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Spectrum Challenges for Wireless Indoor Networks beyond the ”Ultra-Dense Barrier”

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

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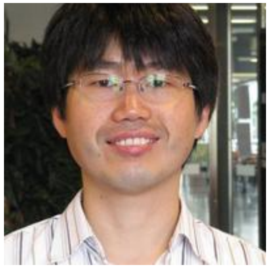
Outline

- **The "1000X" – challenge**
  - Can we reach 1000x capacity = **1 Gbit/s/m^2**?
- **Are Extremely Dense (Indoor) Networks the solution?**
  - Some design issues
- **Is Spectrum shortage the key challenge ?**
  - Should we share spectrum - or not ?

Some acknowledgements

Seong-Lyun Kim
Yonsei Univ



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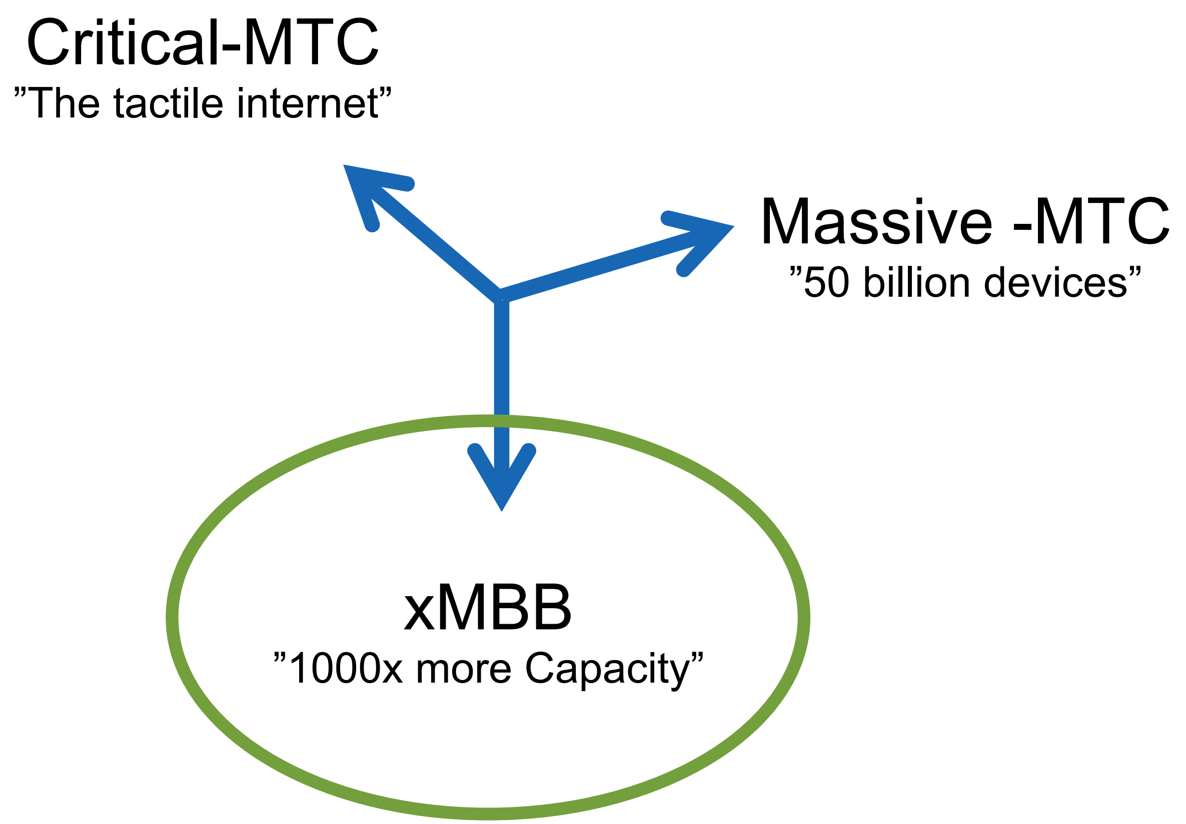
1. Zander, J, "**Beyond the Ultra-Dense Barrier: Paradigm Shifts on the Road Beyond 1000x Wireless Capacity**", *IEEE Wireless Communication Magazine*, June 2017
2. J. Zander, P. Mähönen, "**Riding the Data Tsunami in the Cloud – Myths and Challenges in Future Wireless Access**", IEEE Communications Magazine, March 2013

The 5G Context

The three design dimensions



How do you increase the data rate (coverage) in a (traditional) Cellular Network ??

