The Commercial Sweetspot of Cognitive Radio

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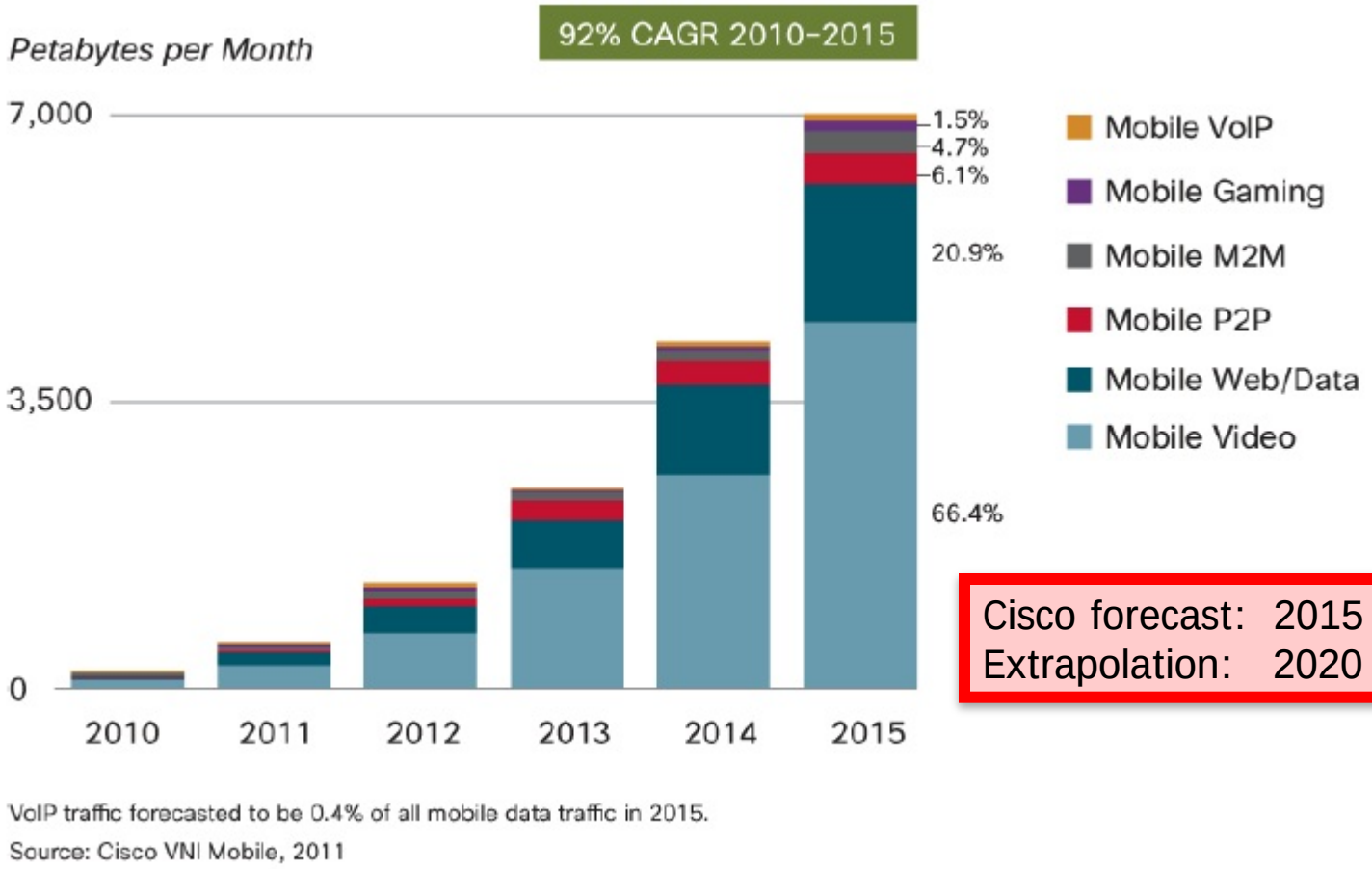
Some lessons from History I - Dominant designs

- From infrastructures driven by ”killer apps” and ”one-trick ponies”
  → general IP-based access infrastructures
- Internet access = dominant design for ALL services (fixed & mobile)
  - Marginalizes other technical solutions – e.g. Wireless P2P, Mesh, ...
  - Story sounds familiar ...?

