Design principles for High-Capacity Wireless Access Networks

IK2514 Wireless Infrastructure Deployment and Economics

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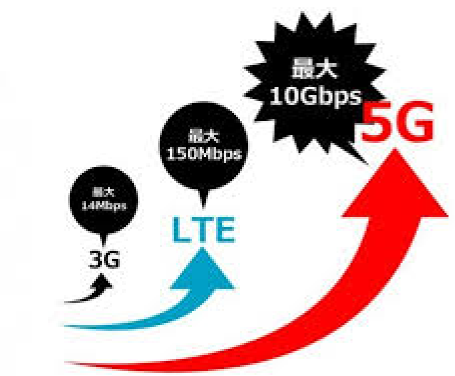
Outline

- **Requirements for future system,
  Do we need 5G ?**
  - Some key trends
  - Transparency & mobile data tsunami
  - The internet of things and senses
- **Design principles for s<u>calable</u> Infrastructure**
  - Key trade-off:s Cost, Energy, Spectrum
  - The two worlds – or are they three ?
- **What about the internet of things ??**

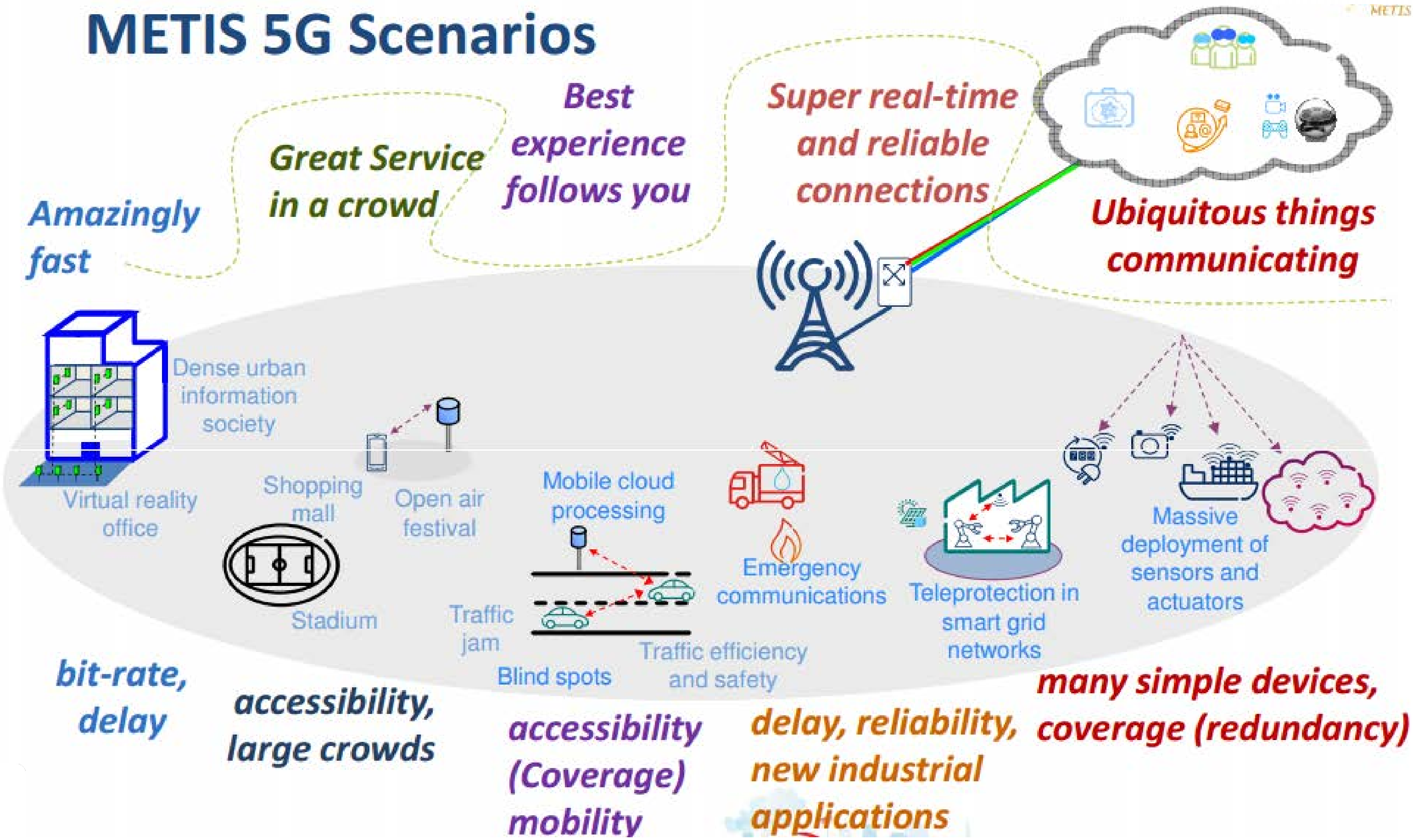
Is it a bird? .. a plane?

No, it's 5G!



