# PCAST and the Future of Spectrum Sharing

## Session III: Fresh Approaches to Spectrum Sharing

Mark Gorenberg (Hummer Winblad Venture Partners, PCAST Study Chair)
Preston Marshall (ISI, Univ. of Southern California)
Peter Stanforth (Spectrum Bridge, Inc.)
Apurva Mody (WhiteSpace Alliance and BAE Systems)
John Stine (Mitre Corp.)
Lynn Grande (IEEE)

Information Sciences Institute

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USC Viterbi School of Engineering

# Panel Participants

Mark Gorenberg (Hummer Winblad Venture Partners, PCAST Study Chair)

— Overview of PCAST Federal Spectrum Report (Longer Segment)

Preston Marshall (Univ. of Southern California)

— Spectrum Sharing: Ready for Prime Time

Peter Stanforth (Spectrum Bridge, Inc.)

— Spectrum Sharing using a Database Management System

Apurva Mody (WhiteSpace Alliance and BAE Systems)

— Fresh Approaches to Spectrum Sharing and Emerging Regulatory Rules in the TV Band WhiteSpaces.

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— Model-Based Spectrum Management: Enabling Dynamic Spectrum Sharing

Lynn Grande (IEEE)

— Supporting Standards for DSA

**Key Discussion Topic: Relate Ideas on Spectrum Sharing to PCAST Analysis and Recommendations**


# PCAST Report Metric: A Quantitative Basis for Policy

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# PCAST Report Metric

- A single Metric Formulation Unifies All of the Technical Proposals
  - *Described in Appendix B*
- Focuses on Spectrum Re-Use, not Use!
  - *Measures how one System Precludes the Use of Spectrum by Other Users*
- Reflects More than Bits/Hertz
  - *Receiver Performance for Guard Bands (LightSquared!)*
  - *System Interference Tolerance for Exclusion Zones*
  - *Range over Which the System Operates, or Requires Exclusive Use*
- Fundamental to the PCAST Vision of Future Spectrum Usage
  - *Area Coverage by Conventional Tower Architecture, with*
  - *Aggregate Capacity Provided by Short Range, Off Load Like Systems*
    - *Femto-Cells, WiFi, New Technologies and Service Models*
  - *Sharing with Low Cost, Low Power, Low Altitude, Urban Devices Much More Practical than with Tower-Based Infrastructure*
- More Spectrum Provides Linear Growth – More Sharing Provides Exponentially More Capacity – Only Way to get to 50 times

Drawn from: P. F. Marshall, *Scaling, Density, and Decision-Making in Cognitive Wireless Networks*, Cambridge University Press, To Be Released in Oct 2012.

# Baseline (Distance Sensitive) PCAST Report Metric

$$\mathrm{Eff}_{Spectrum} = \sum_{n=1}^{k} \frac{R(n)D(n)}{I^2(n)T(n)S(n)} \qquad (1)$$

Where:

| | | |
|---|---|---|
| $\mathrm{Eff}_{Spectrum}$ | Spectrum Effectiveness | Spectrum Effectiveness in terms of data delivered across a range, over the spectrum, area, and time whose usage is precluded |
| $R(n)$ | Communication Range | User $n$'s actual communication range |
| $D(n)$ | Data Delivered | Quantity of data delivered for user $n$ |
| $I(n)$ | Interference Range | User $n$'s interference range, out to which other uses of spectrum are precluded |
| $T(n)$ | Transmitted Data | Quantity of data actually communicated to user $n$ |
| $S(n)$ | Spectrum Precluded | User $n$'s actual spectrum precluded to other users |
| $k$ | Number of Users | Total spectrum users within a block of spectrum and over a region of operation |

Credit for Distance Communicated

Debit for Exclusion Zones Squared!

Application Layer Effectiveness

Poor Receivers "Consume" Spectrum

Time Sharing is Good!

