LTE-A Systems and Beyond

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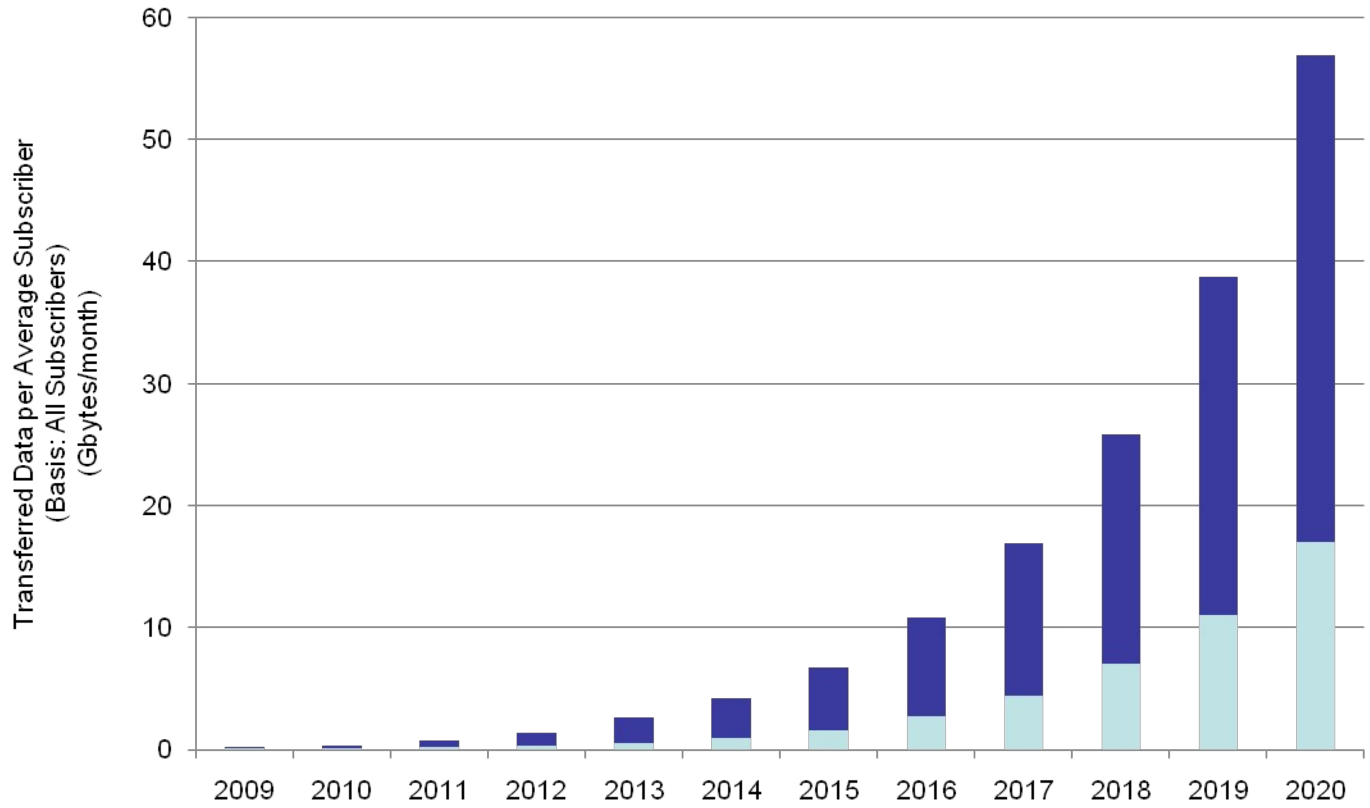
19. FFV Workshop 2011 @ ComNets Aachen, March 2011

Growth of Transferred Data in Western Europe



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Cellular modem	0,09	0,22	0,52	1,09	2,00	3,22	5,16	8,10	12,50	18,80	27,70	39,90
Handset data + VoIP	0,06	0,09	0,17	0,32	0,58	0,96	1,61	2,70	4,40	7,00	11,00	17,00

Source: S. Liu, J. Wu, C. Ha Koh, V.K.N. Lau: A 25Gb/s(/km2) Urban Wireless Network Beyond IMT-Advanced. IEEE Communications Magazine, February 2011, 122-129

The Problem of Cellular – in General: Cell Capacity vs. Distance is Inverse to the Needs

Range of broadband Base Station is limited by
- Attenuation and shadowing
- Transmit power (EIRP limits)

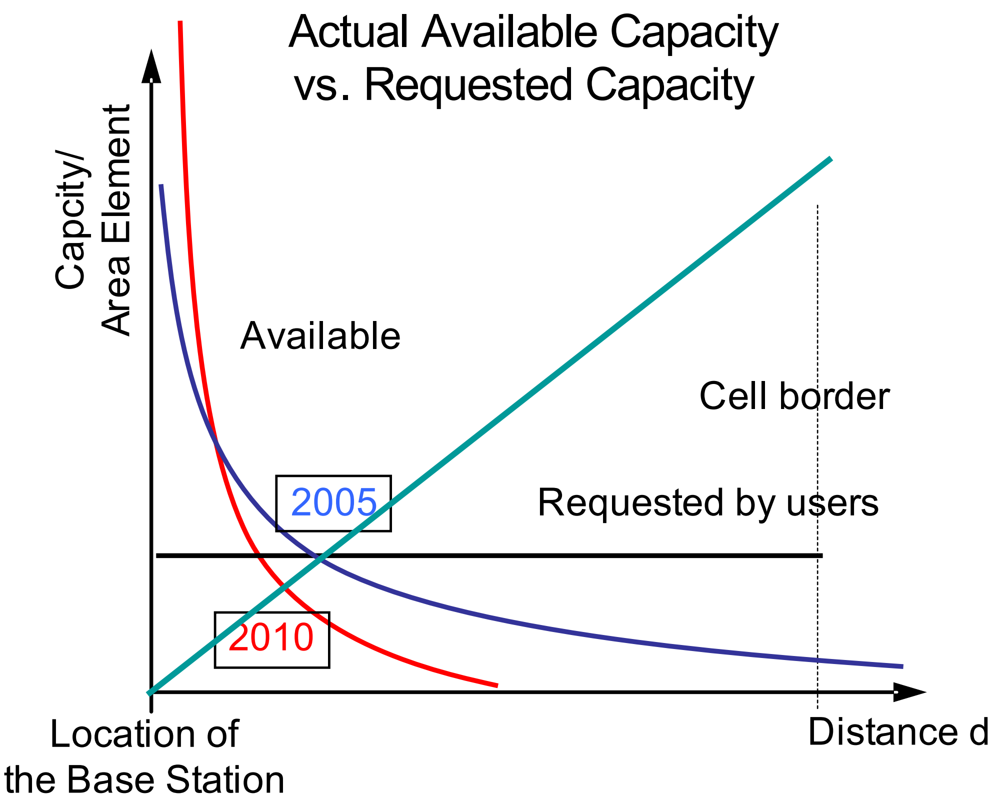
➔ The higher the carrier frequency, the higher the # of BS needed to cover a service area (-> high CAPEX / OPEX)