5G WiFi™

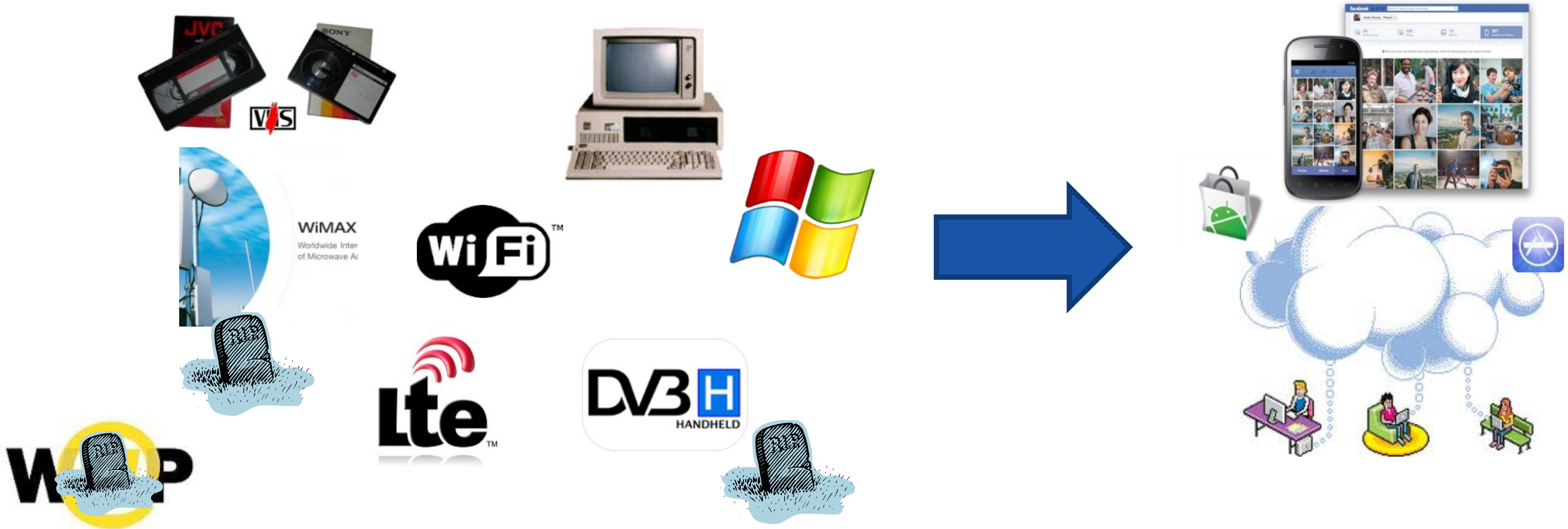
METIS 5G Scenarios



www.metis2020.com

Key trend
Transparency eats efficiency for breakfast

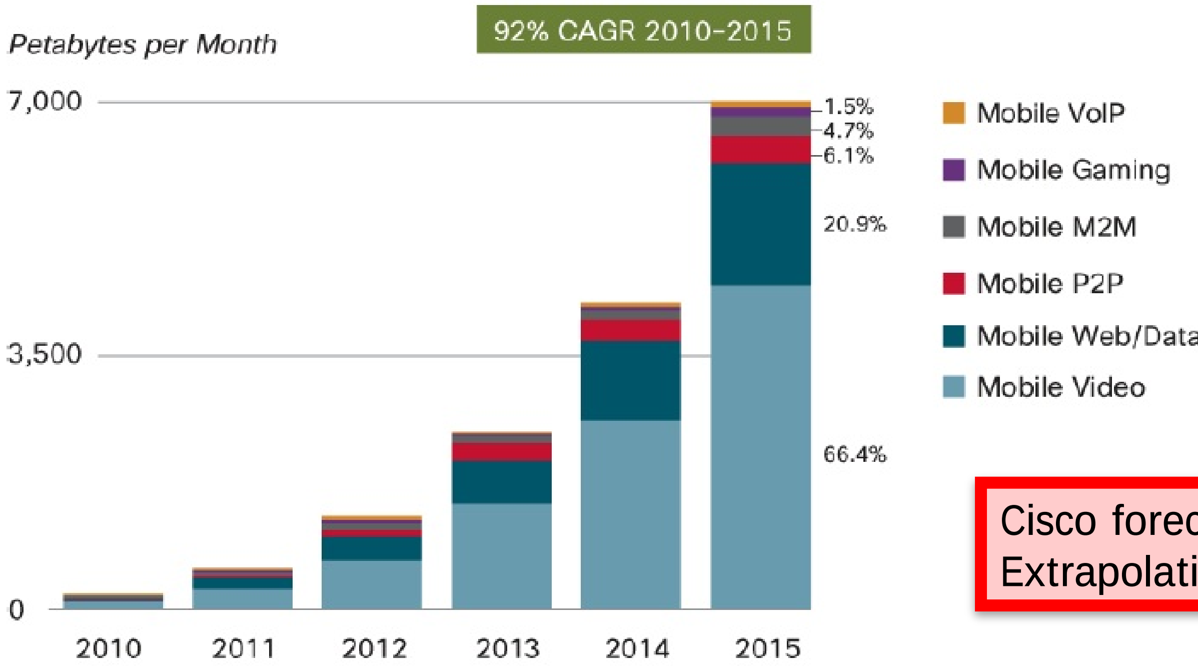
A lessons from History - Dominant designs



- 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 ...?

> ”IP is the answer - now, what was the question ?”
>
> G Q Maguire

The price tag for transparency – the 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