Mobile Data avalanche



VoIP traffic forecasted to be 0.4% of all mobile data traffic in 2015.

Source: Cisco VNI Mobile, 2011

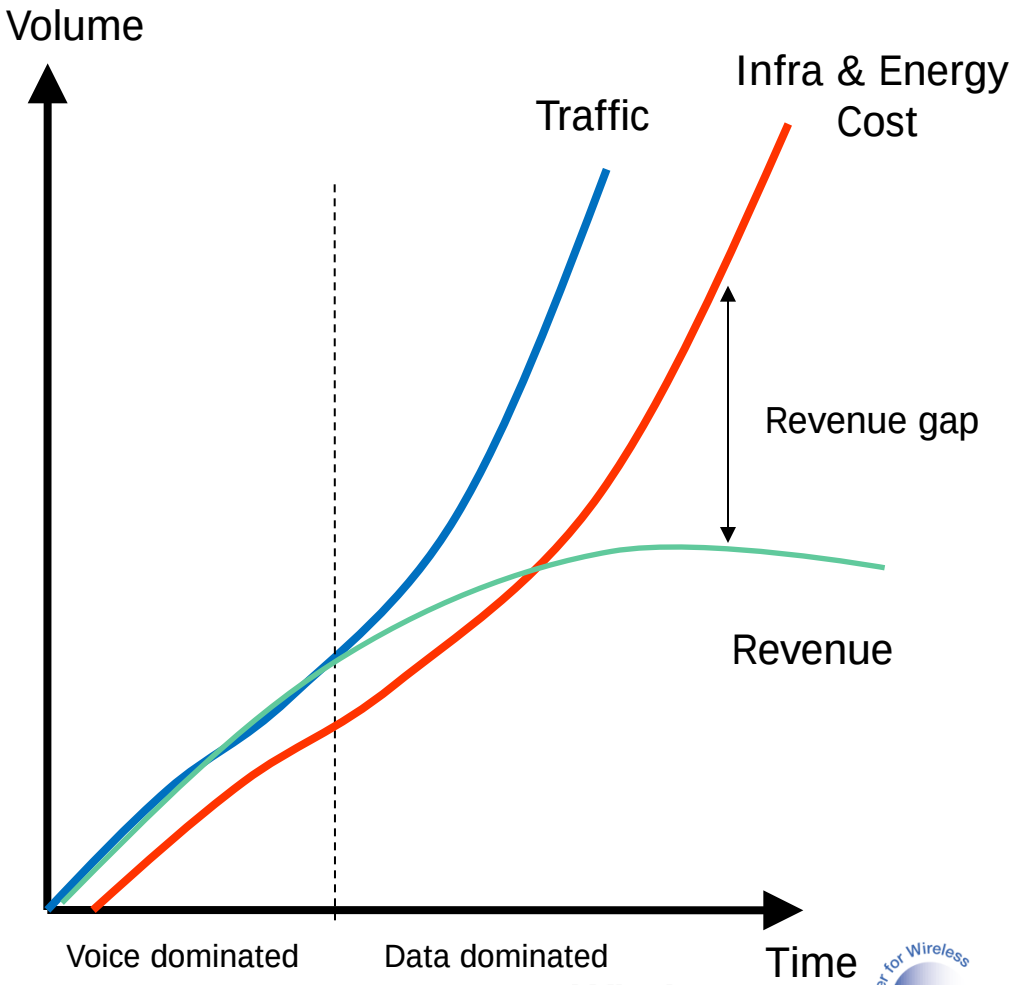
Cisco forecast: 2015 – 26x
Extrapolation: 2020 - 1000x

Exponential growth
Assumes zero marginal cost for access
How long can this be sustained ?

