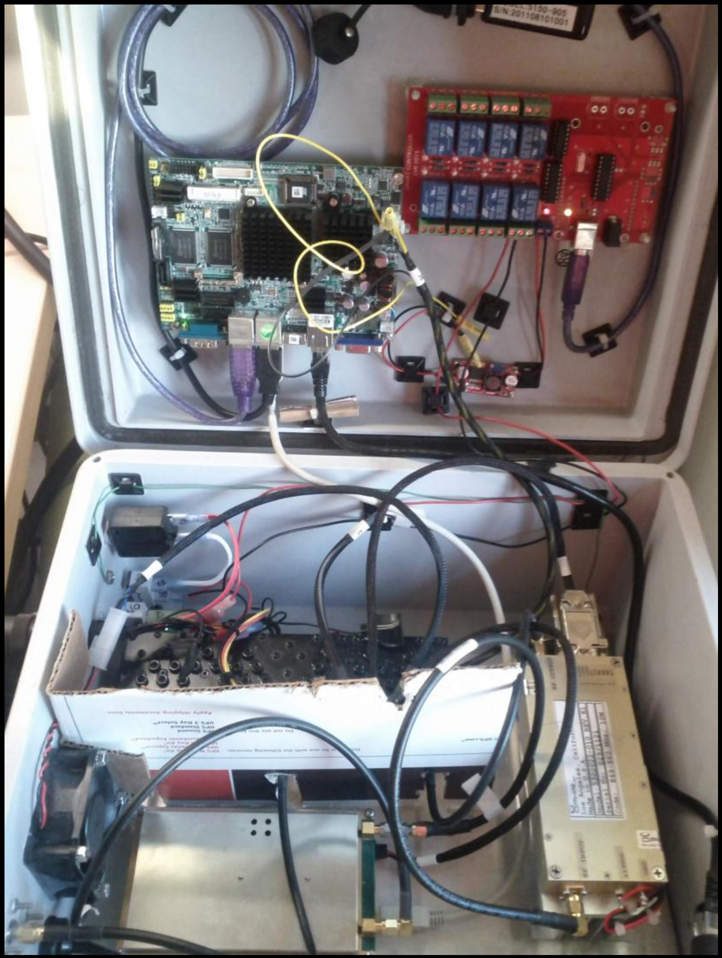
- **Setup:**
  - Range Networks 5150
    - 15000 USD
    - 150W
  - Ubiquiti NanoBridge M2
    - 100 USD
    - 5W

Example: Solar Power

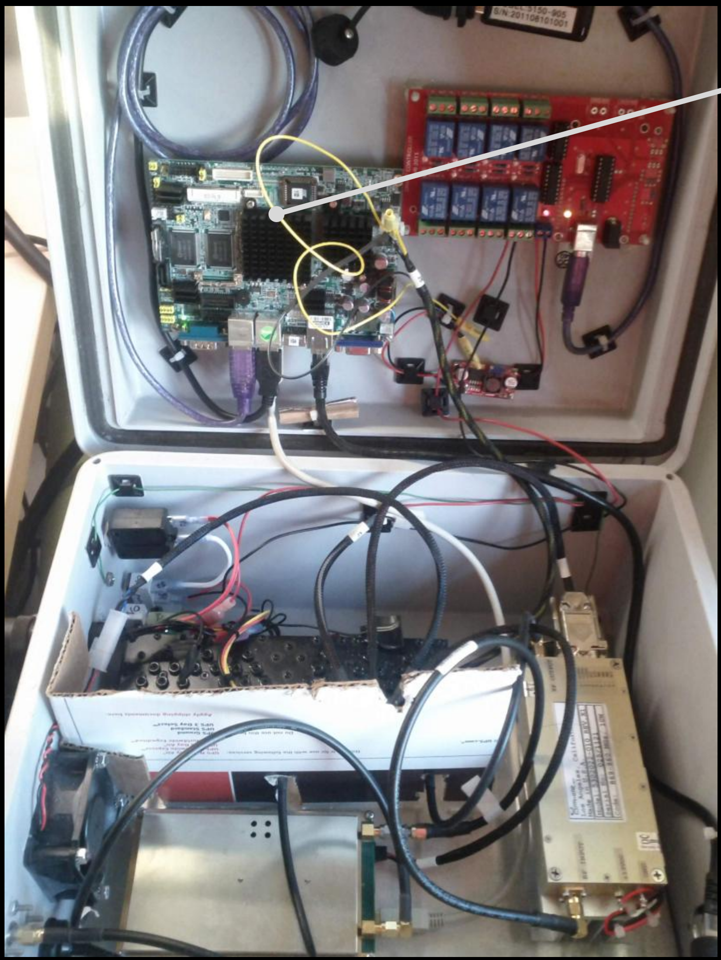
- Setup
- **Requires:**
  - 1000W Solar Panels
  - 3300 AH of Batteries
    - That's 17 68lb (1156lb) deep-cycle batteries
  - 15000 USD worth of equipment
    - 50% of Capex for "Small Vendor"
    - Not including shipping/installation

So how do we reduce the total power draw of a BTS?

Saving Power

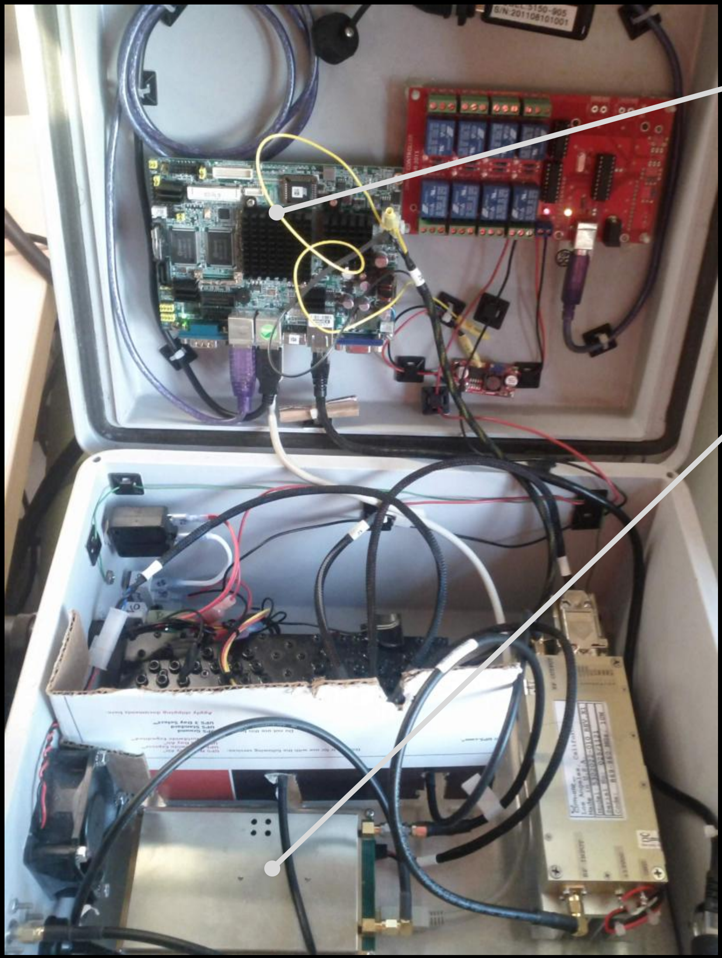


Saving Power



CPU (~10W)

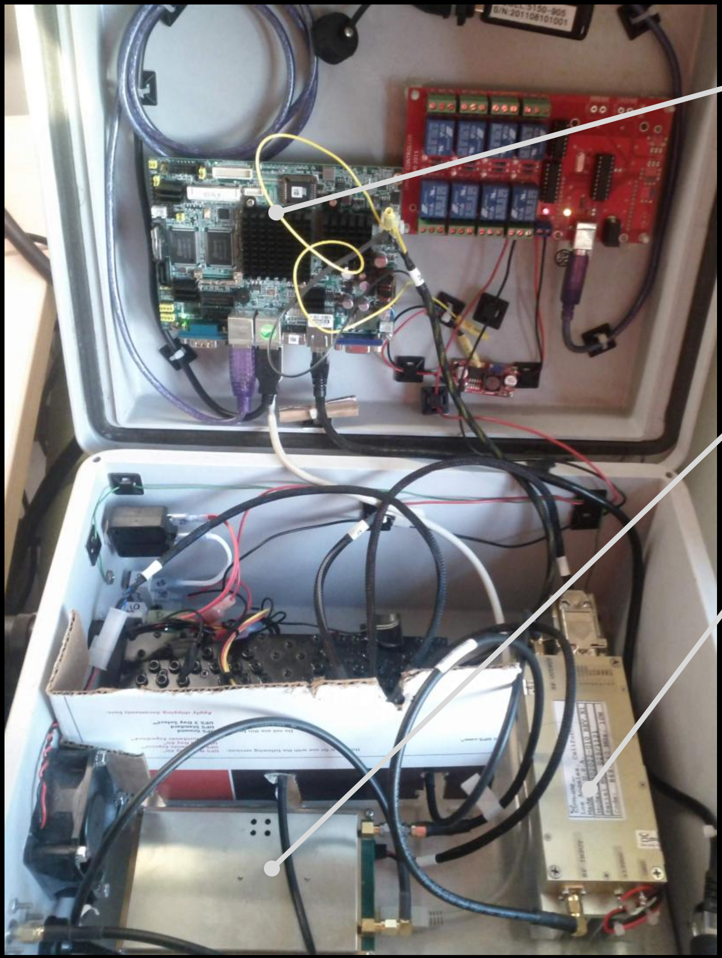
Saving Power



CPU (~10W)

Radio (~15W)

Saving Power



CPU (~10W)

Radio (~15W)

Power Amplifier (~130W)

Saving Power

- Parts of a Base Transceiver Station (BTS)
  - Computer (~10W)
  - Radio (~15W)
  - Power Amplifier (130W)
- Constant Draw (beaconing)

Have to touch power amplifier to save power!

Saving Power

- Power Amplifier (PA)
  - **Draws the most power**

Saving Power

- Power Amplifier (PA)
  - Draws the most power
  - **Determines the coverage radius**
    - To a point (Eventually limited by 2W handsets)

Saving Power

- Power Amplifier (PA)
  - Draws the most power
  - Determines the coverage radius
  - **Determines capacity**
    - 10W on one channel or 2.5W on two
      - Geometric losses as we add more channels

Saving Power

- Power Amplifier (PA)
  - Draws the most power
  - Determines the coverage radius
  - Determines capacity
  - **Can’t just use smaller one**
    - “Macro” BTS = 10-50W Power Amplifier
    - Would limit range
    - Or reduce capacity
    - Permanently!