Provides a Measure of:

$$\frac{\text{Bits Delivered over Distance}}{\text{Spectrum Precluded over an Area}}$$

# Architecture Effectiveness (Distance Insensitive) PCAST Report Metric

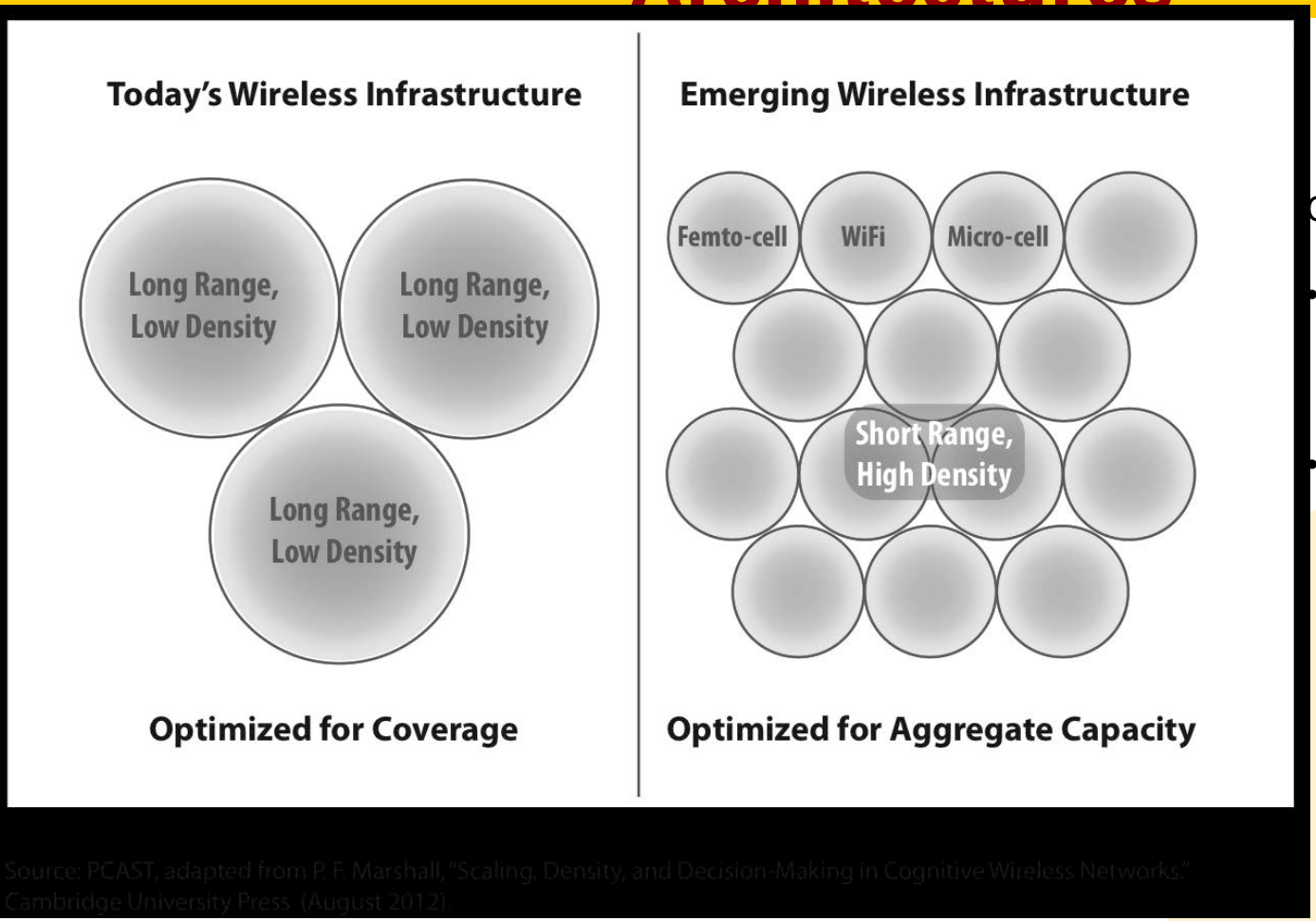
But, … if my goal is just to deliver data and one usage, then there is no credit for distance, and we consider only one capacity ($C_0$), Exclusion area ($I_0^2$) and Spectrum ($S_0$) footprint.

