Is it a bird? .. a plane?

No, it's 5G!

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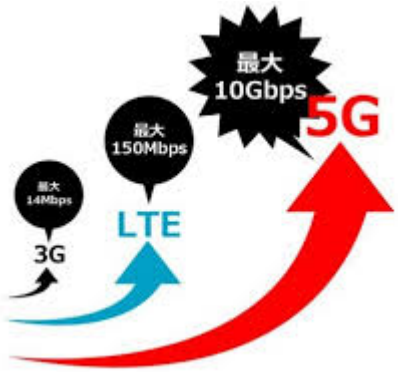

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Outline

- **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

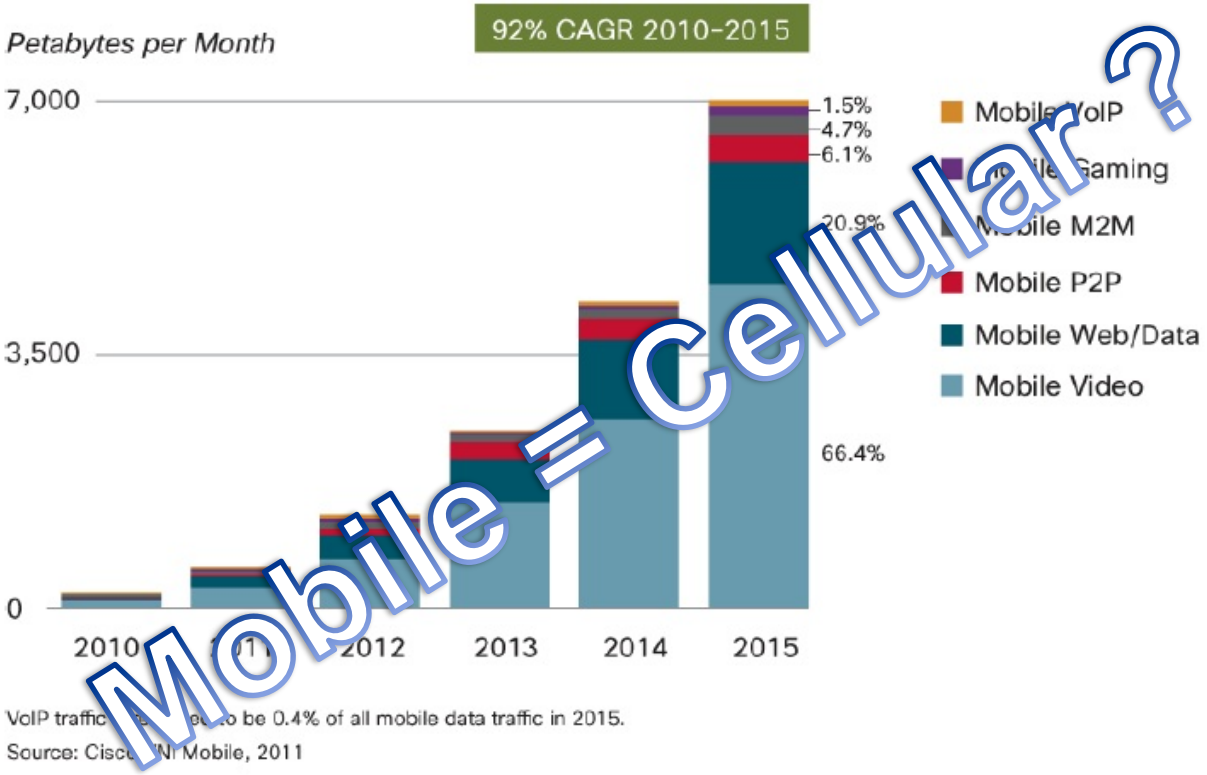
Why do we have a Data Tsunami? Dominant designs

- 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 apllications: 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)



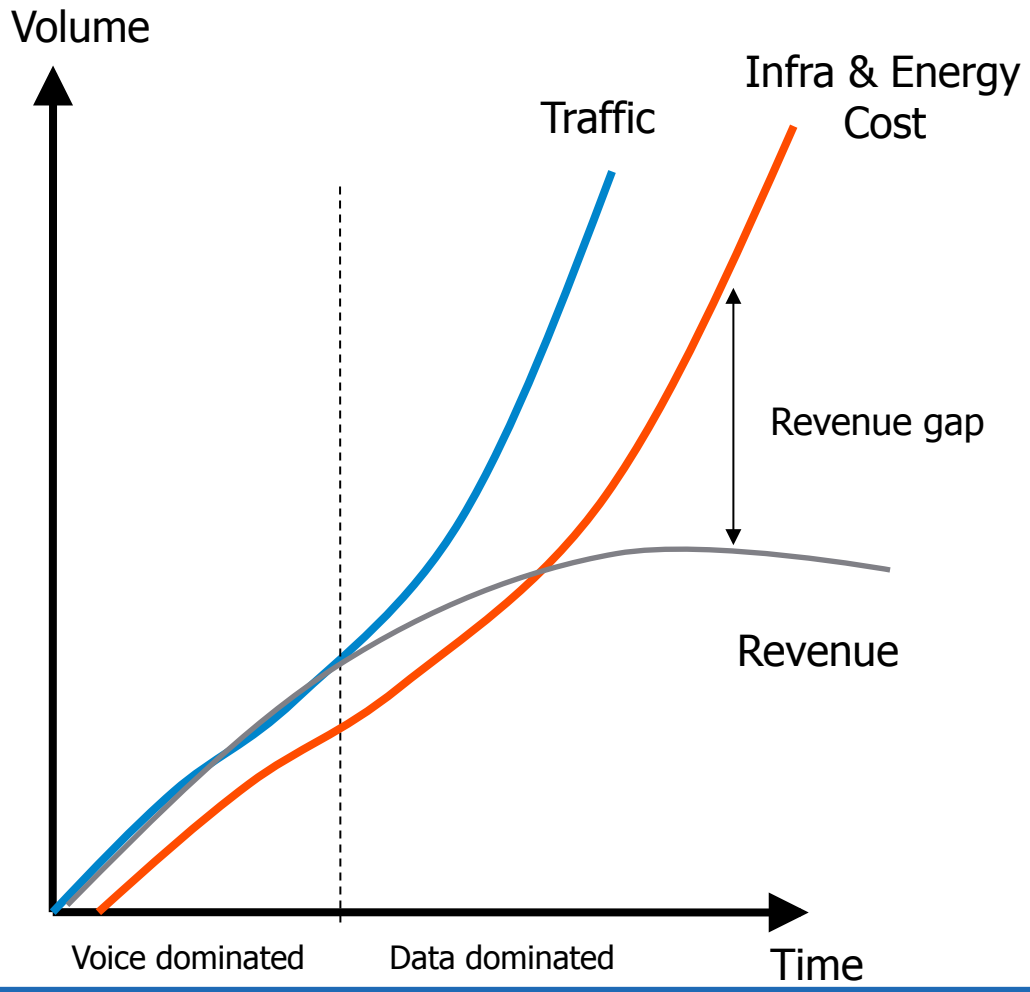
Exponential growth
Assumes **zero marginal cost** for access
How long can this be sustained ?

