Primary Users in Cellular Networks
A Large-Scale Measurement Study

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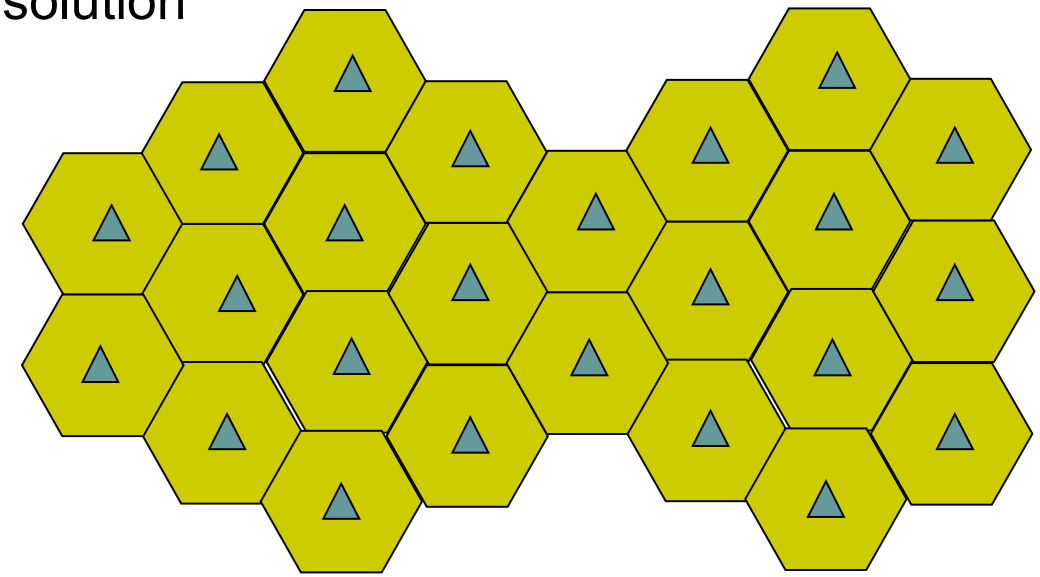
Dynamic Spectrum Alloc. In Cellular Networks

- Primary User (PU) don't use all their spectrum (at all location, all the time)
- Room for Secondary User (SU) to exploit idle spectrum
- But:
  - How much idle spectrum is out there?
  - How does it change (over space and time)?

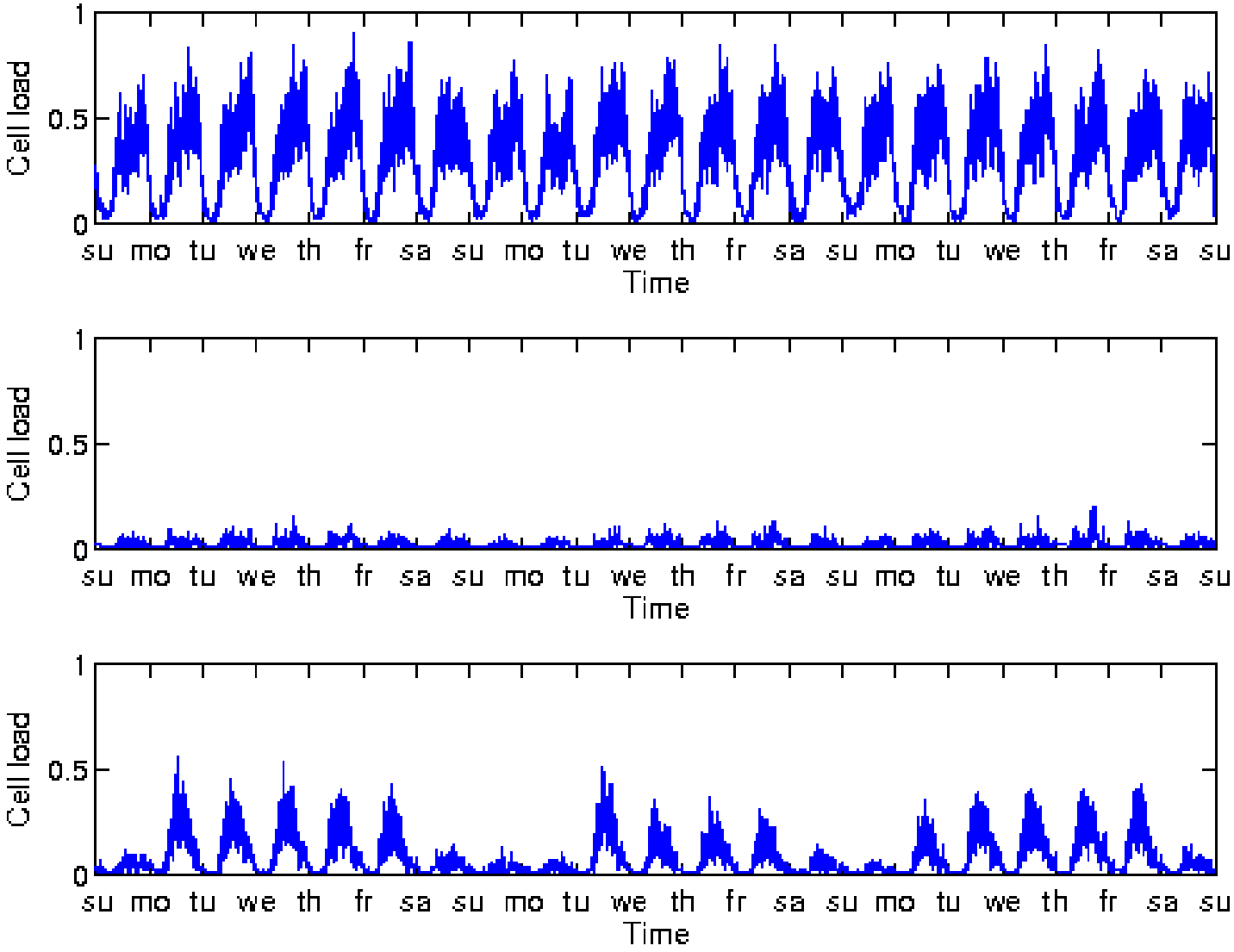
1. Measure behavior of primary users
2. Model behavior of primary users
3. Impact on secondary usage of licensed spectrum