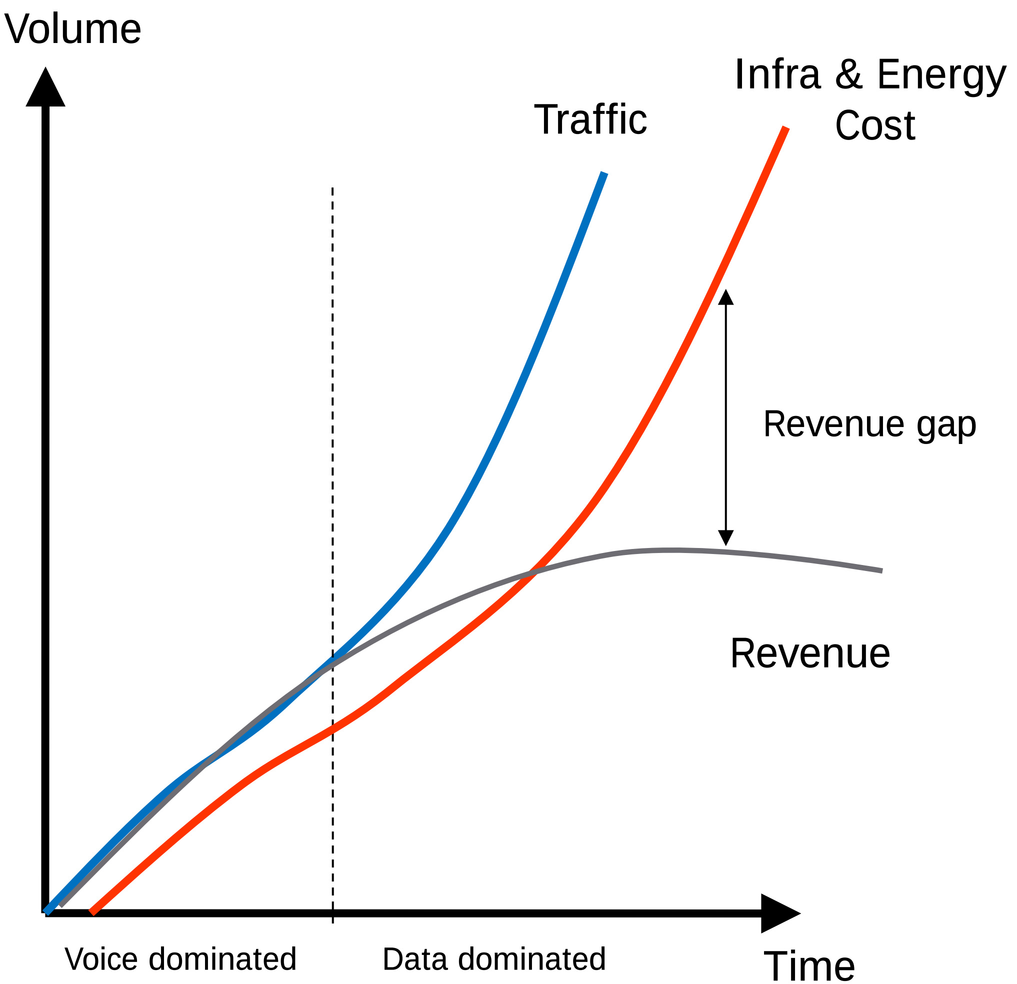
Exponential growth (now slowing down somewhat)
Assumes **zero marginal cost** for access
How long can this be sustained ?

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



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”
(”Tactile Internet”)

Speed of ligth: 300 km/ms

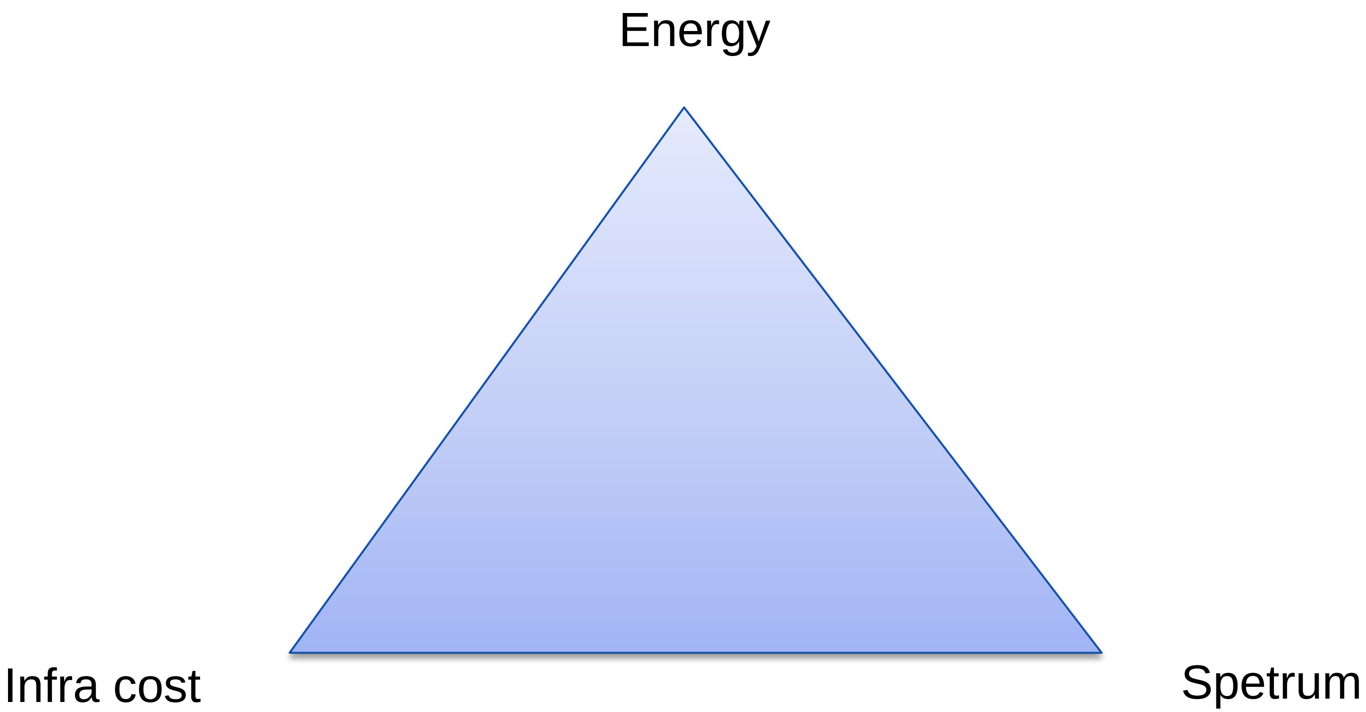
Mission critical communication (Super real-time, super reliable…)

Source: The Economist, April 20th, 2013

Design principles for Scalable Wireless Infrastructures

Design principles for Scalable Wireless Infrastructures

Key Design Constraints



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

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 power (in processing – receiver limitation!)
- More base stations, N_{BS}
  - Expensive
  - More power ?
- More spectrum, W_{SYS}
  - Shortage ?