➔ High cost/bit transmitted

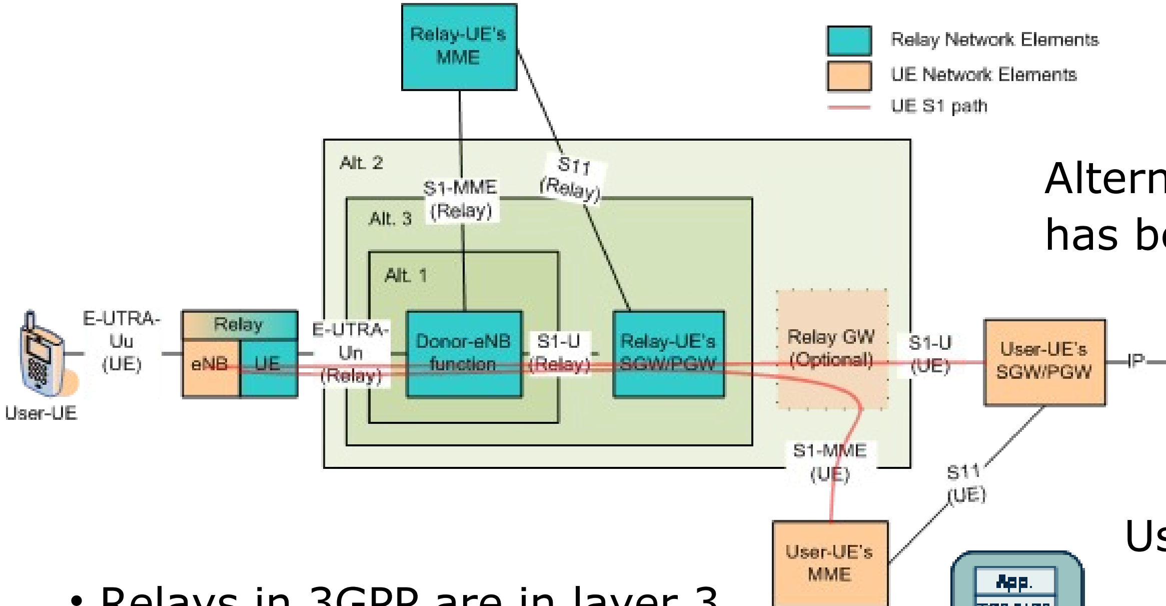
➔ Capacity per service area element is inverse to capacity requested by users

➔ Technology trend worsens situation, cp. 2005 vs. 2010

➔ Re-use 1 in cellular worsens situation compared to re-use >1

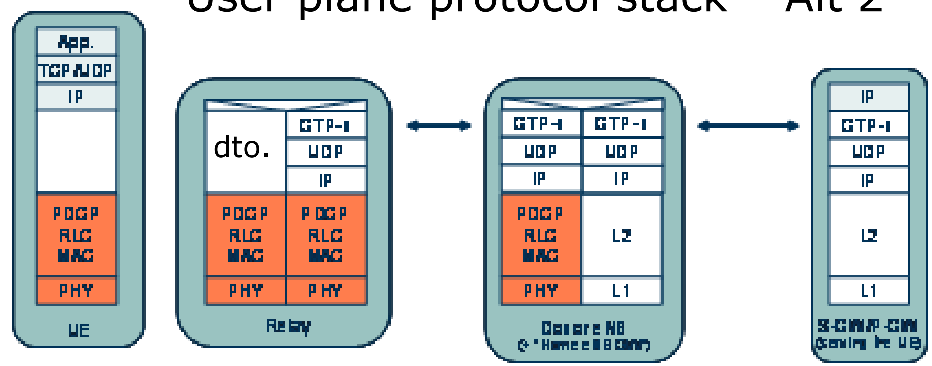


The ComNets Solution to the Problem of Cellular: Multi-hop Relays.
[Picture taken from 3GPP TR 36.806 V2.0.0 (2010-02)]



Alternative 2 of Architecture Family A has been chosen by 3GPP.

User plane protocol stack – Alt 2 -



- Relays in 3GPP are in layer 3.
- Both, eNB and UE functionality is contained in RN.
- eNBs may operate in tandem as relays („eNB backhauling")

B. Walke, R. Pabst, D. Schultz: A *Mobile Broadband System based on Fixed Wireless Routers*. In: *Proc. ICCT 2003 Internat. Conf. on Communication Technology*, 04/2003, Beijing, China

Abstract: A new radio access network architecture for a mobile broadband system is introduced that uses Fixed Wireless Routers (FWR) to provide radio coverage to otherwise shadowed areas.