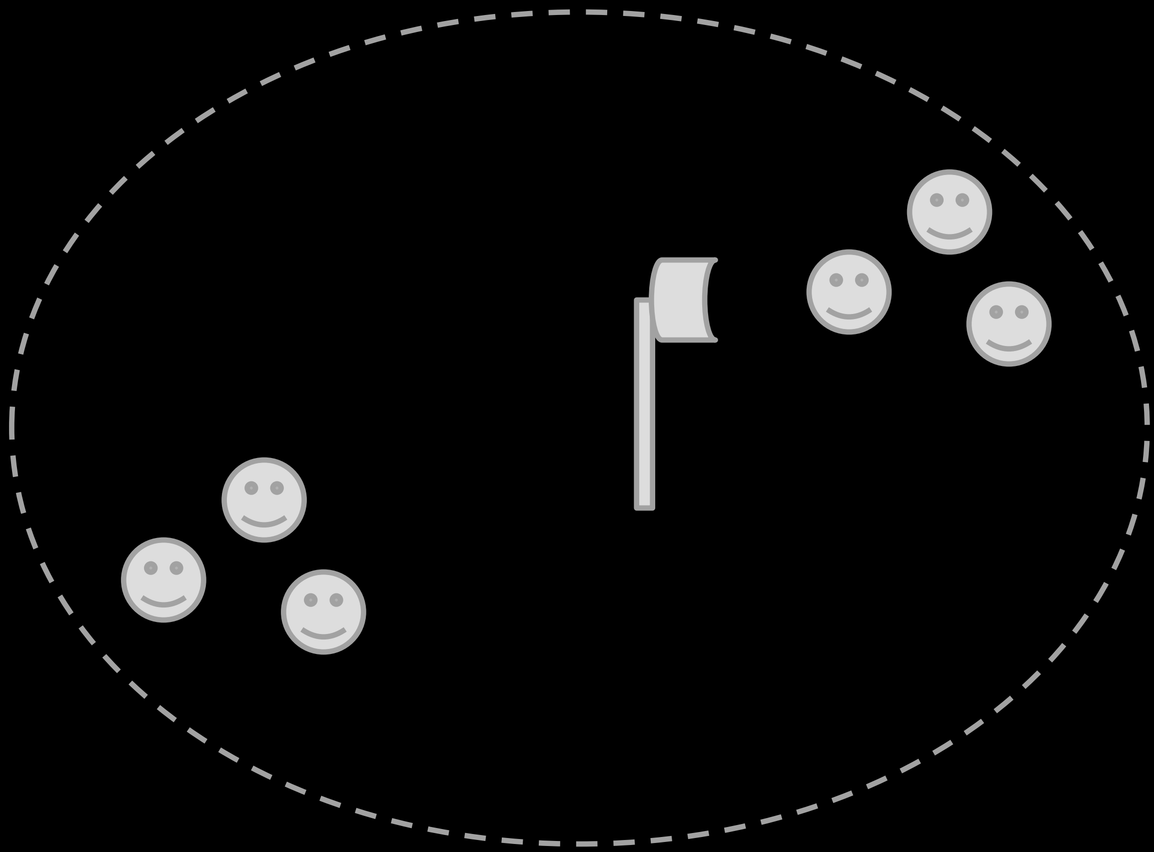
Q: How do we reduce the PA power draw?

A: Same way you do everything else; turn it off when not in use.

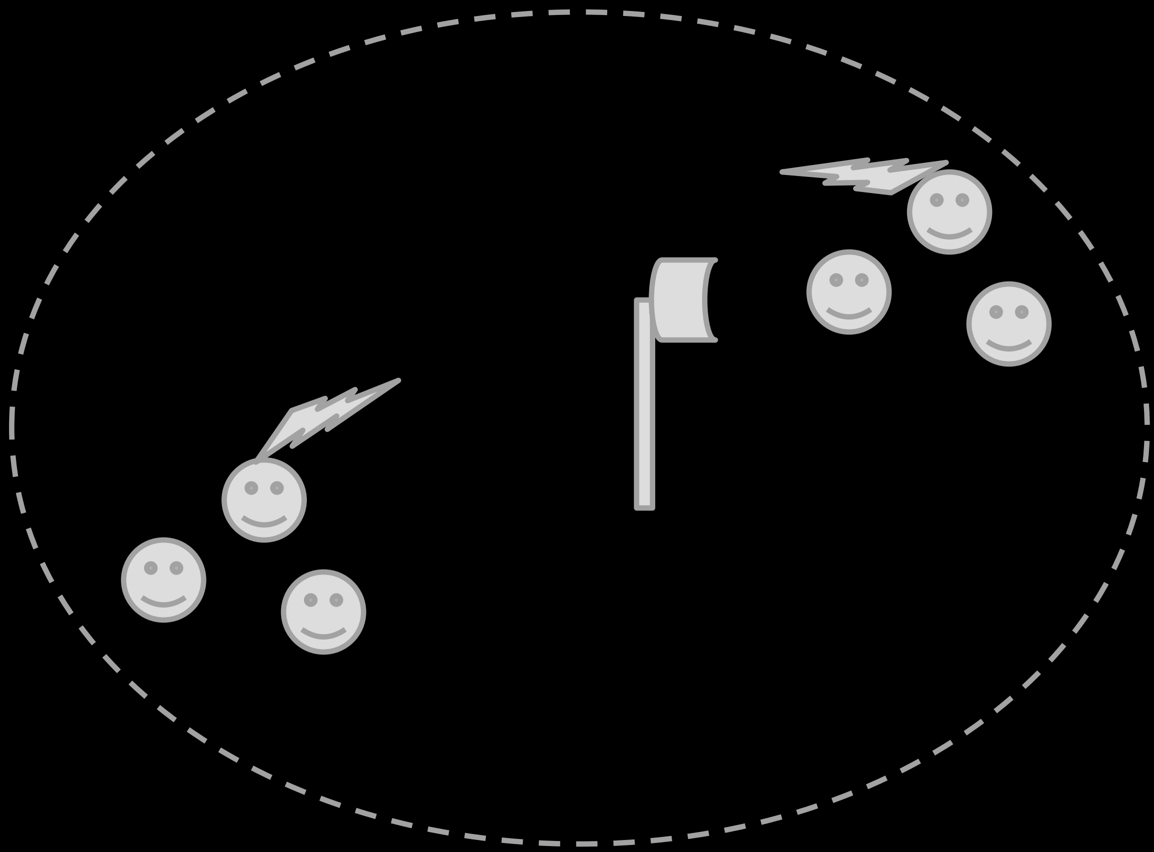
A: Same way you do everything else; turn it off when not in use.

We call this “Virtual Coverage”

Virtual Coverage



Virtual Coverage



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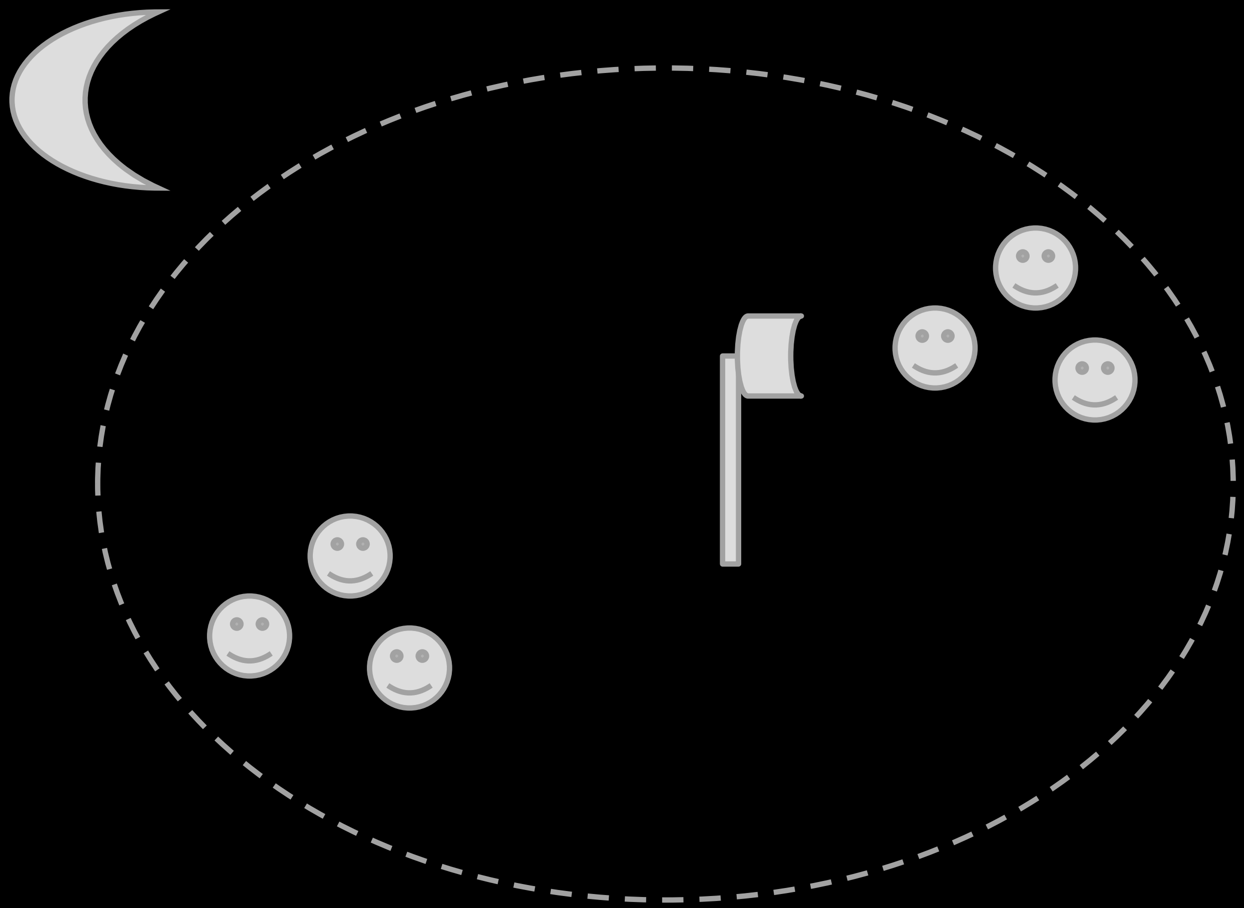

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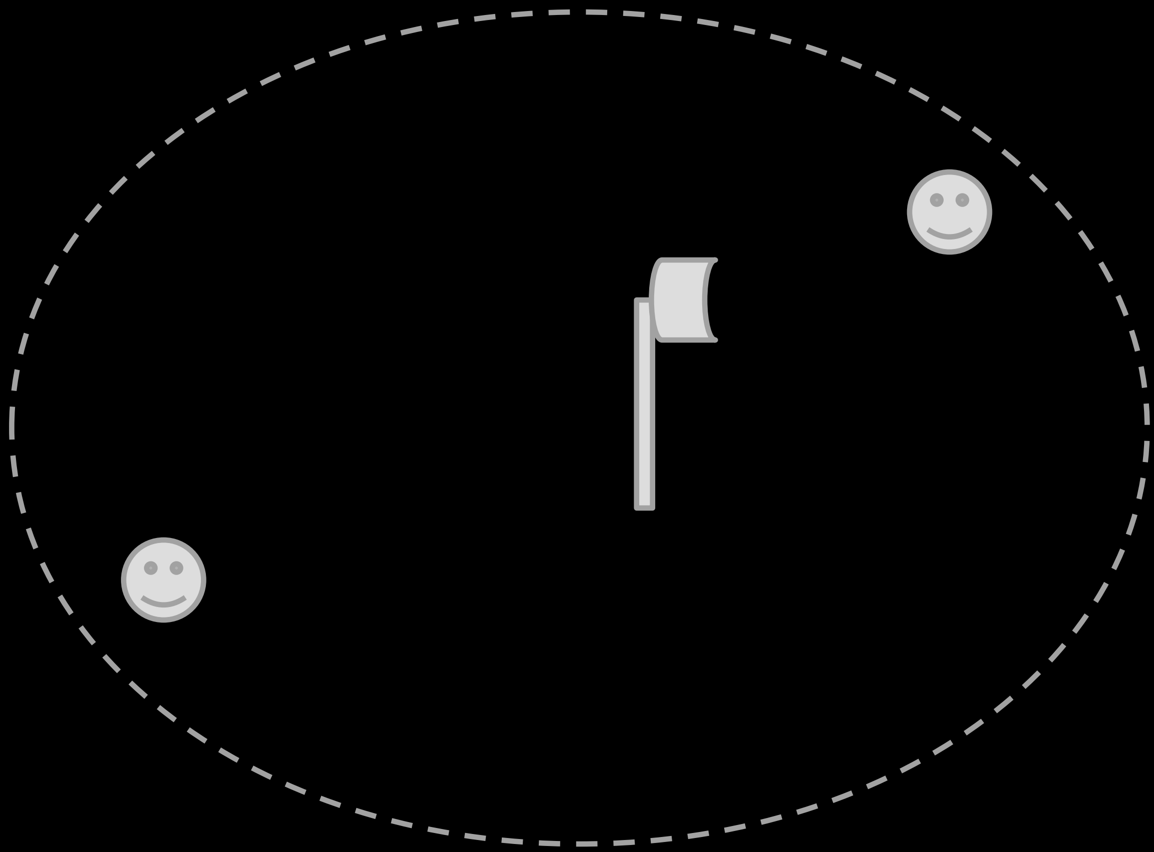
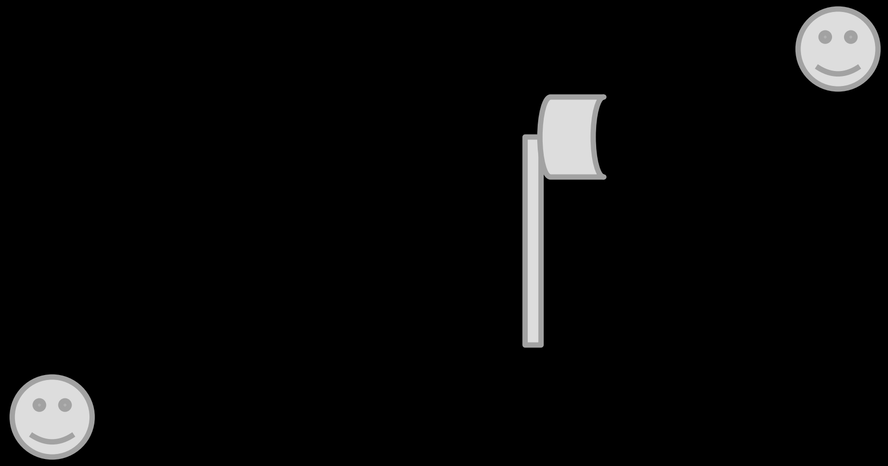