Energy consumption modelling

Power consumption

$$P = N_{BS}\left[aP_{tx} + b_{radio} + b_{backhaul} + y\frac{\overline{R}_{tot}}{N_{BS}}\right] + d$$

Proportional to #base stations

Independent of #base stations

Energy consumption modelling (2)

Spectrum-Infrastructure Cost-Power Trade-off (Shannon Bound)

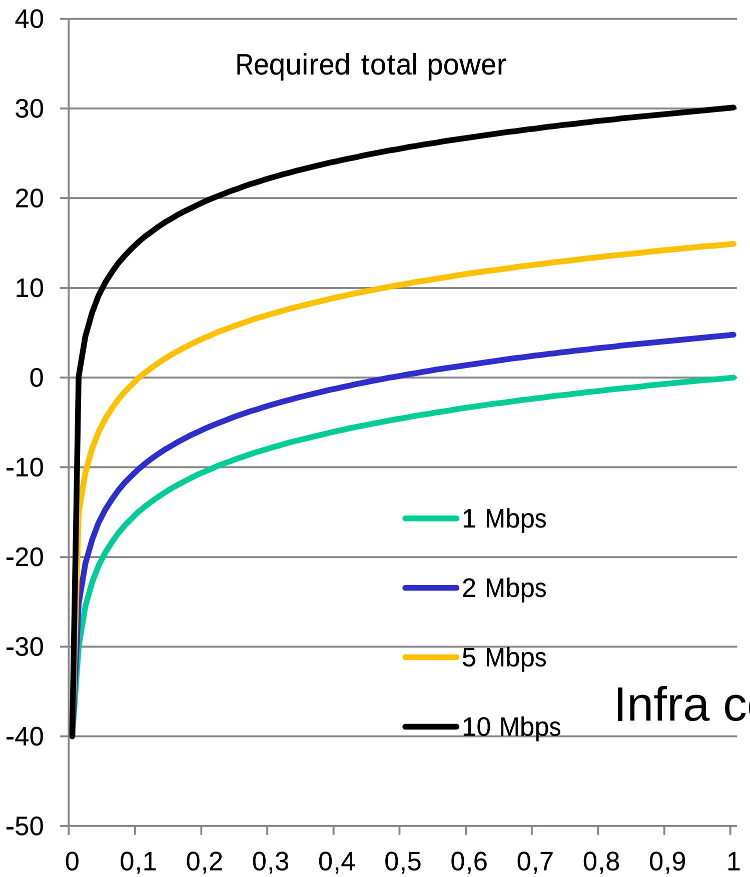
$$P_{rx}(d) = \frac{c' G P_{tx}}{d^{\alpha}} \qquad P_{tx} = \left[2^{\frac{\overline{R}}{W}} - 1 \right] \frac{N_0 W}{cG} R_{cell}{}^{\alpha}$$

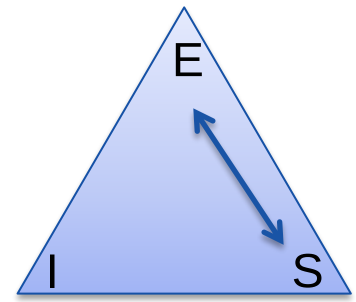
Average spectral efficiency

$$S = \frac{\overline{R}}{W}$$

$$\mathrm{P}_c = \left(N_{BS} \left[a \left\{ \frac{N_o W}{cG} \left(2^{\frac{\overline{R}_{t\,tot}}{N_{BS} W}} - 1 \right) \left(\frac{\mathrm{A}}{\pi \mathrm{N}_{BS}} \right)^{\alpha/2} \right\} + b_{radio} + b_{backhaul} + y \frac{\overline{R}_{tot}}{N_{BS}} \right] + d \right) / A$$

What cell size to use ?





$$\bar{R} \approx c_0 W \log_2\left(1+\frac{c' P_{tot}}{N_0 \bar{r}^{-\alpha-2}}\right)$$

Energy

$$P_{tot} \approx c_1 \bar{r}^{-\alpha-2}\left(2^{\frac{\bar{R}}{c_0 W}}-1\right)$$