Our Measurements

- Network centric view
- 100's base stations, 3 weeks, 10's Mio of calls
- Caveats
  - Beginning and end cell
    - If different, assume static, or mobile (half/half)
  - CDMA – number of calls only estimate of remaining capacity
  - Limited resolution

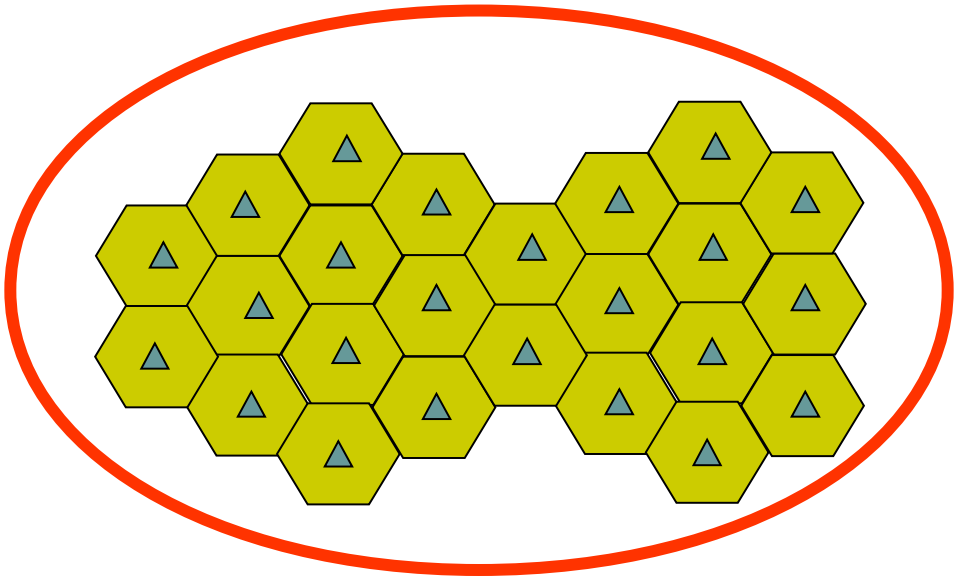


Sample Call Load in 3 Cells

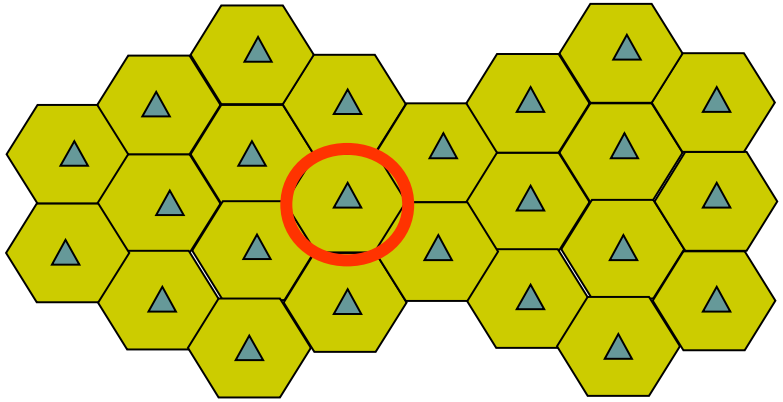