3GPP LTE-A Basic Parameters

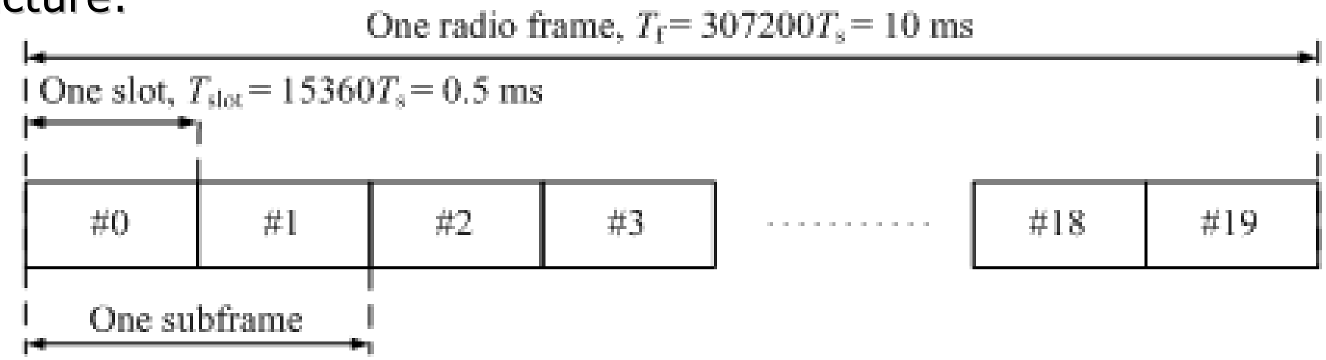
OFDMA, 20 MHz bandwidth, 1 200 sub carriers.

Resource Block: set of resource elements on 12 (subcarriers) *14 (OFDM) modulation symbols. ->100 RBs in frequency domain.
One **sub frame** = 1/10th of a frame duration.

64 QAM modulation (6 bit/symbol): 14 symbols/sub frame = 140 symbols/10 ms.

FDD frame length: Tf = 307200 * Ts =10ms; Frame consists of 20 slots;
Tslot =1536*Ts =0,5 ms, numbered from 0 to 19. Ts = Symbold.
Subframe i consists of slots 2i and 2i+1.

FDD frame structure:



Innovation Areas to Improve Spectral Efficiency of LTE[1]

The following innovations are LTE backward compatible, and considered candidates for future standardisation, or topics for future research studies.

1. Radio Resource Allocation:
Efficient, Flexible Scheduling & Spectrum Allocation.

OFDMA systems require optimum dynamic resource allocation algorithms

Innovative concepts considered in WINNER+:

- QoS scheduling,
- Coordinated MIMO scheduling,
- Spectrum allocation techniques,
- Traffic identification and load balancing,
- MBMS provisioning.

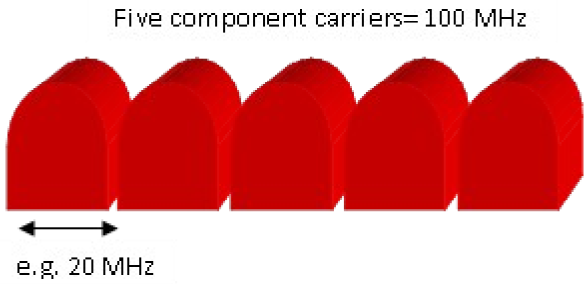
[1] Final Innovation Report (public) CELTIC / CP5-026, Wireless World Initiative New Radio – WINNER+; 07.04.10D1.9.doc

Innovation Areas, cont'd

Carrier Aggregation (CA):

- Supports higher peak data rate and
- Copes with effects deriving from fragmented spectrum ownership of operators.

Example of contiguous intra-band carrier aggregation:



Different spectra are being used synchronously by means of CA. Support for scalable bandwidth up to and including 40 MHz is required.

Significant advantage of non-contiguous over contiguous CA, but increased hardware complexity.

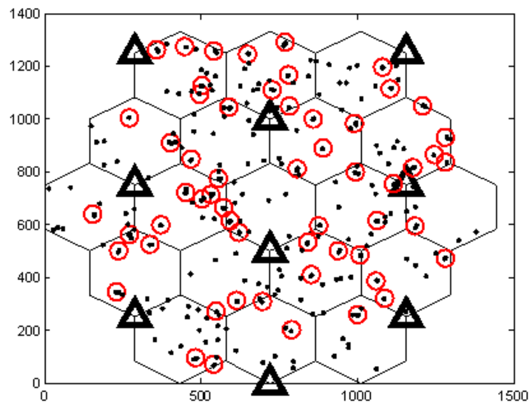
Innovation Areas, cont'd

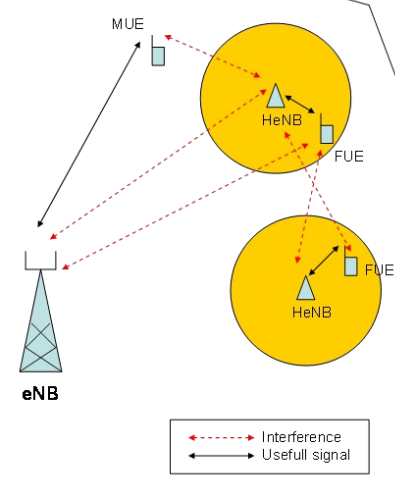
Femtocells (FC) (with / without interference coordination)

A FC is self-organized operated (indoors) inside a sector of a donor (outdoor) cell, re-using its radio resources to connect adjacent UEs via DSL line to the core network.

Left: Example: randomly deployed femto cells (red circles).

Right: Interference problem
H =Home, F=Femto,
M=Macro





For reducing mutual interference, interference coordination by scheduling of radio resources of the donor (macro) cell to be used by a FC is proposed (reducing capacity of the donor cell).