Infra cost

Spetrum

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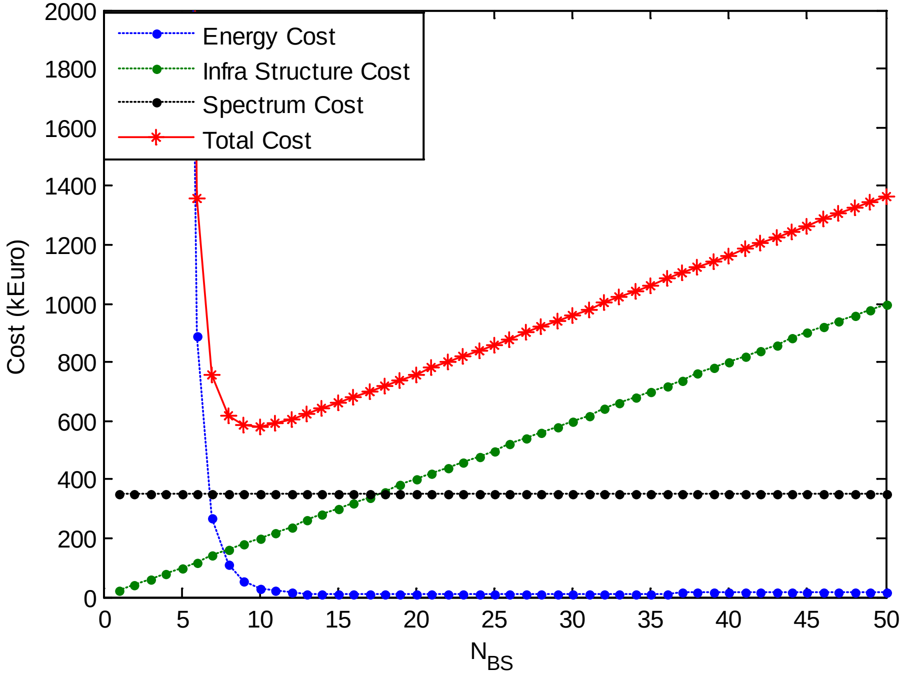
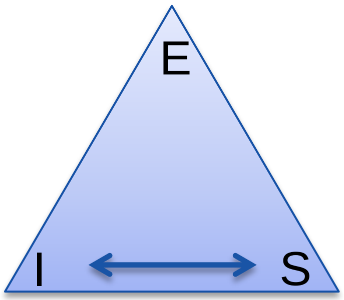
Power – Infrastructure tradeoff

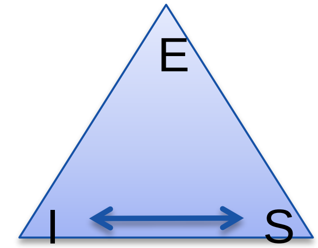




Minimum total cost now occurs at a much lower number of base stations than in the energy-only minimization.

Spectrum cost constant – provides only a level shift of the total cost;

Spectrum / Infrastructure tradeoff



$$C_{sys} \approx c_{BS} N_{BS} = c_{BS} \frac{B_{tot}}{\eta W_{SYS}} \qquad B_{tot} \approx \frac{C_{sys}}{c_{BS}} \eta W_{sys} = \eta N_{BS} W_{sys}$$

More base stations

More spectru

$$B_{tot} + \Delta B \approx \eta N_{BS} W_{sys} + \eta \Delta N W_{sys} + \eta N_{BS} \Delta W$$

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

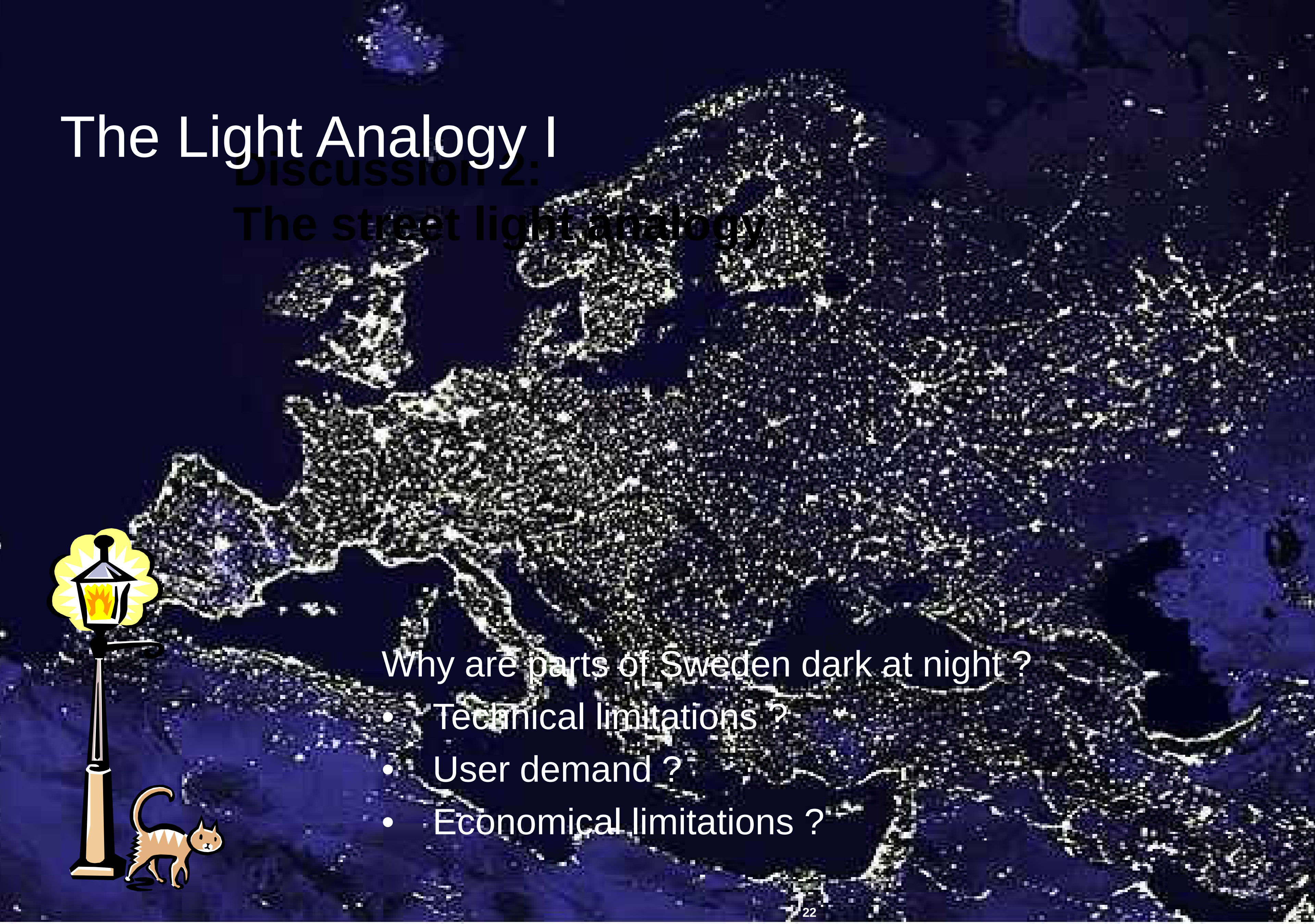
$$\min \Delta C = \min \left(c_{BS} \frac{\Delta B}{\eta W_{SYS}}, \left(\Delta c_{BS} N_{BS} + c_{sp} \right) \frac{\Delta B}{\eta N_{BS}} \right)$$