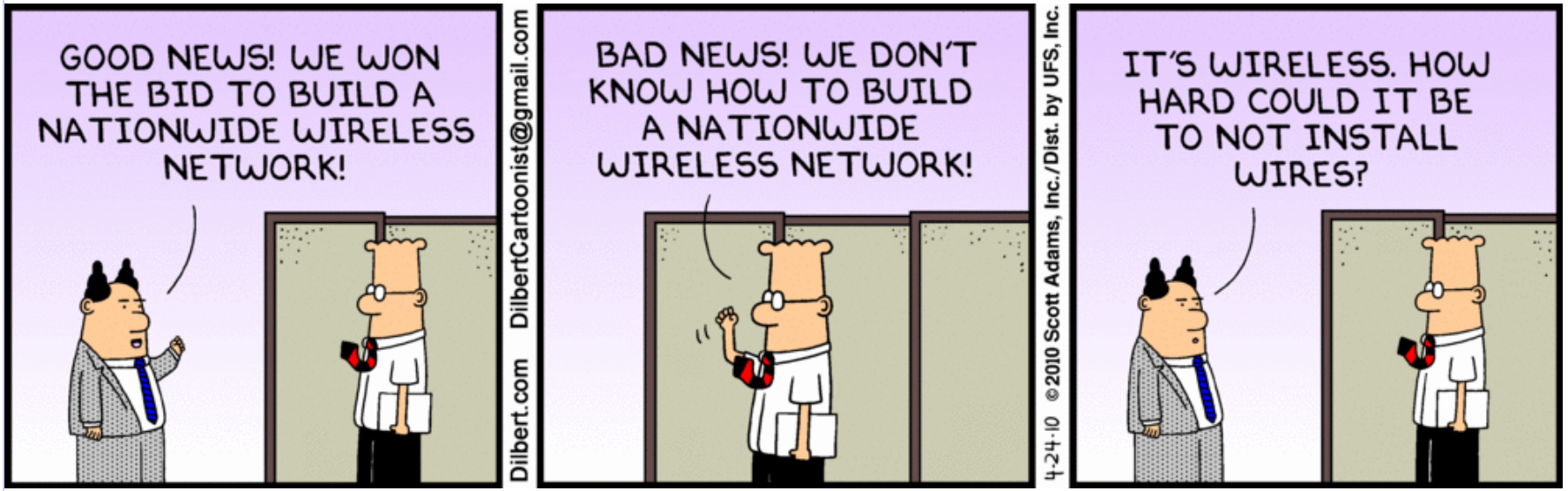
Operator dilemma: More for less money

- Spending capability of user increases with GNP growth (<10% annually)
- Capacity requirements increase by 80-100% annually

$$C_{SYS} = c_{BS} N_{BS}$$



How difficult can it be ?



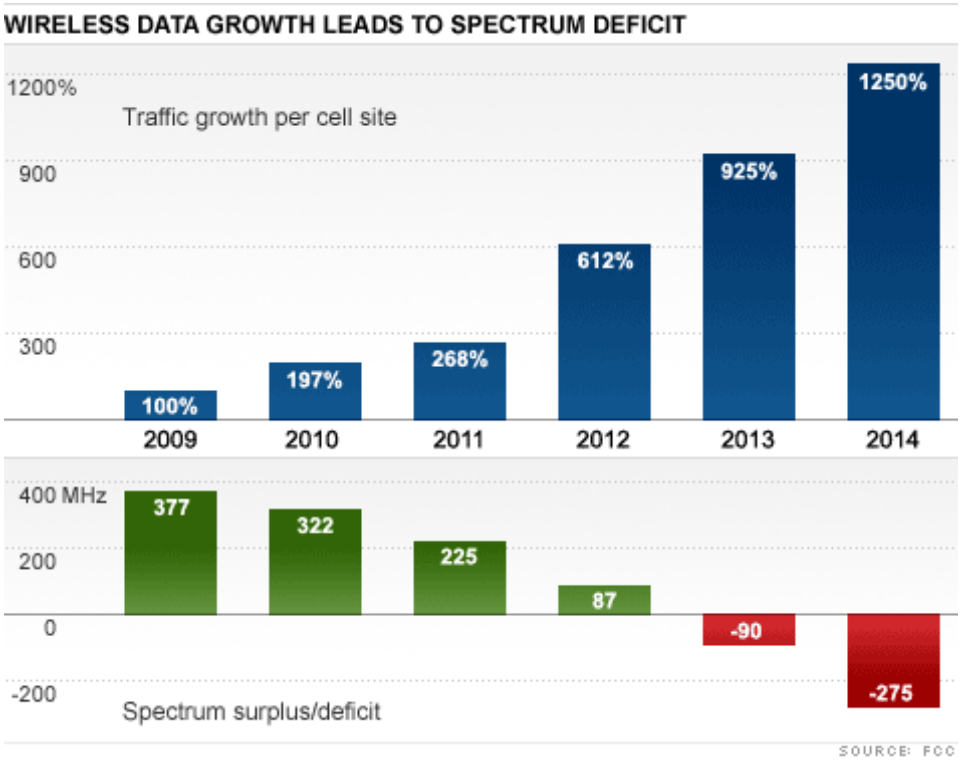
Is more spectrum the solution ?