FCs behave like relays connected out of band (no radio resources used to connect a FC to a donor eNB, but inband mutual interference to base station, if not coordinated).

Innovation Areas, cont'd

Multi-hop Relays in 3GPP LTE Rel. 10 (LTE-A)

- Placed throughout the donor eMB, preferably close to cell edge.
- Operate at layer 3; have eNB functionality but lower transmit power.
- Span up its own cell, transmitting its own cell ID & reference signals.
- Connected by wireless backhaul to pass user data from/to its donor eNB
- Behave transparently to its UEs, thus being back-wards compatible.

- Improve (if properly positioned to have LOS to eNB and antenna gain)
  - the coverage of high data rate at low cost.
  - cell-edge throughput, substantially.
  - group mobility, e.g., of UEs in trains.
  - temporary network deployment.

Relays, in view of

- NGMN group: "an option in achieving a more targeted and homogeneous distribution of signal energy in the field".
- Infrastructure manufacturers: "temporal network elements to be replaced by eNBs when the load evolves in a cellular network".

Innovation Areas, cont'd

Resource Partitioning (RUP) (is part of 3GPP-LTE Rel.10.)

Avoids interference (IF) between relay nodes (RNs) and donor eNB, since radio resources are, **exclusively**, assigned to donor eNB and RNs.

Intra-cell interference in LTE-A is avoided under RUP owing to othogonal resources used.
Inter-cell interference (ICI) is the critical component to overcome and minimize.

Soft/Fractional frequency re-use is applied to minimize ICI.

Measures to reduce ICI / increase SINR:

- Scheduling of radio resources across adjacent cells (applying CoMP).
- Cooperative relaying - combined with MU-MIMO (spatial multiplexing).
- Distributed space time coding.
- Distributed FEC coding.

All these measures substantially increase complexity of cellular networks.

What is Reuse Partitioning ?

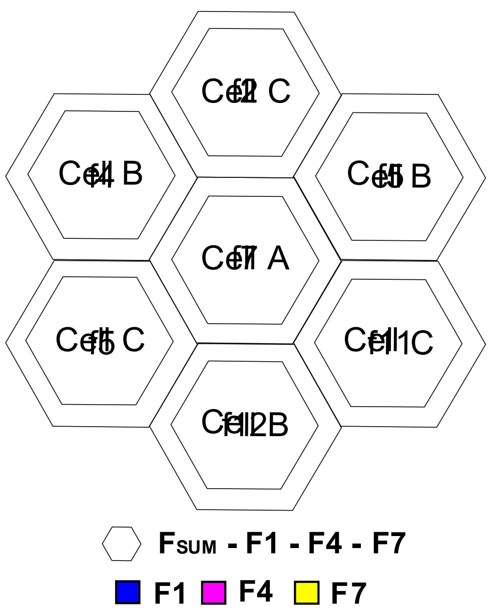
- **Reuse partitioning (RUP)**
  - Geographical channel allocation
    - ❖ Smaller reuse factor for UEs close to BS
    - ❖ Larger reuse factor for UEs far from BS
  - Mitigation of co-channel (CCI) in multi-cell environments
  - Providing both, coverage and higher system capacity
  - Way of frequency re-use: *inclusive* & *exclusive*

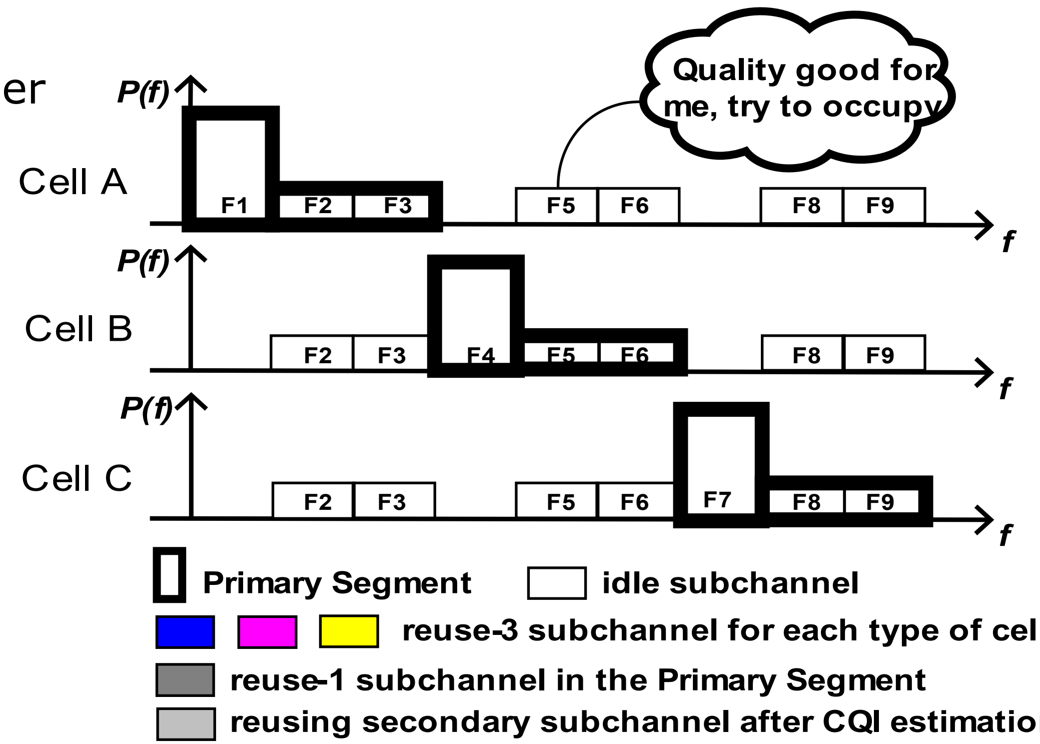
- **Inclusive RUP technique**
  - *S*oft *F*requency *R*euse (SFR) (3GPP LTE standard)