$$c_{sp}^{*} = \frac{c_{BS}}{W_{SYS}} - \Delta c_{BS} N_{BS}$$

Engineering value of spectrum

The Light Analogy I

Discussion 2:
The street light analogy



Why are parts of Sweden dark at night ?

- Technical limitations ?
- User demand ?
- Economical limitations ?

Image and data processing by NOAA's National Geophysical Data Center. Defense Meteorological Satellite Pr
collected by the US Air Force Weather Agency.

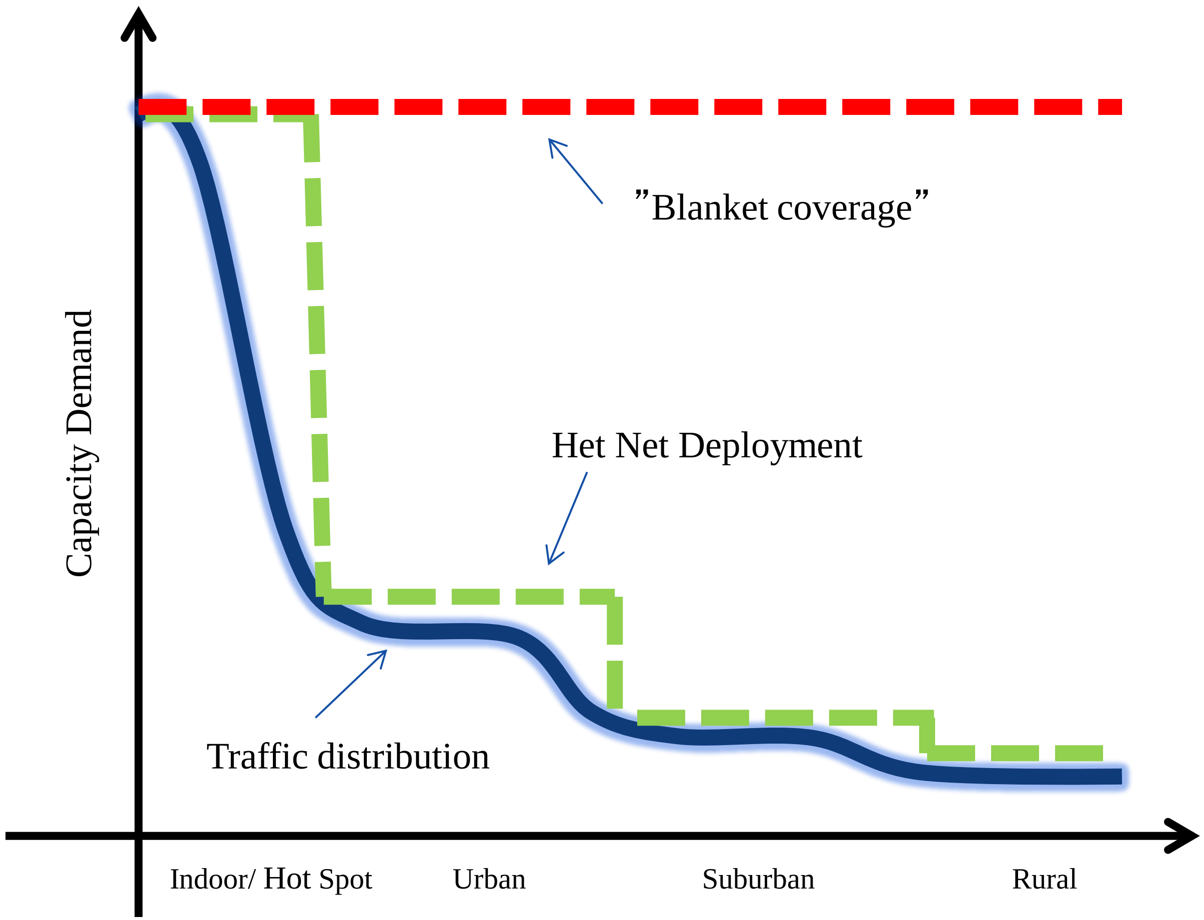
The Light Analogy II : HET NETs

Outdoor – Wide Area

- Indoor – Short Range

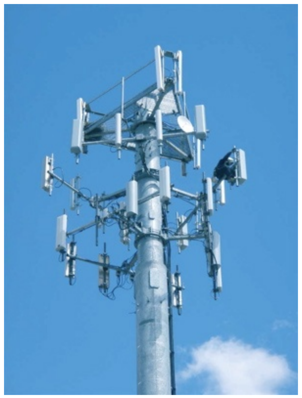
How to lower the cost:

”HET NET”s – deploy according to demand



A World Divided

The coverage world



Public operators

- **Access any-time, anywhere**
- ”Insurance” – guaranteed access at moderate datarates (1-2 Mbit/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 experiences – high data rates
- Ultra dense deployment – Interference
- (Low power, no site cost, existing backhaul)
- Post-code licensing – infrastructure sharing

