Is it a bird? .. a plane?

No, it’s 5G!

Jens Zander
Scientific Director, Wireless@KTH
KTH – The Royal Institute of Technology,
Stockholm, Sweden
Outline

• Why do we need 5G?
  • Transparency & mobile data tsunami
  • Things that communicate & the Internet of Senses

• Are there Scalable Infrastructure Solutions?
  • The two worlds – or are they three?
  • The Resource Triangle: Cost, Energy, Spectrum

• What are the technologies we should 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?"

G Q Maguire
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?

VolP traffic is said to be 0.4% of all mobile data traffic in 2015.
Source: Cisco, "InfraMobile, 2011"
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
Mission critical communication
(Super real-time, super reliable...)

Source: The Economist, April 20th, 2013
METIS 5G Scenarios

- Great Service in a crowd: Amazingly fast
- Best experience follows you
- Super real-time and reliable connections
- Ubiquitous things communicating
- bit-rate, delay
- accessibility, large crowds
- accessibility (Coverage) mobility
- delay, reliability, new industrial applications
- many simple devices, coverage (redundancy)

Virtual reality office
Shopping mall
Open air festival
Mobile cloud processing
Emergency communications
Teleprotection in smart grid networks
Massive deployment of sensors and actuators
Dense urban information society
Stadium
Traffic jam
Blind spots
Traffic efficiency and safety
Is there (one) Scalable Infrastructure Solution?
The Resource Triangle

\[ C_{tot} = C_{spectrum} + C_{infra} + C_{energy} \]
How to increase capacity?

\[
R_{\text{tot}} \approx \frac{\eta}{A} N_{BS} W_{\text{sys}} \quad \text{Gbit/s/m}
\]

\[
C_{\text{SYS}} = c_{BS} N_{BS} + c_{sp} W_{\text{sys}} + c_{E} E_{\text{sys}} (\eta, N_{BS}, W_{\text{sys}})
\]

- Increase \( \eta \), spectral efficiency (signal processing)
  - Close to theoretical limits
  - More power (TX power, processing, receivers)
- More base stations, \( N_{BS} \)
  - Expensive
  - More power?
- More spectrum, \( W_{\text{SYS}} \)
  - Shortage?
How to lower the cost:
”HET NET”s – deploy according to demand

Traffic distribution

Indoor/ Hot Spot  Urban  Suburban  Rural

”Blanket coverage”

Het Net Deployment

Capacity Demand
The Light Analogy I: HET NETs

- Indoor – Short Range

Outdoor – Wide Area
A World Divided

The coverage world

Industry grade equipment
High power/Wide area
24-7 availability
High **system** complexity

The capacity world

Consumer grade equipment
Low power/Short range
Reliability through redundancy
Low **system** complexity
A World Divided

The coverage world

Public operators
- Access any-time, anywhere
- "Insurance" – guaranteed access at moderate data rates (<10Mbit/s)
- Monthly fee
- Power/Site/Backhaul
- Exclusive spectrum licensing – spectrum sharing

The capacity world

Facility owners
- Local access – "off-loading"
- Sanitary requirement / no charge
- User experience – high data rates
- Ultra dense deployment – Interference
- Low power, "no" site cost, existing backhaul
- Post-code licensing – infrastructure sharing

The coverage world vs The capacity world

The capacity world is limited by its own high demand, while the coverage world has limited demand but ample capacity.

A World Divided

The coverage world

The capacity world
Capacity and Economic feasibility

More access points - or more expensive backhaul (for coordination)?
Is there enough capacity?

<table>
<thead>
<tr>
<th></th>
<th>Intersite</th>
<th>Spectrum</th>
<th>No BS</th>
<th>Cap/Site</th>
<th>Area cap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro</td>
<td>300 m</td>
<td>500 MHz</td>
<td>10 /km²</td>
<td>1 Gb/s</td>
<td>10 Gb/s/km² (outdoor)</td>
</tr>
<tr>
<td>WiFi - today</td>
<td>30m</td>
<td>500 MHz</td>
<td>1000/km²</td>
<td>1 Gb/s</td>
<td>1 Tb/s/km²</td>
</tr>
<tr>
<td>WiFi - ideal</td>
<td>1/room</td>
<td>2 GHz</td>
<td>50K/km²</td>
<td>4 Gb/s</td>
<td>200 Tb/s/km²</td>
</tr>
</tbody>
</table>

Simple area-based calculation – outdoor/indoor wall penetration not included
Where are we heading - spectrumwise?

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

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

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

Open Access

Exclusive licensing

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

Wide area access
Spectrum need 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

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?
# Key Trends in spectrum sharing

<table>
<thead>
<tr>
<th>Today</th>
<th>Tomorrow</th>
</tr>
</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>
Can the Things use the same infrastructure?
Very diverse requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Human centric</th>
<th>Machine Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>Very Large</td>
<td>Small</td>
</tr>
<tr>
<td>Number of devices</td>
<td>Moderate</td>
<td>Very large</td>
</tr>
<tr>
<td>Wide area coverage</td>
<td>Important</td>
<td>(Sometimes) Important</td>
</tr>
<tr>
<td>Reliability</td>
<td>Moderate</td>
<td>(Sometimes) High</td>
</tr>
<tr>
<td>Cost</td>
<td>Moderate</td>
<td>(Sometimes) Very low</td>
</tr>
<tr>
<td>Power consumption</td>
<td>Moderate</td>
<td>Sometimes) Very low</td>
</tr>
<tr>
<td>Delay</td>
<td>Moderate</td>
<td>Sometimes) Very low</td>
</tr>
</tbody>
</table>
Everything under one roof? Transparancy 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
Distribution of resources critical

IP Cloud

Edge cloud "Fog"

Air interface delay

Autonomous processing

< 1 ms delay

Speed of light: 300 km/ms
Mobility Foresigth – Alternative (Technical) Mapping

Capacity world (Local Area)

1000 times more capacity

Ultra Dense

Mobile Data

Best effort IP infrastructure for all?

Human-centric Design

User experience

Single infrastructure = traditional operator model?
Mobility Foresigirth

- The Technoclan
- The Flash Mob
- The Red Queens Army
- The Harmonious Empire

High complexity of market structure
Low complexity of market structure
Machine centric design
Human centric design
In Summary:
Fundamental/revolutional 5G challenges

- Spectrum/Infrastructure sharing concepts
- ”Plug-and-play” ultra-dense

• Addressing the Internet-of-Important Things:
  • Scalable, low power, low-cost super-reliable wide-area
  • Extreme low latency
  • Distribution of computational resources
In Summary

5G is

- Not technically needed to contain most of the "Data Tsunami" (can be managed by evolved 4G +WiFi)
- Addressing new challenges in large scale, wide-area infrastructure for M2M applications
- Not only about connectivity but a computational platform to manage generic resources like processing and storage
- Important to the incumbent industry to show renewal and claim (exclusive) spectrum to sustain current business model
Read more!

wireless.kth.se

theunwiredpeople.com

johannesbergsummit.com