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



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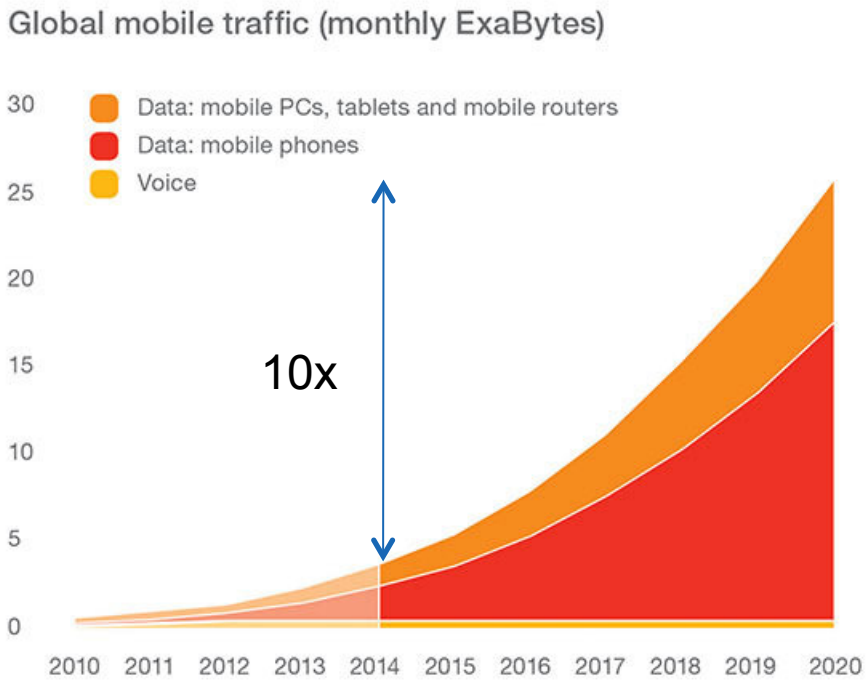
Cellular traffic estimates now more modest



Source: Ericsson Mobility Report, Nov 2014

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

Key trend 2:
Things that communicate & the Internet of Senses

Things that communicate

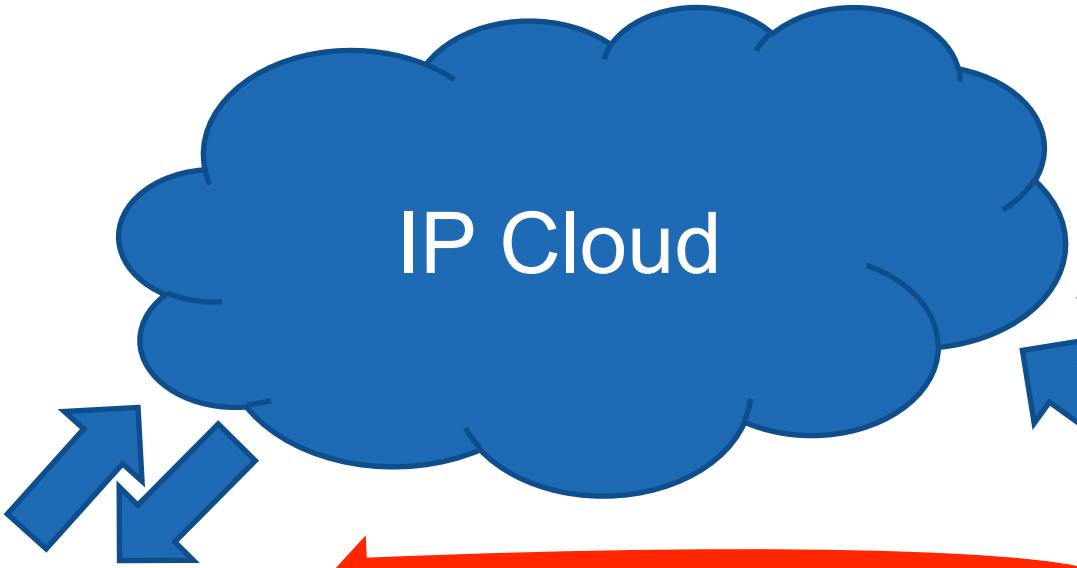
Internet of Things

- 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”)



