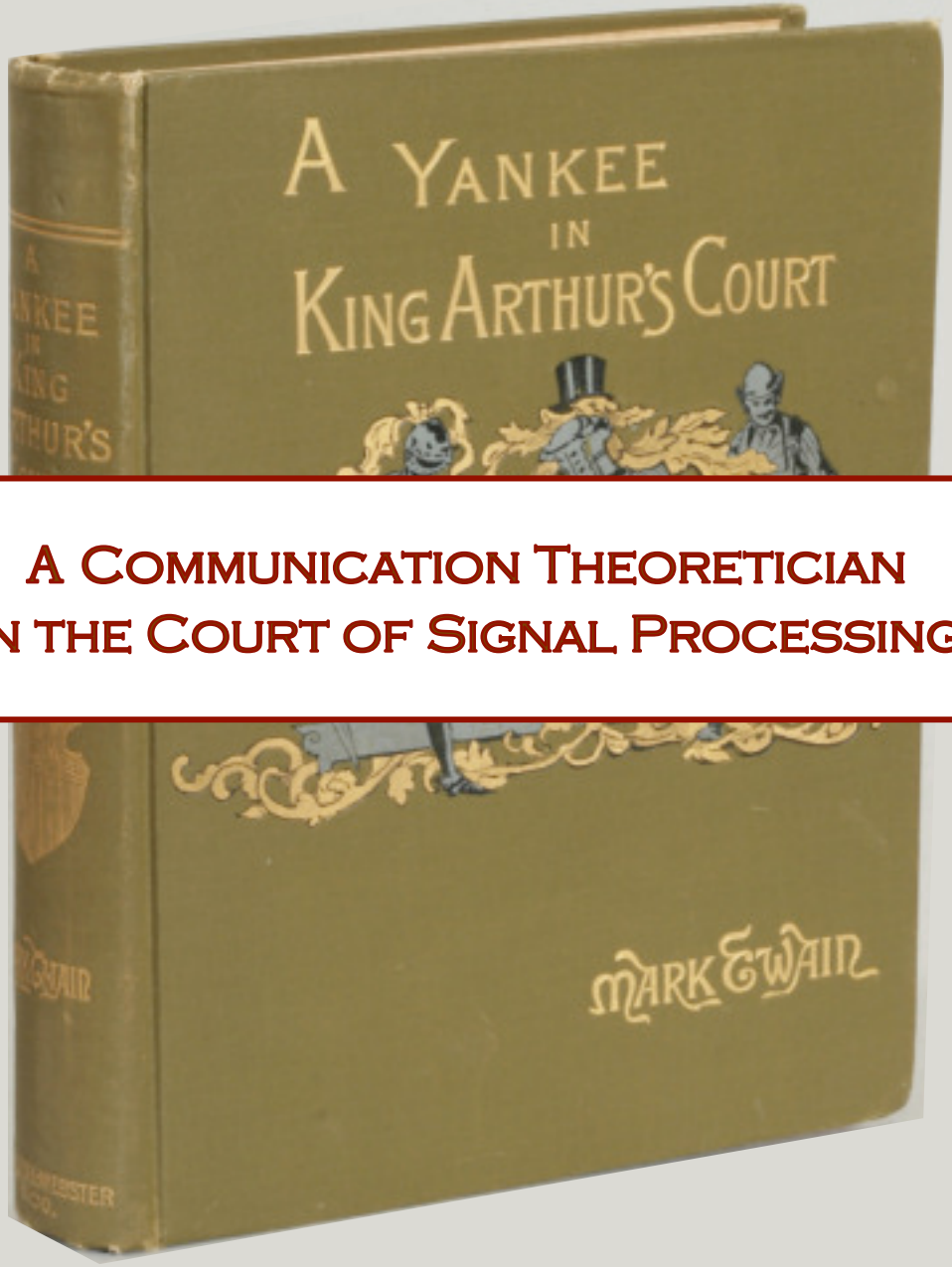
upf. Universitat Pompeu Fabra Barcelona

Angel Lozano

Towards 5G

— A Research Perspective —

HiATUS



A Communication Theoretician in the Court of Signal Processing

upf. Universitat Pompeu Fabra Barcelona

Angel Lozano

Towards 5G

— A Research Perspective —

5G

From Wikipedia, the free encyclopedia

5G (**5th generation mobile networks** or **5th generation wireless systems**) is a term used in some research papers and projects to denote the next major phase of mobile telecommunications standards to be introduced approximately in the early 2020s. However, still no transnational 5G development projects have officially been launched, and there is still a large extent of debate on what 5G is exactly about.

Outline

- Introduction
- 5 Research Reflections (Inspired by 5G)
- Final Remarks

1G (1981) → **2G** (1992) → **3G** (2002) → **4G** (2011)