- **Exclusive RUP techniques**
  - *E*nhanced *F*ractional *F*requency *R*euse (EFFR)
  - EFFR - *A*dvanced (EFFR-A)
  - EFFR - *B*eyond (EFFR-B)

Enhanced Fractional Frequency Reuse (EFFR)

- **Entire frequency spectrum divided into 2 segments**
  - Primary Segment: orthogonal among neighboring cells
  - Secondary Segment: Interference-aware reuse
- ***Exclusive*** **reuse-3 subchannels in Primary Segment**
  - $\text{Priority}_{CEU} > \text{Priority}_{CCU}$
  - Higher transmission power
- **Reuse-1 subchannels**
  - Lower transmission power





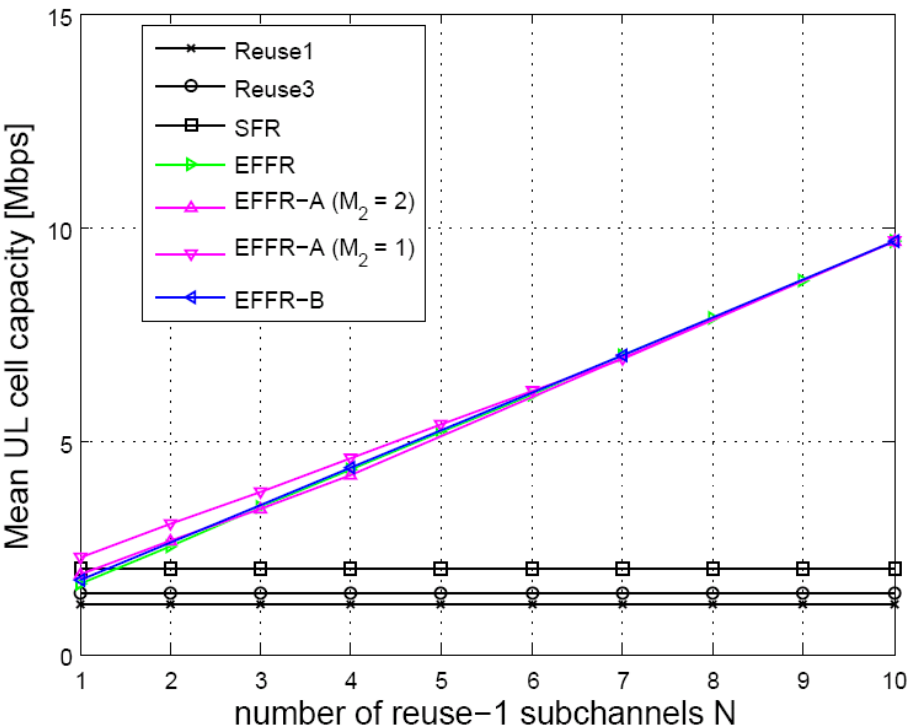
Source: Zheng Xie

Mean Cell Capacity Comparison (Source: Zheng Xie)

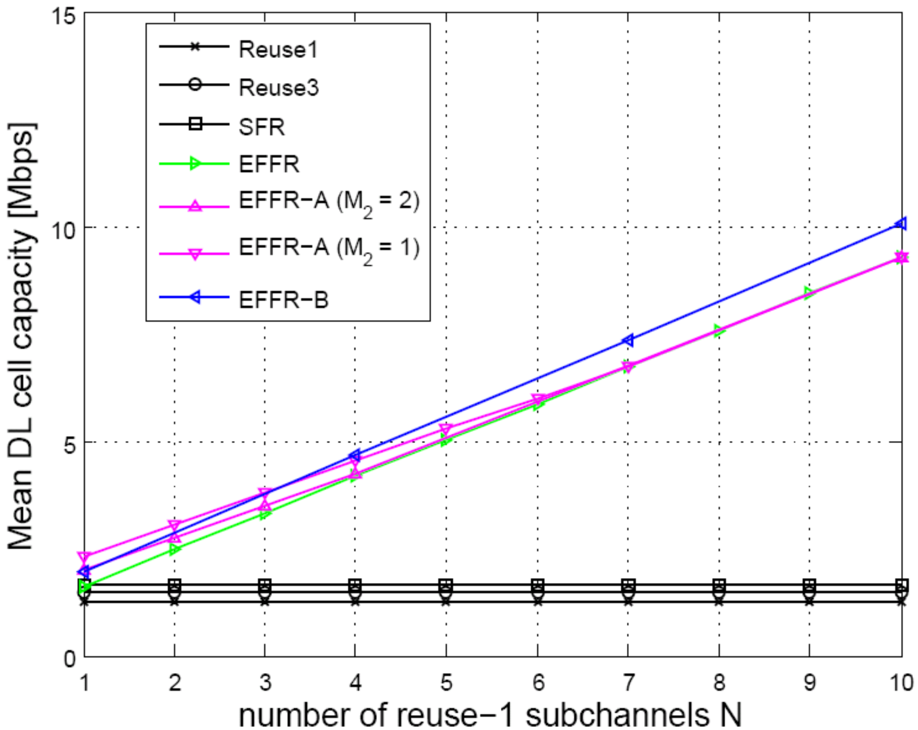
- UL:DL = 1:1
- ***N*** Nr. of reuse-1 subchannels for CCUs in Primary Segment ($0<N<10$)
- EFFR
  M Nr. of reuse-3 subchannels for CEUs in Primary Segment ($M+N=10$)

- EFFR-A
  M_2 Nr. of reuse-9 subchannels for CEUs in Primary Segment ($3 \cdot M_2+M_1+N=10$)
- EFFR-B
  M_2 Nr. of reuse-9 subchannels for CEUs in Primary Segment ($3 \cdot M_2+N=10$)