System-wide vs. Cell-based Model

System-wide model



Cell-based model



Temporal Behavior of PUs

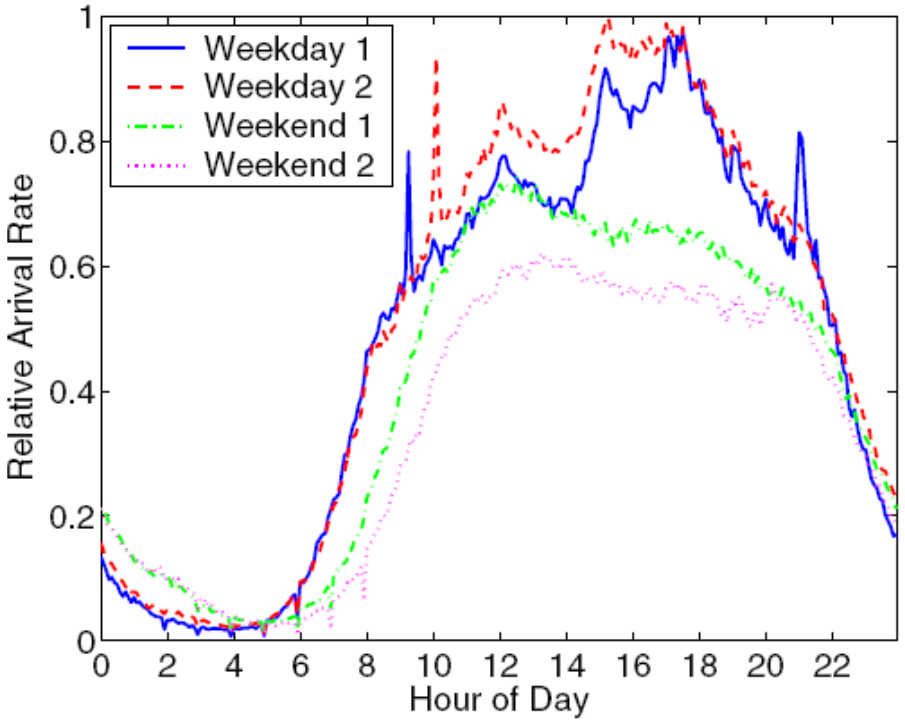
- Capacity = total capacity of all cells (system-wide model)
- Examine total *PU load (t)*
  - *PU load (t)* = nb of calls at time t

Call-based model:

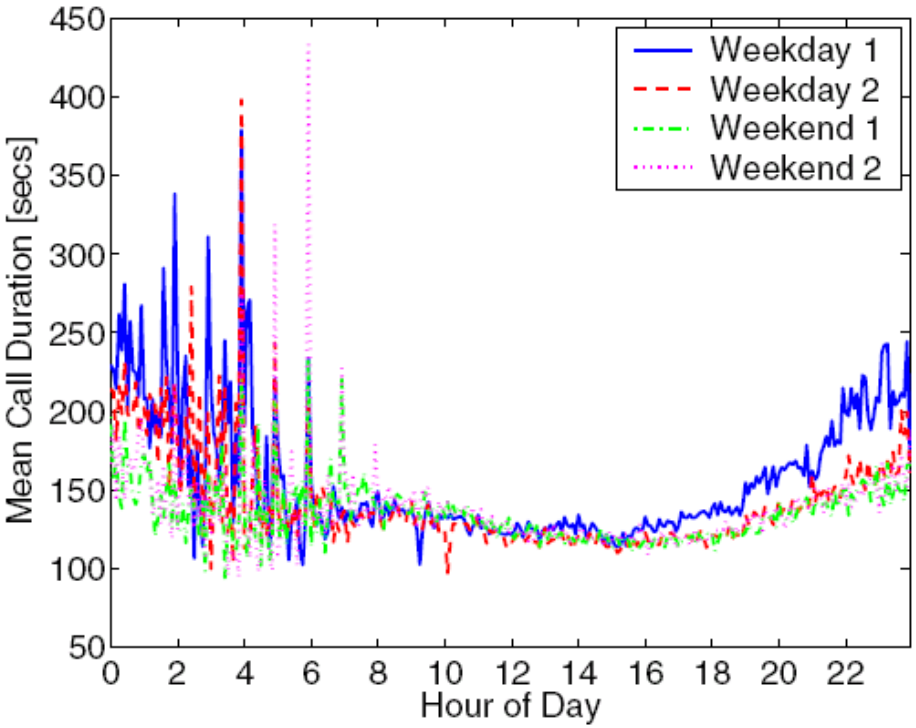
- PU behavior can be defined by call arrival and duration