< 1 ms delay

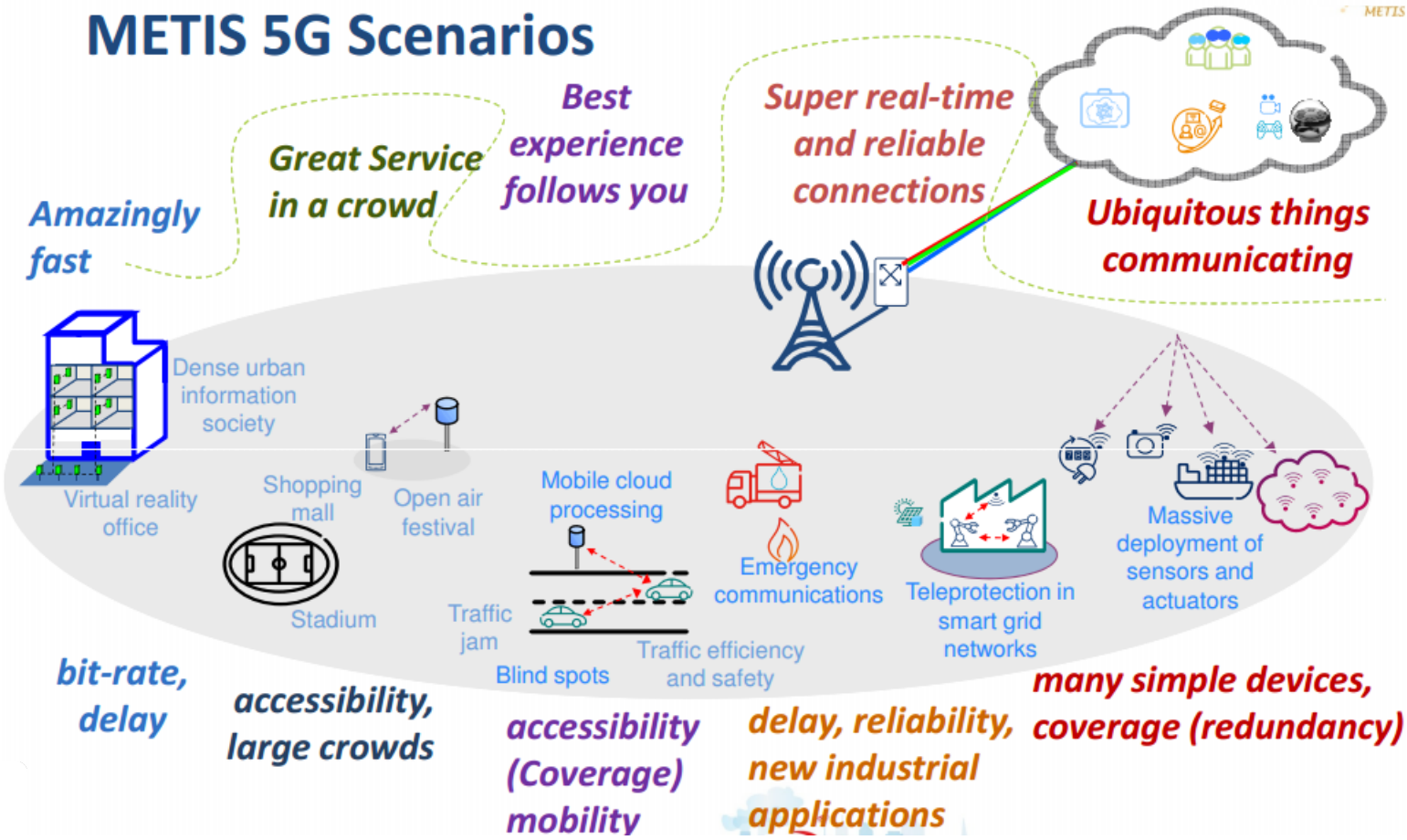
Speed of ligth: 300 km/ms

Mission critical communication (Super real-time, super reliable…)

Source: The Economist, April 20th, 2013

www.metis2020.com

METIS 5G Scenarios



SEVENTH FRAMEWORK PROGRAMME

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Is there (one) Scalable Infrastructure Solution ?

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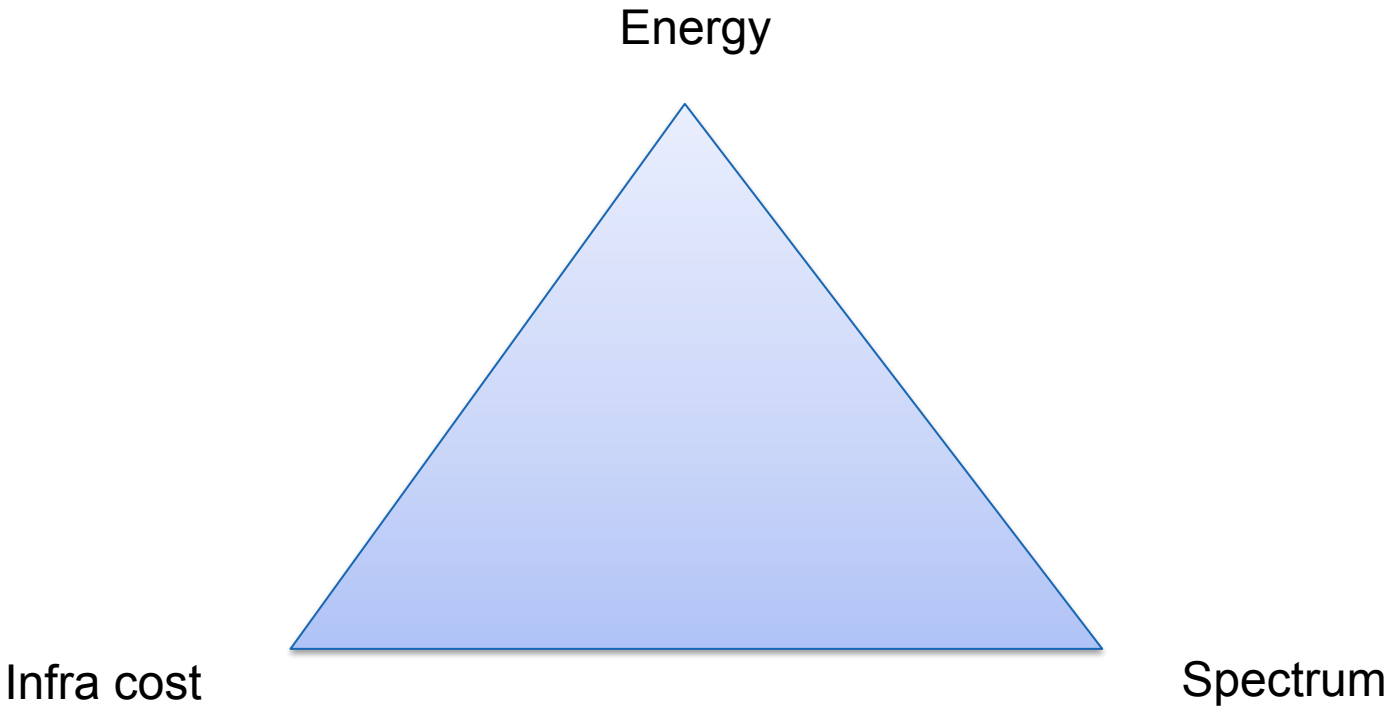
The Resource Triangle