➢ Mean UL cell capacity



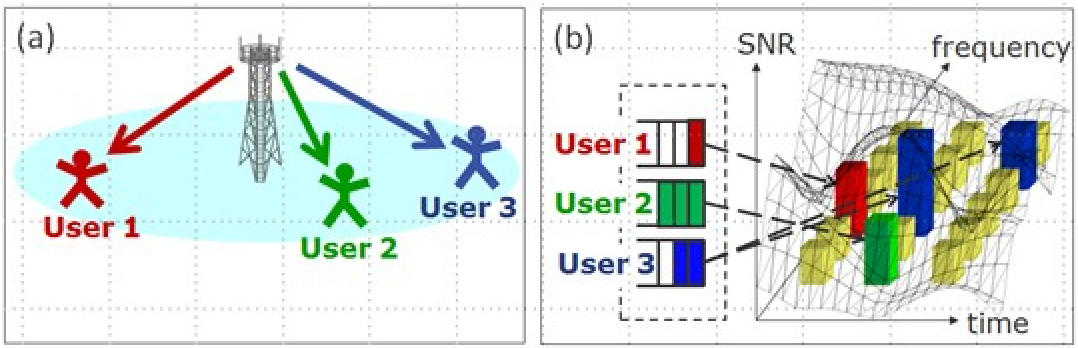
➢ Mean DL cell capacity



Innovation Areas cont'd

- **Multi-User Multiple-Input-Multiple-Output** systems (esp. Channel State Information (CSI) acquisition; Optimisation possible without standardisation.

- **Quality of Service (QoS) control** (efficient scheduling, cross-layer design). Optimisation possible without standardisation.



OFDMA multi-user resource allocation: An eNB serving multiple users (a) assigns user data with various QoS requirements (b) to resources in time and frequency taking channel conditions into account. **BE traffic** is scheduled when possible.

- **Network Coding:** May provide a diversity order of 3, but major signalling and architecture changes to the network are required.

Facts to Consider

- Spectral efficiency with 3GPP LTE R8/R10 will be about 1,6/3,5 bps/Hz.
  (45% is used as PHY overhead; >30% is used as protocol overhead, leaving 33% for the user)
- Shannon: $C = M * B * \log_2 (1 + SINR)$
  (B= Bandwidth, M = number of transmission channels in B)
- MIMO in LTE R8 supports up to M=4 layers in B=20 MHz (layer = data stream, spatially separated from others).
- LTE R 10 (LTE-A) will support M=8 layers on DL, partly by increasing B through CA (up to 100 MHz), partly by introducing CoMP – the most complex new feature.
- Owing to high traffic asymmetry of DL:UL = 9:1, most interest is in DL capacity increase.

Innovation Areas cont'd

Coordinated Multiple Point (CoMP) Transmission

CoMP: new family of LTE-A features, based on the common idea of introducing coordination schemes for radio transmission/reception.
This technique has been studied in the late 90-ties, named as „Simulcast“

CoMP targets on interference (ICI) reduction in cellular networks, thereby increasing SINR and capacity, see Shannon law, above.

SINR = intra-cell IF + ICI + thermal noise

Intra-cell IF in LTE is avoided thanks to OFDM orthogonality

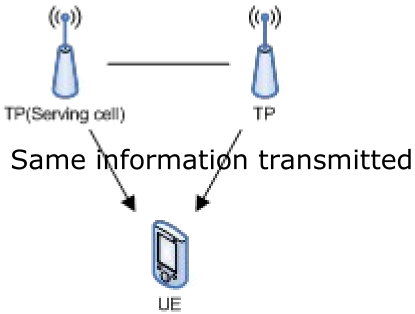
ICI is the critical component to be minimized by CoMP.

CoMP occupies resources at multiple eNBs, thereby reducing capacity.

CoMP has two approaches:

1. Joint Processing (JP): data is available at each of the geometrically separated points, involved, and PDCH transmission occurs from multiple points.

Cooperation of spatially separated transceivers improves SINR as seen at the receiving terminal (UE or eNB).



Theoretical radio performance figures for CoMP-JP show potential capacity gains of 82%, experiences in real deployments show about 27% gain.

JP introduces very complex requirements to the network:

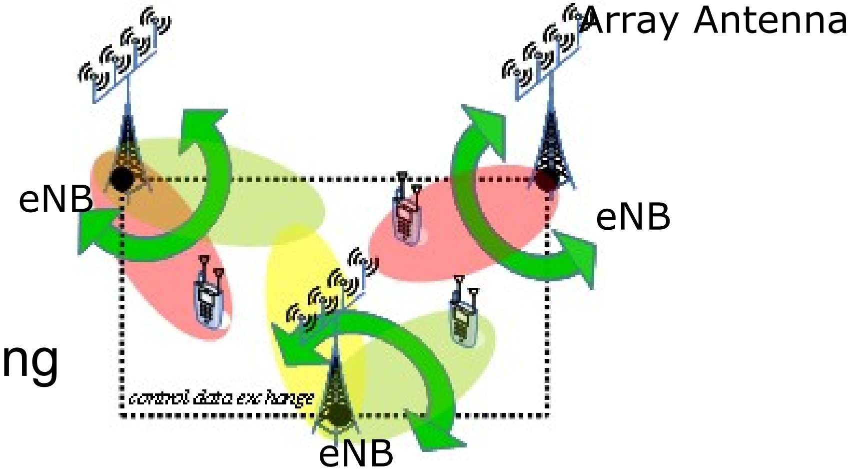
- Tight timing synchronisation of eNBs involved,
- Low back-haul latencies in the order of milliseconds and
- High back-haul capacity to exchange data via X2 interface

are the most critical factors, for which it is unlikely that operators will implement JP across sites in the near future.

CoMP has two approaches:

2. Coordinated Scheduling/Beamforming (CS/BF): data is only available at serving cell but user scheduling / beamforming decisions are made with coordination among cells.