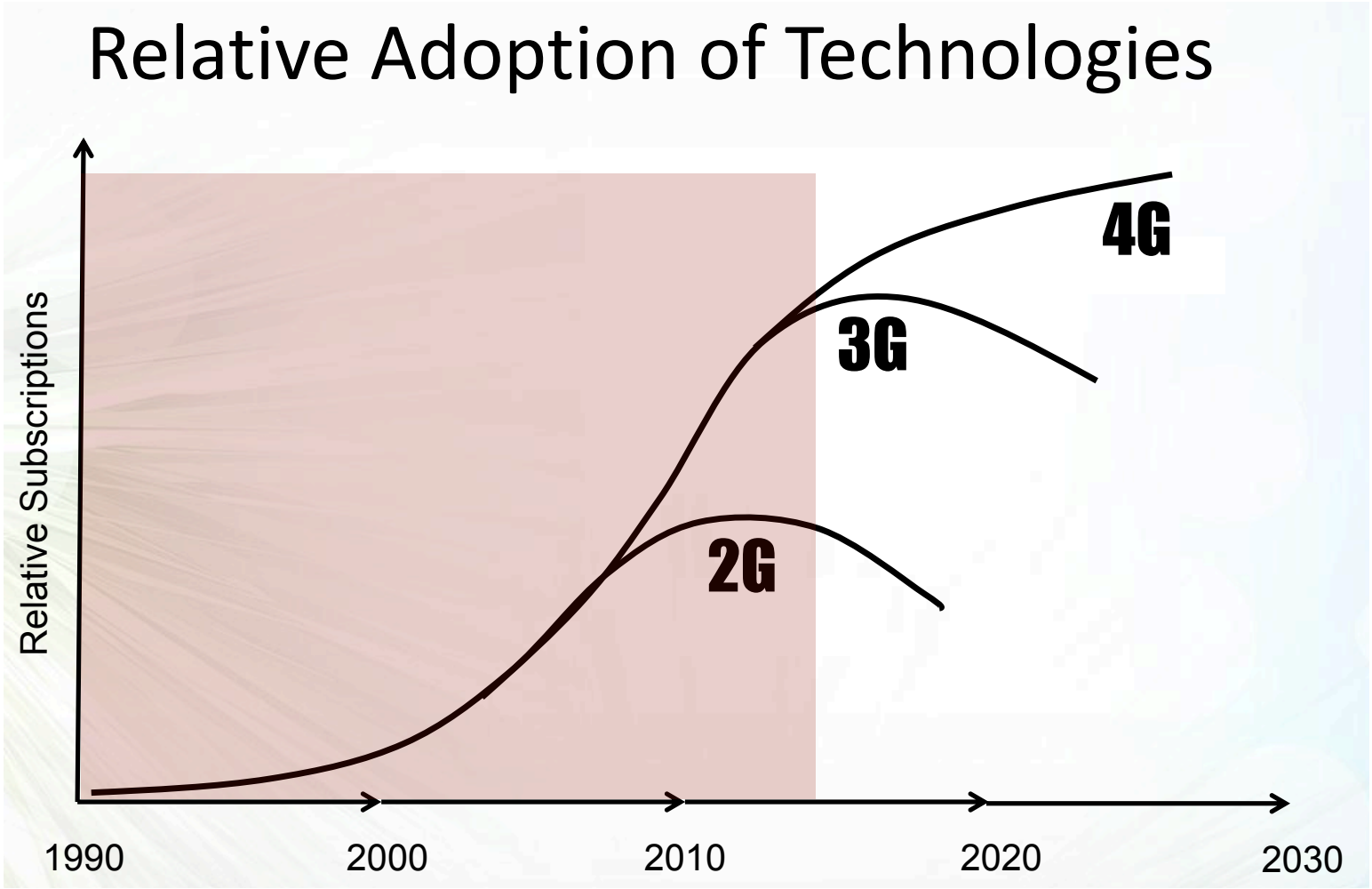
Analog

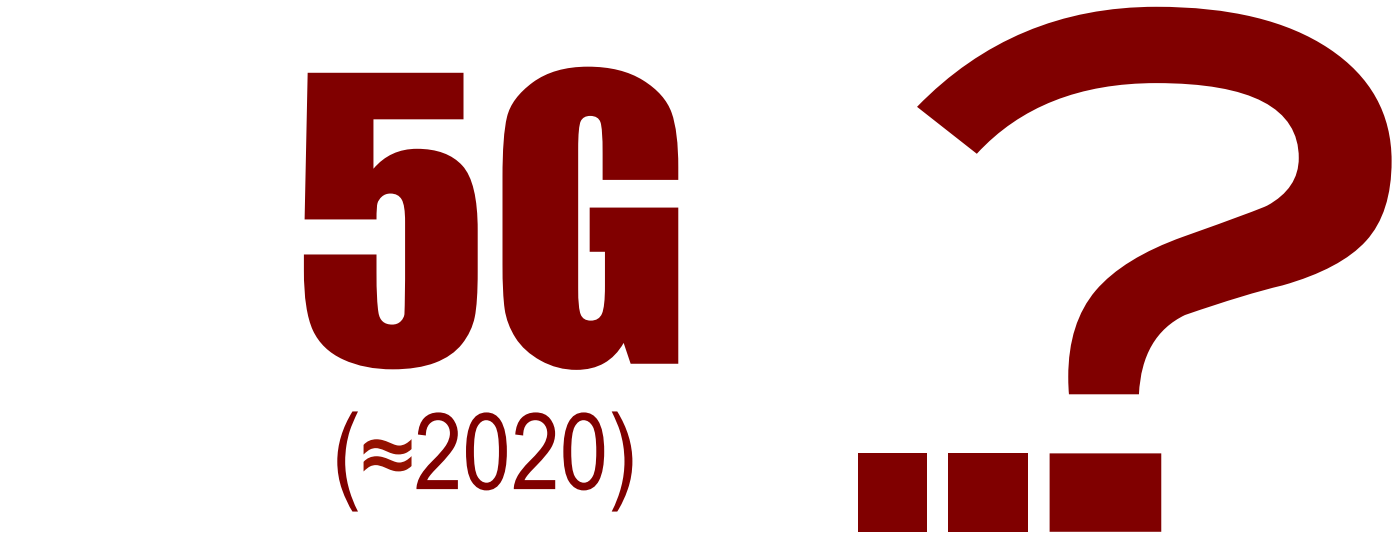
Digital

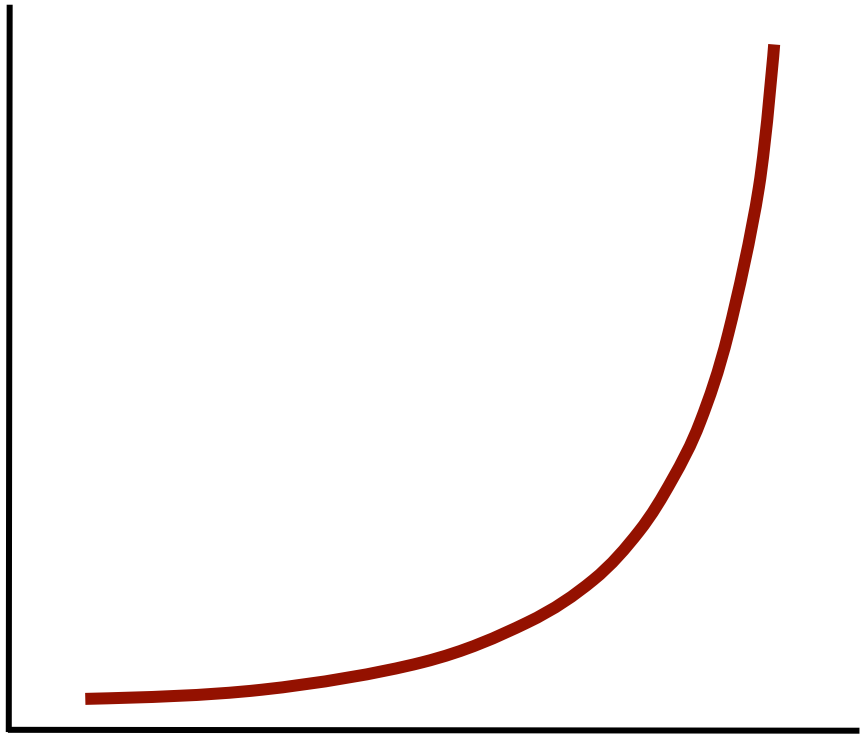
Multimedia

"Citius Altius Fortius"

Relative Adoption of Technologies




5G
(≈2020)
?
...



MASSIVE INCREASE IN WIRELESS TRAFFIC
AND IN NUMBER OF CONNECTED DEVICES

- Smartphones
- The Cloud
- M2M

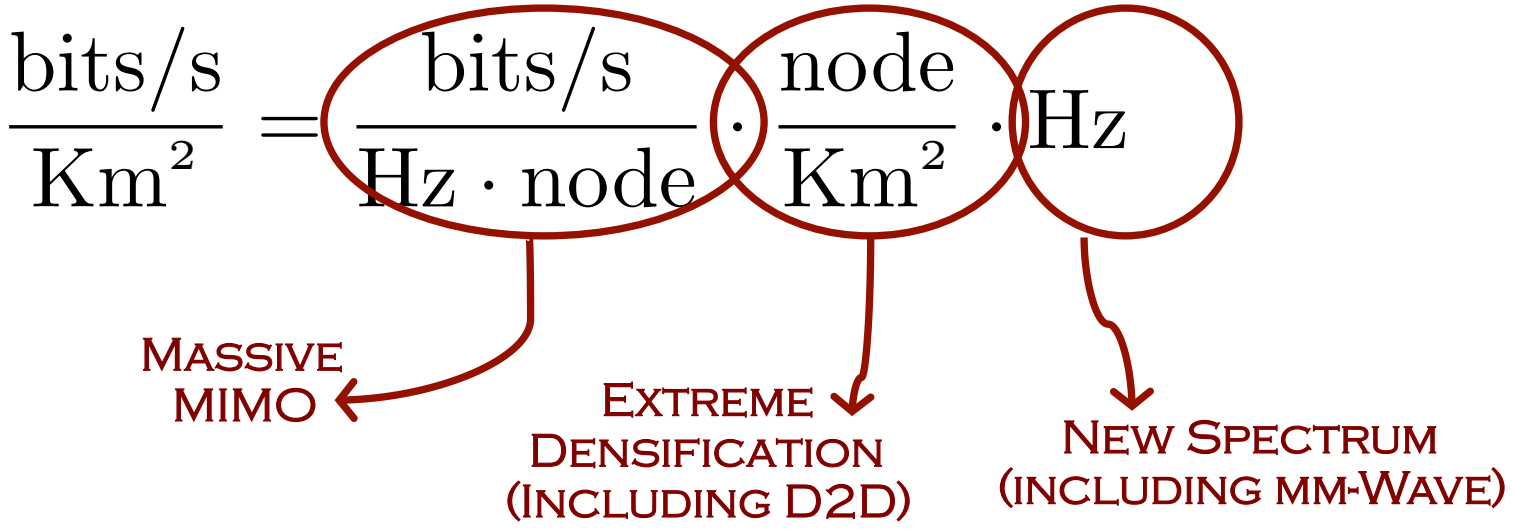
Traffic
×1000

Devices
100

Vast Range of Bit Rate
& Latency Requirements

www.qualcomm.com/1000x
www.ericsson.com/res/docs/whitepapers/wp-5g.pdf

Can we improve the utilization of radio resources by 1000?



Interference Management
New Signal Waveforms
Full-Duplex Relays
Data Caching

Etc...

International activities on 5G getting momentum

EU
- Framework Program 7, e.g. METIS and 5GNow projects
- 5G PPP in Horizon 2020

UK – 5G Innovation Centre (5GIC) at University of Surrey

US
- Intel Strategic Research Alliance (ISRA)
- NYU Wireless Research Center

China
- 863 Research Program
- Future Forum
- IMT-2020 (5G) Promotion Group

Japan – 2020 and Beyond Ad-Hoc Group under ARIB's Advanced Wireless Communications Study Committee

Korea – 5G Forum as PPP

Taiwan – Ministry of Economic Affairs, National Science Council

Russia – 5GRUS by Russia's Icom-Invest

NGMN – White paper on future requirements

- Company internal research

Source: 5G Infrastructure Association.

European Commission

5G Infrastructure PPP: The next generation of communication networks will be “Made in EU”.