Virtual Coverage



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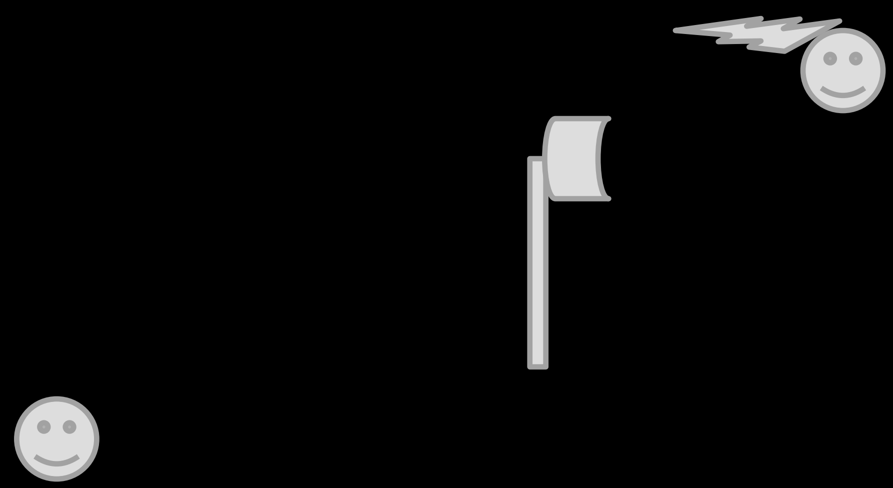

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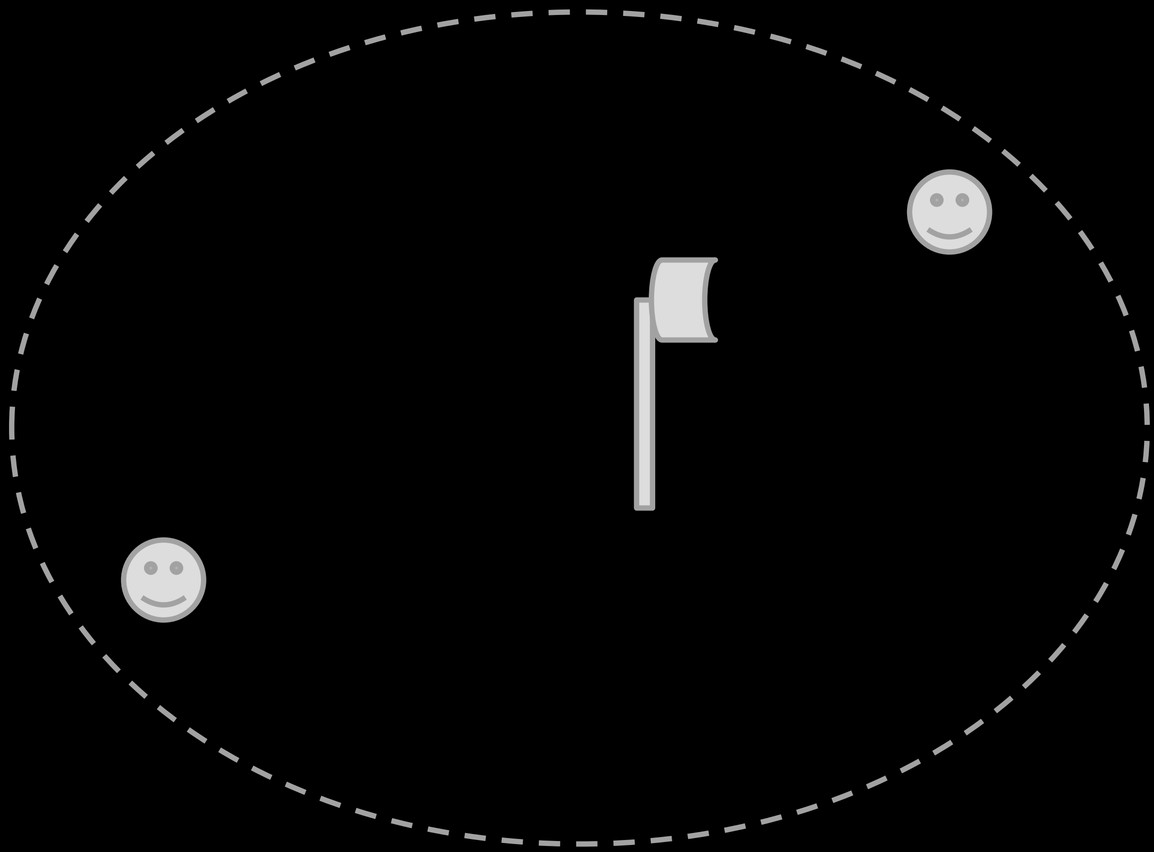

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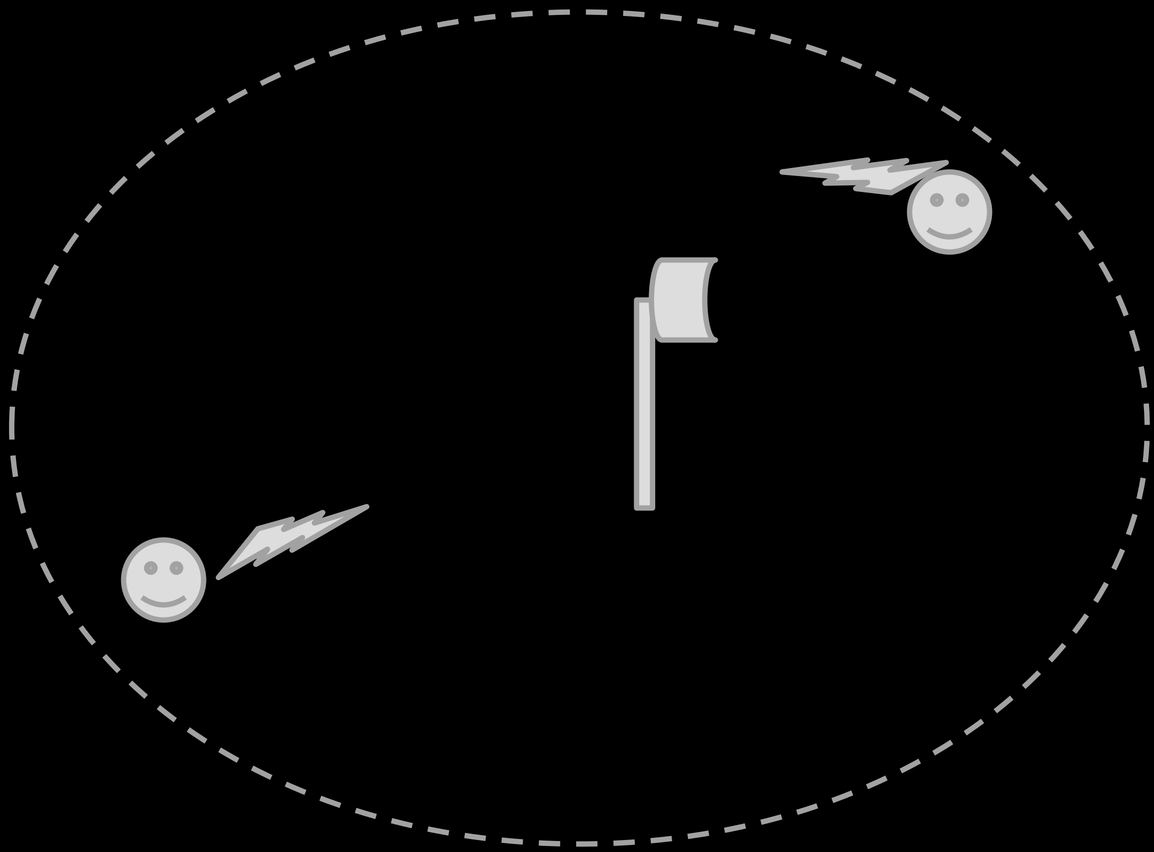

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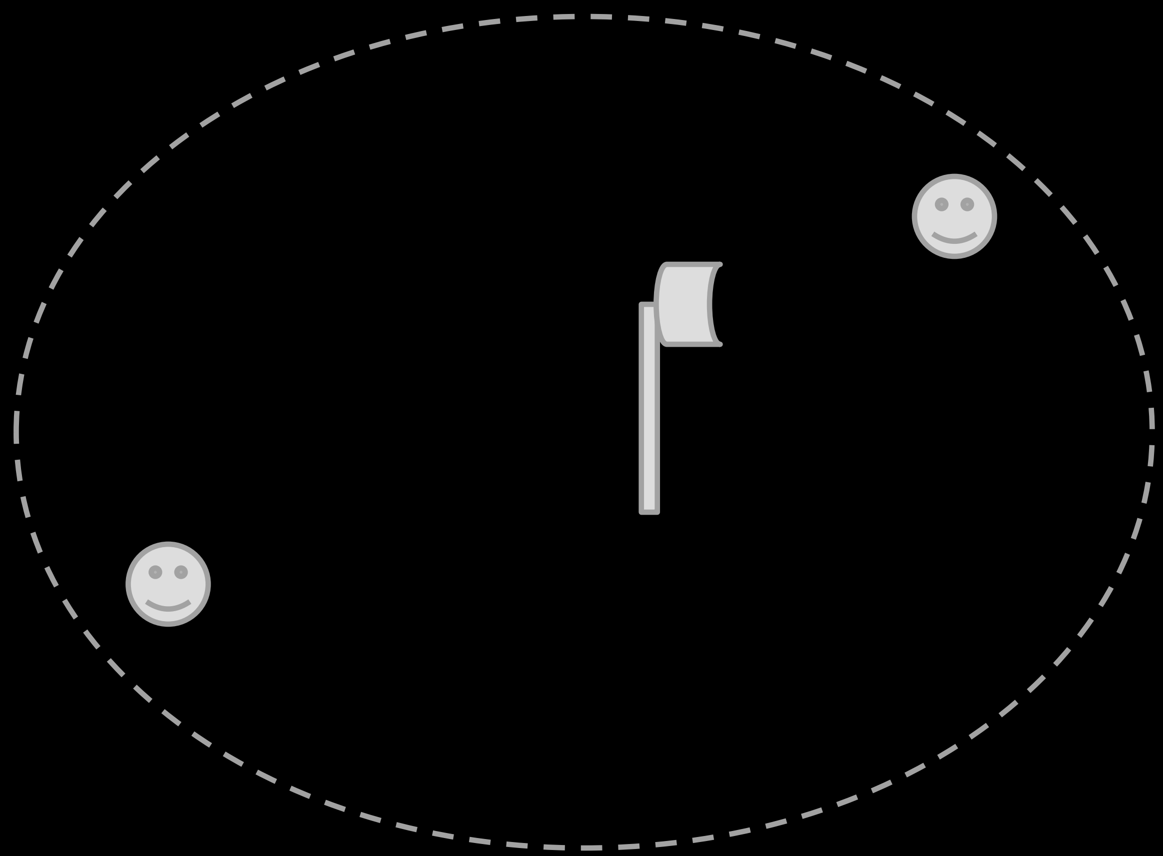