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

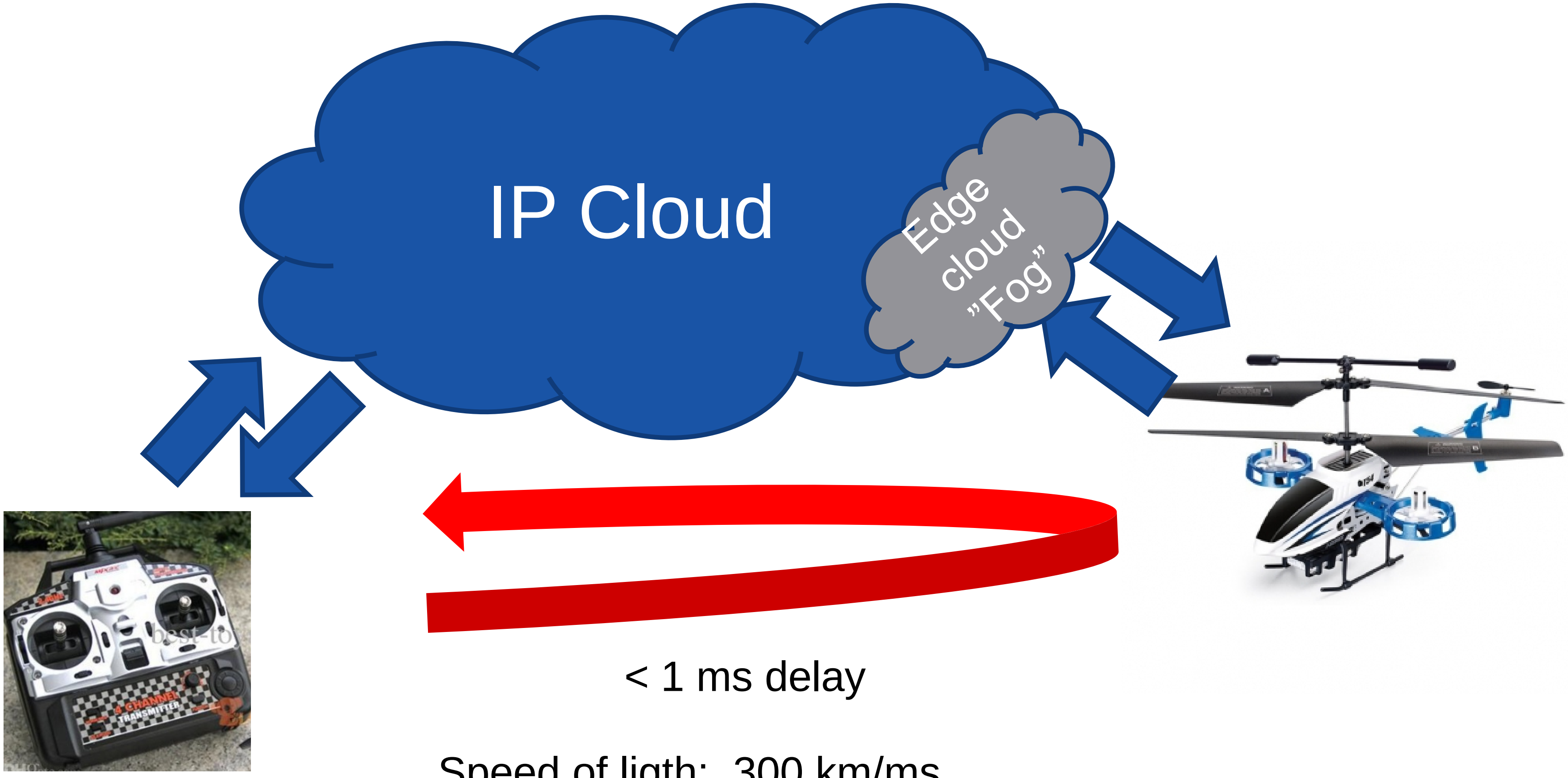
Spectrum: There is potentially lots of spectrum < 20 GHz for indoor short range use (on secondary basis)