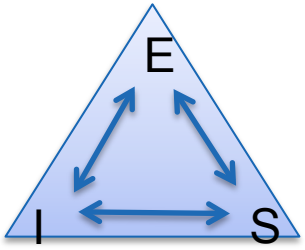
$$C_{tot} = C_{spectrum} + C_{\inf ra} + C_{energy}$$

How to increase capacity ?

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

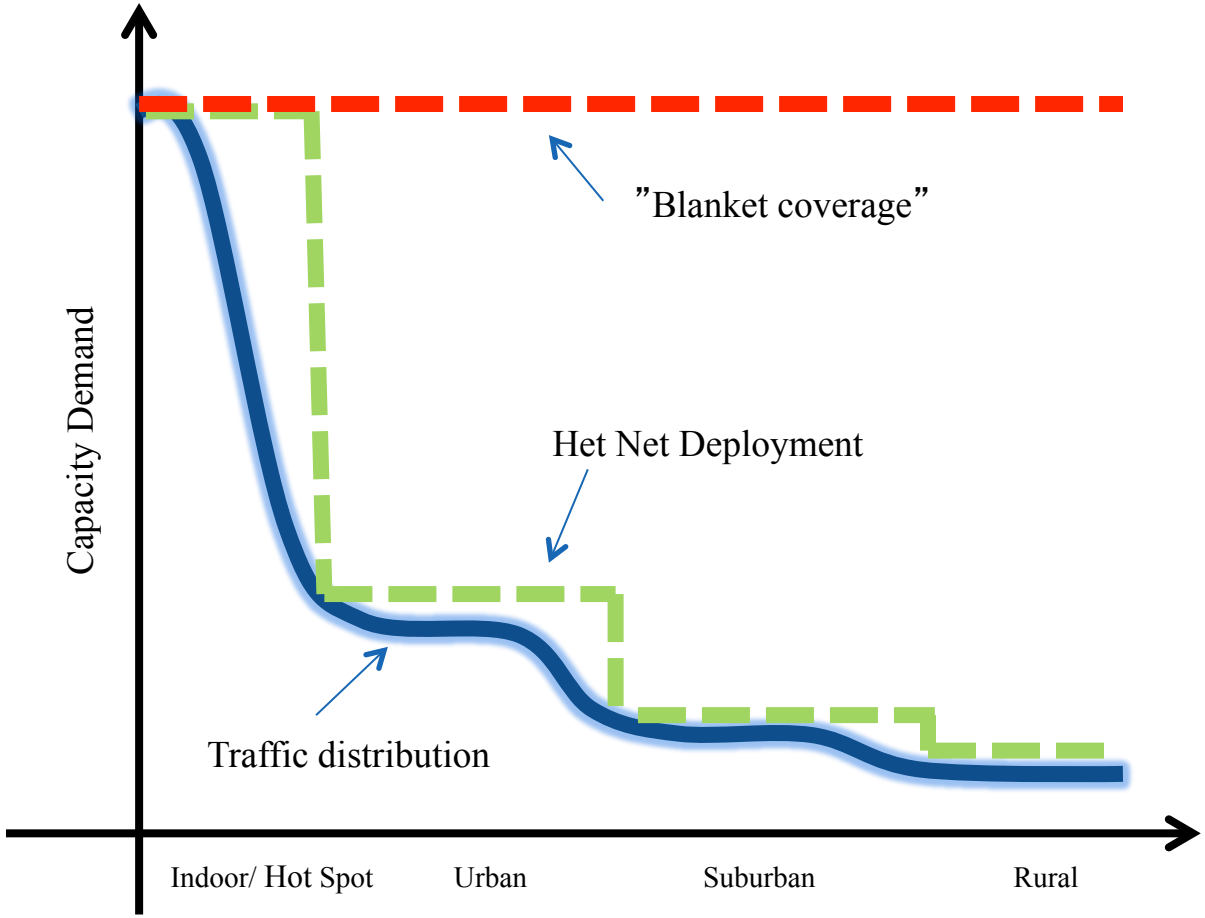
$$C_{SYS} = c_{BS} N_{BS} + c_{sp} W_{sys} + c_E E_{sys}(\eta, N_{BS}, W_{sys})$$

- Increase η , 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_{SYS}
  - Shortage ?