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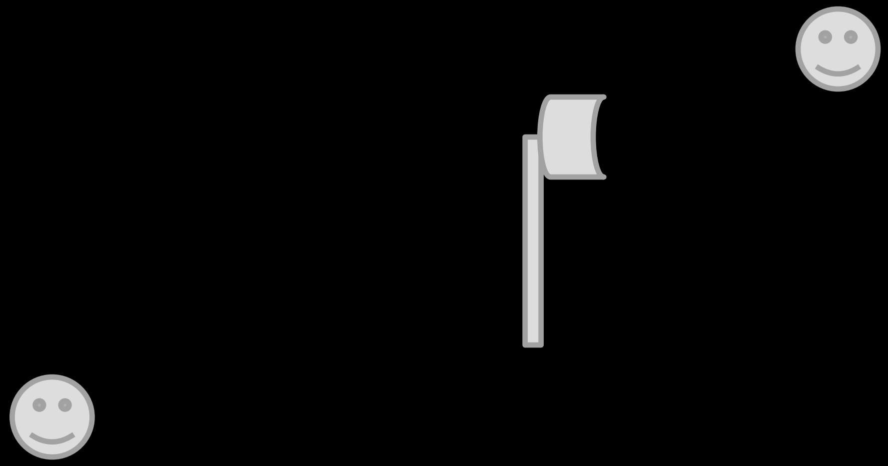

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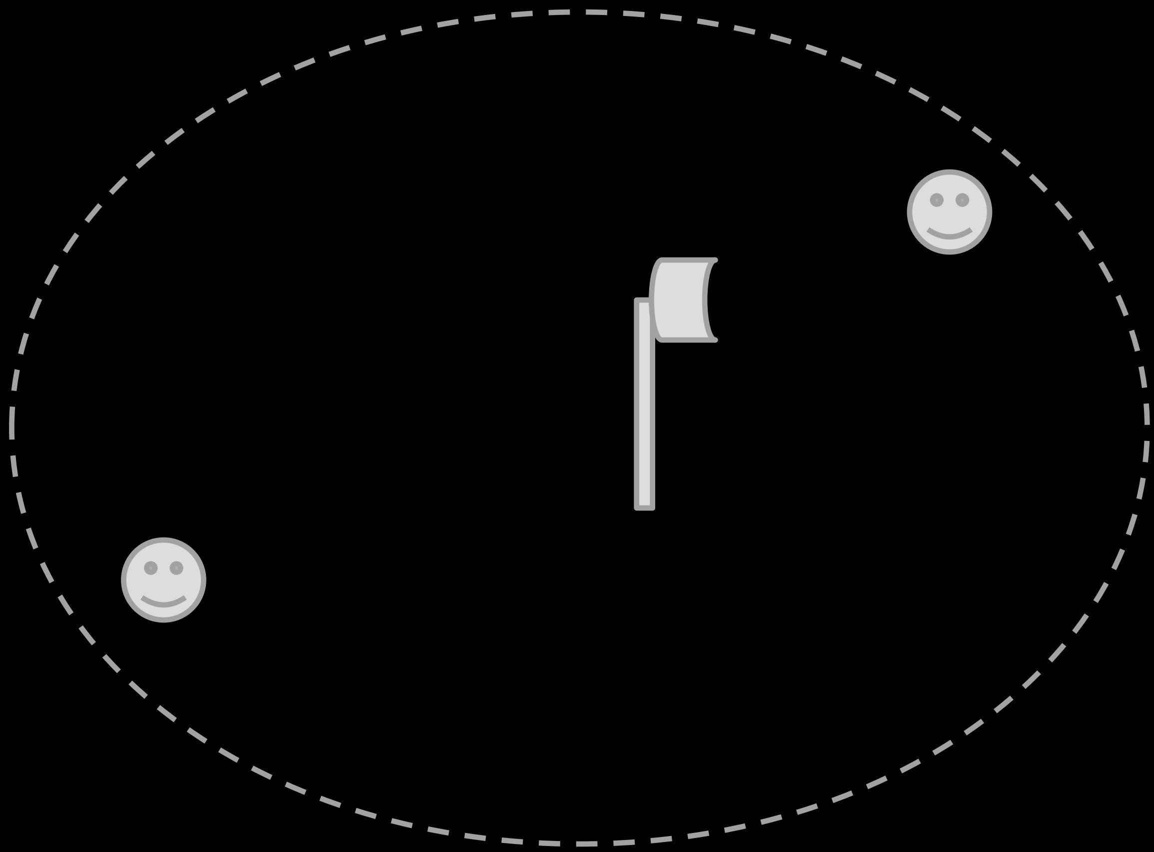

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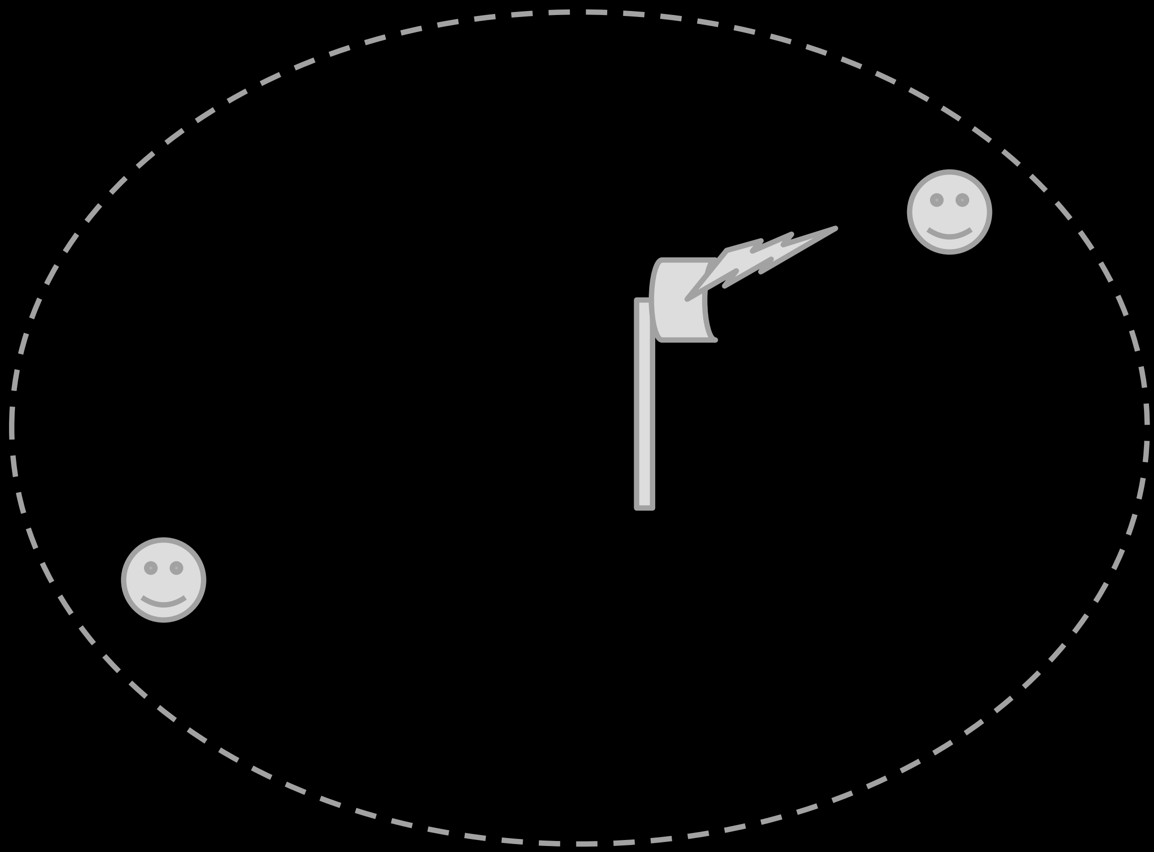
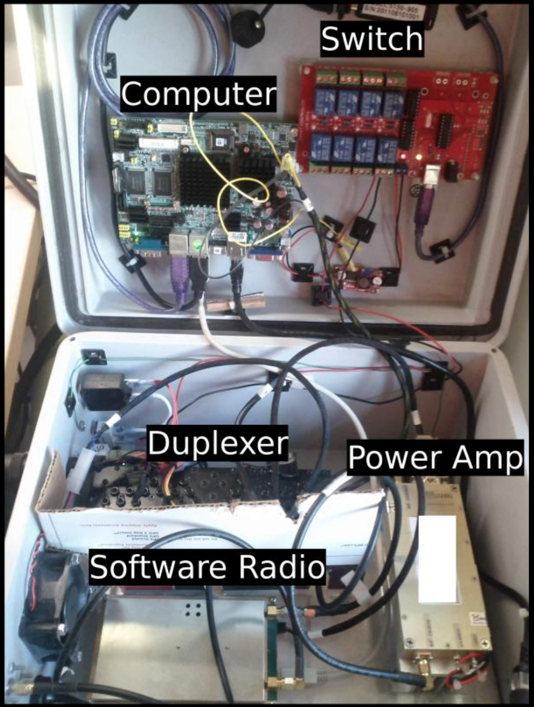


Implementation

- **BTS-Side**
  - Hardware
    - Add switch controlling PA
    - Any communication means PA is "On"
  - Changes to transceiver
    - Daemon with GSM/PA state
    - Detect bursts by hearing any output above limit on channel



Implementation

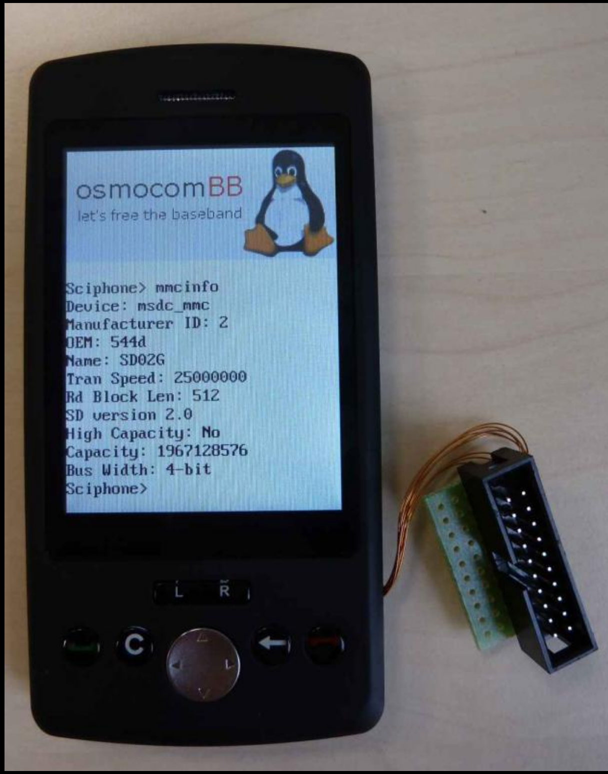
- **User-side: Outgoing**
  - How to send burst to BTS?