$$\text{Eff}_{Architecture} = \frac{C_0}{I_0^2 S_0} \qquad (3)$$

Conclusions:

- *Spectrum is only a Linear Contributor to Capacity – 50 Times User Bandwidth can not be Obtained by Doubling Carrier Spectrum or Bits/Hertz ($C_0/S_0$)!*
- *Spectrum Reuse is Driver of Aggregate Capacity*
- *Most Significant Factor is Interference Exclusion Zone, Therefore:*
  - *Shorten Communications Range*
  - *Add Interference Tolerance*
- *Example:*
  - *Move from 1.2 km Range Tower to 60 Meter FemtoCell or WiFi*
  - *Provide 6 dB of Interference Tolerance (Reduces Exclusion Range by Half)*
- *Metric Improvement:*
  - *20 times from Range Reduction, 2 times from Interference Tolerance = $40^2$, or a Metric Improvement of 1,600*

# The PCAST Metric View of Future Wireless Architectures




Source: PCAST, adapted from P. F. Marshall, "Scaling, Density, and Decision-Making in Cognitive Wireless Networks," Cambridge University Press (August 2012)

Overall Take Away:

- More Spectrum is Not a Viable Mechanism to Keep up with Capacity Needs
- Increasing Wireless Access Mechanisms are the Key, and Flexible, Shared Spectrum is the Way to Enable Exponential Growth in Access