- Typically assumed stationary
- Typically modeled by exponential distributions
  - E.g. Cellular spectrum pricing: Dyspan07, Infocom08

Mean Call Arrival Rate and Duration



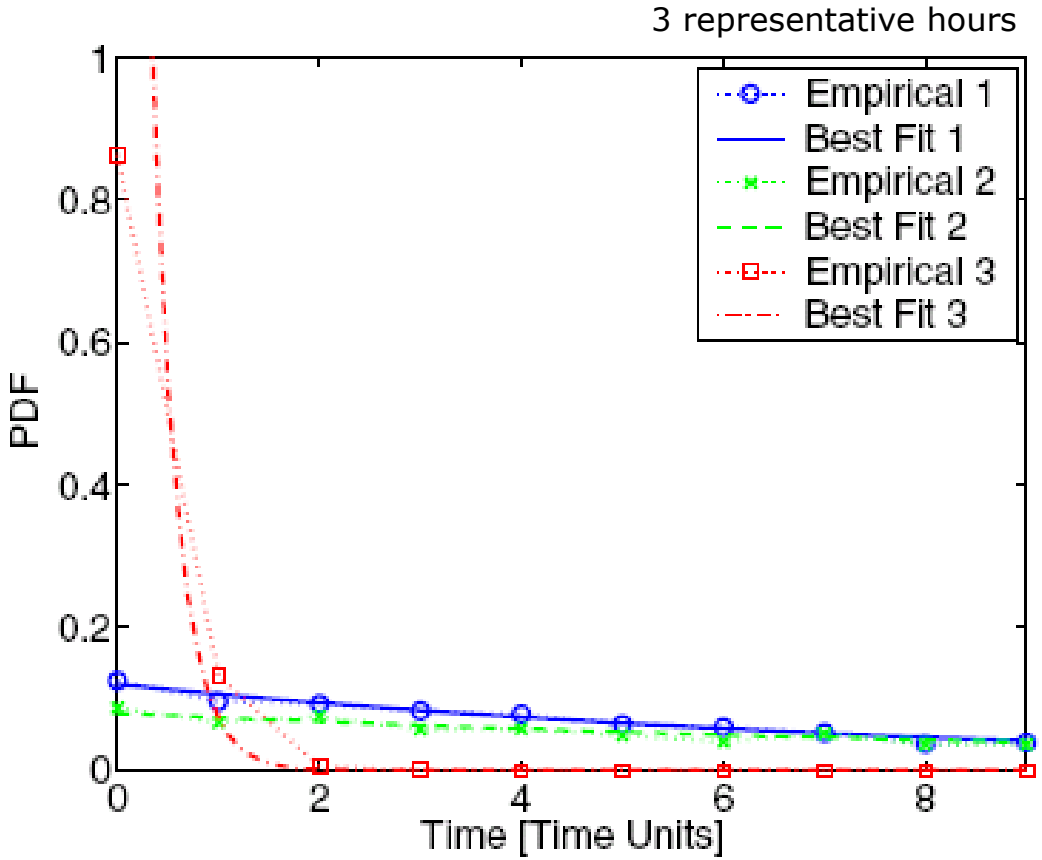
mean call arrival rate



mean call duration

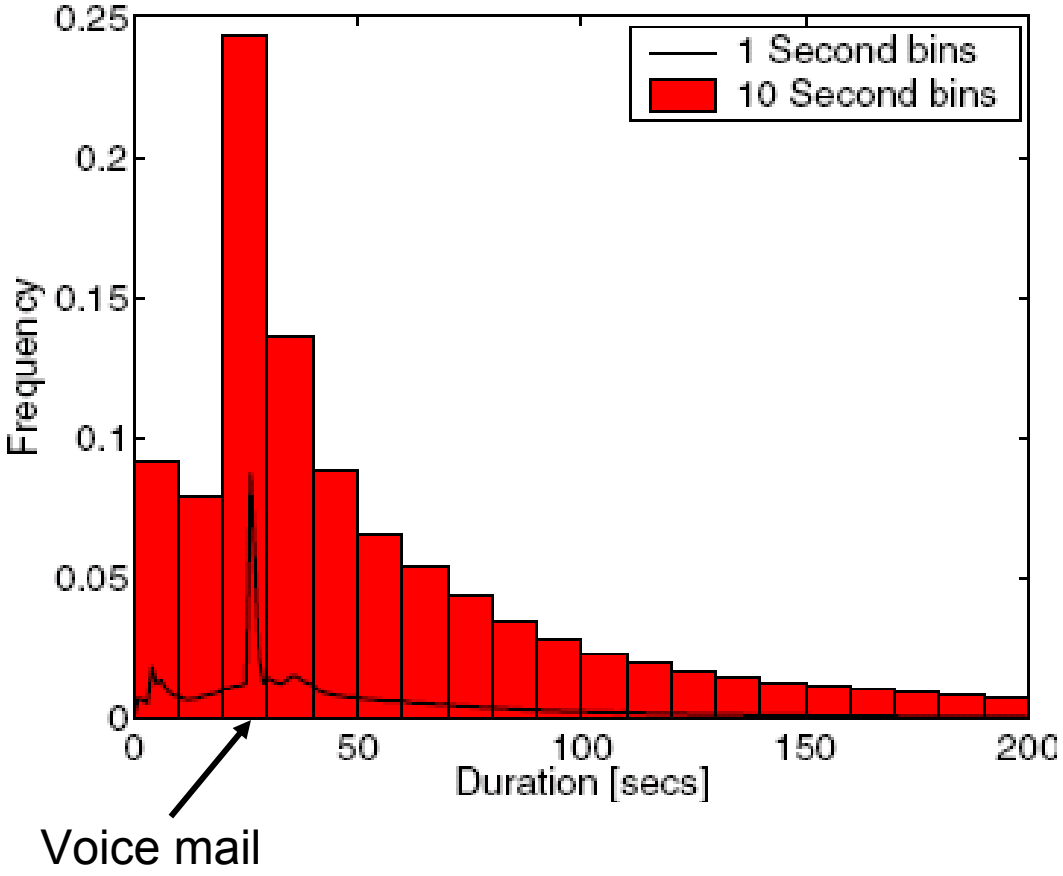
- ***Non stationary*** (assume stationary over 1 hour)