Implementation

- User-side: Outgoing
- **Answer 1: Wakeup Radio**
  - Supports legacy phones
    - Average 25 seconds of wait
  - Deployment strategies
    - Each user/home has one
    - Centralized “phone booth”

Implementation

- User-side: Outgoing
- Answer 1: Wakeup Radio
- **Answer 2: Wakeup Phone**
  – OsmocomBB on Motorola
  – Send burst, then immediately “camp”
    - Adds ~2 seconds
  – Can’t camp: move to another BTS



Implementation

- **User-side: Incoming**
  - No change to handset
  - Wake BTS
  - Wait for handset attach
  - Then:
    - Hold
    - Call Back

User Impact

- Fundamental change:
  - Involve users in power provisioning
  - Prior research has shown that users in rural areas often know more about their networks (1)

1) K. Heimerl and T. S. Parikh. How users understand cellular infrastructure.

Technical Details

There's a lot of technical details (GSM camping, timings, etc) we've omitted for time/space. Read the paper!

Power Infrastructure Savings

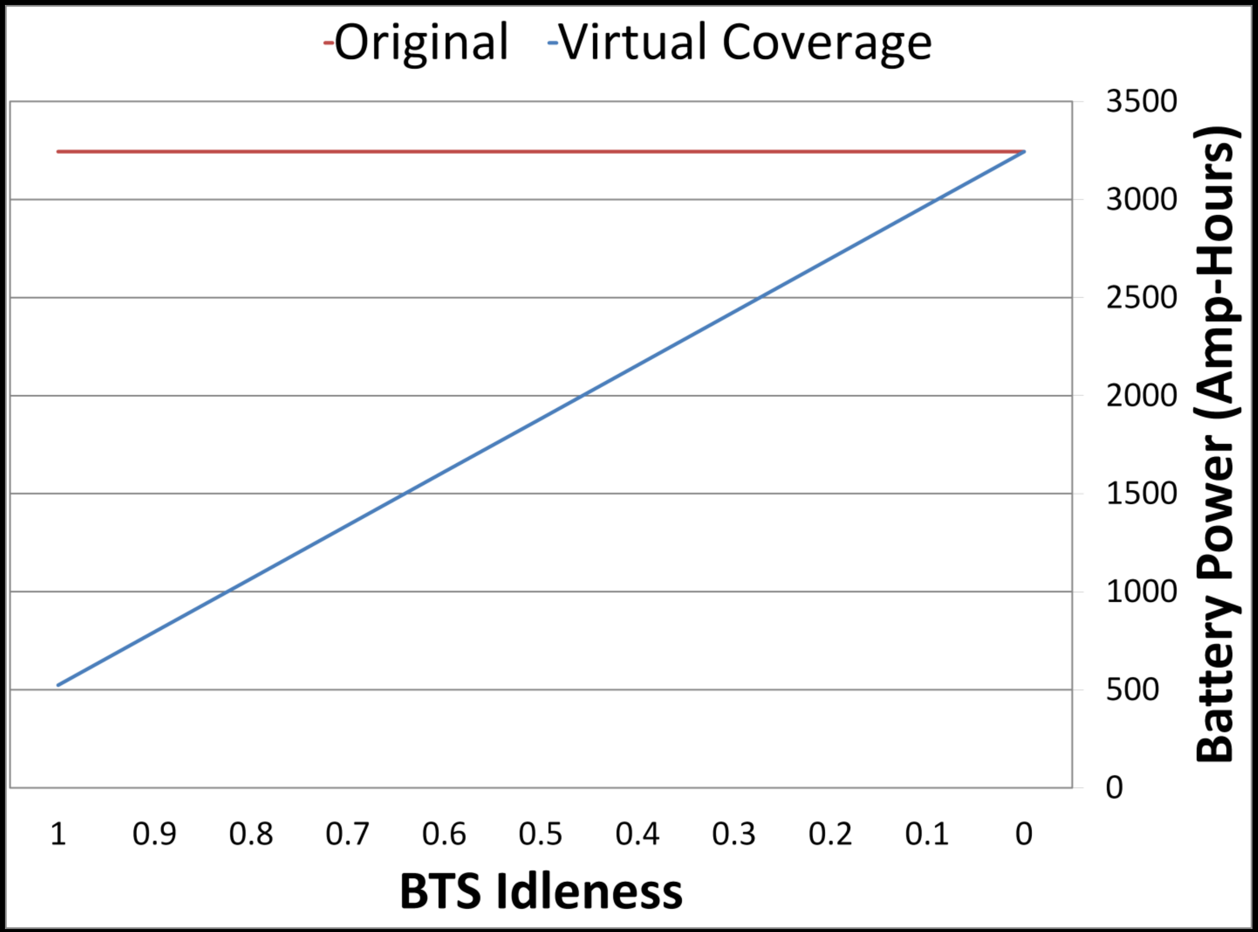
BTS

- Range Networks 5150
- 50W PA
- 1000W Solar
- 3300 AH
  - 17 Batteries
- Infrastructure Cost:
  - 15000USD

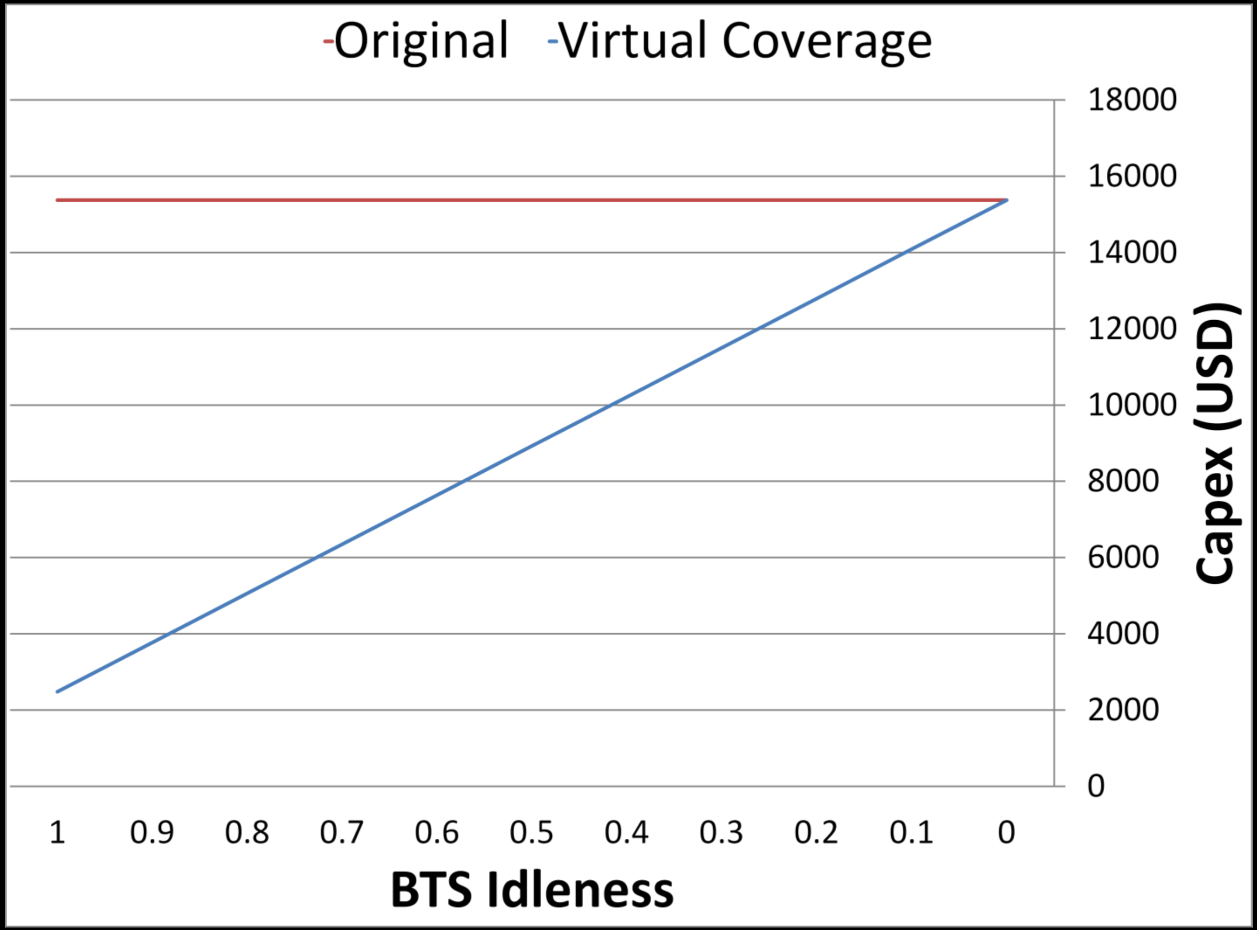
BTS w/ VC (100% Idle)

- Modified 5150
- Effectively no PA
- 150W Solar
- 500 AH
  - 3 batteries
- Infrastructure Cost:
  - 2500 USD
- 84% Savings

Power Proportionality



Power Capex Proportionality



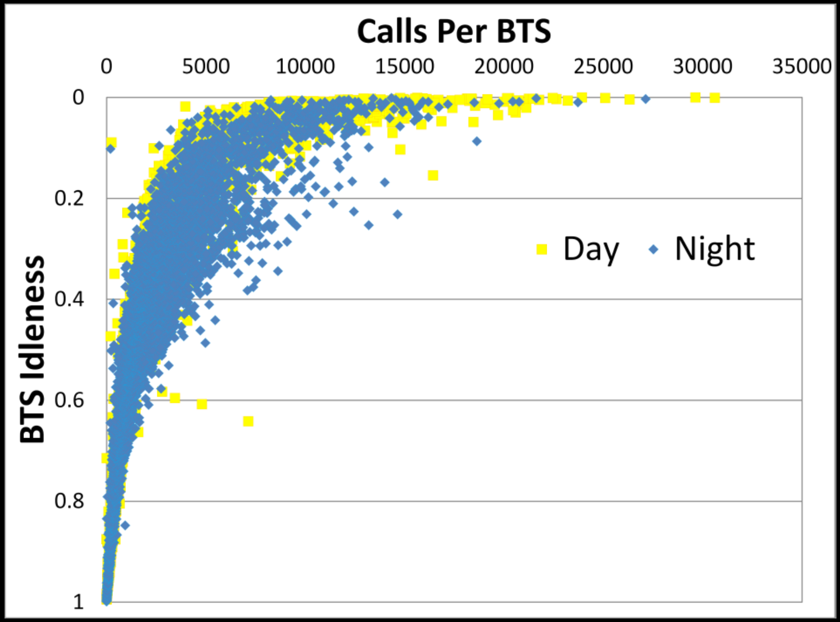
How idle are cellular networks?