More power, Fewer walls, advanced technology

$$R_{user} \approx W_{SYS} \log\left(1 + c\eta N_{BS}^{\alpha}\right) \quad \text{bit/s}$$

More radio spectrum

More Base stations

How do you increase the capacity in Cellular Networks ??

More Advanced Technology (Interference mgmt)

More radio spectrum

$$R_{tot} \approx \frac{\eta}{A} N_{BS} W_{sys}$$

(bit/s/km^2)

More Base stations

What can be done with today's technology?

	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
* 1 AP/room , perfect wall attenuation

1000x more than today = 1 Gbit/s/m^2

(1000 Tb/s/km^2)

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What are Extremely Dense Networks?

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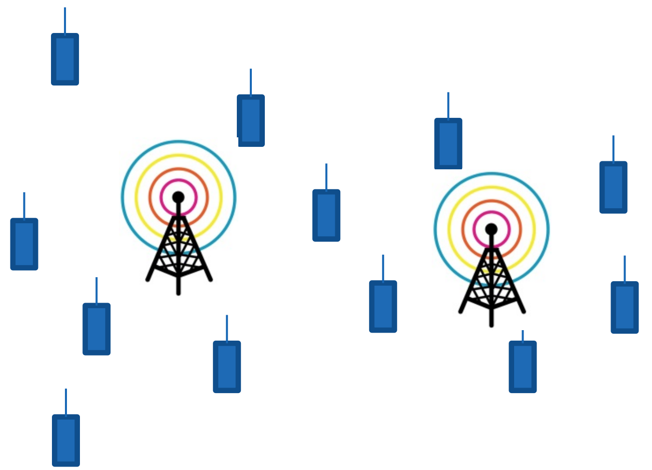
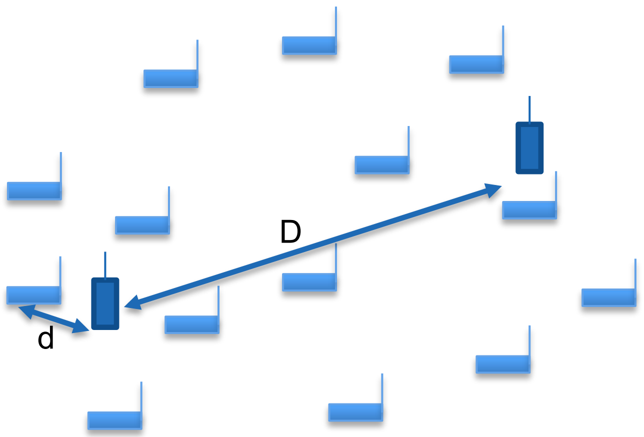
What is an Extremely dense system



Cellular System

$\lambda_{AP} << \lambda_{T}$



Extremely-dense access system

$\lambda_{AP} >> \lambda_{T}$

- Extremely Dense Network = (Many) More Access Points than Terminals (the “ultra-dense barrier”)
- Area capacities > 1 Gbit/s/sqm

Area capacity and Power

$$\text{Area capacity} \propto \begin{cases} \lambda_U W_{SYS} \log\left(1 + c\left(\frac{\lambda_{AP}}{\lambda_U}\right)^{\alpha/2}\right) & \lambda_{AP} \leq \lambda^*_{AP}(R_{\max}) \\ R_{\max}\lambda_U & \lambda_{AP} > \lambda^*_{AP}(R_{\max}) \end{cases}$$

$$\text{Power/User} = \frac{c_1}{\lambda_{AP}^{\alpha/2}} + c_2 \frac{\lambda_{AP}}{\lambda_U}$$

Conventional frequency reuse, Stochastic geometry model

What makes indoor system special ?