- Building the foundations of the next decade communications networks
- Addressing the future “connectivity” needs in key societal and economic domains
- Boosting European industrial leadership in telecommunications

- *IEEE Communications Magazine*, Special Issue on “5G Wireless Communication Systems: Prospects and Challenges,” Feb. 2014
- *IEEE Signal Processing Magazine*, Special Issue on “Signal Processing for the 5G Revolution,” Nov. 2014
- *IEEE JSAC,* Special Issue on “5G Wireless Communication Systems,” Dec. 2014

5 Research Reflections (Inspired by 5G)

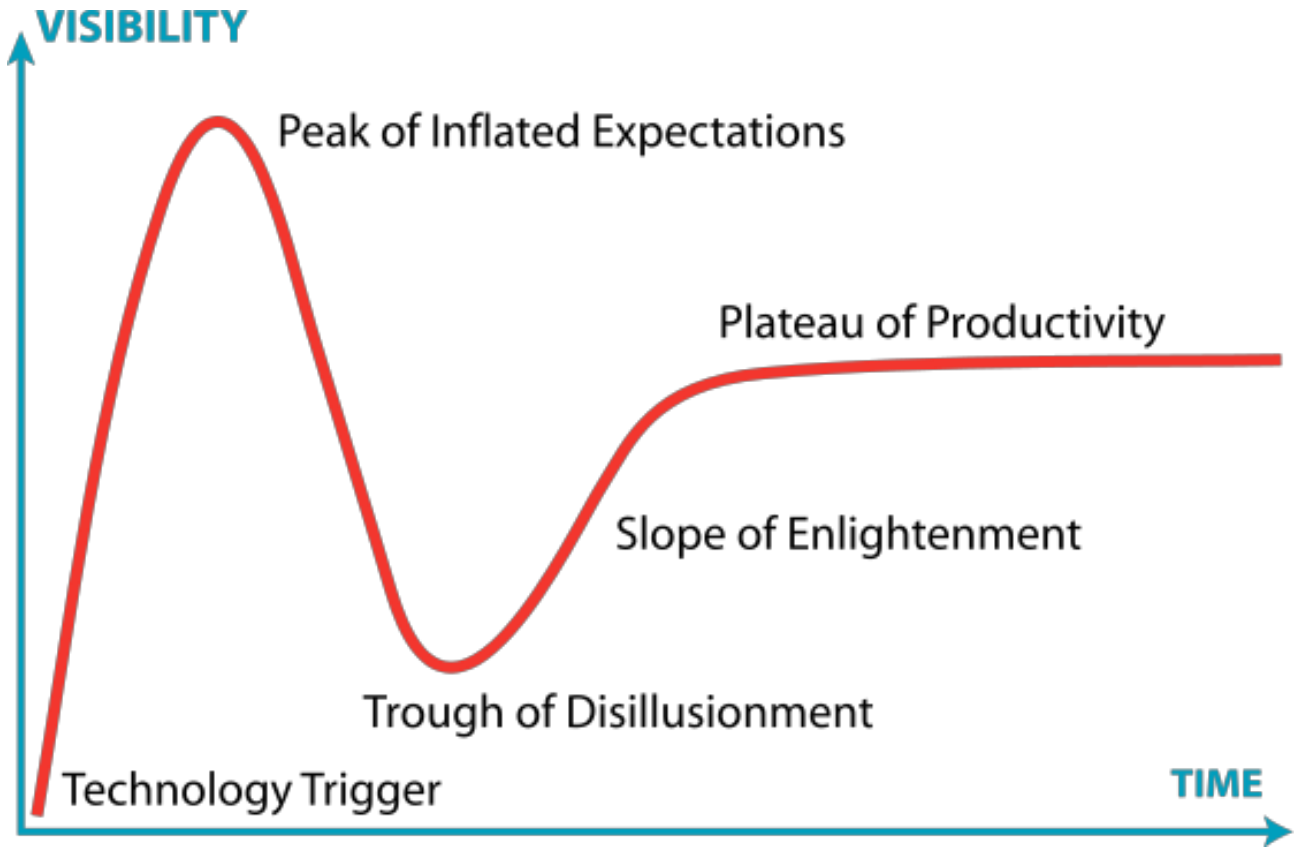
① Beware of hype
② Interference is not the problem
③ Embrace messiness
④ Virtualization is coming to town
⑤ Cutting the wireless wire

① Beware of Hype

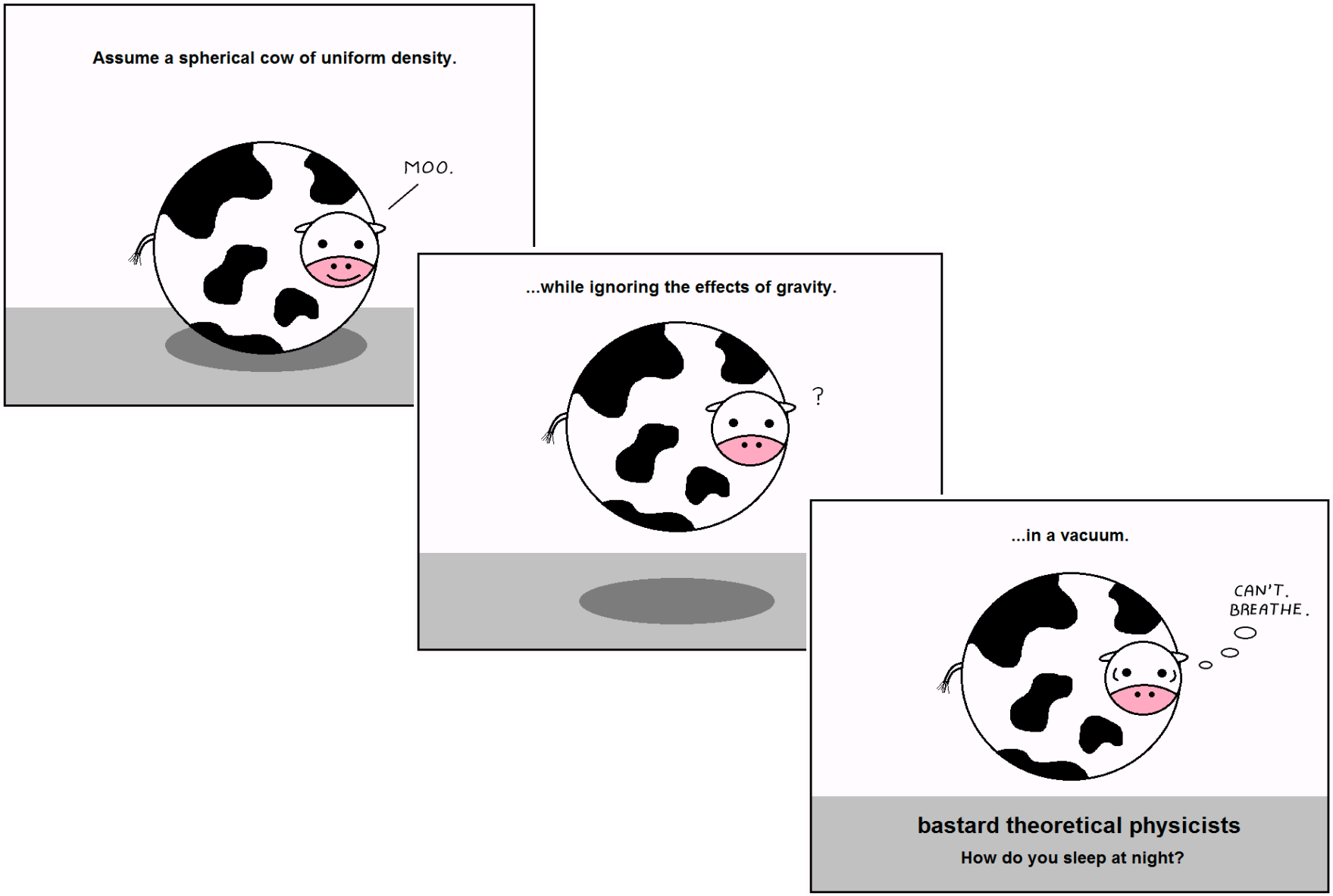
"It is a good morning exercise for a researcher to discard a pet hypothesis every day before breakfast"

K. Lorenz

① Beware of Hype

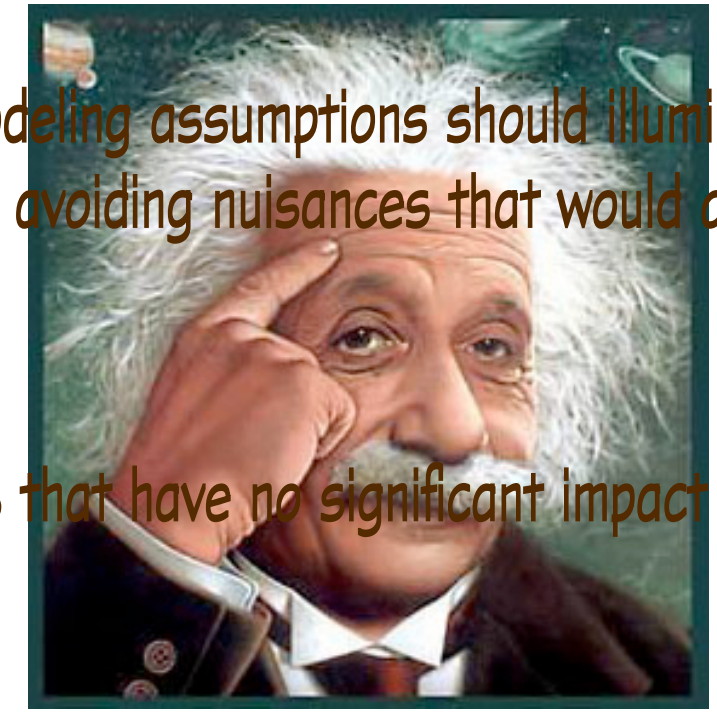


① Beware of Hype



① Beware of Hype

- The choice of modeling assumptions should illuminate the problem and maximize insight, avoiding nuisances that would otherwise be distracting