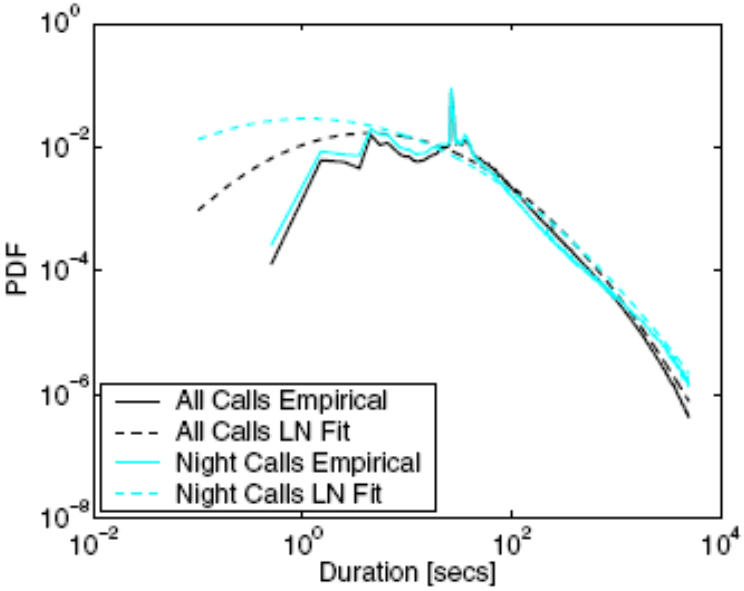
Distribution of Call Inter-arrival Times