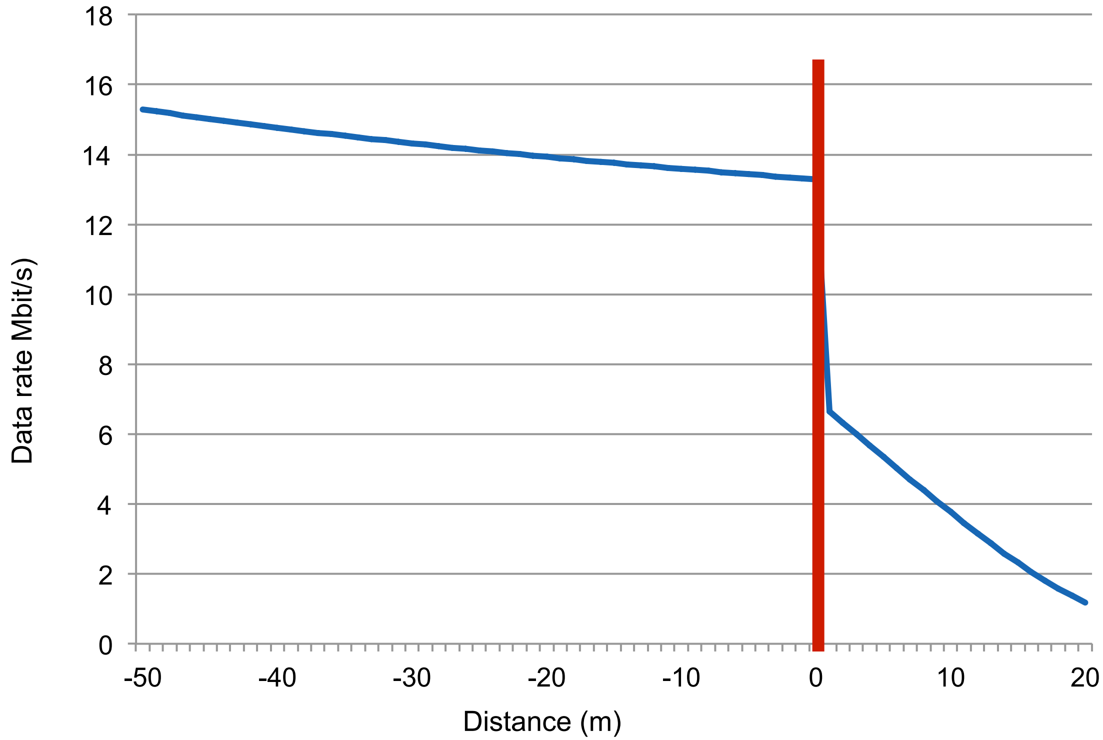
Design Characteristics – a paradigm shift

Characteristic	Cellular, Wide-area paradigm	High-Density, Short Range
Propagation	Distance loss, shadowing, rich multipath	Mostly LOS, Body shadowing
Interference	Interference sum of many components (averaging)	Extremely varying interference
Duplexing	Up & Downlink have different characteristics (power) and must be separated	Link direction irrelevant Access points/terminals can be defined at higher layers.
Engineering limitations	Range, Interference, Energy	Interference
Peak rate limitation set by	Noise & Interference	Equipment (very high SNR)

Design Characteristics, cont.

Characteristic	Cellular, Wide-area paradigm	High-Density, Short Range
Cost limitations	Sites: Acquisition, Antennas, Equipment, Deployment, Backhaul, Spectrum licenses	Backhaul, Deployment
Active Users/Base station	1-100	0,01 - 1
Available radio bandwidth	< 0,5 GHz Licensed	> 5 GHz Secondary sharing
Business model	Subscription based service Per month or per MB charging	Free to all tenants and visitors in building (similar to A/C, lighting, running warm water)
Design paradigm	Industrial grade, Centralized control, "mandatory complexity"	Consumer grade, Distributed control, plug-and-play
Maintenance model	Single point of failure - 24/7 monitoring	Graceful degradation – replace when time available