How to lower the cost:

”HET NET”s – deploy according to demand



The Light Analogy I : HET NETs

Outdoor – Wide Area

- Indoor – Short Range

A World Divided

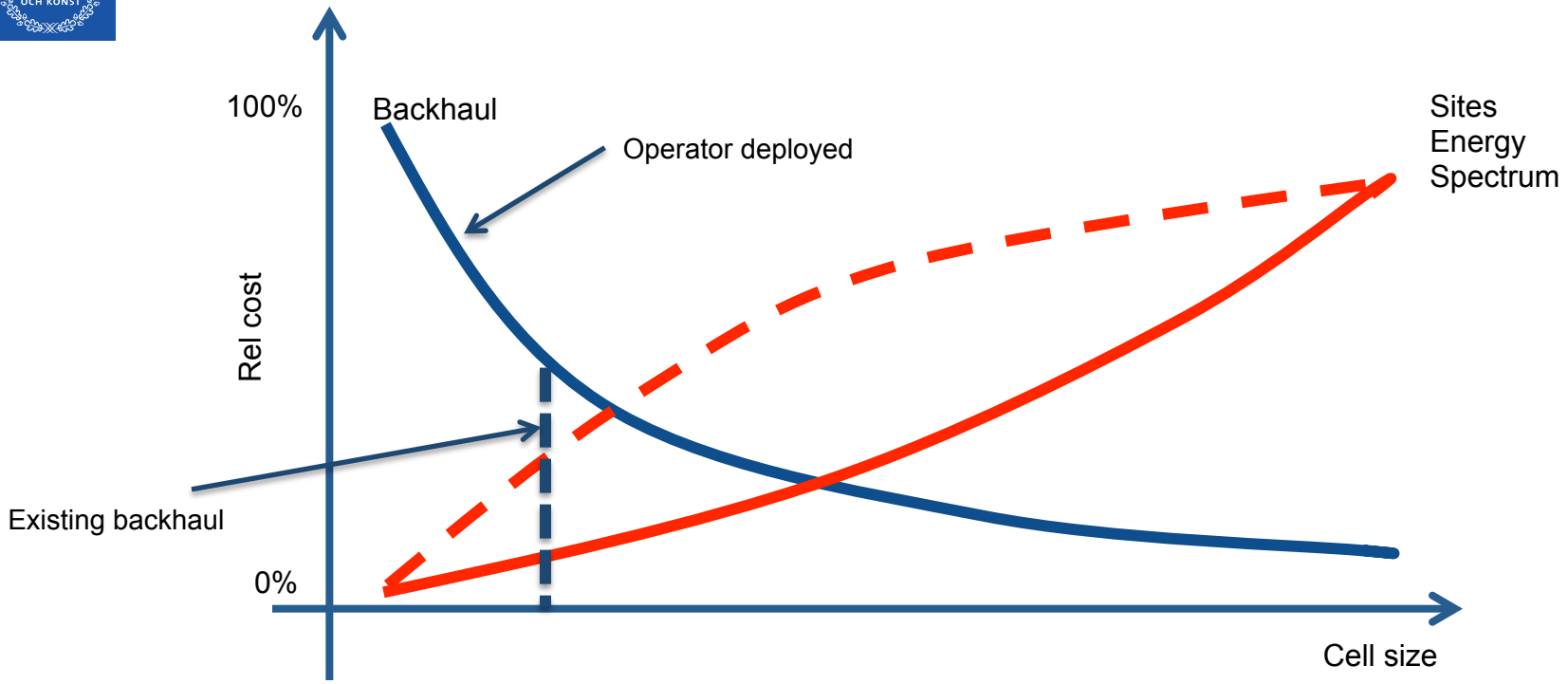
The coverage world

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

The capacity world

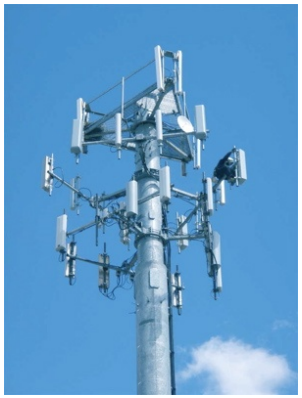
Consumer grade equipment
Low power/Short range
Reliability through redundancy
Low **system** complexity

Cost factors



A World Divided

The coverage world



Public operators

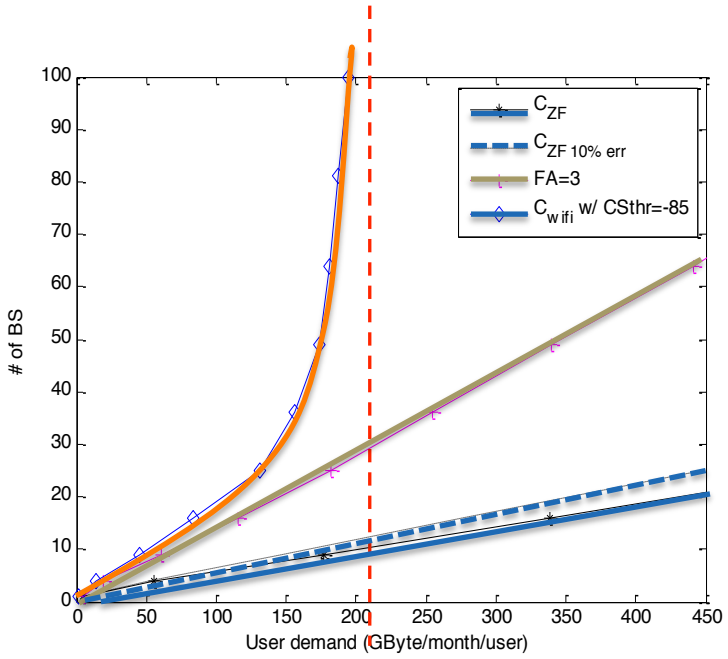
- **Access any-time, anywhere**
- ”Insurance” – guaranteed access at moderate datarates (<10Mbit/s)
- Monthly fee
- Power/Site/Backhaul
- Exclusive spectrum licensing – spectrum sharing