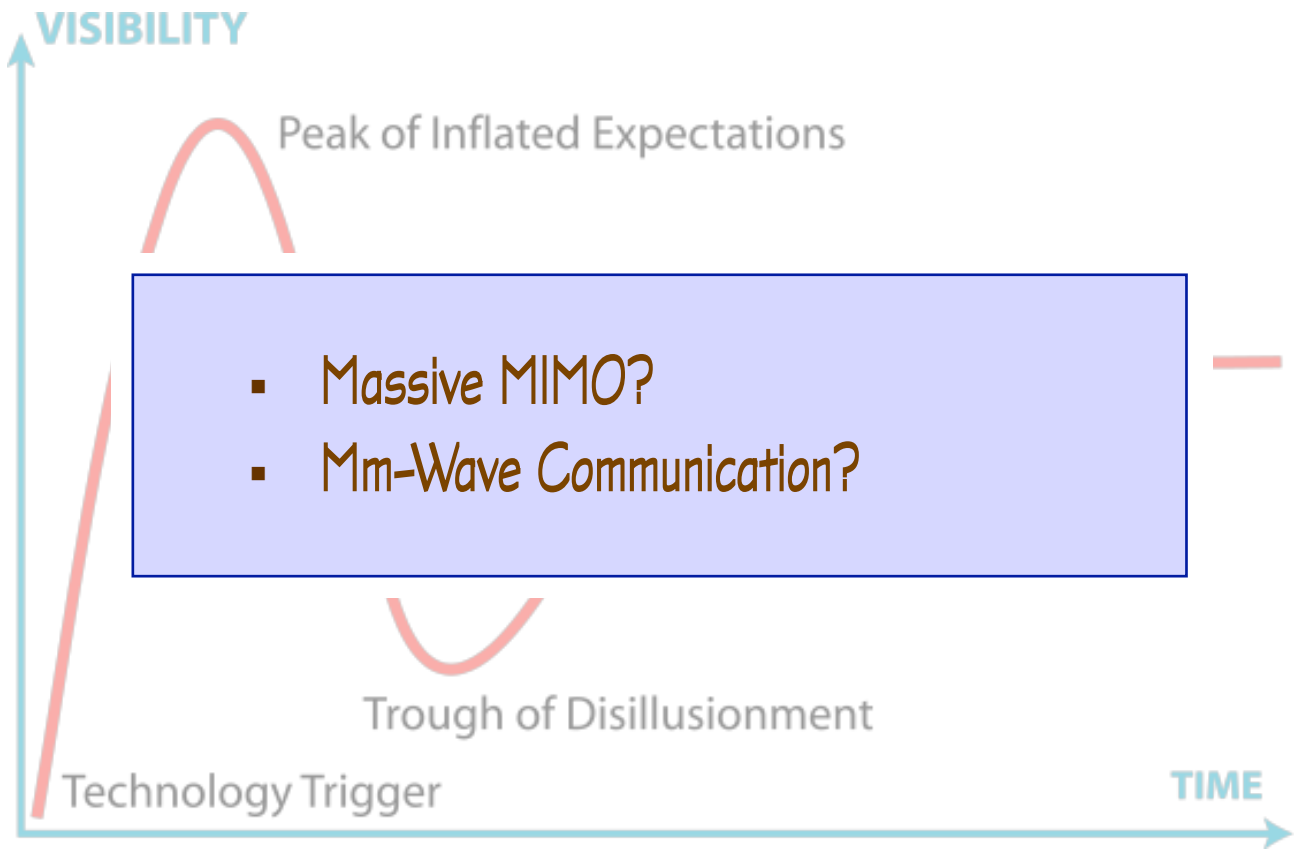
- Only distractions that have no significant impact on the result can be avoided!

"Everything should be made as simple as possible, but not simpler"

Albert Einstein

① Beware of Hype

① Beware of Hype



② Interference is not the Problem

② Interference is not the Problem

IN modern wireless communication systems, interference has become the major factor that limits performance.

Cellular networks are fundamentally limited by inter-cell interference.

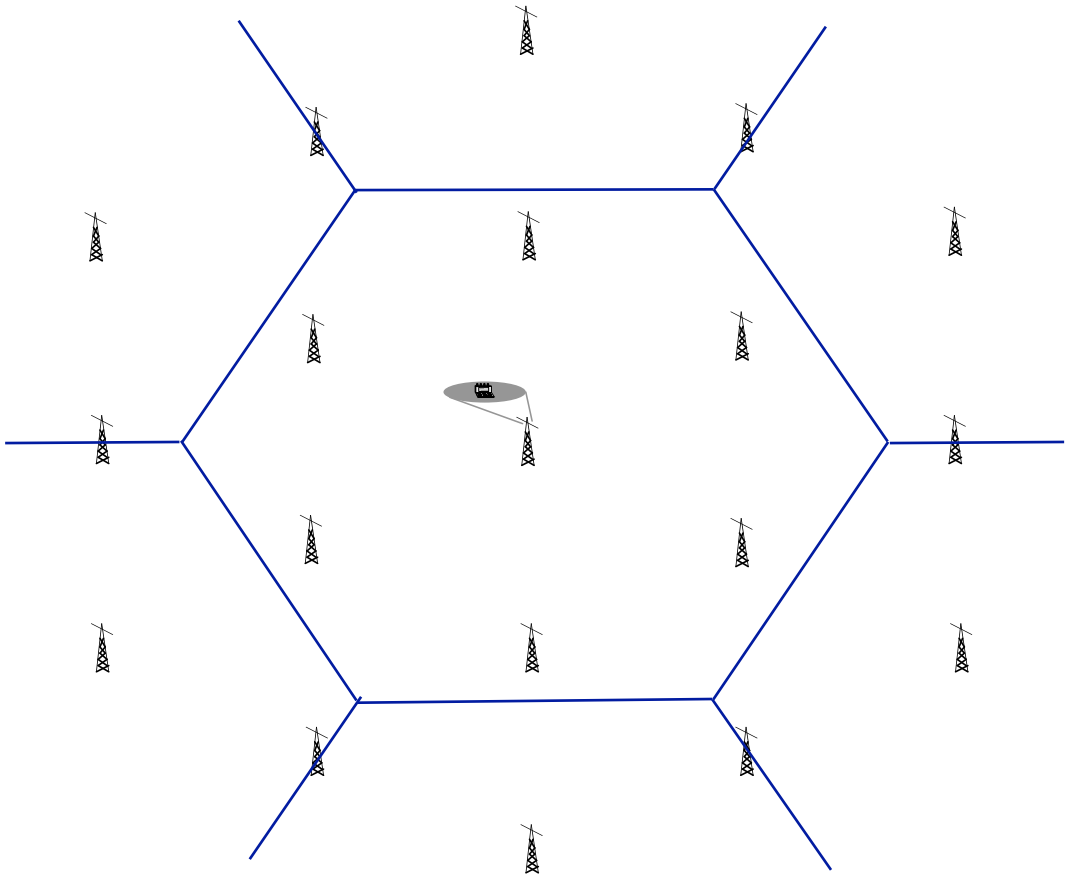
INTERFERENCE management is a fundamental challenge in wireless cellular systems.

Intercell interference is arguably the most severe impairment in contemporary wireless systems

FADING and interference are the two key challenges faced by designers of mobile communication systems.