Hitting the (brick) wall



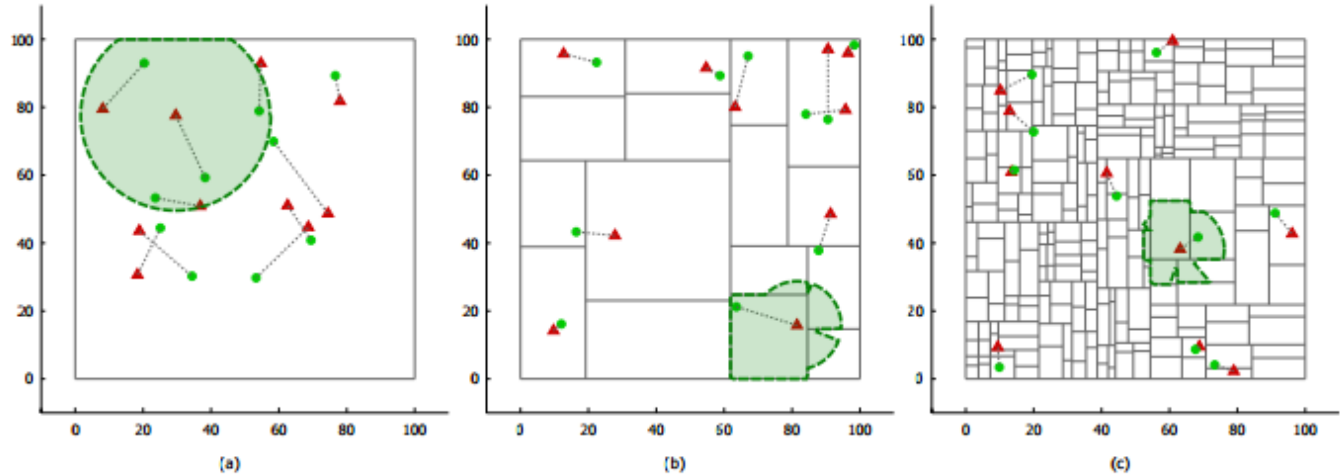
- ”Wireless Friendly” buildings:metalized windows & reinforced concrete
- 20 dB loss (at window)   30- 40 dB loss 10-20m into building

Modelling issues

SPPP-models convenient – mathematically – but do they capture essential features of dense indoor deployments ?

- Strong interference coupling between BS
- Walls – simple deployment strategies take these into account

Alternative approach – stochastic room/wall models



Özyagci, Sung, Zander, "Effect of propagation environment on area throughput of dense WLAN deployments", Globecom BWA WS, 2013

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Indoor EDN:s design issues

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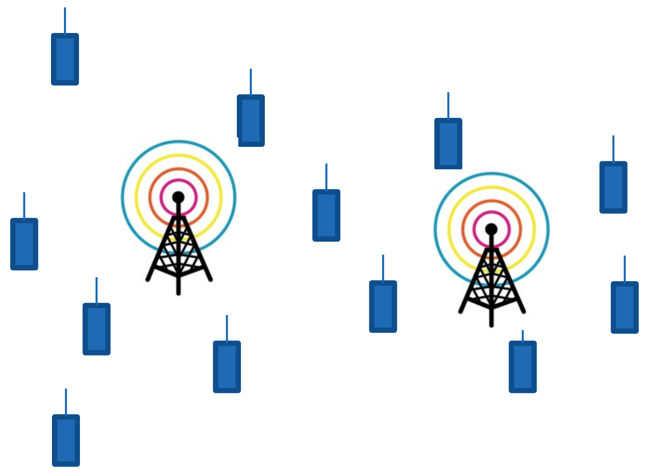
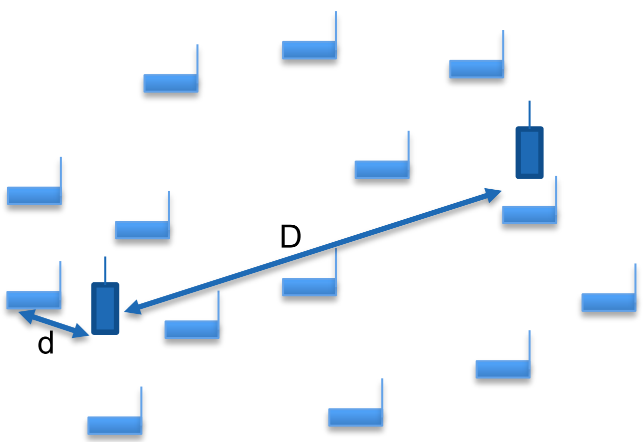
What is an Extremely dense system