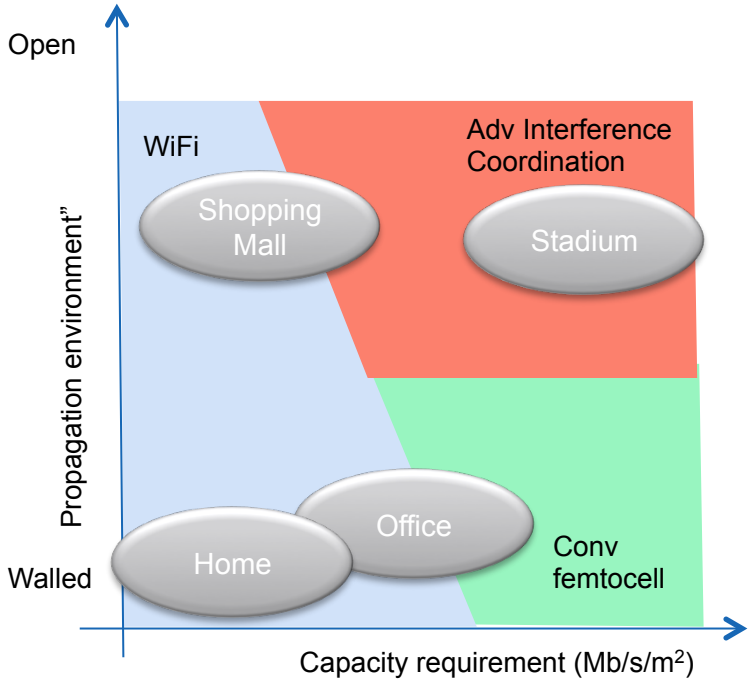
The capacity world

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

Capacity and Economic feasibility





More access points - or more expensive backhaul (for coordination) ?

Is there enough capacity ?

	Intersite	Spectrum	No BS	Cap/Site	Area cap
Macro	300 m	500 MHz	10 /km^2	1Gb/s	10 Gb/s/km^2 (outdoor)
WiFi - today	30m	500 MHz	1000/km^2	1 Gb/s	1 Tb/s/km^2
WiFi -ideal	1/room	2 GHz	50K/km^2	4 Gb/s	200 Tb/s/km^2

Simple area-based calculation – outdoor/indoor wall penetration not included

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

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 ?

Exclusive licensing

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Where are we heading - spectrumwise?

Wide area access

Spectrum need to lower infrastructurecost

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

Today	Tomorrow
Transmitter specification	Receiver specification
Interference Limits	”Pain Sharing
Secondary access	Sharing / Co-primary

Can the Things use the same infrastrucure ?

Very diverse requirements

Requirement	Human centric	Machine Type
Capacity	Very Large	Small
Number of devices	Moderate	Very large
Wide area coverage	Important	(Sometimes) Important
Reliability	Moderate	(Sometimes) High
Cost	Moderate	(Sometimes) Very low
Power consumption	Moderate	Sometimes) Very low
Delay	Moderate	Sometimes) Very low