② Interference is not the Problem

② Interference is not the Problem



$$\text{SINR}_i = \frac{P_i}{\sum_{j \in 1^{\text{st}}\text{ tier}} P_j + \sum_{j \notin 1^{\text{st}}\text{ tier}} P_j + N} \Rightarrow \text{SINR}_i = \frac{P_i + \sum_{j \in 1^{\text{st}}\text{ tier}} P_j}{\sum_{j \notin 1^{\text{st}}\text{ tier}} P_j + N}$$

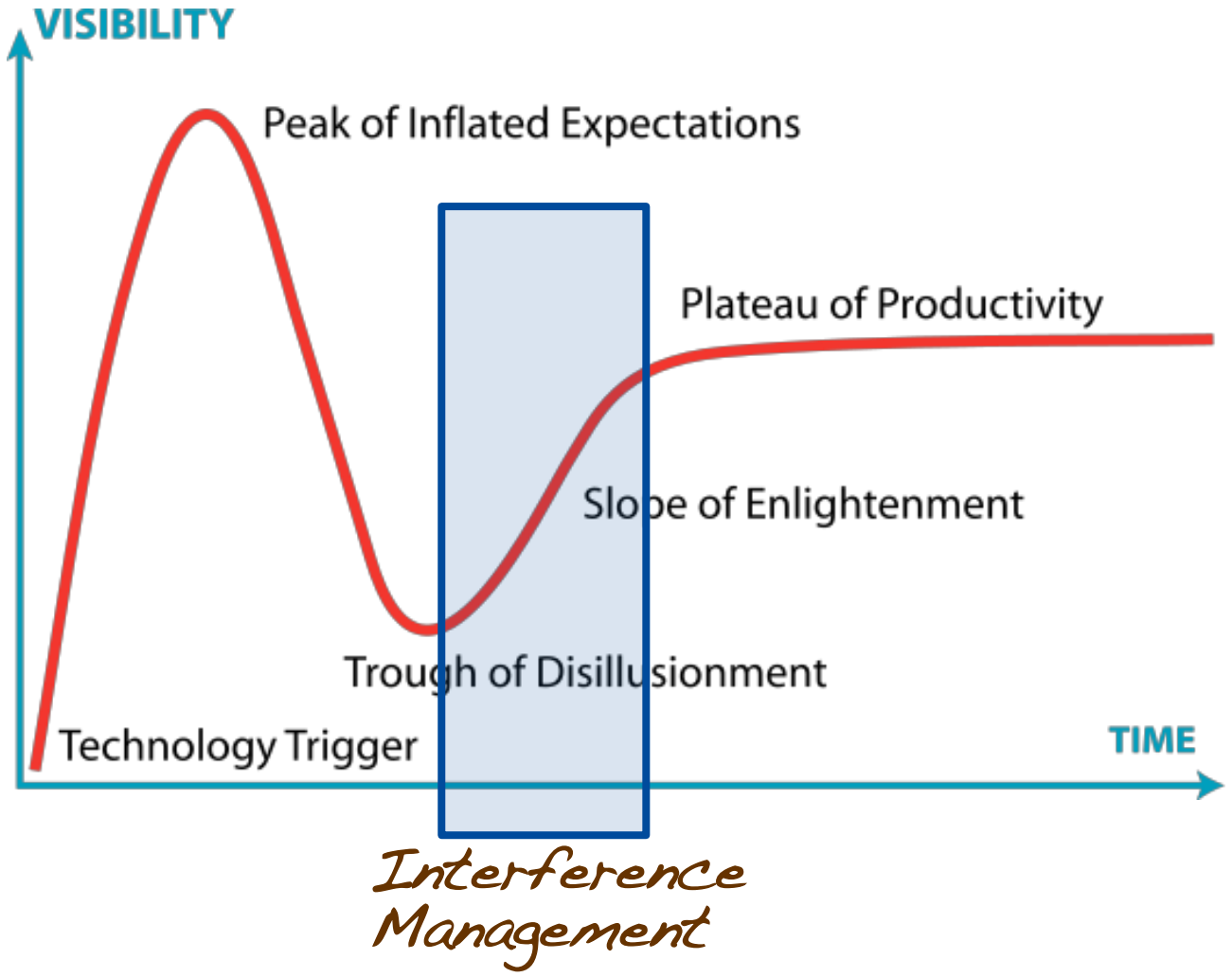
② Interference is not the Problem

Some examples...

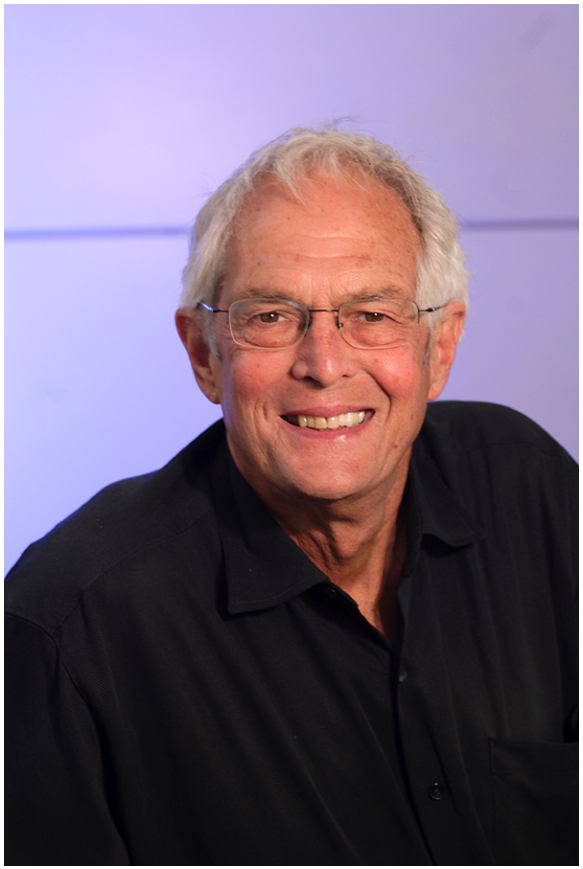
Company	Increase in Traffic	Report
Qualcomm	≤ 20%	CTW 2011 Keynote
Alcatel-Lucent	≤ 10%	ICC 2012 Keynote
Huawei	≤ 8%	[2013]

Interference is a problem but it's not the problem

② Interference is not the Problem



② Interference is not the Problem



"We should join the noise, rather than fight it"

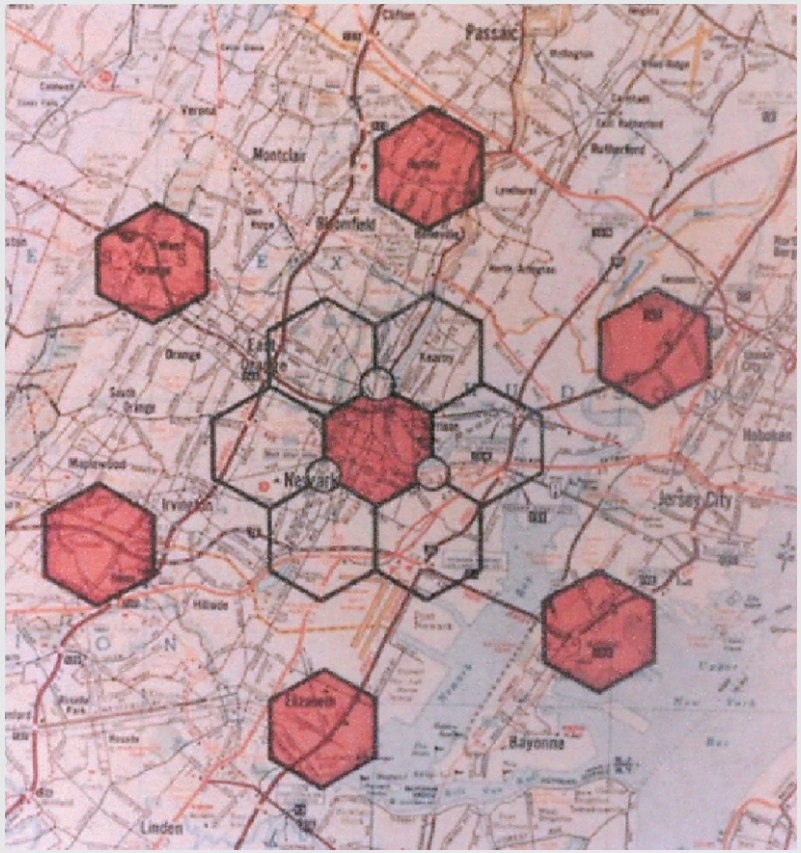
Tom Cover

③ Embrace Messiness

"For every complex problem there is a simple solution,
and it's wrong"