# Spectrum Sharing: Ready for Prime Time

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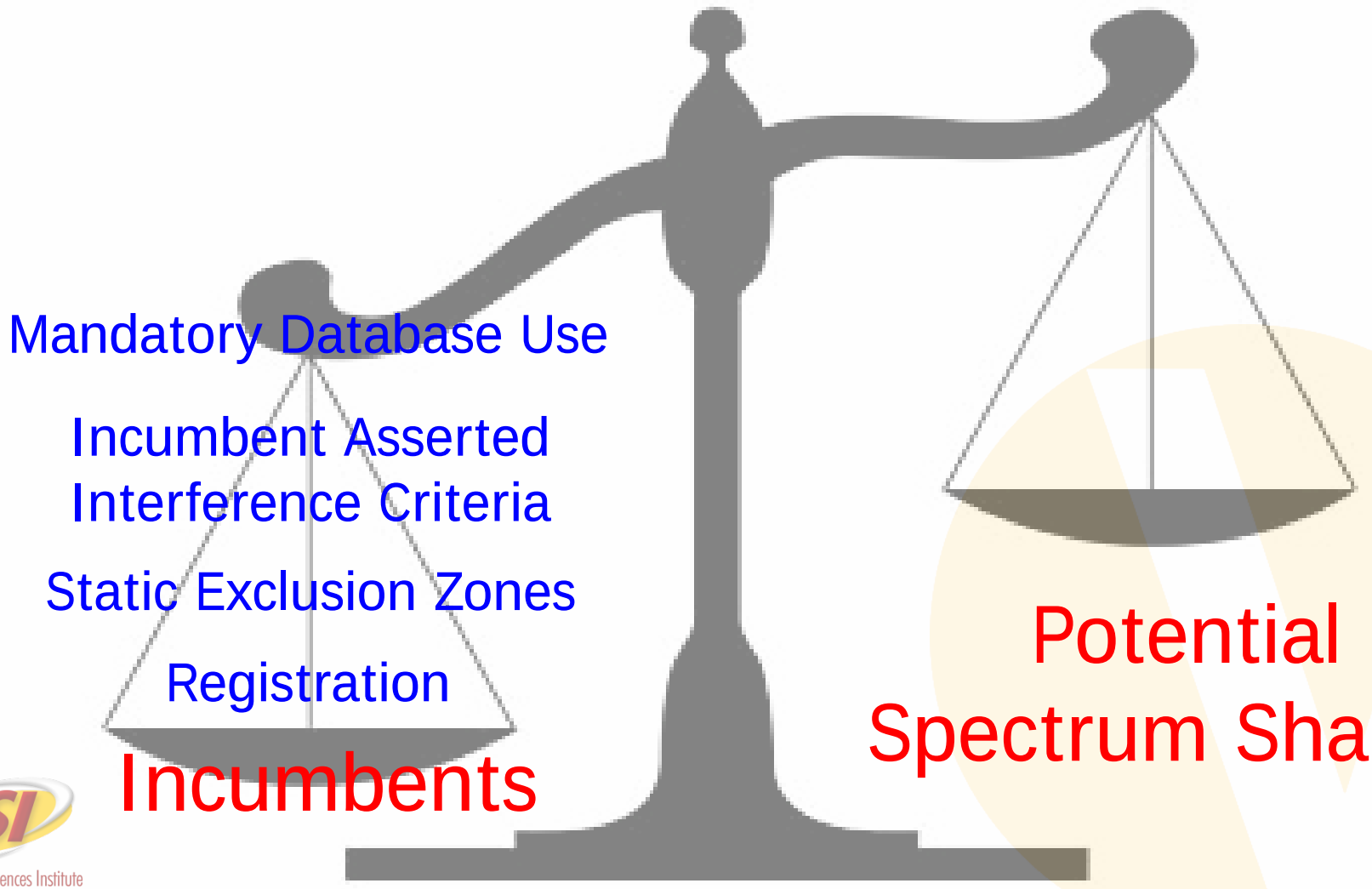
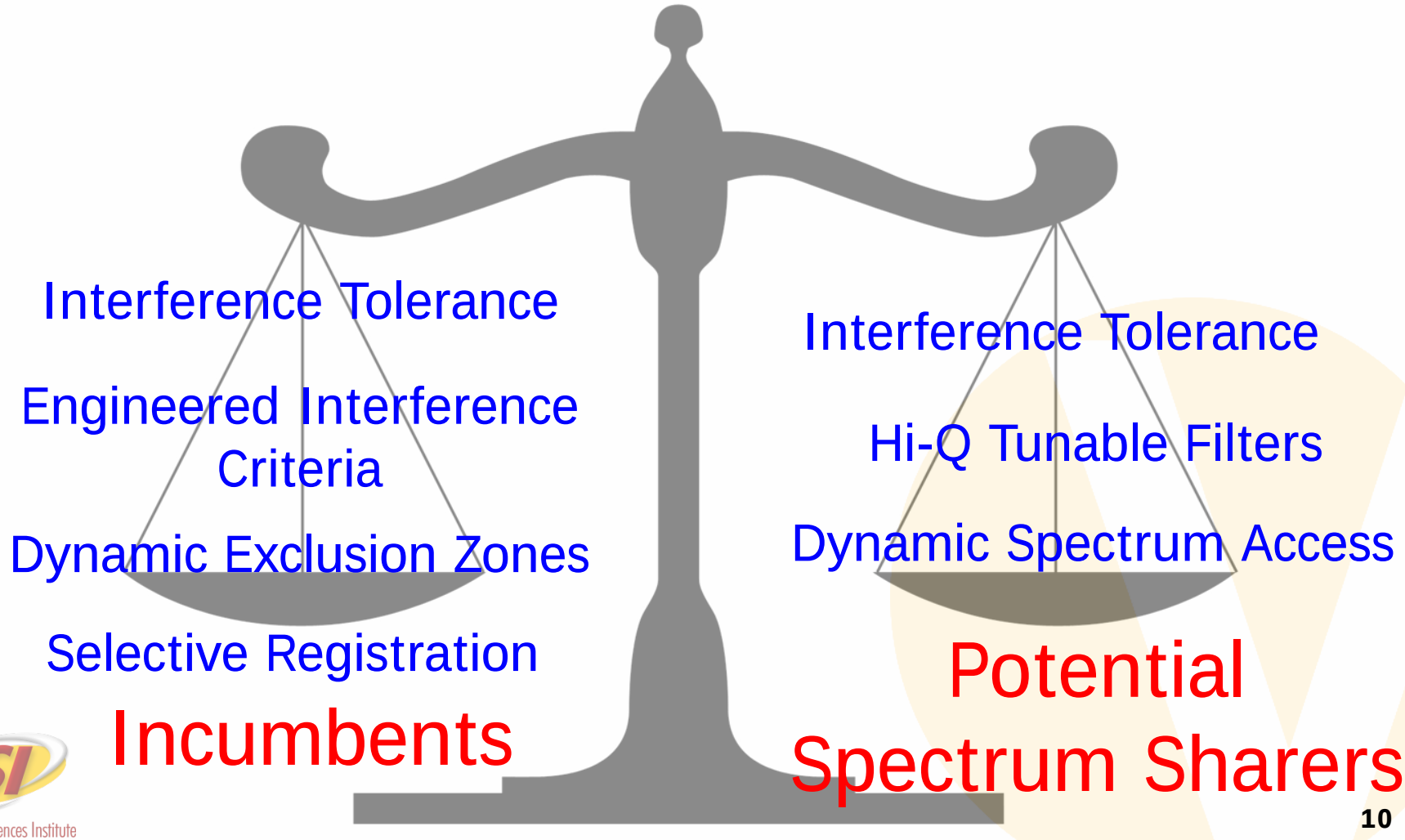
# Initial Adoption Will Require Suboptimal and Highly Conservative Assumptions