Everything under one roof ?
Transparancy vs Efficiency

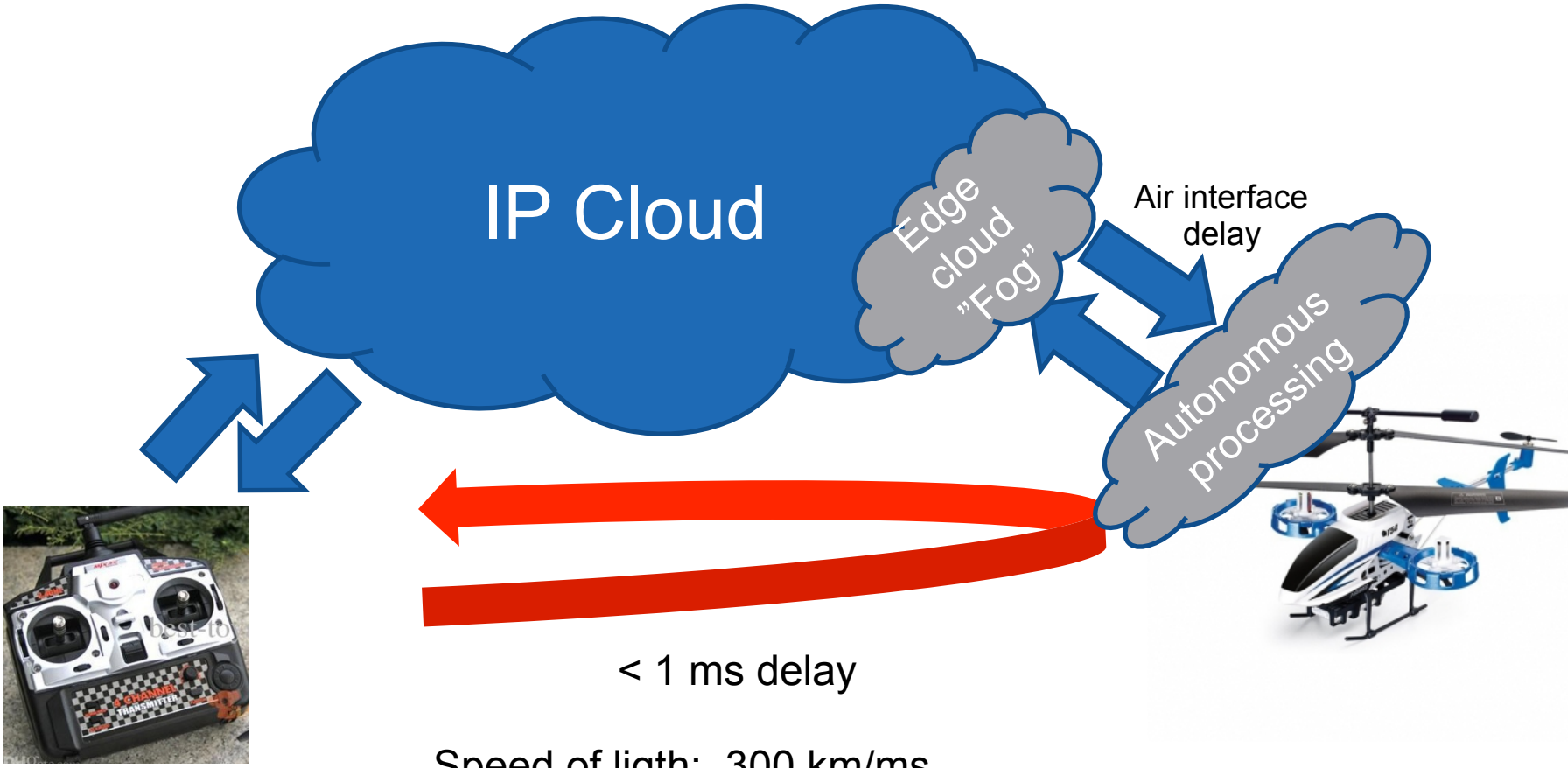
The IP-access world

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

The MTC world

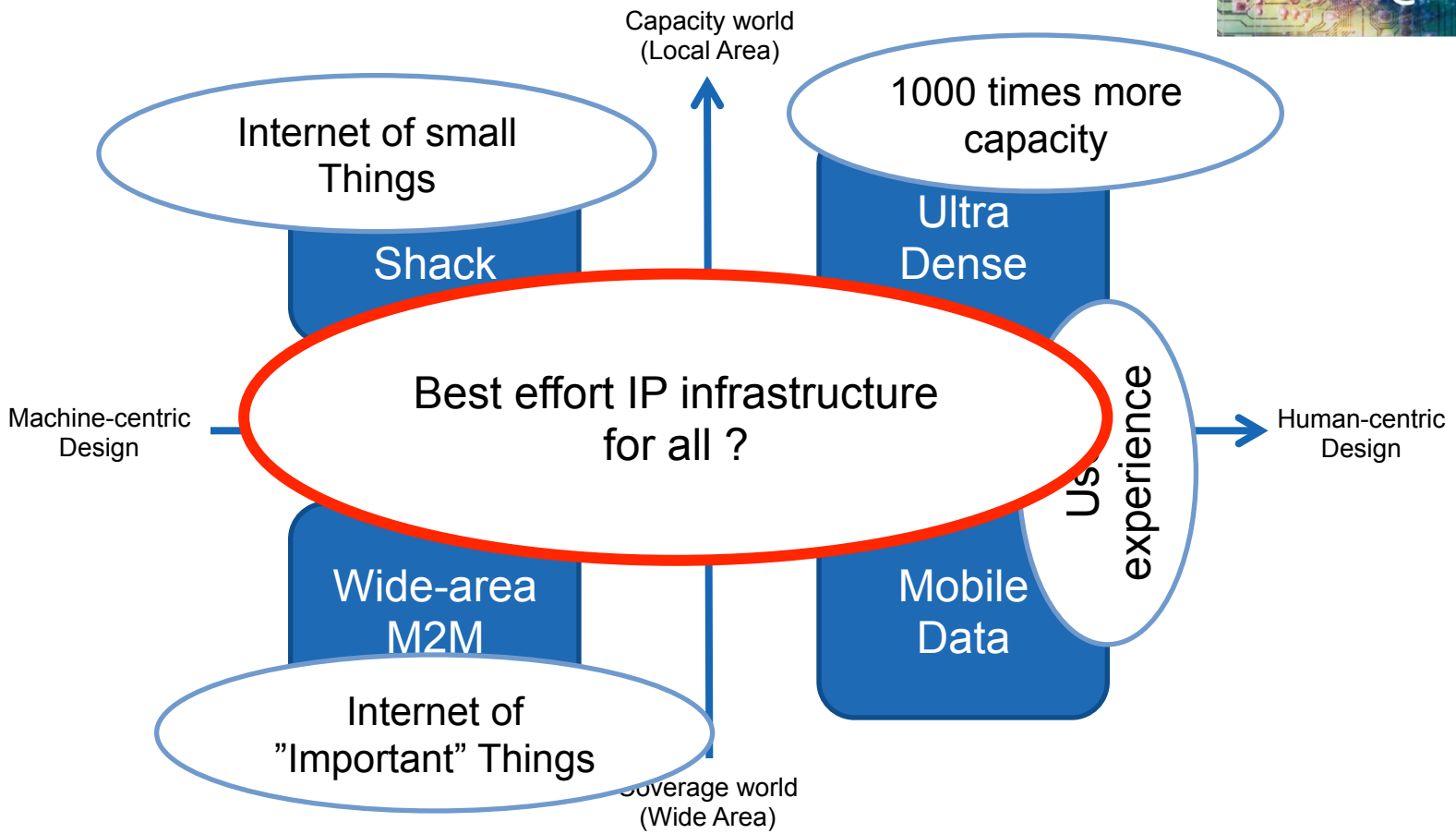
- Large volumes
- Very diverse requirement on power, delay, cost…
- Non-standardized equipment, no unified platforms
- Rational decisions based on savings