U. Eco

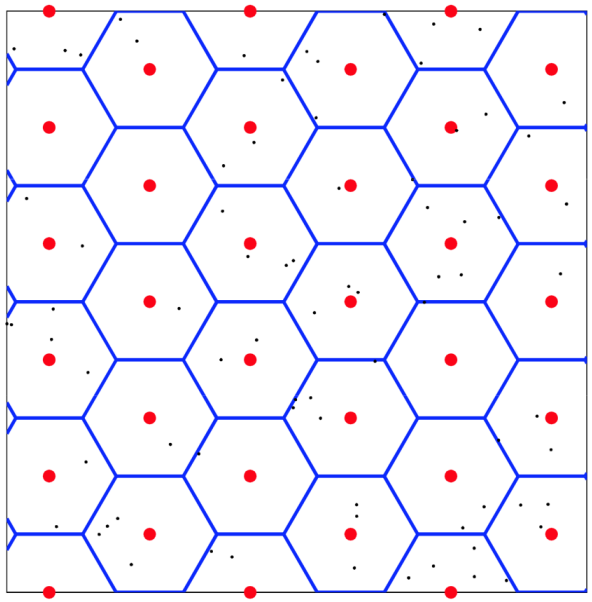
Cellular Service Trial — Chicago

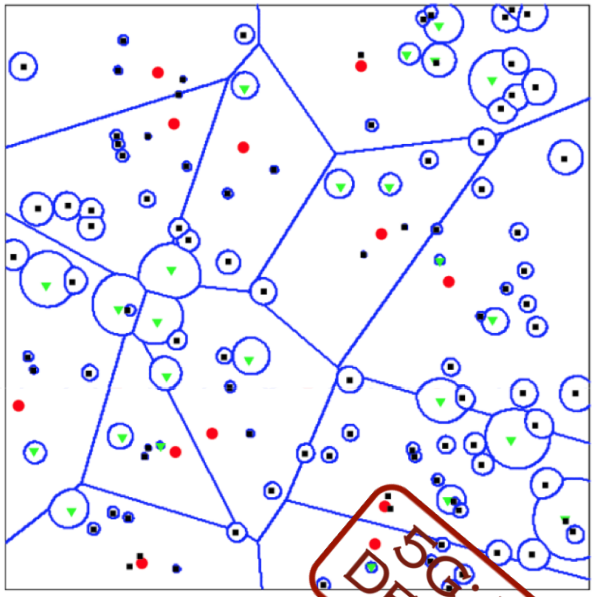


Cellular testbed — Newark

Figure 3. *Coverage maps for the Chicago and Newark trials.*

③ Embrace Messiness



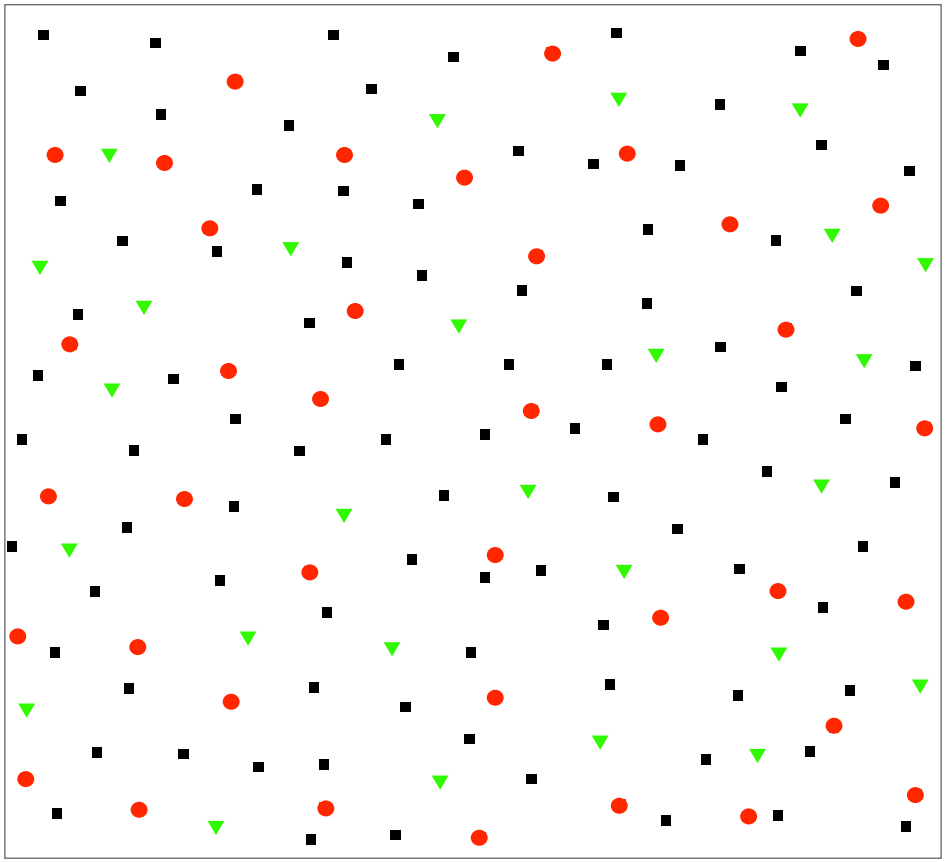


5G: EXTREME DENSIFICATION

- HetNets: macrocells, microcells, picocells, femtocells…
- CoMP
- Separate uplink/downlink routes
- Direct D2D

Figures courtesy of Prof. Jeff Andrews (UT Austin) and Prof. Martin Haenggi (U. of Notre Dame)

③ Embrace Messiness

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Cambridge Series in Statistical and Probabilistic Mathematics
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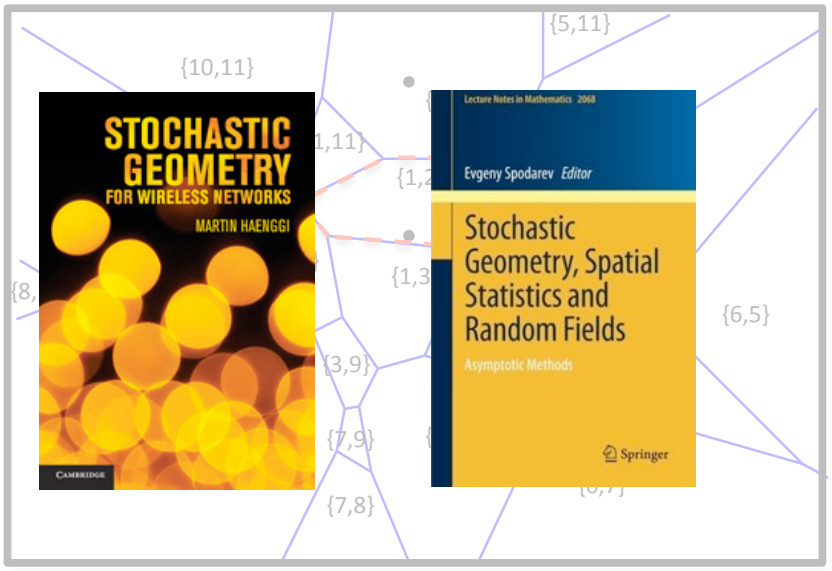
From Statistical Physics to Information Systems
Massimo Franceschetti, Ronald Meester
Foundations and Trends® in Networking
3:3–4
Stochastic Geometry and Wireless Networks
Volume I: Theory
Francois Baccelli and Bartlomiej Blaszczyszyn
now
the essence of knowledge

(a)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{3,9}
{7,9}
{7,8}
STOCHASTIC GEOMETRY
FOR WIRELESS NETWORKS
MARTIN HAENGGI
CAMBRIDGE
Lecture Notes in Mathematics 2068
Evgeny Spodarev Editor
Stochastic Geometry, Spatial Statistics and Random Fields
Asymptotic Methods
Springer

(b)

Embrace Messi-ness

④ Virtualization is Coming to Town

"He that will not apply new remedies
must expect new evils:
for time is the greatest innovator"