Idleness - Evaluation

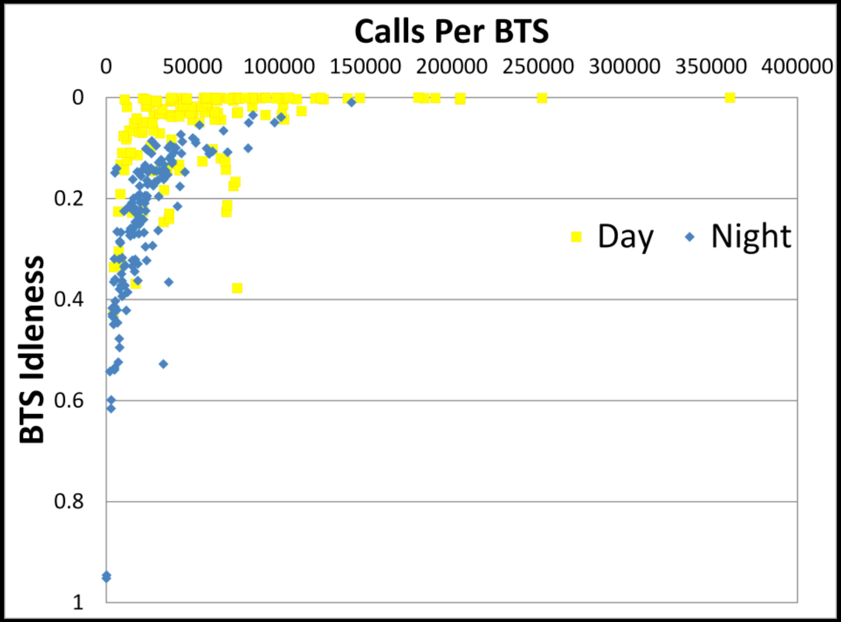
- Acquired one weeks call logs from two nation-scale telecommunication firms
  - South Asia
    - 35 mil calls/5000 towers (4000/tower median)
  - Sub-Saharan Africa
    - 15 mil calls/150 towers (70000/tower median)

Idleness

South Asia

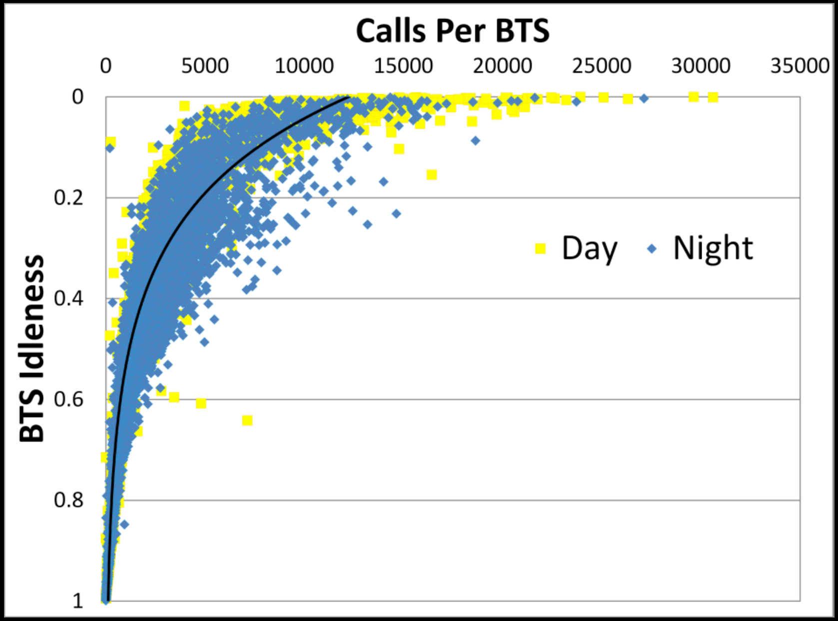


Sub-Saharan Africa



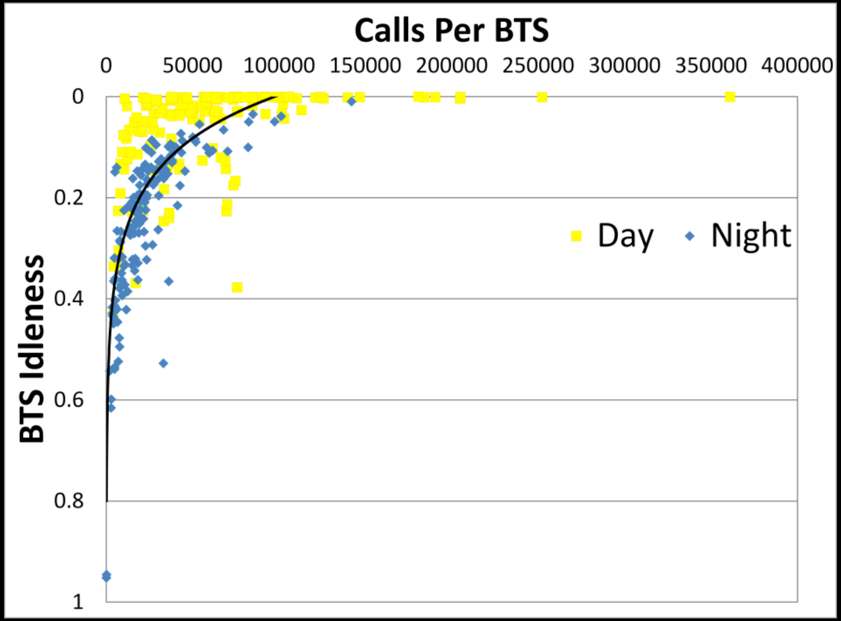
Idleness

South Asia



$$y = 0.2135\ln(x) - 1.0089$$
$$R^2 = 0.8848$$

Sub-Saharan Africa

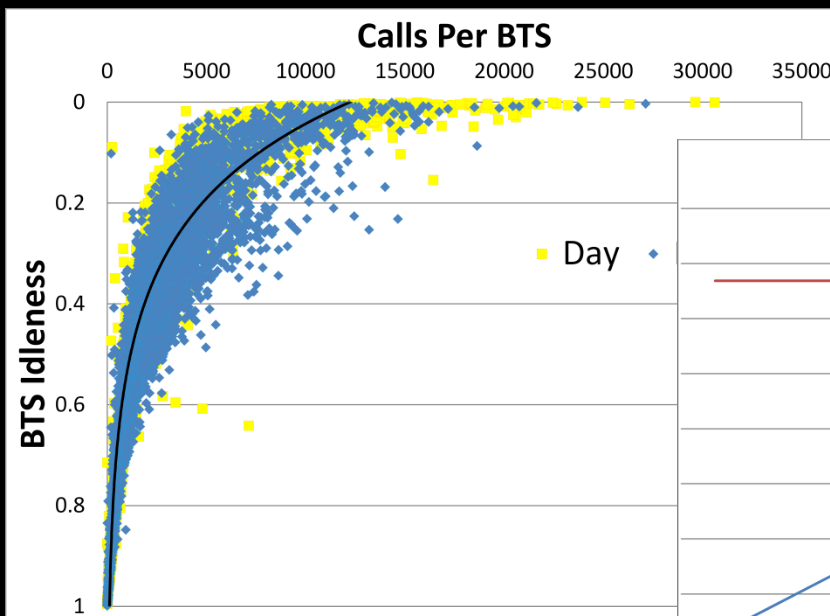


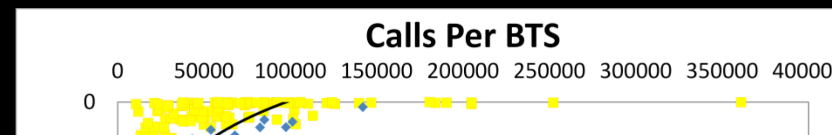
$$y = 0.1234\ln(x) - 0.418$$
$$R^2 = 0.655$$

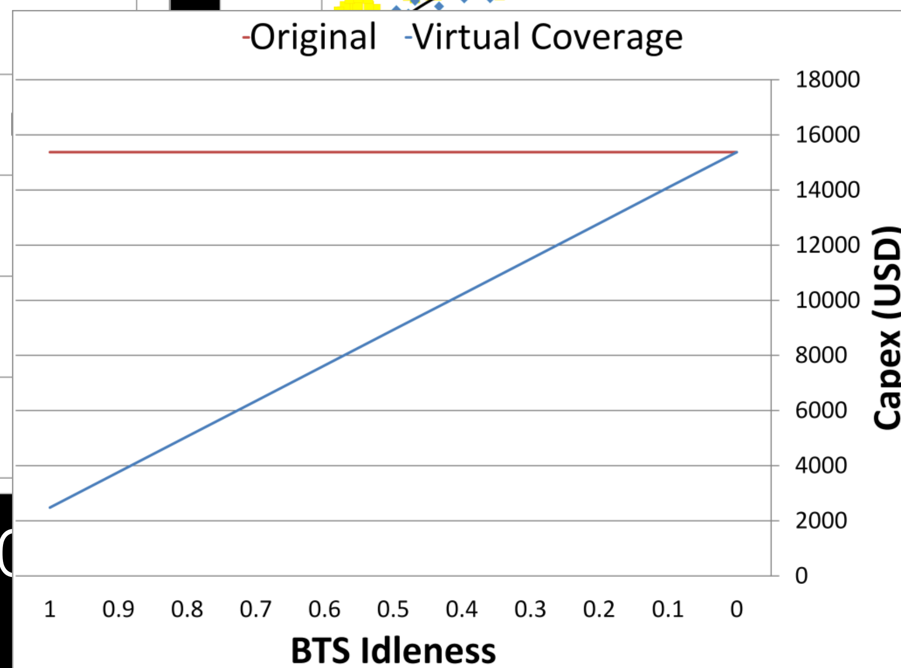
Idleness

South Asia

Sub-Saharan Africa







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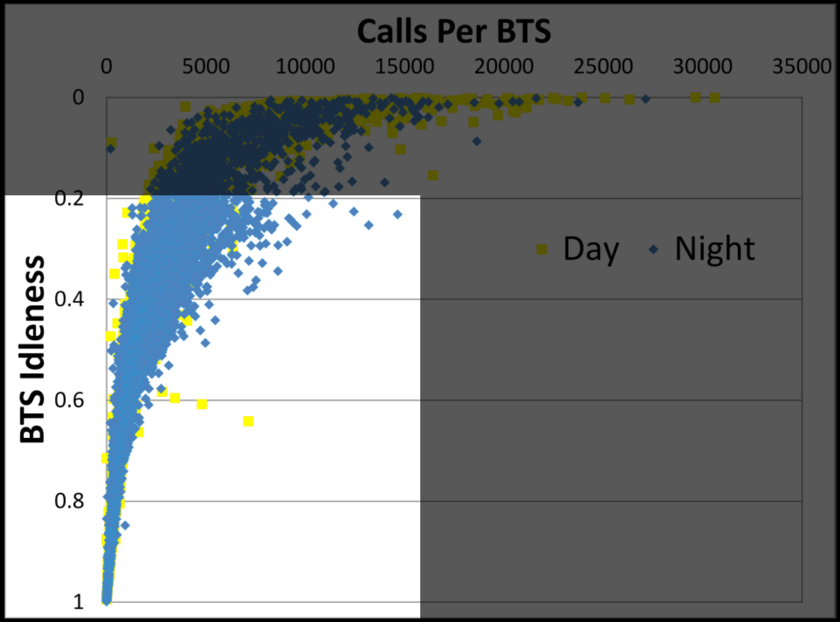
8