$\lambda_{AP} << \lambda_T$



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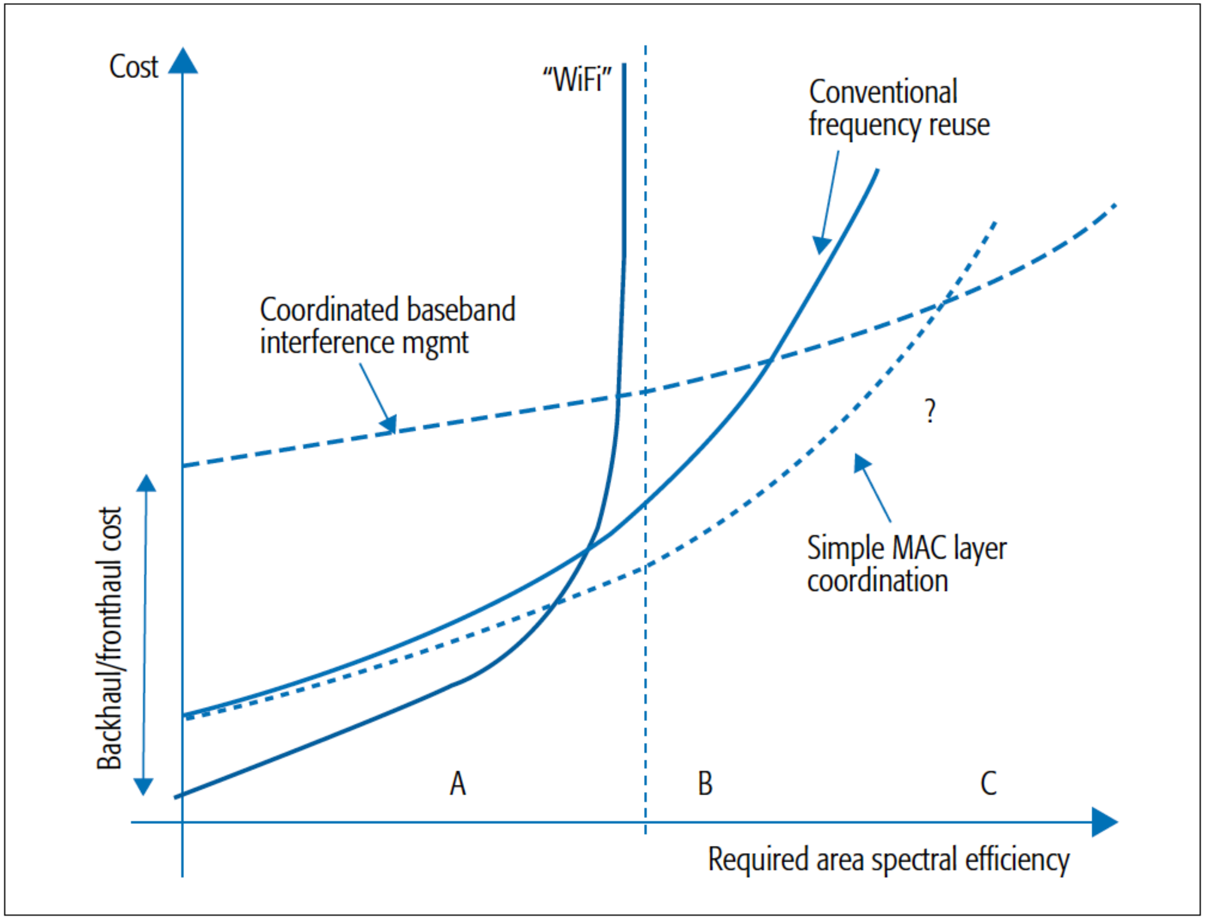
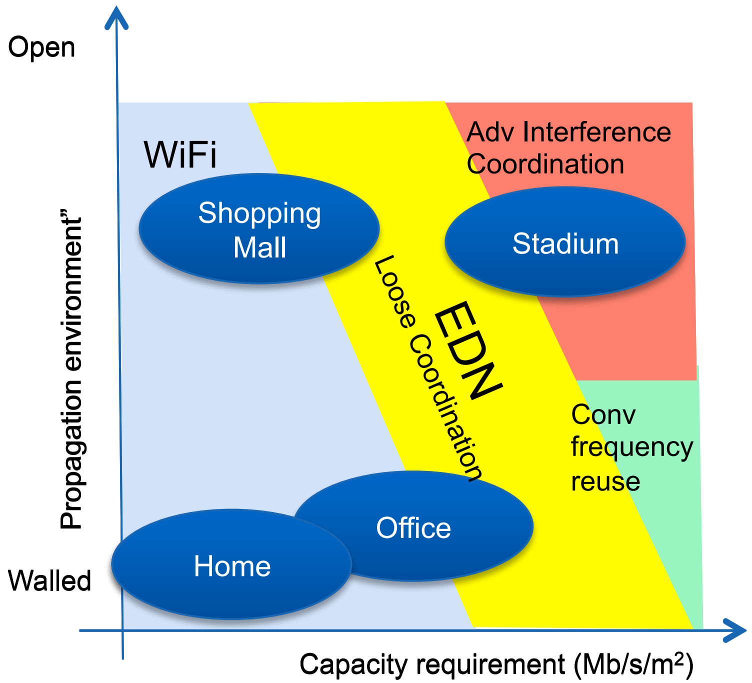
Conventional frequency reuse, Stochastic geometry model

