Cognitive Radio – a "Dead Duck"?
- on the Commercial Viability of Secondary Spectrum

Jens Zander, Project Manager
Wireless@KTH Seminar
November 16, 2012
# Buzzword Bingo

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QUASAR a glance

The Project
- FP7 STREP (Future Networks)
- 30 Month (Jan 2010 – June 2012)
- 5 MEuro / 3 MEuro
- KTH - Coordinator

The Output
- Tools & Methods
- Regulatory input
- Publications (14+63)
- Workshops
Do we need more spectrum?
Cisco forecast: 2015 – 26x
Extrapolation: 2020 - 1000x
FCC “spectrum deficit”
What to do about the "Capacity Crunch"?

<table>
<thead>
<tr>
<th>Company</th>
<th>Spectrum</th>
<th>Spectral efficiency</th>
<th>Densification</th>
<th>Total capacity increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nokia Siemens</td>
<td>10X</td>
<td>10X</td>
<td>10X</td>
<td>1000</td>
</tr>
<tr>
<td>Huawei</td>
<td>3X</td>
<td>3.3X</td>
<td>10X</td>
<td>100</td>
</tr>
<tr>
<td>NTT DoCoMo</td>
<td>2.8X</td>
<td>24X</td>
<td>15X</td>
<td>1000</td>
</tr>
<tr>
<td>Our suggestion</td>
<td>3X</td>
<td>5X</td>
<td>66X</td>
<td>1000</td>
</tr>
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</table>

Reference: Today's allocation < 6GHz 2-300 MHz exclusive Mobile, 4-500+ MHz shared for "WiFi"

Conclusion:
- Spectrum is ONE of factors - no "absolute" necessity for more spectrum
- More spectrum can save energy & infrastructure cost, simpler receivers
Spectrum shortage?

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

- **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
The cost of spectrum

\[
C_{sys} \approx c_{BS} N_{BS} = c_{BS} \frac{R_{tot}}{\eta W_{SYS}} A
\]

\[
R_{tot} \approx \frac{C_{sys}}{c_{BS} A} \eta W_{sys} = \frac{\eta}{A} N_{BS} W_{sys}
\]

\[
R_{tot} + \Delta R \approx \frac{\eta}{A} N_{BS} W_{sys} + \frac{\eta}{A} \Delta N W_{sys} + \frac{\eta}{A} N_{BS} \Delta W
\]

\[
C_{sys} + \Delta C \approx C_{sys} + c_{BS} \Delta N + \left( \Delta c_{BS} N_{BS} + c_{sp} \right) \Delta W
\]

\[
\min \Delta C = \min \left( c_{BS} \frac{\Delta R}{\eta W_{SYS}} A, \left( \Delta c_{BS} N_{BS} + c_{sp} \right) \frac{\Delta R}{\eta N_{BS}} A \right)
\]

\[
c_{sp}^* = \frac{C_{BS}}{W_{SYS}} - \Delta c_{BS} N_{BS} \quad \text{Engineering value of spectrum}
\]
Is mobile spectrum still "cheap"?

Source: B G Mölleryd and J Markendahl
Valuation of spectrum for mobile broadband services - The case of Sweden and India
ITS Regional Conference, New Dehli, Feb 2012
Where can we find spectrum?

30-300MHz
Good coverage, low availability

300MHz -3GHz
Good coverage, moderate availability

3GHz -30GHz
Poor coverage, high capacity/ availability

30GHz -300GHz
"No" coverage, very high capacity/availability
## Spectrum options

<table>
<thead>
<tr>
<th></th>
<th>Exclusive &lt;6 GHz</th>
<th>Shared &lt; 6 GHz</th>
<th>Secondary &lt;6 GHz</th>
<th>Exclusive &gt; 10 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>Very Low</td>
<td>Moderate</td>
<td>Good (&gt;1 GHz) for indoor use</td>
<td>Very good</td>
</tr>
<tr>
<td>Advantages</td>
<td>• Guaranteed QoS</td>
<td>• Spectrum available</td>
<td>• Spectrum available</td>
<td>Very high capacity</td>
</tr>
<tr>
<td></td>
<td>• Long-term investments</td>
<td>• Low cost equipment/deployment</td>
<td>• Low cost equipment/deployment</td>
<td>Low interference</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>High deployment cost</td>
<td>• No QoS guarantees</td>
<td>• Limited QoS guarantees</td>
<td>LOS propagation, Dedicated Deployment</td>
</tr>
<tr>
<td></td>
<td>• Low availability</td>
<td>• Regulatory uncertainty</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Secondary spectrum

How to "borrow" someone's else's spectrum without causing problems ...
Some definitions

- **Primary user**
  - Formally: has the right to transmit using a certain signal, power, location (transmitter permit, block license)
  - In practice: has the right to receive signals without interference

- **Secondary user**
  - Has the right to use the frequencies, blocks of the primary as long as no interference is caused
  - Has to share this right with other primary users (in some way)
Criteria for successful secondary sharing

- **Different usage patterns**
  - If primary and secondary systems compete for the same frequency in the same time & space, this will be a competition the secondary will lose.