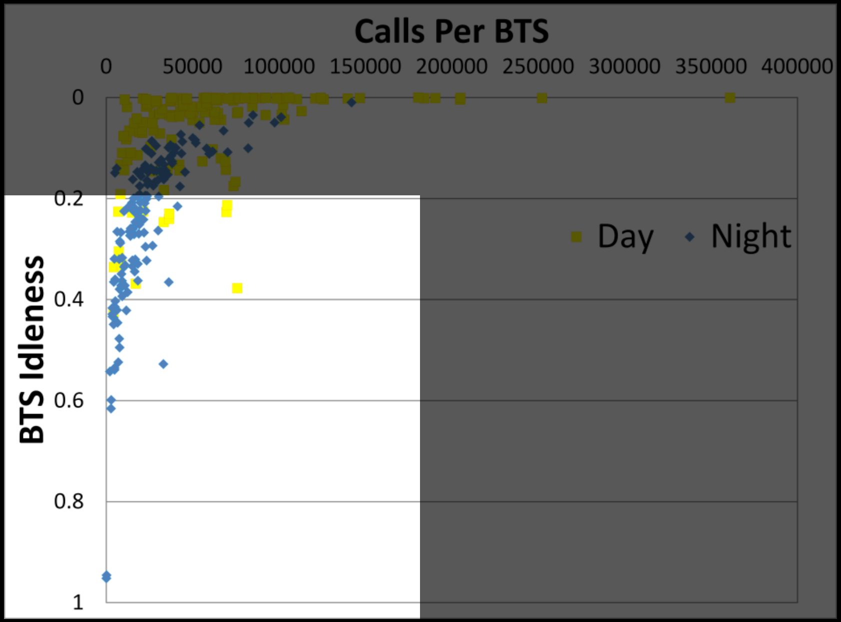
Idleness

South Asia



86% over 20% idle at night

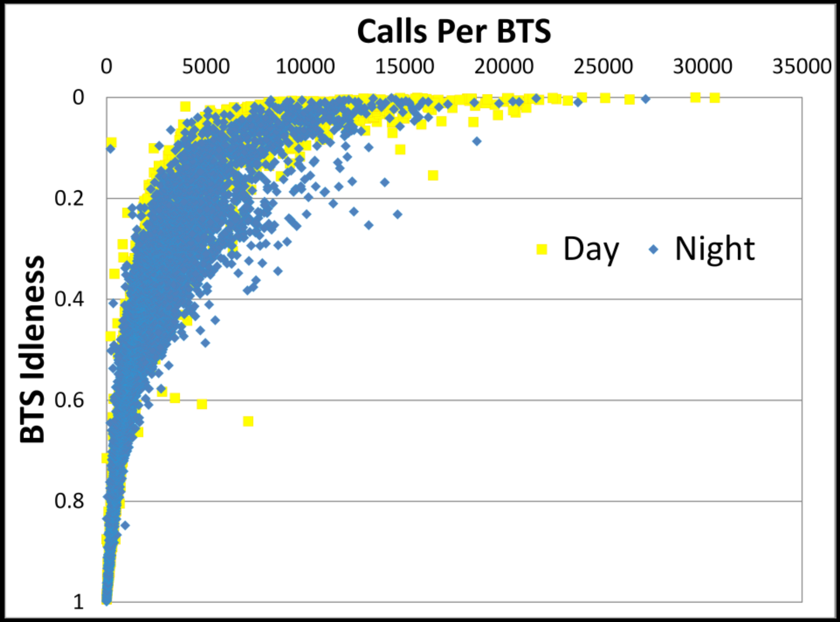
Sub-Saharan Africa



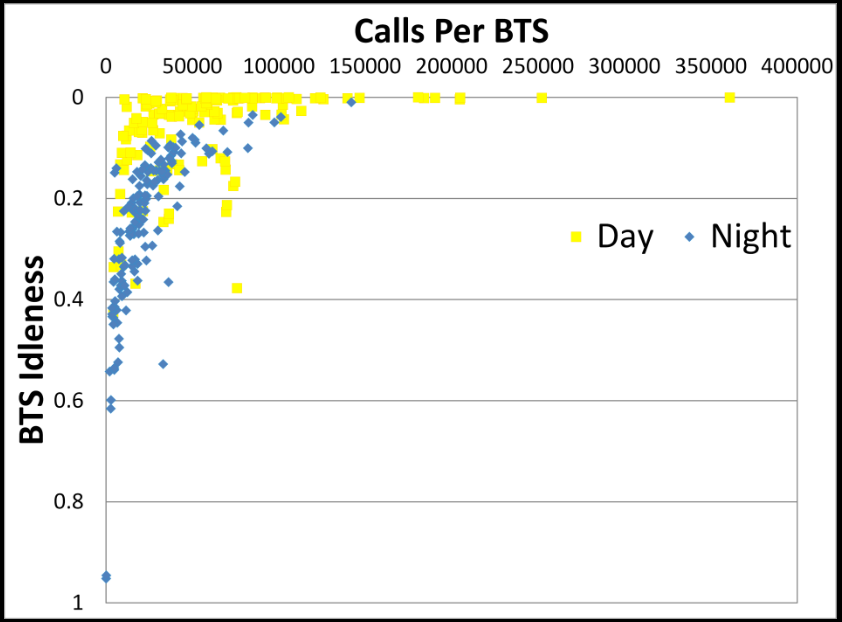
53% over 20% idle at night

Idleness

South Asia



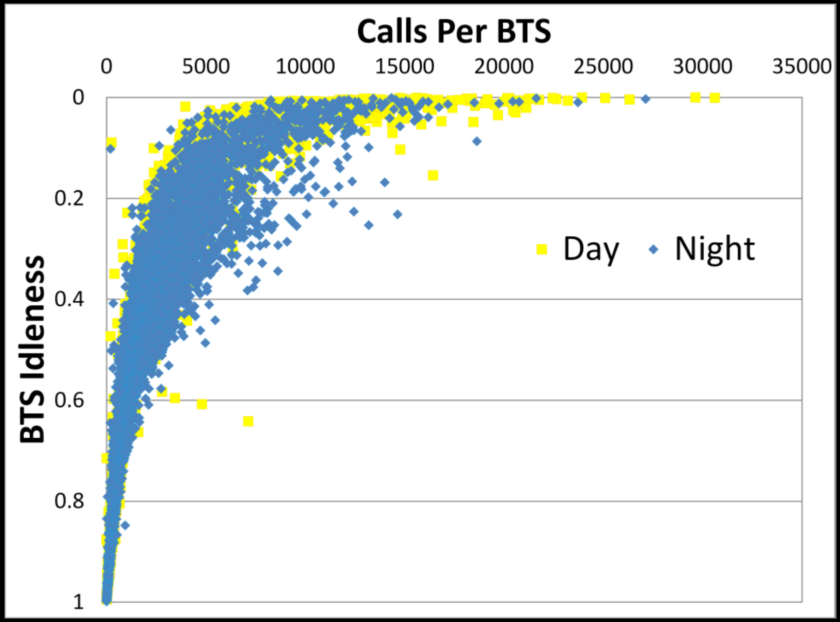
Sub-Saharan Africa

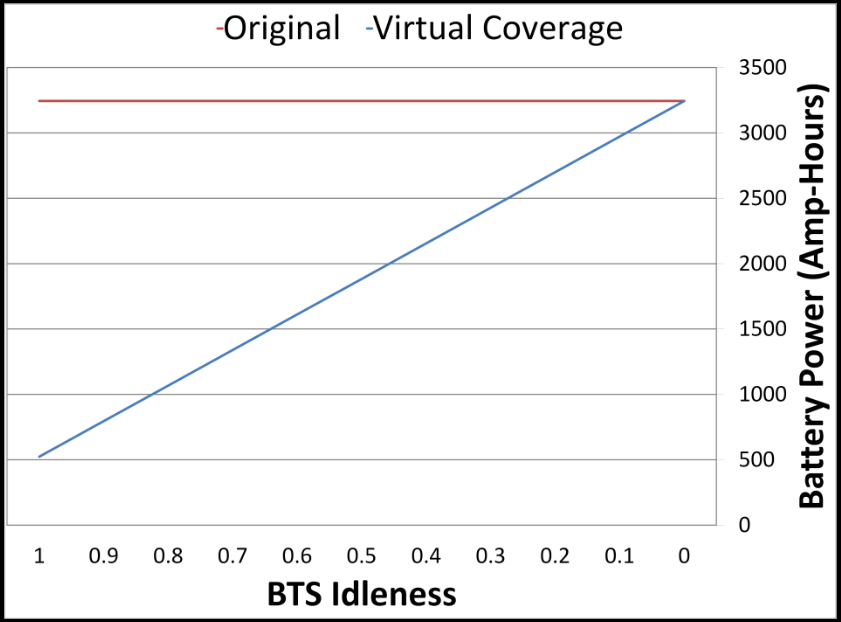


These networks are designed for high utilization.
The idleness in areas without coverage will be higher.

Total Energy Savings

Idleness + **Power Draw**





Combine these two to create estimate of total power savings in each entire cellular network.

Total Energy Savings

South Asia

	Power Draw	Energy Savings
Original	249MWh	0%
VC Day	98MWh	21.3%
VC Night	82MWh	34.3%
VC Total	180MWh	27.7%

Sub-Saharan Africa

	Power Draw	Energy Savings
Original	7.7MWh	0%
VC Day	3.5MWh	7.2%
VC Night	3.0MWh	20.7%
VC Total	6.6MWh	12.9%

Total Energy Savings

South Asia

	Power Draw	Energy Savings
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	Power Draw	Energy Savings
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VC Total	6.6MWh	12.9%

HOORAY! LOTS OF POWER SAVINGS!

Bringing it all Together

- **28% power savings for existing network**
  - Effectively an "lower bound" on idleness
  - If you can build a tower with 20% idleness, you will!

Bringing it all Together

- 28% power savings for existing network
- **Proxy measurement**
  - We care about idleness in areas where there is currently no coverage

Bringing it all Together

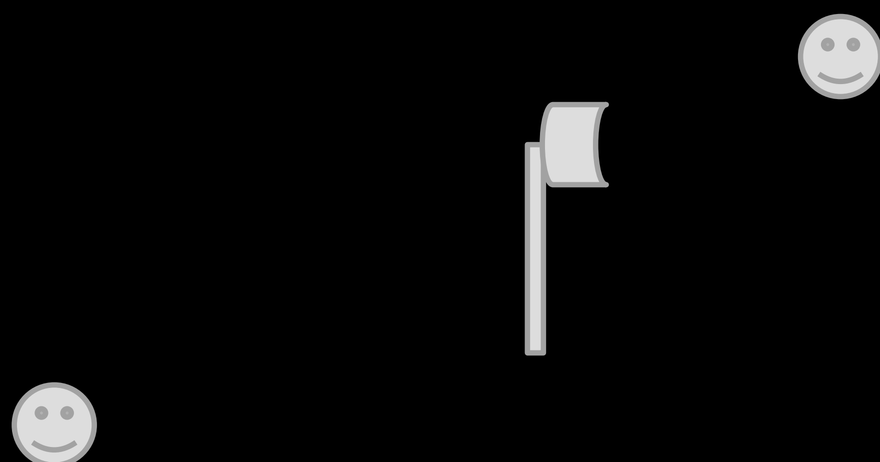
- 28% power savings for existing network
- Proxy measurement
- **Expected Power Savings**
  - Going to depend on specific target
  - 80% Idle = 67% power savings
  - **60% Idle = 50% power savings**

Our Goal:
Reduce GSM base station (BTS) power draw; reducing the cost of rural installations

Result:
Virtual coverage reduces the power of a BTS by up to 84%, with an expectation of > 50%

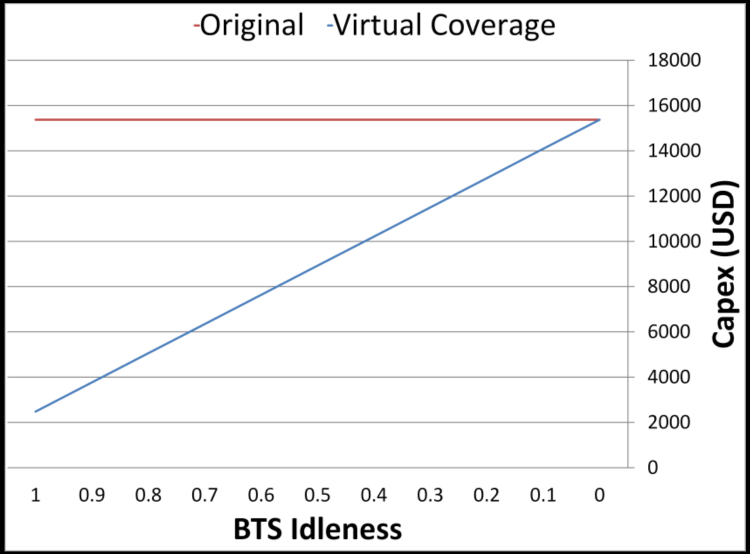
Conclusion

- **Virtual Coverage**
  - Involve users in power decisions
  - Save power with GSM "idle" mode



Conclusion

- Virtual Coverage
- **Micro-benchmarks**
  - Power infrastructure scales with use



Conclusion

- Virtual Coverage
- Micro-benchmarks
- **Macro-benchmarks**
  - Logs from two carriers
    - South Asia
    - Sub-Saharan Africa
  - Lots of idleness in real cellular networks

	Power Draw	**Energy Savings**
Orig	249MWh	0%
Day	98MWh	21.3%
Night	82MWh	34.3%
Total	180MWh	27.7%

	Power Draw	**Energy Savings**
Orig	7.7MWh	0%
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Total	6.6MWh	12.9%

Current Research

- Deployment in rural Papua, Indonesia
  - Late February 2013
  - Village Base Station project
  - 3 Wakeup Radios
    - 2 in Kiosks
    - 1 in Market
  - Study ongoing

Demo Today at 6!
Questions?