How to increase capacity ?

$$R_{tot} \approx \frac{\eta}{A} N_{BS} W_{sys} \qquad C_{SYS} = c_{BS} N_{BS} + c_{sp} W_{sys}$$

- Increase η , spectral efficiency (signal processing)
  - Close to theoretical limits
- More base stations, N_{BS}
  - Expensive
- More spectrum, W_{SYS}
  - Shortage ?

FCC – Spectrum deficit ?

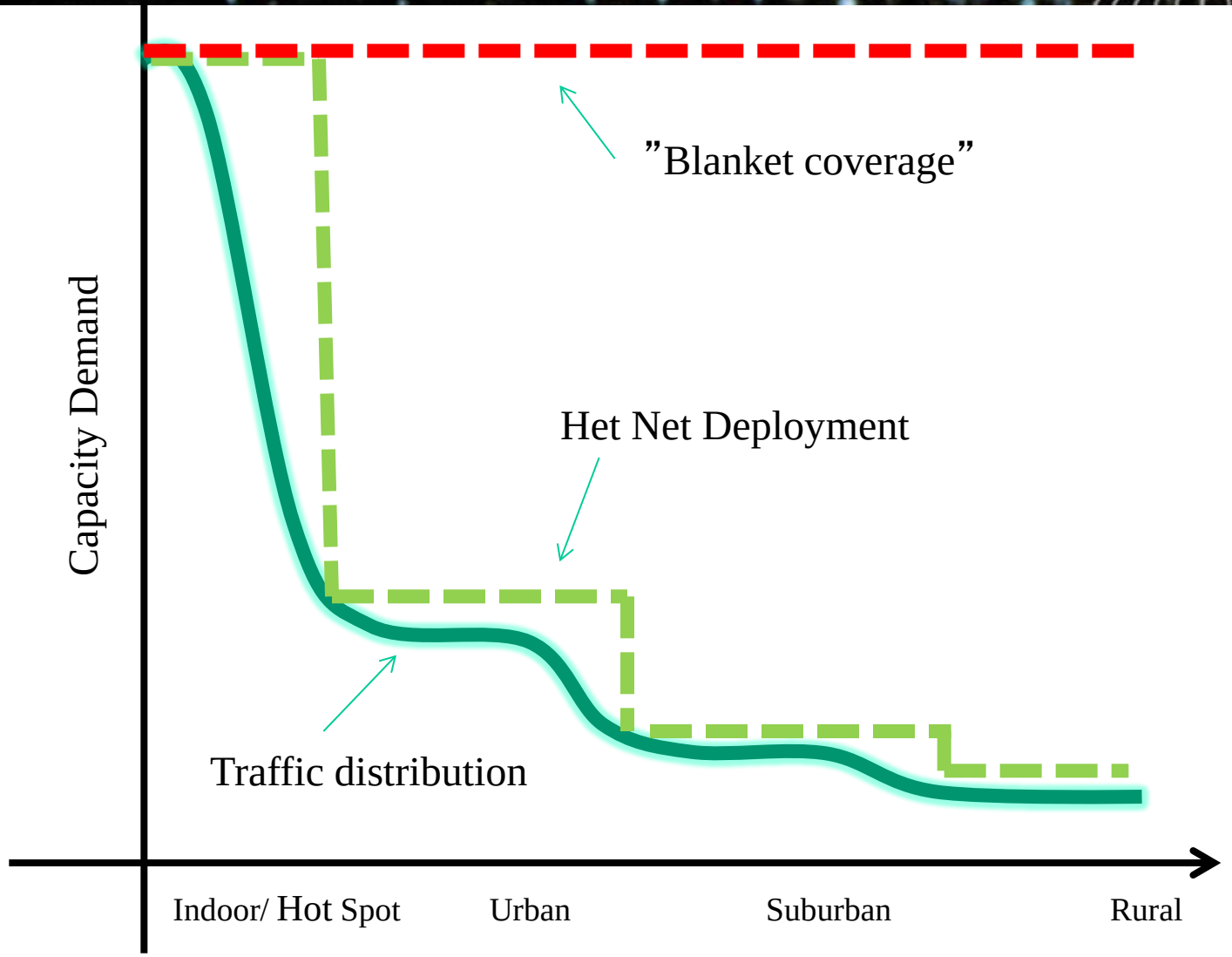


Key assumptions

Reasonable extrapolation of

- current deployment strategies (=moderate increase in base stations)
- transmission technologies.

How to lower the cost ”HET NET”s – deploy according to demand



HET NETs - The Light Analogy -

- Outdoor – Wide Area

- Indoor – Short Range

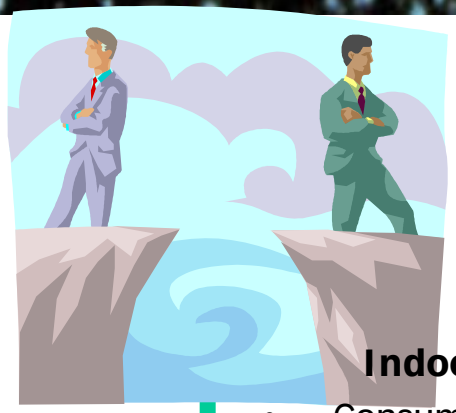
Densification: Technology shift

Wide Area (Macro)

- Industry grade eq
- High power
- 24-7 availabilty
- High **system** complexity
- High site costs (towers, backhaul..)

Small cell (Micro)

- Industry grade eq
- Medium power
- 24-7 availabilty
- High **system** complexity
- Backhaul limited
- Wall loss limitation



Indoor (Pico/Femto)

- Consumer grade eq
- Low power/Short range
- Low **system** complexity (P&P, SON)
- Massive deployment
- Reliability through redundancy
- Backhaul-limited - Deploy where backhaul available

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quasar

Assessing **real life** benefits of Cognitive Radio

The ”Why” & ”When” of Cognitive Radio ?

- Findings of QUASAR

”Cognitive” Technologies – key applications

- **Self-organizing networks**
  - Interference & capacity management,
  - ”user-deployed” access networks
  - **Lowers deployment cost !**
- **Secondary / Dynamic Spectrum Access**
  - Is there a shortage of spectrum ?
  - Is there secondary spectrum out there and when to use it ?
  - **Is it business-wise feasible** ?
  - (Can it be built ?)

Spectrum shortage ?

- **Spectrum availability**
  - Long-term, fundamental – time-scale: Decades
  - Regulatory/planning process, licensing
  - Important for large scale, long-term infrastructure deployment

  About 1 GHz of spectrum available for IP-Access (<6 GHz)
- **Spectrum access**
  - Short-term, ”Can I get access for my product now ?
  - Issue: ”Temporary” under-utilization of spectrum
  - Important for innovation, products with short life cycle

When is spectrum availability the barrier ?

