Spectrum for "5G" – where is the problem?

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Outline

• Why do we need 5G?
  • Transparency & mobile data tsunami
  • Things that communicate & the Internet of Senses
• Who needs more spectrum?
  • The two worlds – or are they three?
• What spectrum should we be looking for?
Key trend 1: Transparency eats efficiency for breakfast
Why do we have a Data Tsunami?
Dominant designs

- **Internet access** + Cloud based solution = the Dominant Design for all application involving communication – since 2007 also on mobile

- Simple interface **IP** for all "apps" creates explosive growth – works on all platforms

- Inefficient for (almost) all applications: we buy flexibility at the expense of large data volumes data

- Other specific communication technologies (e.g. P2P, Multi-hop) and "one trick ponies" (e.g. Broadcast Radio/TV) become marginalized

"IP is the answer - now, what was the question?"
The price tag for transparency – the Mobile Data avalanche (as seen in 2010)

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

\[ C_{SYS} = c_{BS} N_{BS} \]

Challenge: 1000x lower cost/bit
Cellular traffic estimates now more modest

- Market saturation?
  - Everyone has a smartphone?
- Volume based charging?
  - "Buckets" instead of "all-you-can-eat"
- Bulk of the traffic off-loaded elsewhere?
  - WiFi

Source: Ericsson Mobility Report, Nov 2014
Key trend 2: Things that communicate & the Internet of Senses
Things that communicate

Internet of Things

- Billions of devices
- Low power
- Low cost
- High reliability
- Low delay

4G not a scalable solution
SIM-cards in every device?
"The internet of senses"
(a.k.a. "The Tactile Internet")

IP Cloud

< 1 ms delay
Speed of light: 300 km/ms
Everything under one roof?  
Transparency vs Efficiency

The IP-access world
- Large volumes of standardized equipment, unified platforms
- Low efficiency, overprovisioning of resources
- Willingness to pay for flexibility

The MTC world
- Large volumes
- Very diverse requirement on power, delay, cost...
- Non-standardized equipment, no unified platforms
- Rational decisions based on savings
How difficult can it be?

..and is more spectrum the solution?
Who needs more spectrum?
How to increase capacity?

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

$$R_{tot} \approx \frac{\eta}{A} N_{BS} W_{sys} \quad C_{SYS} = c_{BS} N_{BS} + c_{sp} W_{sys}$$
Solving “all” problems with more spectrum - the “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

Traffic distribution

Capacity Demand

Indoor/ Hot Spot  Urban  Suburban  Rural

"Blanket coverage"

Het Net Deployment
HET NETs - The Light Analogy

- Indoor – Short Range
- Outdoor – Wide Area
A World Divided – business aspects

The coverage world

Public operators
Access any-time, anywhere
"Insurance" – guaranteed access
Monthly fee

Power/Site/Backhaul
Exclusive spectrum licensing

The capacity world

Facility owners
Sanitary requirement / no charge
User experience – high data rates

Ultra dense deployment – Interference
(Low power, no site cost, existing backhaul)
Where is the "new" spectrum?
What kind of spectrum?
## Spectrum options

<table>
<thead>
<tr>
<th></th>
<th>Exclusive &lt;6 GHz</th>
<th>Unlicensed &lt; 6 GHz</th>
<th>Secondary &lt;10 GHz</th>
<th>Exclusive &gt; 10 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Availability</strong></td>
<td>Very Low</td>
<td>Moderate</td>
<td>Good (&gt;1 GHz) for indoor use</td>
<td>Very good</td>
</tr>
<tr>
<td><strong>Advantages</strong></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><strong>Disadvantages</strong></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></td>
<td>• Low availability</td>
<td>• Regulatory uncertainty</td>
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</tbody>
</table>

Plenty of spectrum for short range indoor - in total close to 1 GHz for wireless access
Spectrum sharing?
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?
• where are the primary receivers and what interference will they tolerate?

Inefficient spectrum utilization of the primary system spectrum
• e.g. the efficiency of the primary system is limited by legacy technology
Co-channel & Adjacent channel interference

Lei Shi, “Efficient Spectrum Utilization of UHF Broadcast Band”
Ph.D. Thesis, KTH June 2014
The Commercial Sweetspot of spectrum use

Short range/indoor high capacity systems

Success due to physics - not due to smart regulation or "cognitive" technology
Example: ATC radar spectrum shared indoor

Different usage patterns

(Detailed) Knowledge about the primary system behavior

Inefficient spectrum utilization of the primary system spectrum

Stockholm case study
Co-channel, Outdoor, $P=10\text{dBm}$ $h=1.5\text{m}$
600 users/sqkm, 15% activity

IEEE International Symposium on Dynamic Spectrum Access Networks (DYSSPAN), McLean, VA, USA, April 1-4, 2014
Microwave link – Indoor sharing scenario

- Different usage patterns (spatial separation)
- (Detailed) Knowledge about the primary system behavior
- Inefficient spectrum utilization of the primary system spectrum (very limited spatial region)
# Key Trends in spectrum sharing

<table>
<thead>
<tr>
<th>Today</th>
<th>Tomorrow</th>
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</thead>
<tbody>
<tr>
<td>Transmitter specification</td>
<td>Receiver specification</td>
</tr>
<tr>
<td>Interference Limits</td>
<td>&quot;Pain Sharing&quot;</td>
</tr>
<tr>
<td>Secondary access</td>
<td>Sharing / Co-primary</td>
</tr>
</tbody>
</table>
Where are we heading - spectrumwise?

Wide-Area outdoor
- Large, long-term infrastructure investments (>> spectrum cost)
- Low frequencies (<3 GHz)
- Wide coverage → interference with other services

Exclusive licensing

Mobile short range, indoor
- Low/moderate investment
- Moderate frequencies (3-30 GHz)
- Indoor Short range → limited interference with other services

Millimeter-Wave, short range, indoor
- Low investment
- High frequencies (>30 GHz)
- Very short range → very limited interference with other services

Open Access

Vertical / Horizontal sharing?
Exclusive – LSS – Open Access?
Where are we heading - spectrumwise?

Wide area access
Spectrum needed to lower infrastructure cost
Block-licensed spectrum to match long-term
RF-specific investment (<3 GHz)
Repurposing of UHF from TV -> IP access
• Digital dividends 800, 700, 600 MHz etc
Millimeter-waves to get exclusive spectrum?

Short range access
Plenty of potential spectrum <10 GHz
Higher frequencies (>3 GHz) for high
capacity (lower interference)
Local & temporal spectrum regimes (National
Block-licensing inefficient)
Unlicensed, Secondary, LSA, ”Instant
licensing”

Infrastructure vs Spectrum Sharing?
Some conclusions

- Wireless Cloud Access – the dominant design of future services!?
- Indoor ultra-dense deployment – a completely different ballgame
  - Systems constraints
  - Spectrum sharing feasible
- Spectrum not really a fundamental limiting factor for capacity
  - Matching to infrastructure investment life cycle