- ***Call inter-arrivals are exponentially distributed***

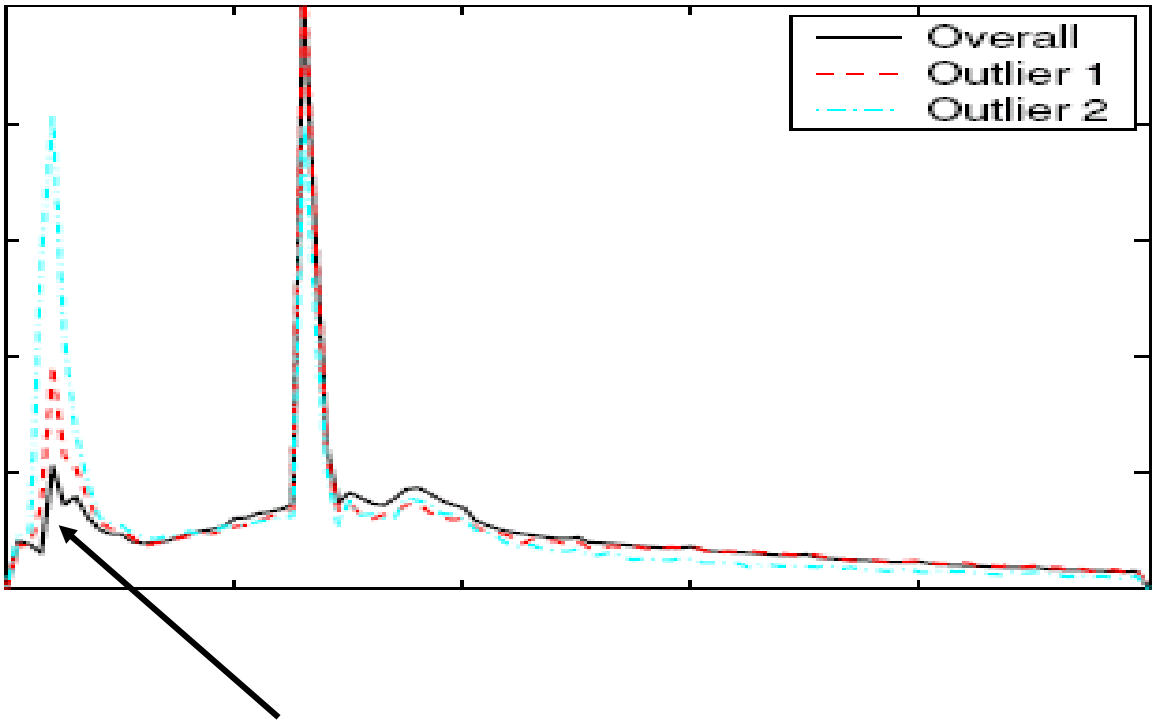
Distribution of Call Duration





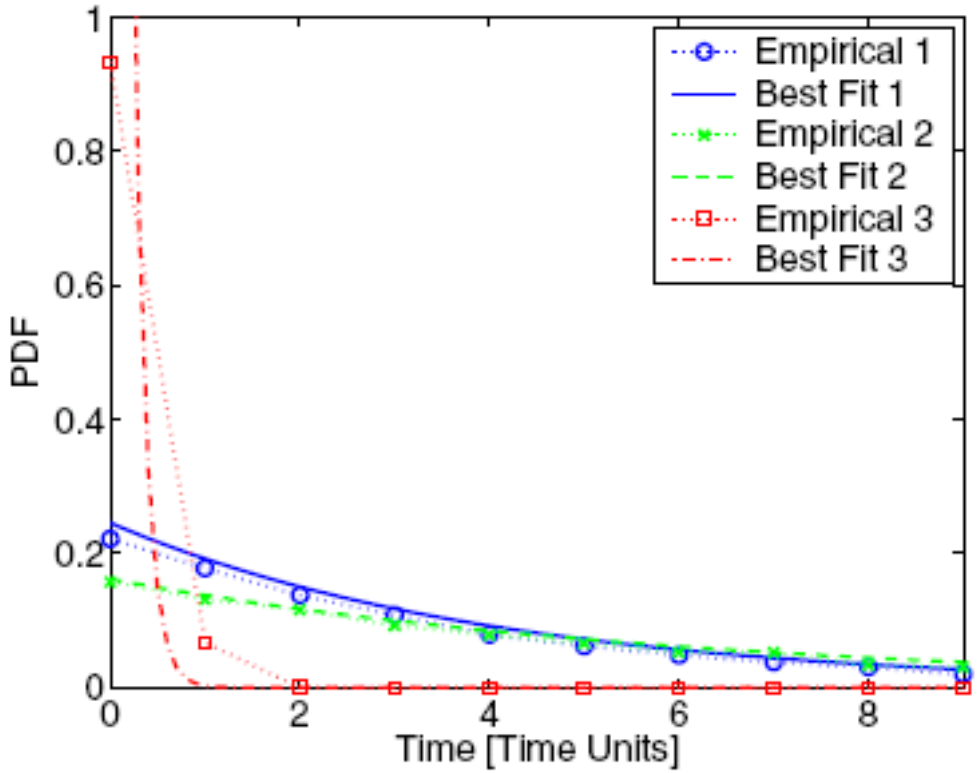
- ***Call durations are not exponentially distributed***
- ***Call durations are not log-normal***