A world divided

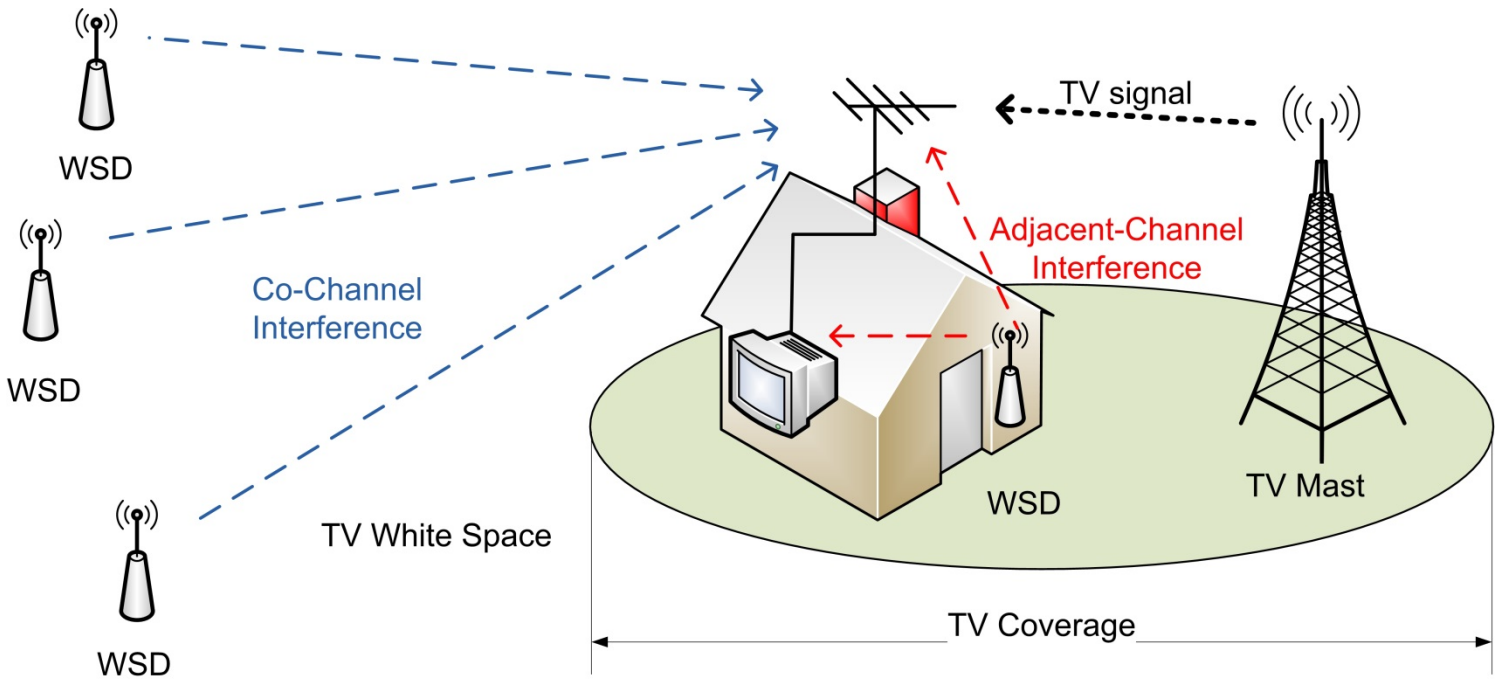
Urban

- Issue: Capacity
  - Spectrum
- Characteristics:
  - High data rates
  - Low power
  - Mass market – drives product & service development
  - Profitable

Rural

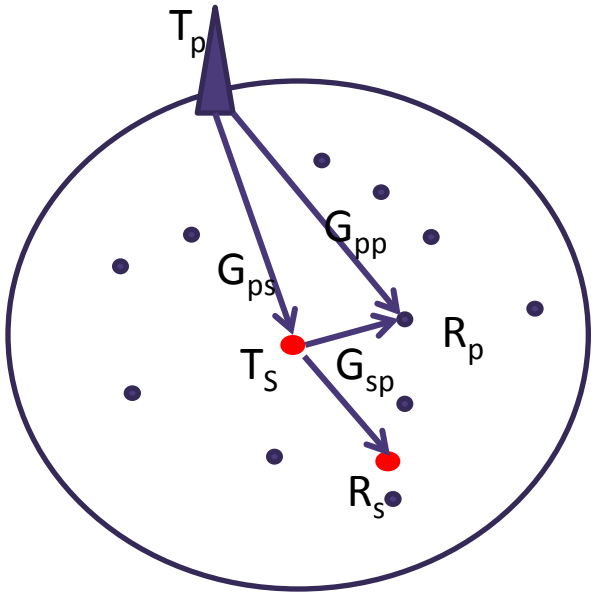
- Issue: Coverage
  - Infrastructure Cost/User
- Characteristics:
  - Moderate data rates
  - High power
  - Limited market
  - Not profitable