# Technology and Experience Needed to Balance Incumbent and Other Sharing Interests



# Shared Spectrum is Not Just for Unlicensed Technology

- Unlicensed Has Seen Massive Innovation, Rapid Product Evolution, …
  - *But, No Technical Reason to Believe that Unlicensed vs. Renewable, Long Term, Exclusive Licenses are the only Choices*
- Technology May flourish with Short-Term, Selectively Acquired, Licenses
  - *Enable Rapid Turnover of Technology and Licenses*
- Identical Systems and Products in Both Licensed (Protected) and Unprotected Modes
  - *In Low Density, May not Need Exclusive Rights -- Unlicensed LTE?*
- Technical Predictions:
  - *CMRS Services Will be Increasingly Dependent on Offload, LTE willnot be the Major Bandwidth Carrier, despite Carrier Advertisements!*
  - *WiFi is Primary Mechanism Today, but Shared Spectrum Could Provide Opportunities for a Wider Range of Technologies and Market Models*
  - *Wholesale Suppliers, Femtocell services, …*
  - *Flexibility to Innovate Will be Enabled by Multiple Spectrum Access Options*

# Technology Shortfalls for Full Exploitation of Sharing

- Better Interference Models
  - *Not Looking at One on One Sharing Cases, but All Possible Modes vs. All Possible Modes Exclusion Zones*
- Filters, Filters, Filters!
  - *No One is going to build a Cell Phone with 1 GHz Tuning Range out of SAW Filters!*
- Wider Range of DSA Large Scale Experimentation and Experience
  - *XG Experiments Still Largest Field Trial*
  - *DFS is Only Operational Experience*
  - *It May Take a New Generation of Federal Systems to Be Interference Tolerant of Occasional DSA "Errors"*
  - *I Believe in DSA, But No One is Going to Let it into their Spectrum Until it is SHOWN to be Massively Reliable, or they are Interference Tolerance*

# Receiver Technology Requirements

- Flexible Spectrum Usage Policy Introduces a Fundamental Issue
  - *Receiver Designers Design around the Existing Adjacent Channel Usage*
  - *Designers Have No Ability to Predict who Might be there in Future*
- System Operators Have Small Incentive to Invest in Better Equipment Based on all Ranges of Possible Future Incumbents
  - *Easier/Cheaper to Complain to FCC if it Happens!!*
- Shared Spectrum Implies Freedom to Innovate and Create Rapid Changes in Usage in Shared Bands Inconsistent with Current Interference Resolution
  - *Non Lawyer Version – "Bad Incumbent Equipment Blocks New Uses"*
- A Truly Flexible Spectrum Regime Must Provide Expectations (PFD) for Future Use of All Spectrum
  - *With Criteria, We can Use Automation to Manage Adjacent Band Energy to Within Prescribed Limits*
  - *If New Uses are Consistent – Tough Luck, Build a Better Receiver*
  - *Keep FCC, Congress, Courts out of these Issues*

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