- **(Detailed) Knowledge about the primary system behavior**
  - where are the primary transmitters, when and on which frequencies will they transmit..

- **Inefficient spectrum utilization of the primary system spectrum**
  - e.g. the efficiency of the primary system is limited by legacy technology
Scenarios

Secondary sharing with legacy systems

1. Cellular use of white spaces
2. WiFi-like use of white spaces
3. Secondary wireless backhaul
4. Secondary spectrum commons in radar band
5. Indoor broadband in aeronautical spectrum
6. Cognitive machine-to-machine
Low spectrum Occupancy = Available Spectrum?

Source: L Khalid, A. Anpalagan. "Emerging cognitive radio technology: Principles, challenges and opportunities"
QUASAR Key question

- Is there secondary spectrum out there that lends itself for **commercial** use?
  - Can it be detected efficiently?
  - Does it scale? Is there enough spectrum of “sufficient quality”?
  - What are the applications that can benefit from secondary sharing?
”Cognitive Radio”
The Cognitive Cycle

Mitola, Maguire: “Cognitive radio: making software radios more personal”

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"Spectrum Holes" ≠ Reuse opportunities

Challenges for secondary spectrum access:

How to find reuse opportunities and use them without exceeding tolerable limits

- Co-channel interference
- Adjacent channel interference
- Aggregate interference
Adjacent channel interference

Explains “low utilization”: Significant parts of the spectrum are used to enable low cost receivers

Source: OFCOM/ERA: DVB-T Interference into DTT Receivers
Co-channel & Adjacent channel interference
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)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Standard deviation</th>
<th>IM (95%)</th>
<th>IM (99%)</th>
<th>Rate (IM=95%)</th>
<th>Rate (IM=99%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low detection correlation ( =0)</td>
<td>23,0</td>
<td>37,8</td>
<td>53,5</td>
<td>1,66E-04</td>
<td>4,51E-06</td>
</tr>
<tr>
<td>High detection correlation ( =1)</td>
<td>21,5</td>
<td>35,4</td>
<td>50,1</td>
<td>2,86E-04</td>
<td>9,75E-06</td>
</tr>
<tr>
<td>Known primary receiver position</td>
<td>11,3</td>
<td>18,6</td>
<td>26,3</td>
<td>1,38E-02</td>
<td>2,33E-03</td>
</tr>
<tr>
<td>Known path gain</td>
<td>8,0</td>
<td>13,2</td>
<td>18,6</td>
<td>4,83E-02</td>
<td>1,38E-02</td>
</tr>
<tr>
<td>Genie aided access (full knowledge)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
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Where could ”cognitive radio” work?

- Two-way primary systems
  - DME aeronautical navigation

- Primary Receiver & Transmitter co-located
  - Radar systems
  - Short range primary systems
Spectrum Geolocation Database

- Secondary user request "channel" at certain location – Database grants access & maximum power level
- "Instant licensing"
- Possibility to control aggregate interference

Source: Ofcom
Location dependent spectrum availability

- Varying spectrum availability
- Large system bandwidth needed to guarantee sufficient available secondary bandwidth
TV / Cellular

Figure 4.25 Total available downlink WSD throughput capacity for mobile link using SE43 rules and with a separation distance of 100 m in Germany and Sweden.
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 interesting to improve/calibrate database propagation models
Issues not considered....

- **Broadband systems**
  - Example: TV Band: 470 - 790 MHz \((Δf/f = 50\%)\)
- **Amplifier efficiency**
- **Antenna efficiency**
- **Receiver blocking/IM**
The Commercial Sweetspot

Business feasibility
Key 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
Why not cellular in TVWS?

- Competing targets - both systems target wide-area availability

- Time-scale clash: why use "temporary spectrum" for long-term investments (20+ years)?

- Secondary spectrum available where it is not needed

- System cost dominated by infrastructure cost
  - Exclusive spectrum is relatively "cheap"
  - High risk with new technology - marginal gains
“White Space Offloading”

- More spectrum needed
  - More capacity, less energy
- Mostly short range deployment
  - Hot spot/Indoor capacity enhancement
  - Low cost equipment
  - Complement wide-area access services
- White Space Offloading
  - Low cost wireless equipment
  - Most investment in fixed infrastructure
  - Access to specific spectrum not critical
Other scenarios

- **Rural Broadband & M2M based on secondary spectrum**
  - Technical feasible, opens market for new actors – but plenty of excess capacity in traditional licensed spectrum

- **Wide - area cellular based on secondary spectrum**
  - May work in some (rural)areas, but technical availability is too limited/erratic where the large demand is to motivate long-term investments
Conclusions

● A methodology for assessing the technical availability of spectrum and the business requirements.

● Plenty of spectrum available - but very scenario, time & location specific, which limits the commercial value.

● "Cognitive" sensing not very effective in many popular scenarios - geolocation based techniques preferable.

● The "Commercial Sweetspot" of secondary spectrum.

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

● Hits on "cognitive radio" in Google Scholar
Thank You for Your attention!

http://quasarspectrum.eu