Technical issues in secondary access



What's wrong with (traditional) cognitive radio (=sensing ?)

- Opportunity (NOT signal) Detection problem
- In many popular scenarios there is nothing to "learn" and no feedback will be given
- Even with "perfect" signal detection uncertainty remains about
  - Primary receiver location
  - Primary system path loss
  - Aggregate interference
- → High interference margins and (very)



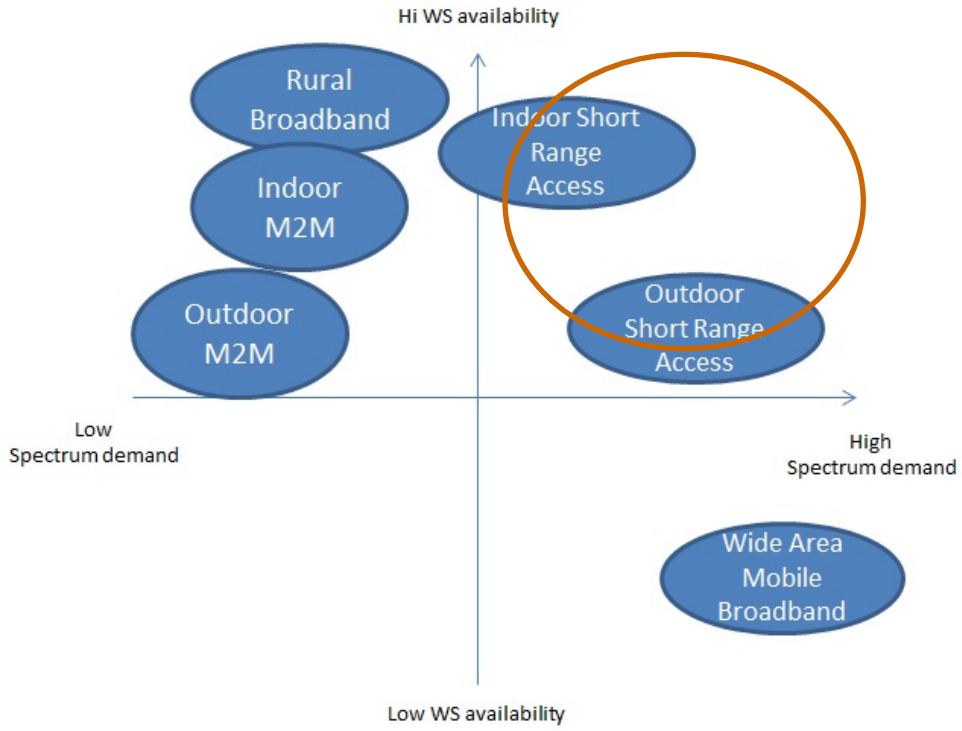
Scenario	Standard deviation	*IM* (95%)	*IM* (99%)	Rate (*IM*=95%)	Rate (*IM*=99%)
Low detection correlation (=0)	23,0	37,8	53,5	1,66E-04	4,51E-06
High detection correlation (=1)	21,5	35,4	50,1	2,86E-04	9,75E-06
Known primary receiver position	11,3	18,6	26,3	1,38E-02	2,33E-03
Known path gain	8,0	13,2	18,6	4,83E-02	1,38E-02
Genie aided access (full knowledge)	0	0	0	1	1

Key technical findings

- **Plenty of spectrum available – but very scenario, time & location specific - commercial success is where we can live with this**
- **Aggregate interference critical for the scalability , i.e. For massive scale use of secondary spectrum**
  - Both co-channel & and adjacent channel interference has to be considered
- **Classical ”Cognitive” sensing is not very effective in most of the scenarios – geolocation based techniques are preferable**
  - Limited knowledge of victim receiver location
  - Difficult to assess aggregate interference
  - Sensing may be interesting to improve/calibrate database propagation models

Seconday access = ”temporary” or localized solution

Key business findings: Which of the QUASAR scenarios are commercially promising?