Distribution of Call Duration – Outlier Events



Alternate Model: Random Walk

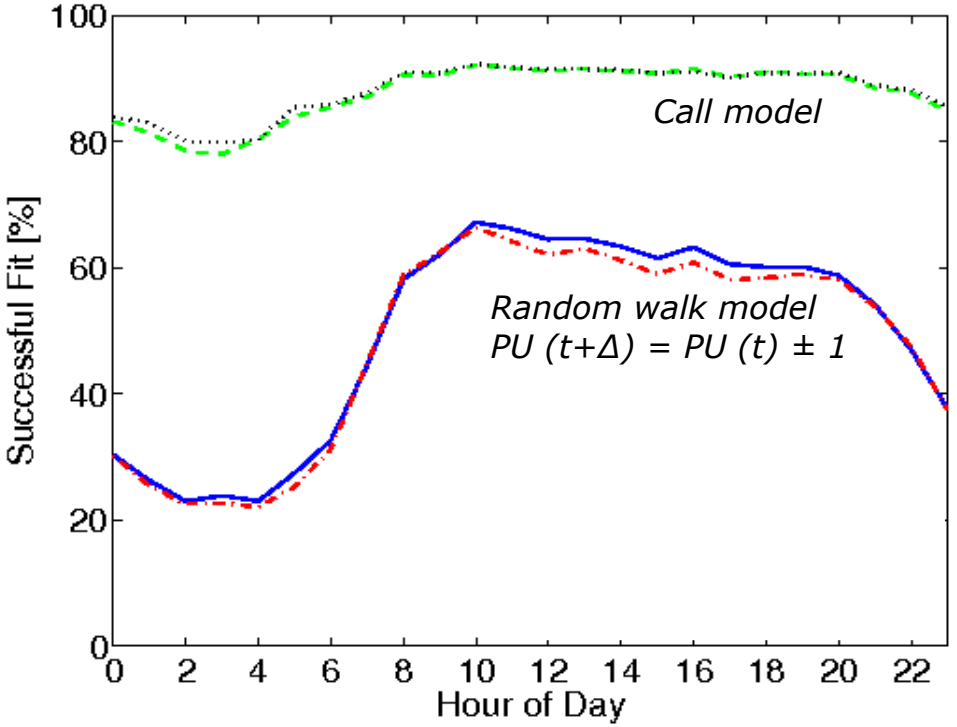
- Call duration hard to model => abstract out
- *PU load (t + Δ) = PU load (t) + (-1)$^{\phi}$*



- ***Δ consistent with exponential***

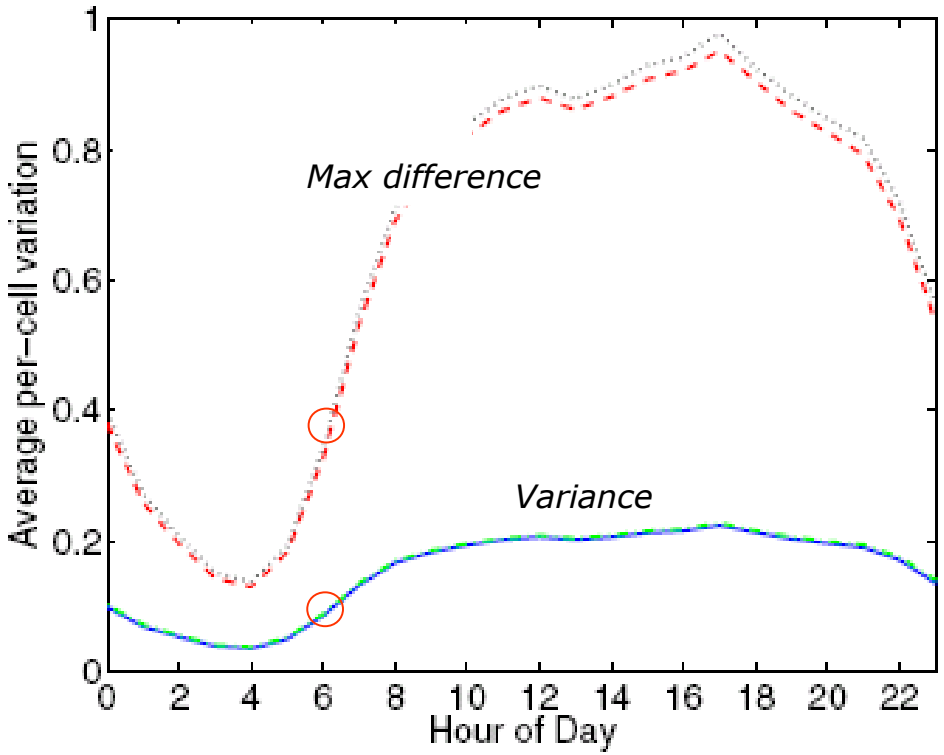
Temporal Behavior of PUs – Cell-based

- Examine *PU load (t)* in one cell only
- How well do earlier models work?