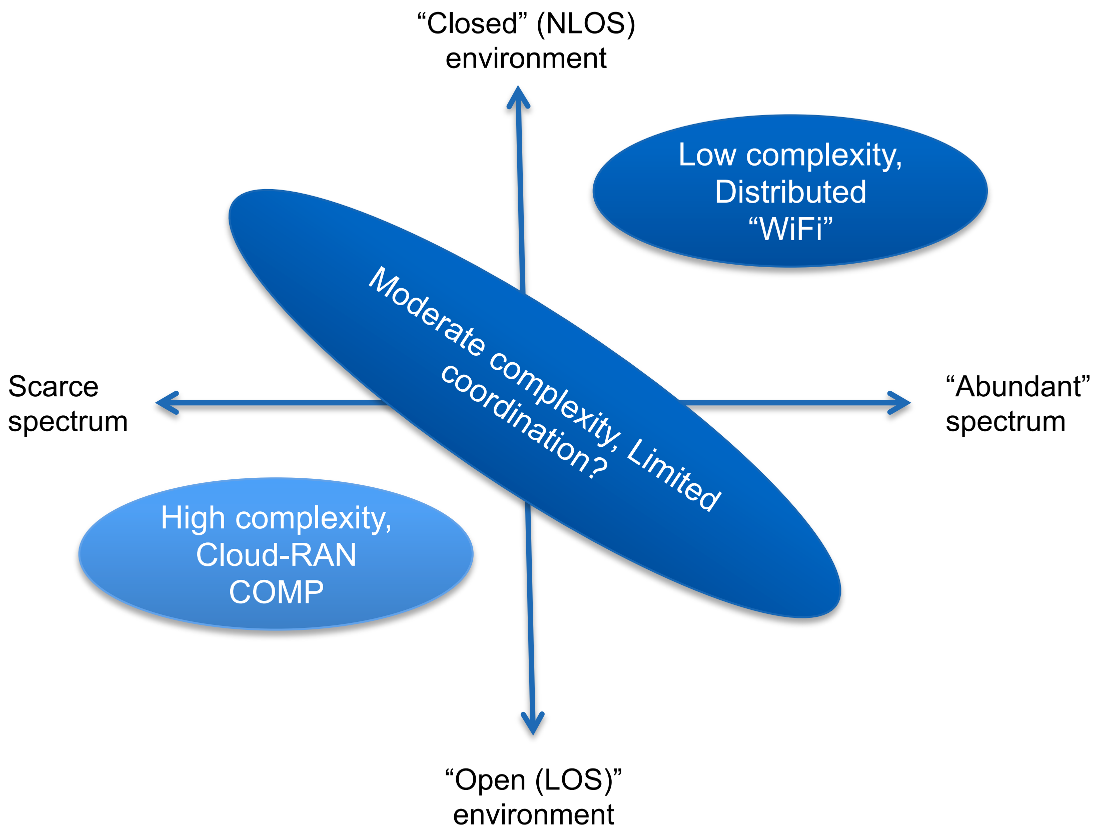
Design options for high capacity systems