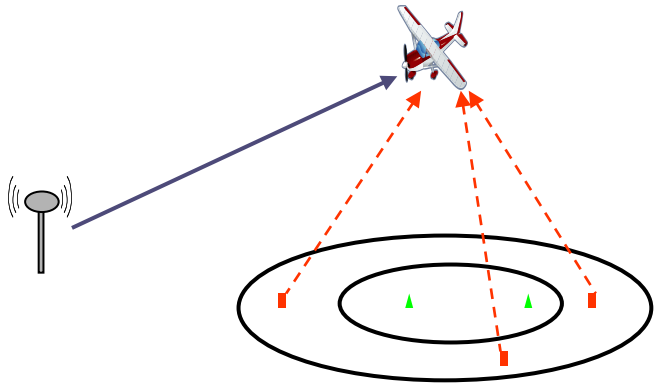


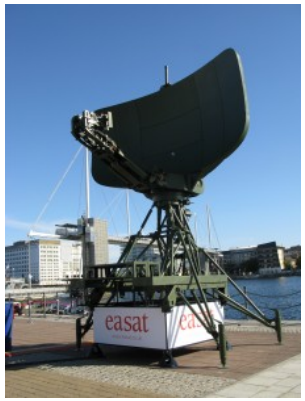
The **”Commercial Sweetspot”** of secondary spectrum

Short range/indoor high capacity systems = where large demand for and technical availability of spectrum meet

Where could ”cognitive radio” work ?

- **Two-way primary systems**
  - DME aeronautical navigation
- **Primary Receiver & Transmitter co-located**
  - Radar systems
  - Short range primary systems
- **Very low power systems**
  - Interference avoidance (e.g. WSN)





Not all bands are created equal
- limitations to spectrum use

- **New ”distant” frequency band**
  - Requires new hardware(technology)
    ”Yet another radio” in base stations, terminals etc
- **Unsuitable propagation conditions (low η)**
  - Too short(coverage), too long range (interference)
- **Wide band radios & antennas**
  - Efficiency loss outweigths spectrum access benefit ?
- **Access limitations & business uncertainty**
  - Sharing with other users (e.g. Secondary spectrum)
  - Mismatch between licensing regime and usage
  - Mismatch between licensing regime and investments

What are we making of all this ?

Spectrum licensing regimes

- **Wide area systems**
  - Low spectrum preferred
  - Interference protection over wide areas
  - Heavy, long-term investments in radio infrastructure – bulk of investments owned by operator
- **Long term national block licensing**
  - Advantage: Few regulatory decisions
  - Drawback: Oligopolistic market structure

- **Local / indoor systems**
  - High spectrum preferred
  - Interference protection over very small areas
  - Small investments in radio infrastructure - bulk of infrastructure owned by premises owners
- **Very local, light licensing**
  - Many, local actors
  - Local monopoly –matches access to premised

Where are we (should we be) heading ?

Wide area access

- Licensed spectrum to match long-term RF-specific investments (<3 GHz)
- Repurposing of UHF from TV -> IP access
  - Digital dividends 800, 700, 600 MHz etc

Short range access

•Higher frequencies (>3 GHz) for high capacity (lower interference)

•Local & temporal spectrum regimes (National Block-licensing inefficient)

•Unlicensed, Secondary, LSA, ”Instant licensing”

Some conclusions

- Wireless Cloud Access – the dominant design of future services
- Spectrum not really a fundamental limiting factor
  - Matching to infrastructure investment life cycle
  - Secondary access not suitable for large scale use
  - Mobile/fixed internet access replaces other dedicated services
- Cognitive techniques promising in ”Self-configuring Networks” – to lower the cost of deployment