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Backup slides

Camping

- Phone scans band
  - Finds specific ARFCN
- Sends message
  - RACCH
- BTS Responds
  - CCCH
- Every N minutes
  - Configured by BTS

Implementation

- **User-side: SMS/Data**
  1. **Virtual Coverage**
     - Nothing about our technique depends on the communications themselves

Implementation

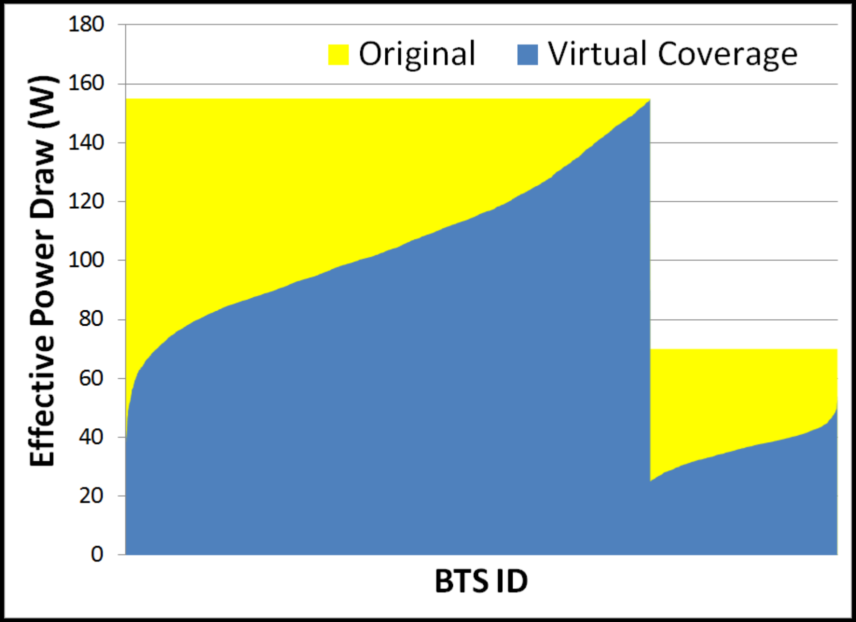
- **User-side: SMS/Data**
  1. Virtual Coverage
  2. **Sync during other activity**
     - SMS/Data both Asynchronous
     - Periodic updates if no other activity

Power Savings

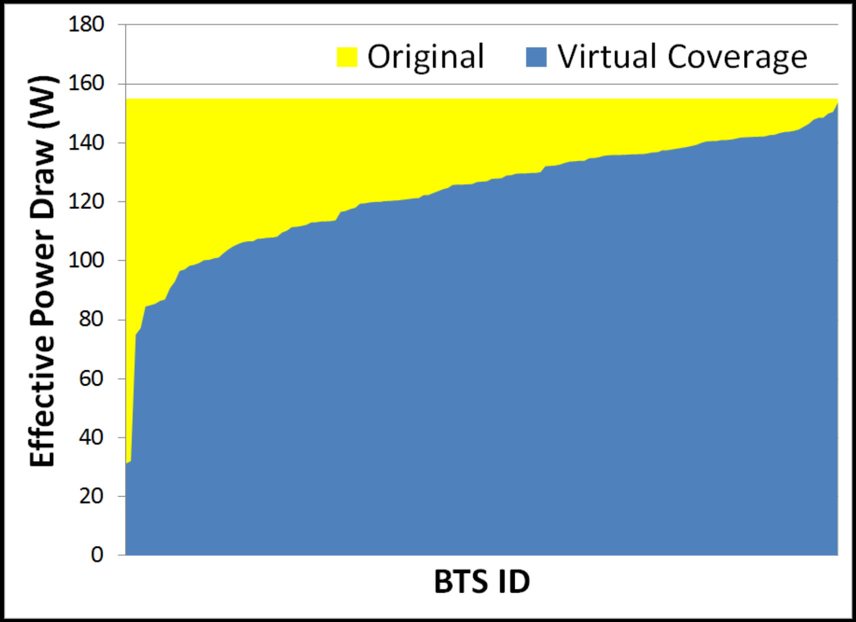
- Assume we want maximum range
  - No BTS < 10W Amplifier
- 10W PA for any BTS handling < 7 calls
  - 1 Channel/10W Range Networks 5150
  - 70W Total/Idle saves 65%
- 50W PA for any BTS handling > 7 calls
  - 5 Channel/50W Range Networks 5150
  - 155W Total/Idle saves 84% of the power

Night Power Savings

South Asia

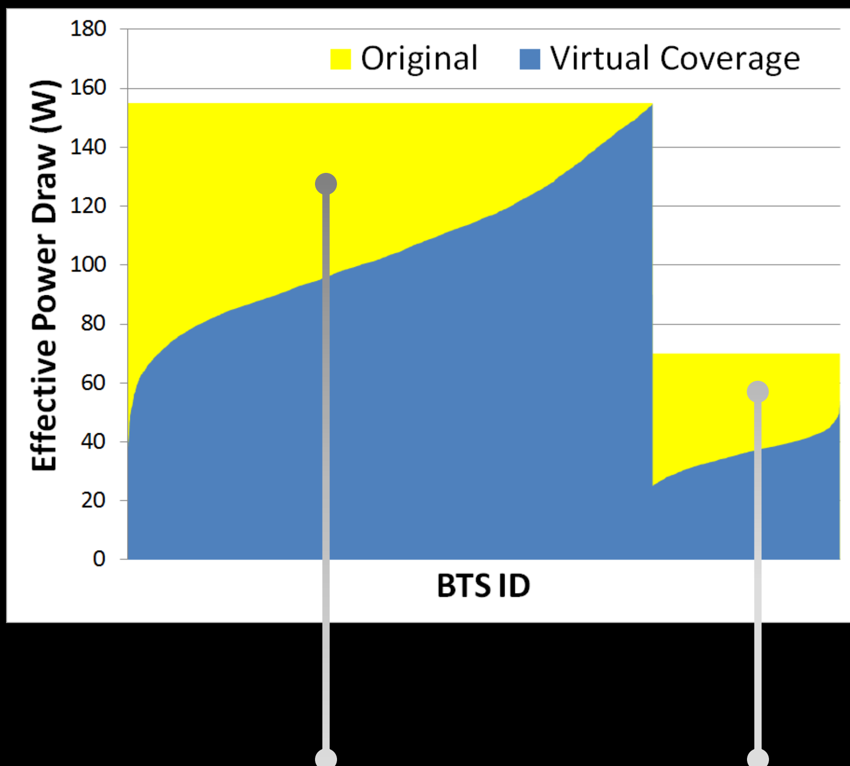


Sub-Saharan Africa



Night Power Savings

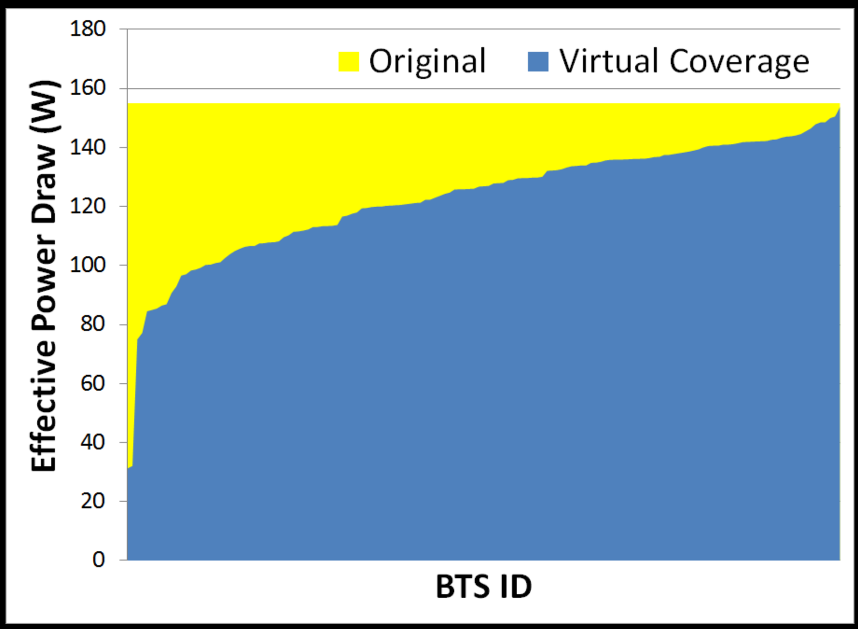
South Asia



155W BTS

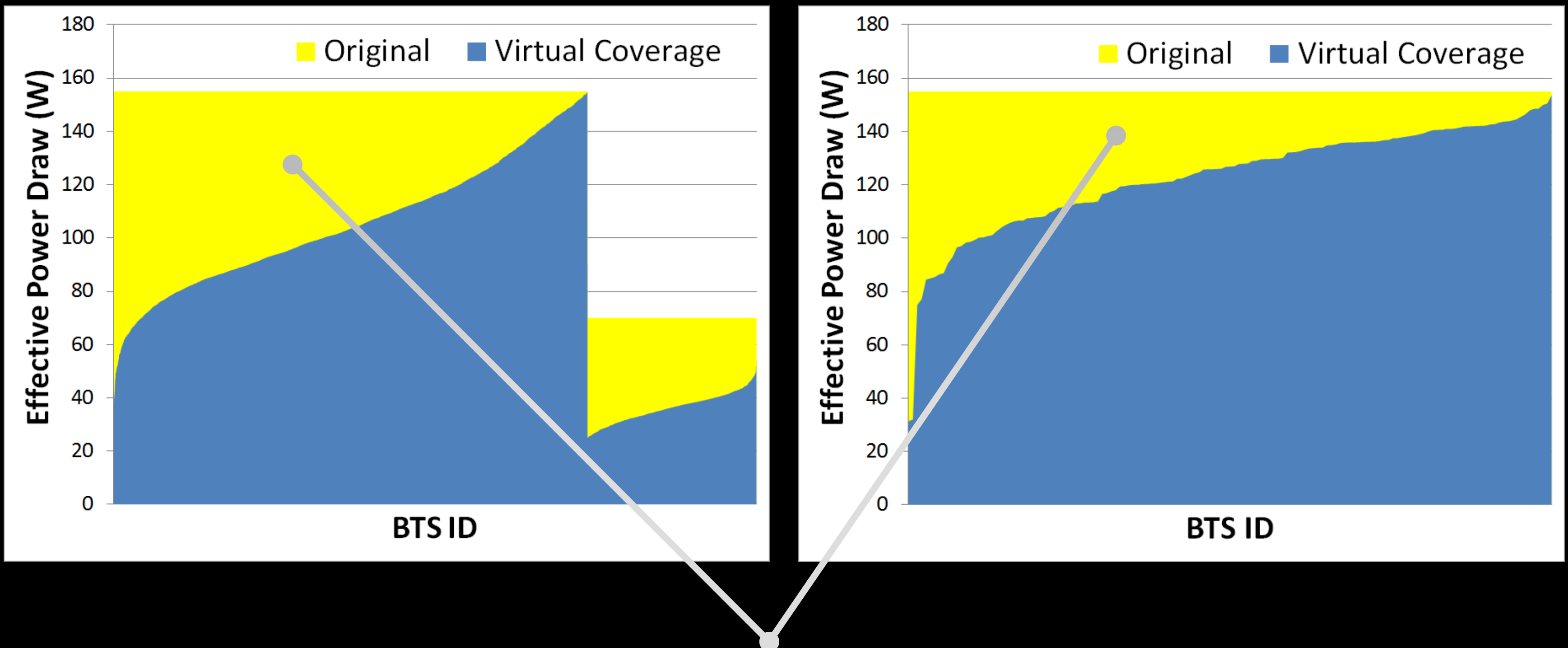
70W BTS

Sub-Saharan Africa



Night Power Savings

South Asia **Sub-Saharan Africa**



Total Night Power Savings