Adapted from: D. H. Kang, K. W. Sung, and J. Zander, "High Capacity Indoor and Hotspot Wireless Systems in Shared Spectrum:A Techno-Economic Analysis," IEEE Commun. Mag., Dec. 2013.

Impact of propagation environment




"Closed" (NLOS) environment
Low complexity, Distributed "WiFi"
Moderate complexity, Limited coordination?
Scarce spectrum
"Abundant" spectrum
High complexity, Cloud-RAN COMP
"Open (LOS)" environment

Moderate (MAC-layer) Coordination - Candidate Technologies

Requirement:

- Can use existing Ethernet backhaul
- ms –delay, Signaling rate << Payload rate

Candidates:

- **Cognitive radio:**
  - Distributed Sensing: CSMA – works but has limitations
- **Coordinated beam steering**
  - Works at higher frequencies (mm-Waves)
  - Beam steering at packet level (ms-level)
  - Moderate backhaul requirement
  - Example: IEEE 802.11ad (WiGig)

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Is there a spectrum shortage ?

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Traditional spectrum management

Each applications :

- Has its own technical solution
- Needs ”exclusive” spectrum

→

- Complex regulation
- Fragmentation of spectrum

Today: A single solution for all needs

- Internet access + Cloud based application seems to be the solution to a vast majority of applications
- A single, simple interface - **IP** – for all applications - inefficient – but highly flexible and transparent
- Highly scalable – massive growth in applications and usaga
- Convergence to a single infrastructure – wireless IP-access is no longer a service – it is the THE platform

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

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 <20 GHz

Higher frequencies (>3 GHz) for high capacity (lower interference)

Local & temporal spectrum regimes (National Block-licensing inefficient)

Unlicensed, Secondary, LSA, "Instant licensing"

Spectrum → Infrastructure Sharing!

Spectrum for indoor access

Spectrum range	Sharing scheme	Pros	Cons
<6 GHz	Unlicensed/ Licensed	Good propagation	Limited spectrum availability
6-20 GHz	Secondary sharing	Moderate prop., Large amounts of available spectrum	Sharing with existing services
>20 GHz	Unlicensed/ Licensed	Large amounts of available (exclusive) spectrum	Poor propagation for mobile usage

Coexistence studies

- D H Kang et al, “High Capacity Indoor and Hotspot Wireless Systems in Shared Spectrum: A Techno-Economic Analysis, IEEE Com Mag, Dec 2013
- D H Kang, “Interference Coordination for Low-cost Indoor Wireless Systems in Shared Spectrum”, Ph.D. Thesis, KTH 2014.
- E. Semaan et al, “Outdoor-to-Indoor Coverage in High Frequency Bands”, IEEE Globecom Workshop, 2014.
- M Tercero et al, “Coexistence between 5G and Fixed Services”, IEEE VTC Spring 2016

Some conclusions

- **1000x capacity does not require new technology** – ”only” 10x more (shared) spectrum
- **Advanced cellular technology** (e.g. beamforming, interference management) **lowers spectrum requirement but requires costly new infrastructure**
- **Two ways forward:**
  - Low power indoor spectrum sharing with outdoor services above 6 GHz in modern buildings
  - MAC:s with moderate coordination over existing backhaul