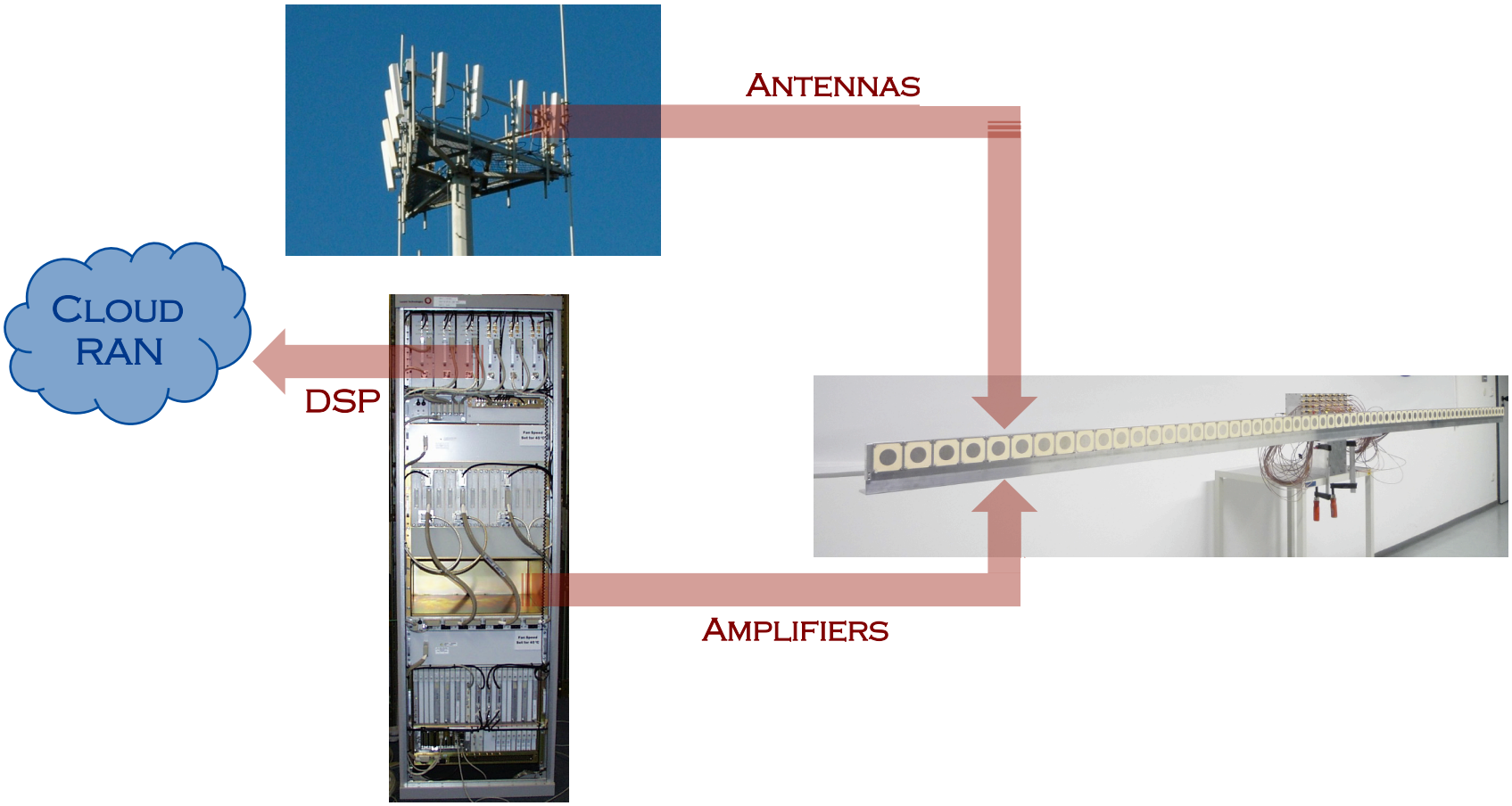
Francis Bacon

④ Virtualization is Coming to Town

- Extreme densification
- Massive MIMO

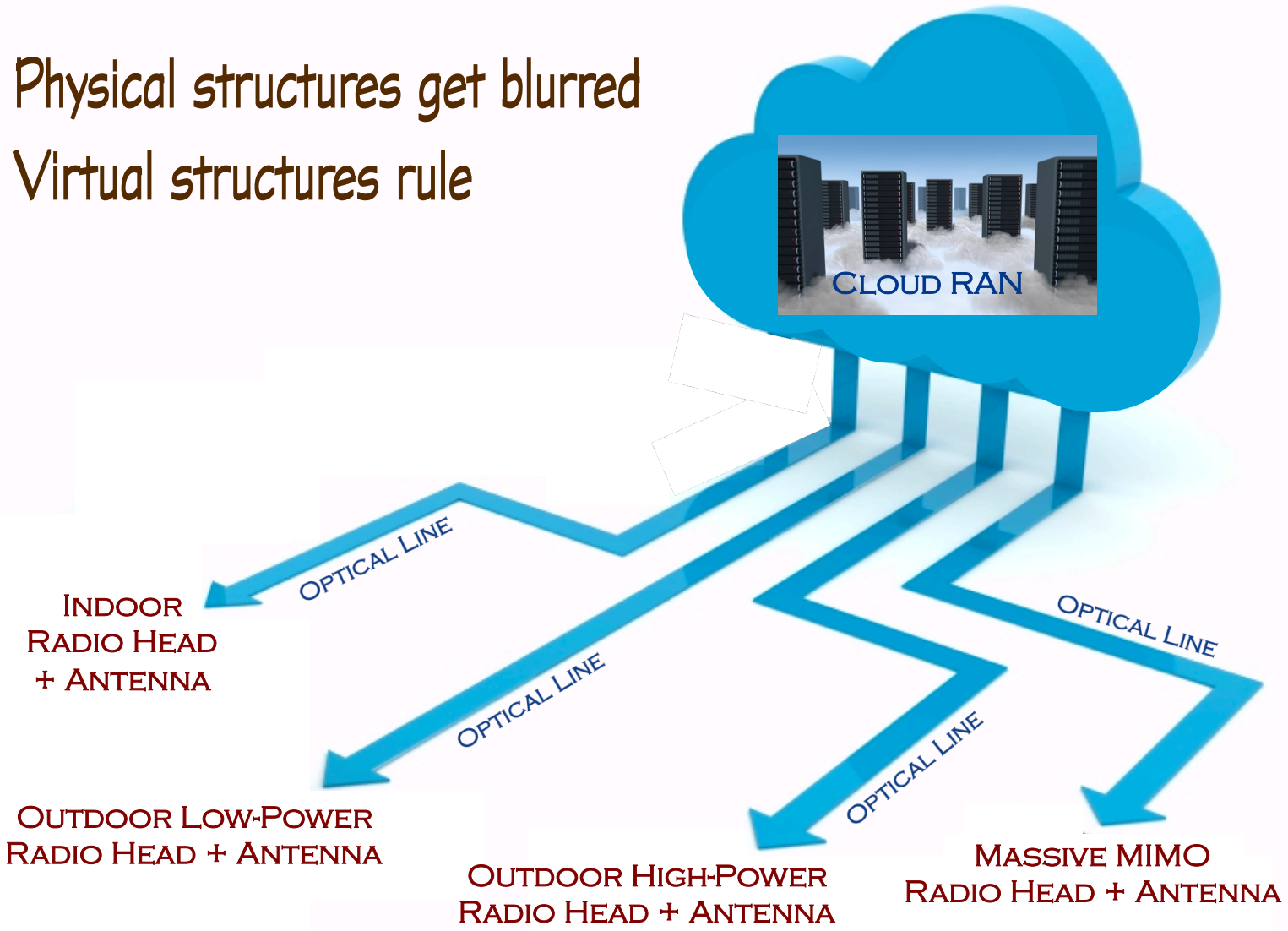
④ Virtualization is Coming to Town

④ Virtualization is Coming to Town

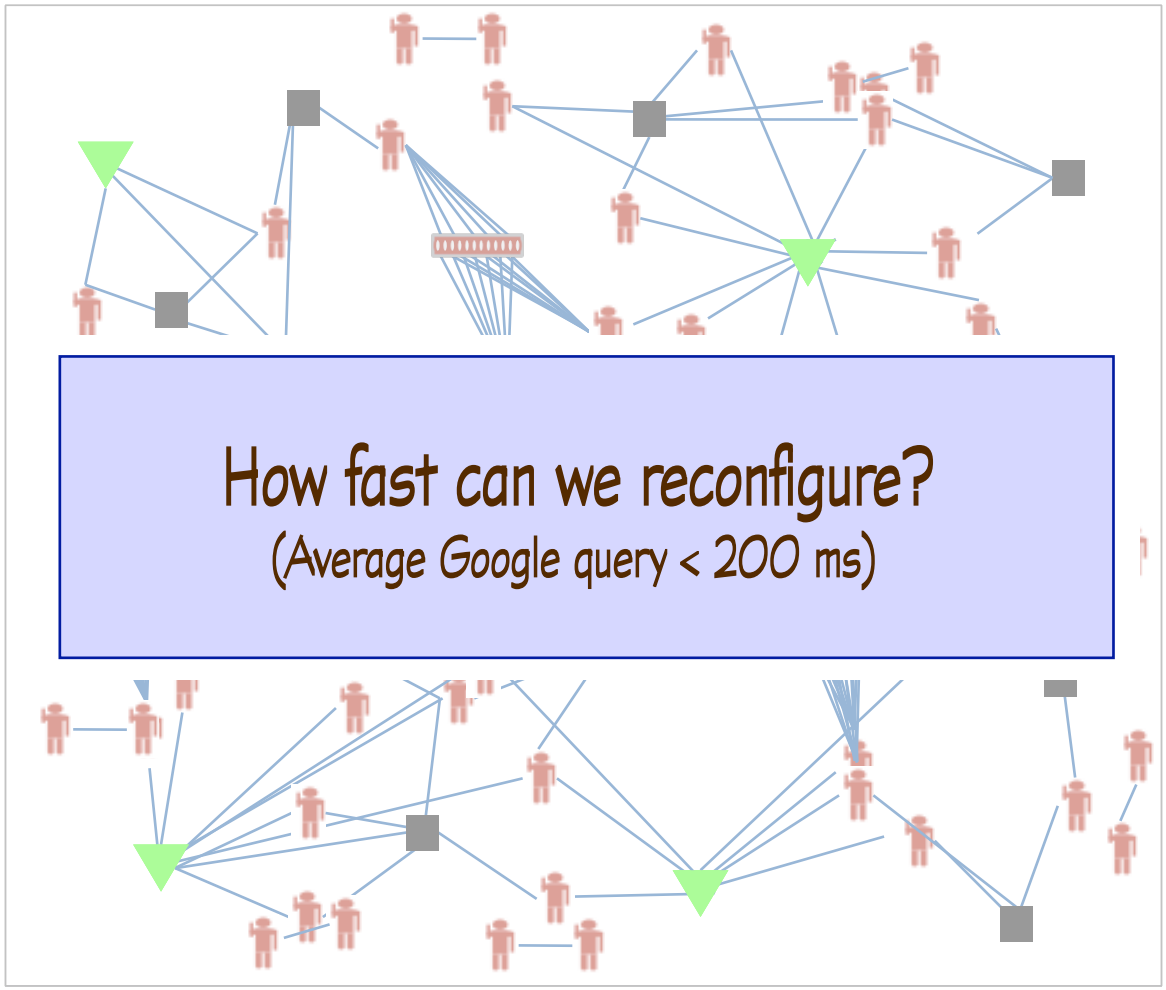


④ Virtualization is Coming to Town

- Physical structures get blurred
- Virtual structures rule



④ Virtualization is Coming to Town



Cloud RAN

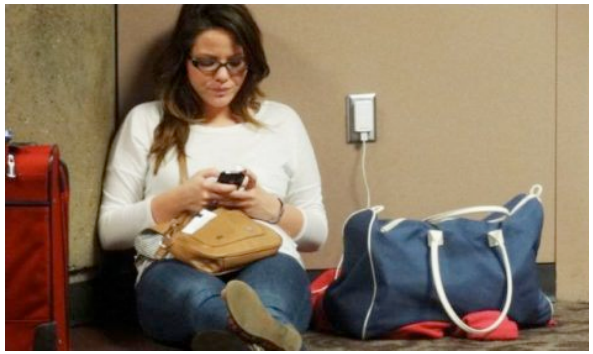
Caching at the Edges

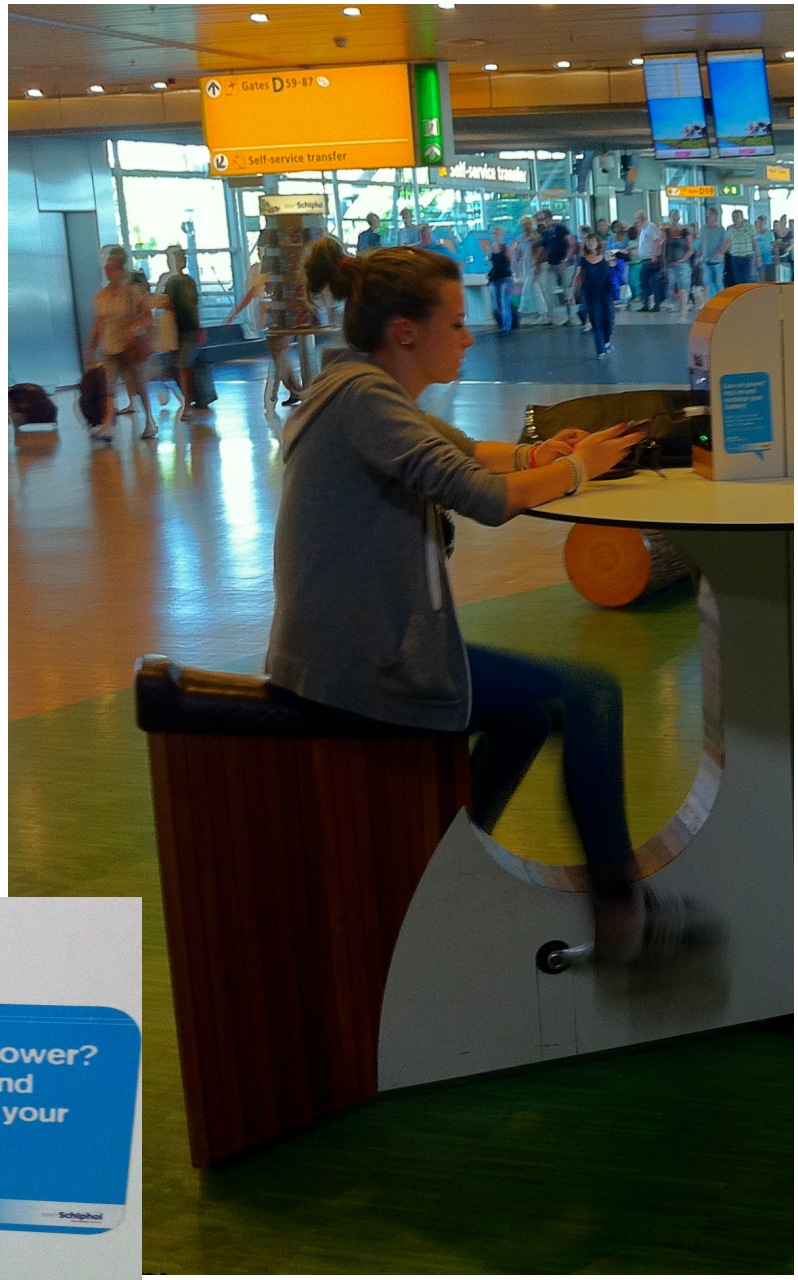
⑤ Cutting the Wireless Wire

⑤ Cutting the Wireless Wire


PAPER
TRASH

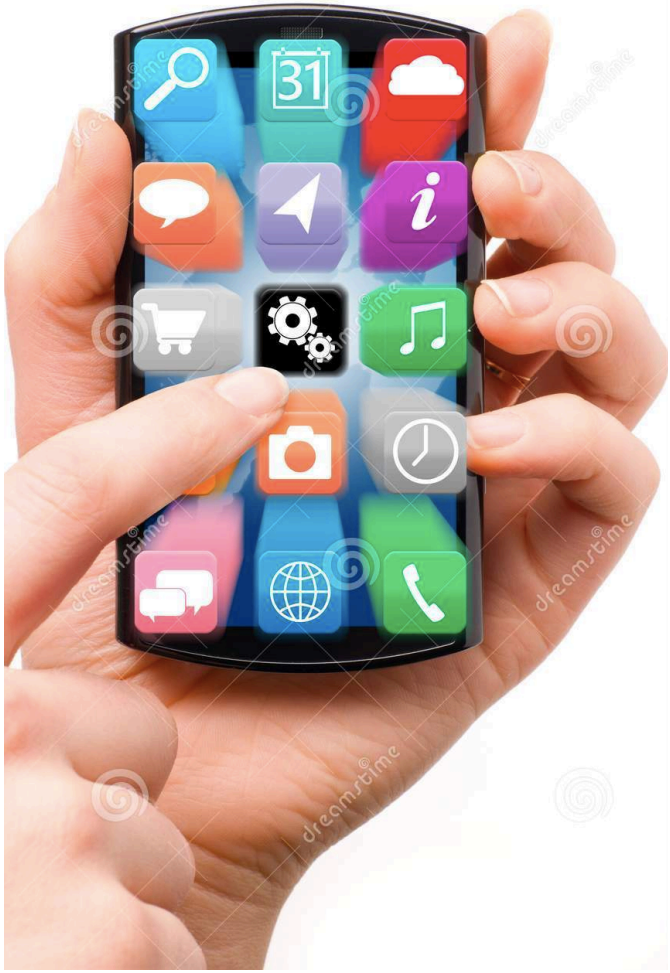

Incheon Airport
USB
220V



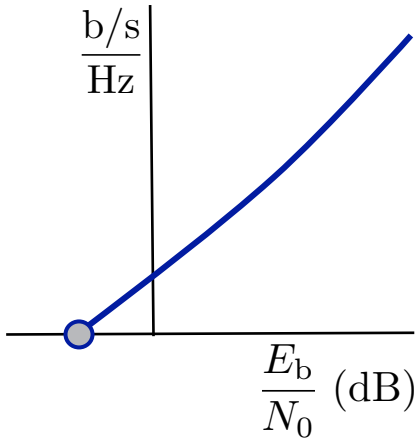

Gates D 59-87
Self-service transfer
Low on power?
Hop on and
recharge your
battery!
Check-in
to Sustainability
Schiphol

⑤ Cutting the Wireless Wire

- ~~A solution to the "perfect storm"?~~ 
- The "curse" of Moore's Law



⑤ Cutting the Wireless Wire



High energy efficiency

Low spectral efficiency

MOBILE USER PERSPECTIVE

$$\text{bits/s} = \frac{\text{bits/s}}{\text{Hz} \cdot \text{antenna}} \cdot \text{antennas} \cdot \text{Hz}$$

Careful with the high-SNR infatuation...

Final Remarks

- Watch out for hype
- Let's not lose sleep over interference
- There are no cells, only nodes
- Think messy, think virtual
- Energy efficiency also matters

DON'Ts of Mathematical Modeling

"Cum grano salis"
(Don't believe the 33rd order consequences of a 1st order model)

"Use only as directed"
(Don't apply any model till you understand the simplifying assumptions on which it's based, and can test their ability)

"Don't go off the deep end"
(Don't extrapolate beyond the region of fit)

"Don't beat a dead horse"
(Don't retain a discredited model)

Solomon W. Golomb, 1970