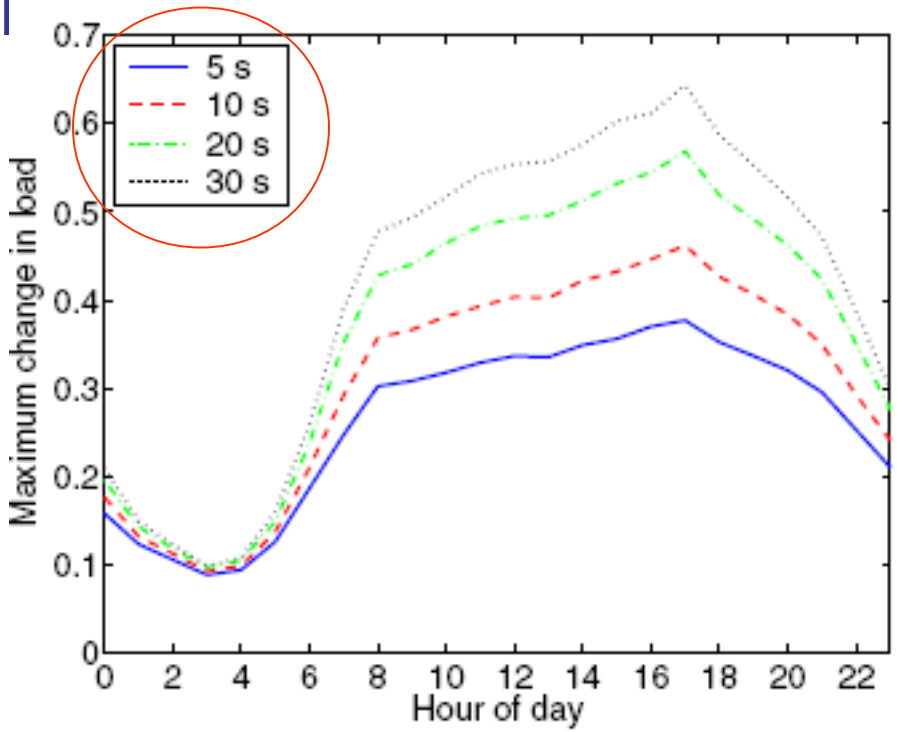
- ***Call model good for 90% of the hours***
- ***Random walk model only ok***

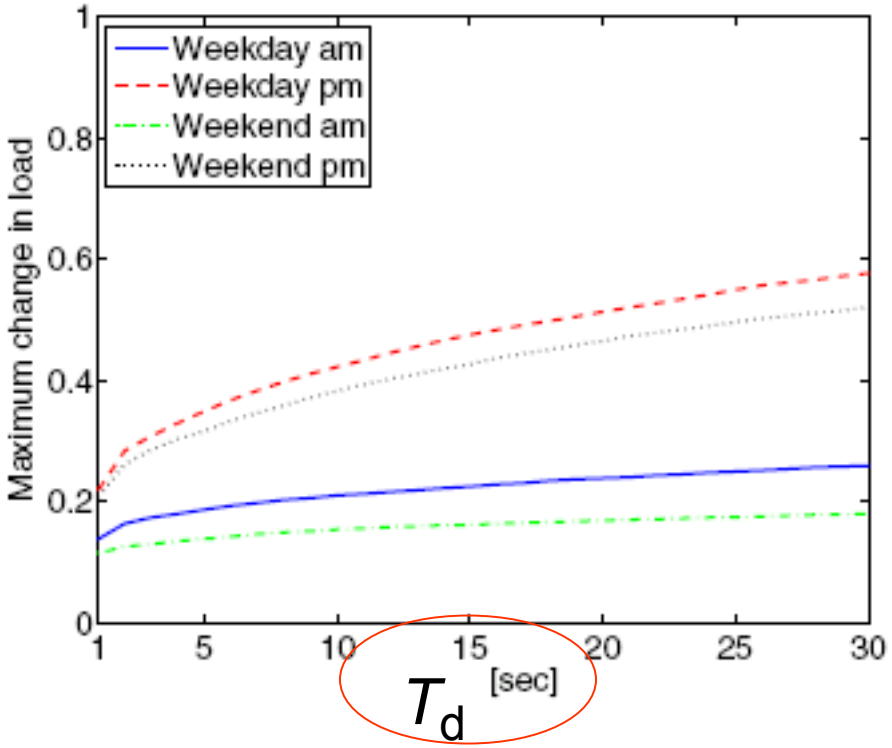
Impact on SUs – Stability of Available Spectrum



- Variation of PU load within 1 hour
  - Measure 1-minute load
  - Compute variance and max difference, avg over all cells
- Steady availability of spectrum at night
- Large variations => short data transmission T_d (period for periodic sensing)?

Choosing a Data Transmission Time T_d





- ***Pick large T_d at night***
- ***Pick low T_d during day, lowest in afternoon***

Key Takeaways

- A lot of unused spectrum in cellular bands
  - Secondary usage possible, especially night and weekends
- (In)validate models of PU behavior
  - Arrival process Poisson, but non stationary
  - Duration **NOT** Poisson
    - process complex (not log-normal either)
    - different day and night
  - “Burstiness” especially at high loads
- Application to DSA
  - PU model to price/negotiate spectrum usage
  - Need to adjust data tranmission period to time of day

Thank you

- Joint work with SPRINT Research, CA, USA
- Results presented in
  DySPAN 2008 (best paper award in the technical track)
  IEEE Communication Magazine, March 2009

Thank you for your attention

Questions?

Comments?