Schematic representation of coordinated beamforming



Cooperation of eNBs is based on control information exchanged, rather than real user data exchange.

CS/BF is a promising next step for further advancements in improved interference cancellation.

Simulation results for radio performance figures of CS/BF show potential capacity gains of 55%, experiences in real deployments show about 25% gain.

Self Organizing Networks in Beyond LTE-A

Future RANs beyond LTE-A aim to offer an area throughput of 25 Gbps/km2 for data traffic at urban locations with high user density, energy efficiently.

Assuming

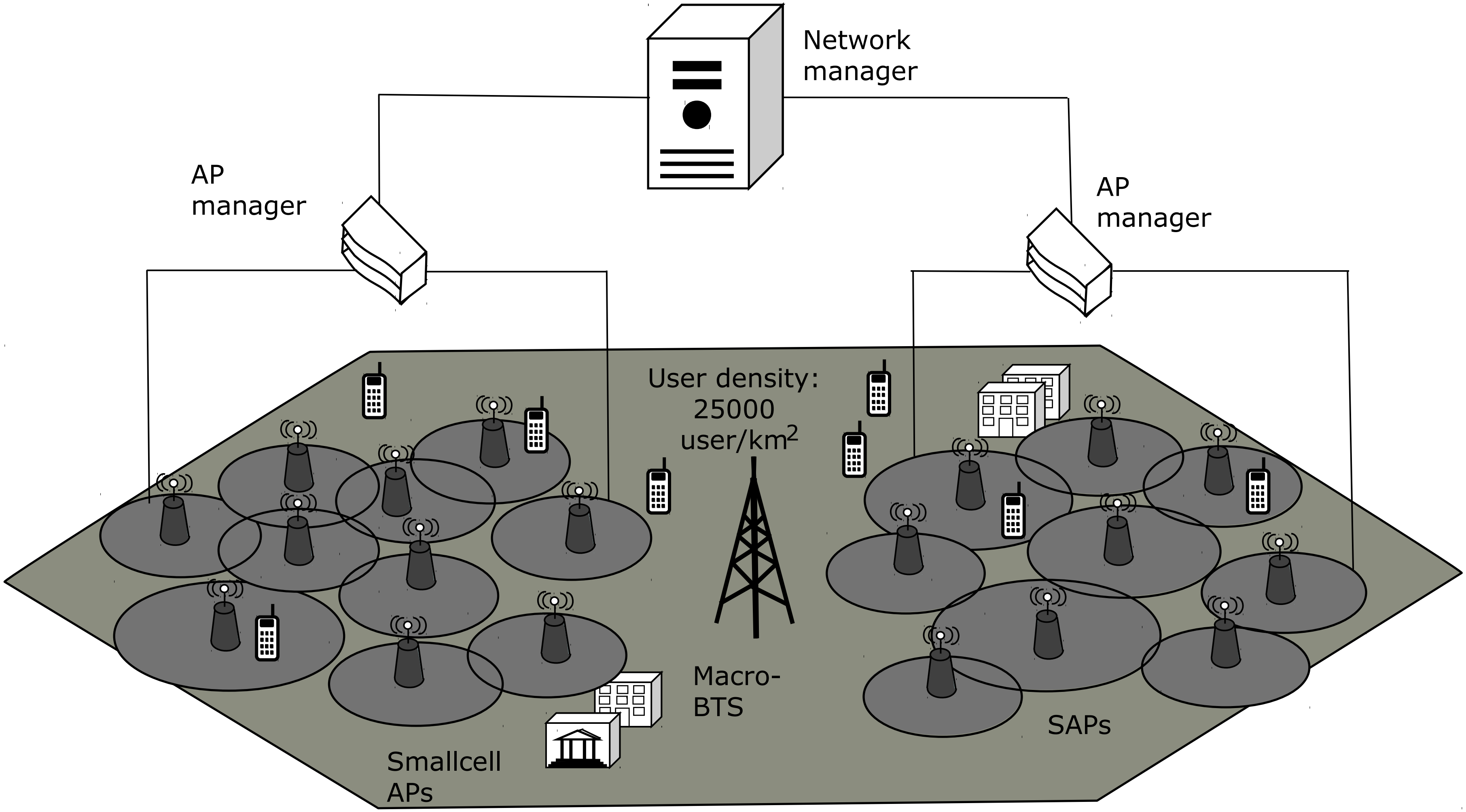
- a mean bit rate of 1 Mbps/user during the busy hour
- 25,000 users/km2,

230 MHz bandwidth is required under 3.7 bps/Hz/cell to achieve 25 Gb/s/km2 under LTE-A with 200 m intersite distance.

The cost of site maintenance in dense small cell networks will be excessively high, if each node does not support self-organizing operations such as

- self-configuration,
- self-optimization and
- self-healing.

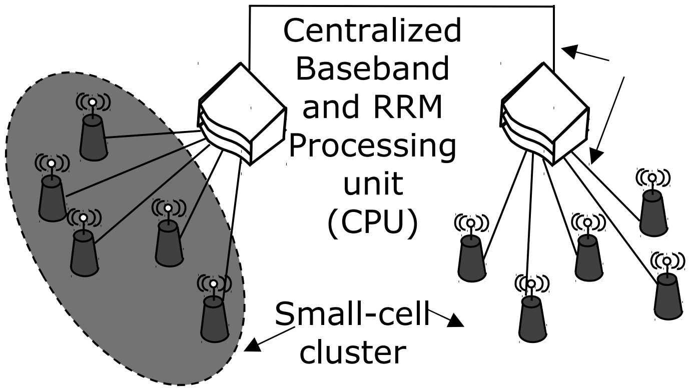
Dense Small Cell Network architecture (many SAPs controlled by AP manager within a macro cell) form a wireless backhaul by relaying