Distribution of resources critical



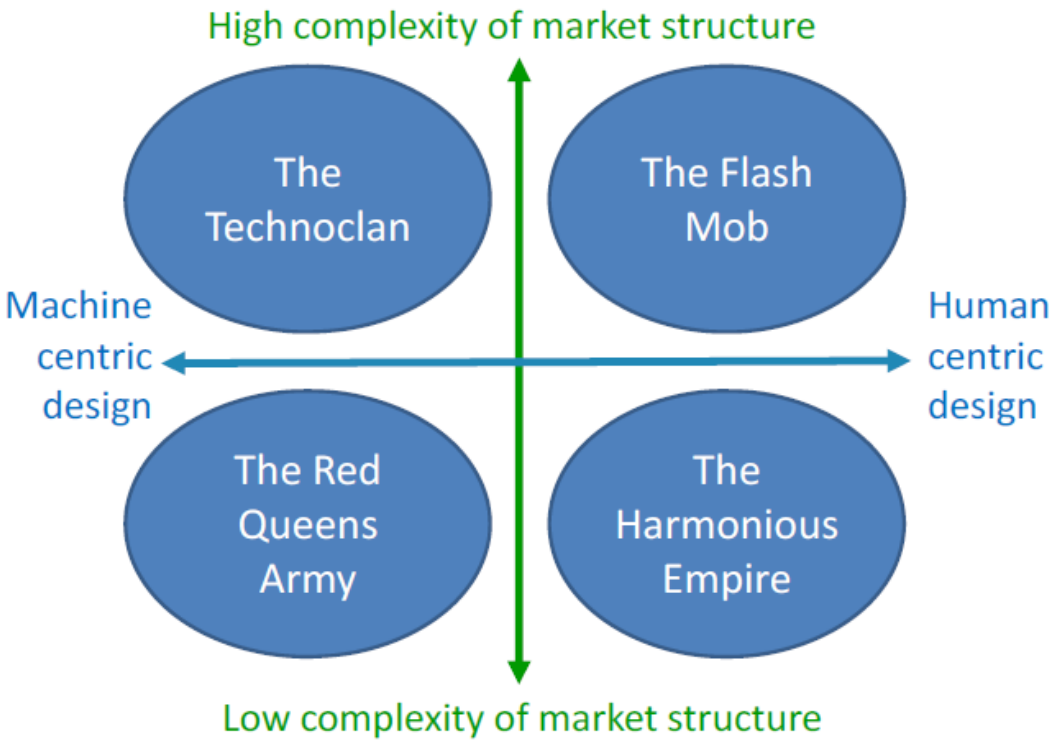
Mobility Foresigth –

Alternative (Technical) Mapping



Single infrastructure = traditional operator model ?

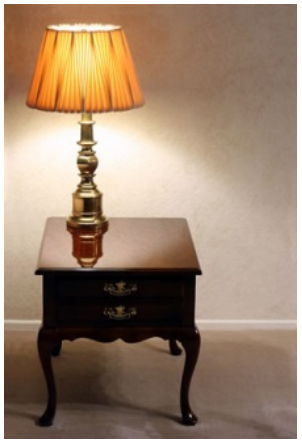
Mobility Foresigth



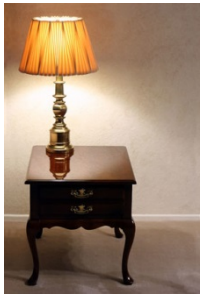
In Summary:
Fundamental/revolutional 5G challenges

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

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



In Summary



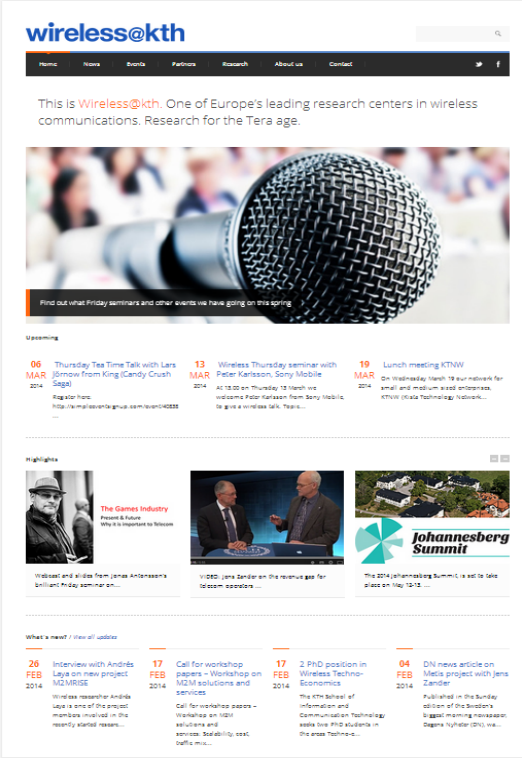
5G is

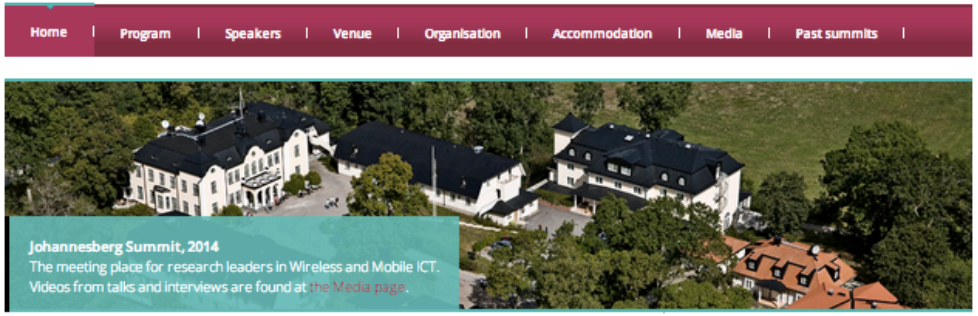
- **Not technically needed to contain most of the ”Data Tsunami**” (can be managed by evolved 4G +WiFi)
- Addressing new challenges in **large scale, wide-area infrastructure for M2M** applications
- Not only about connectivity but a **computational platform** to manage generic resources like processing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

Read more !

theunwiredpeople.com

wireless.kth.se





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