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

Distribution of resources critical



< 1 ms delay

Speed of ligth: 300 km/ms

Everything under one roof ?
Transparancy vs Efficiency

The IP-access world

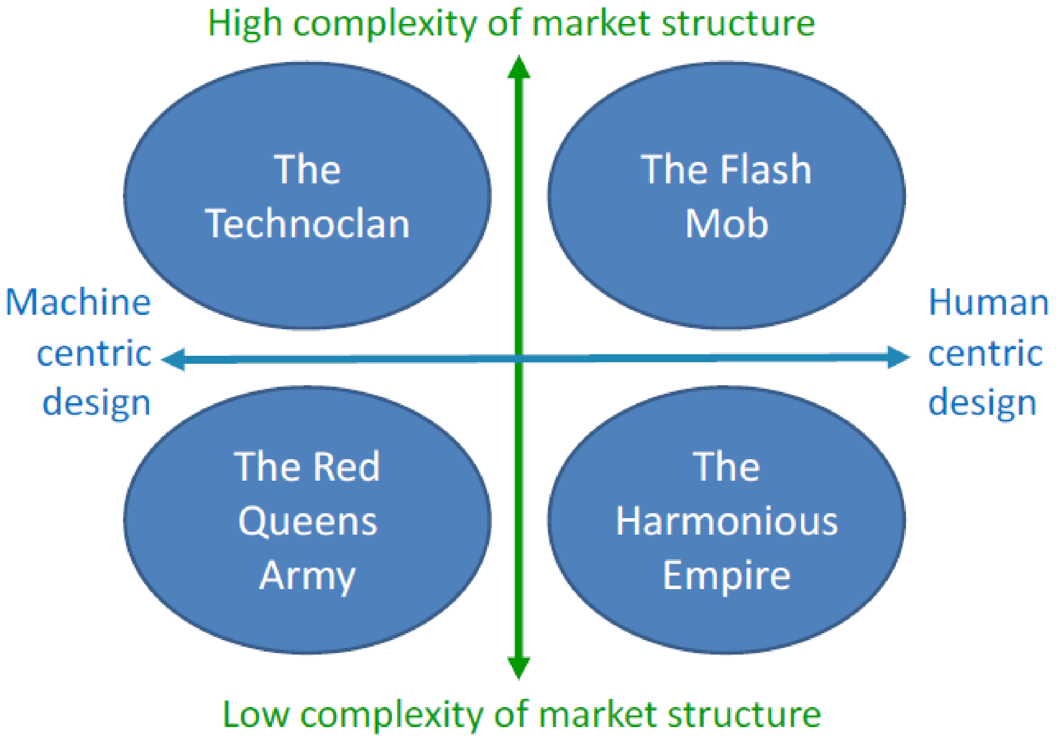
- Large volumes of standardized equipment, unified platforms
- Low efficiency, overprovisioning of resources
- Willingness to pay for flexibility

The MTC world

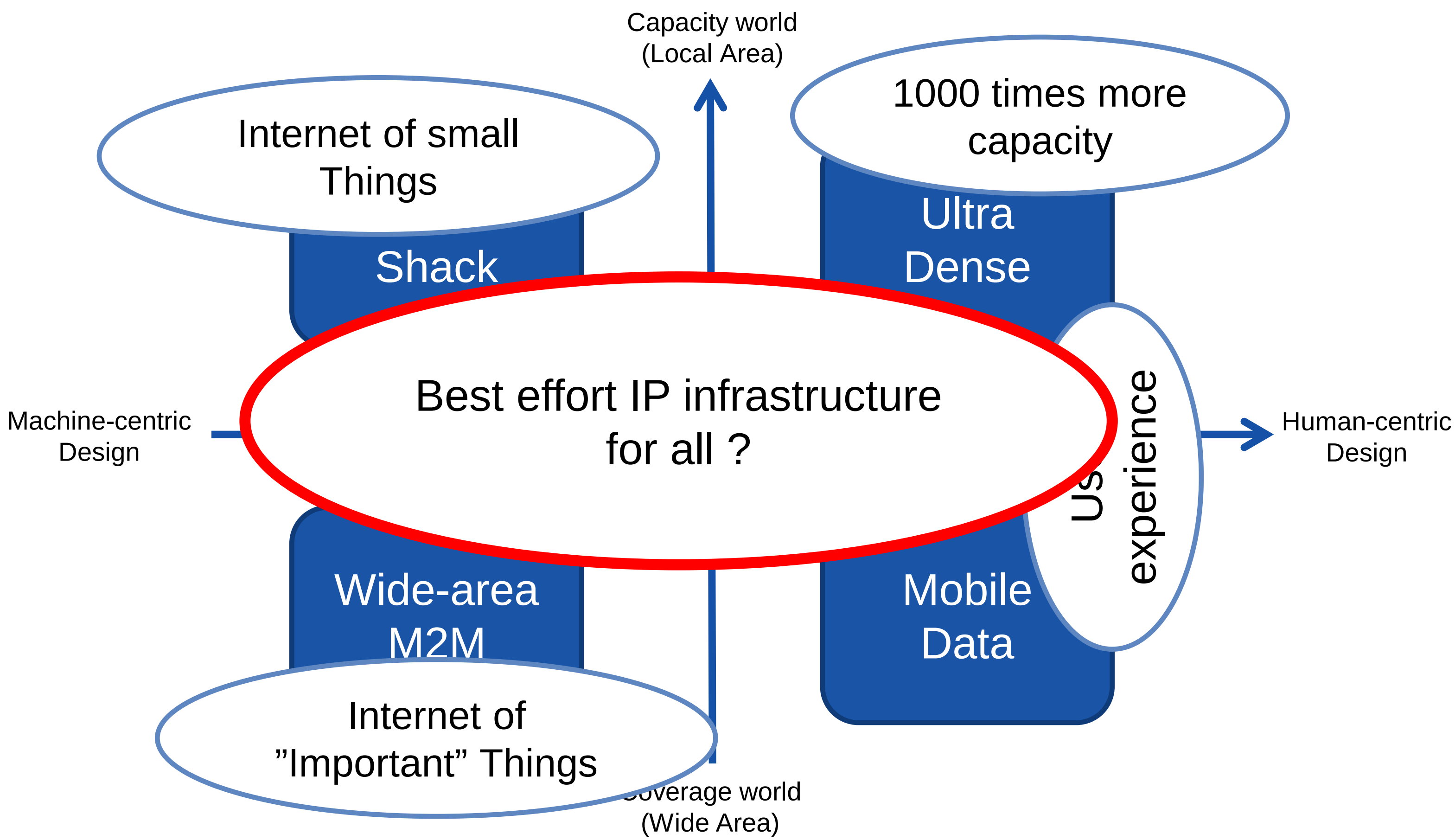
- Large volumes
- Very diverse requirement on power, delay, cost…
- Non-standardized equipment, no unified platforms
- Rational decisions based on savings

Who will provide infrastructure and services ?

Mobility Foresigth



Alternative (Technical) Mapping of MobFor scenarios



Single infrastructure = traditional operator model ?

In Summary

5G is

- **Not techically needed to contain 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**