Source: S. Liu, J. Wu, C. Ha Koh, V.K.N. Lau: A 25Gb/s(/km2) Urban Wireless Network Beyond IMT-Advanced. IEEE Communications Magazine, February 2011, 122-129

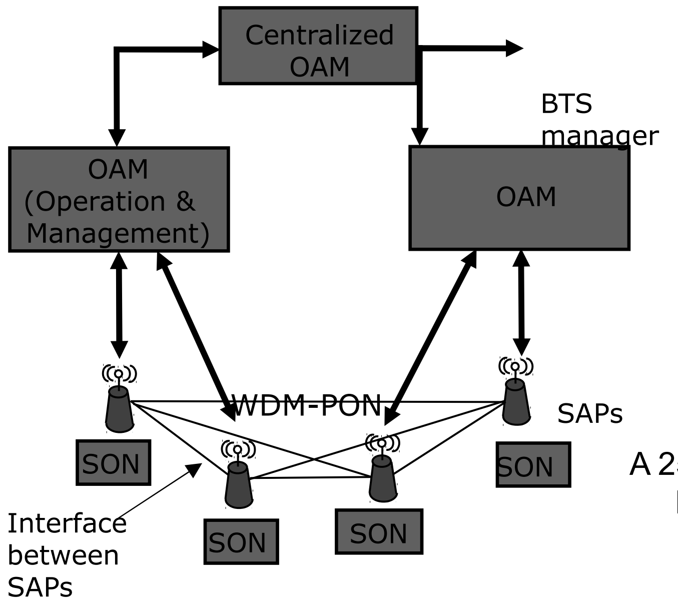
RAN Architectures:
a) Centralized Cloud b) Distributed Self-Organized RAN

a) Cloud RAN



The centralized RAN architecture is one of the most efficient ways to overcome the issues of interference and resource managemens in small cell deployment.
However: scalability is lacking.
Solution:
- Cloud RAN or
- Distributed self-organized network,SON

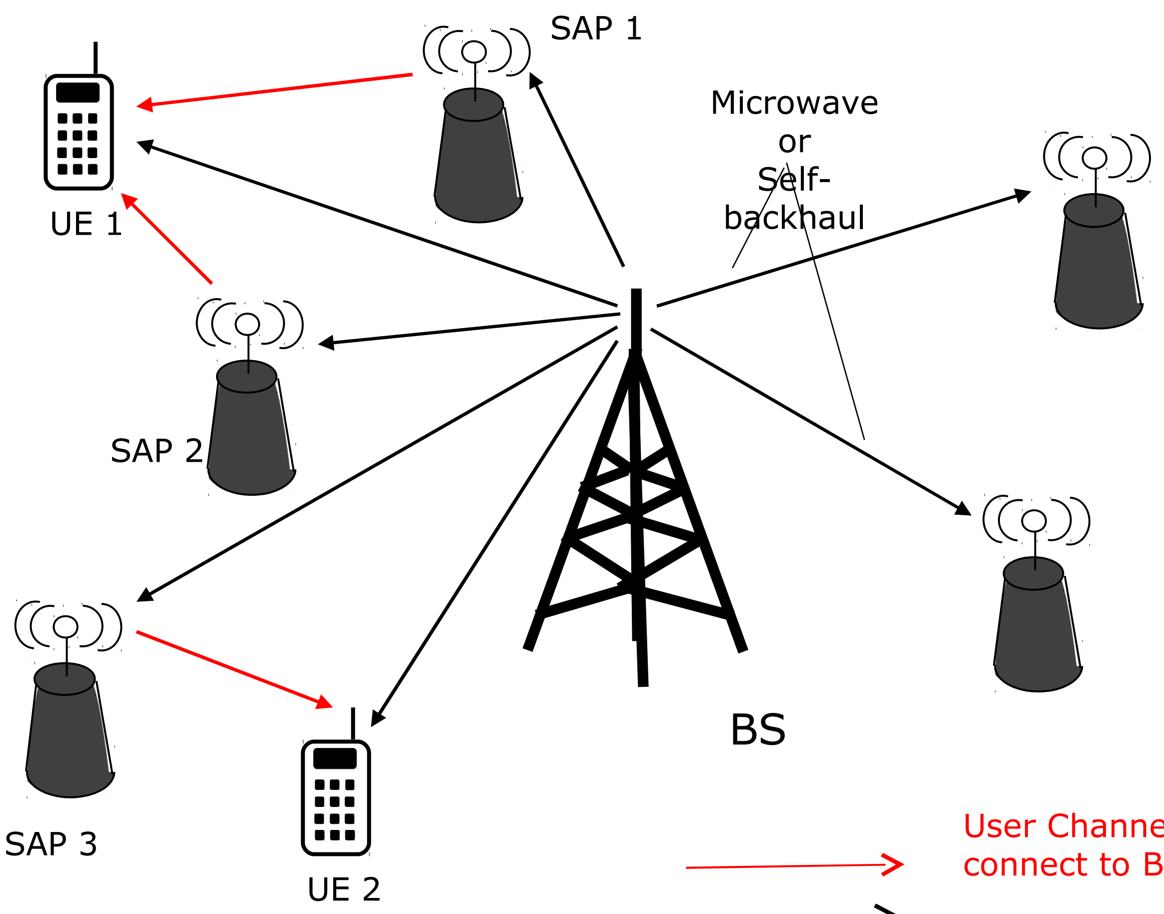
b) Distributed SON network



Wave Division Multiplex Passive Optical Network (WDM-PON) to connect Dense Small Cell Networks and SONs of RAN

Source: S. Liu, J. Wu, C. Ha Koh, V.K.N. Lau:
A 25Gb/s(/km2) Urban Wireless Network Beyond IMT-Advanced.
IEEE Communications Magazine, February 2011, 122-129

User Plane/Control Plane Separated Hierarchical Cell Structure

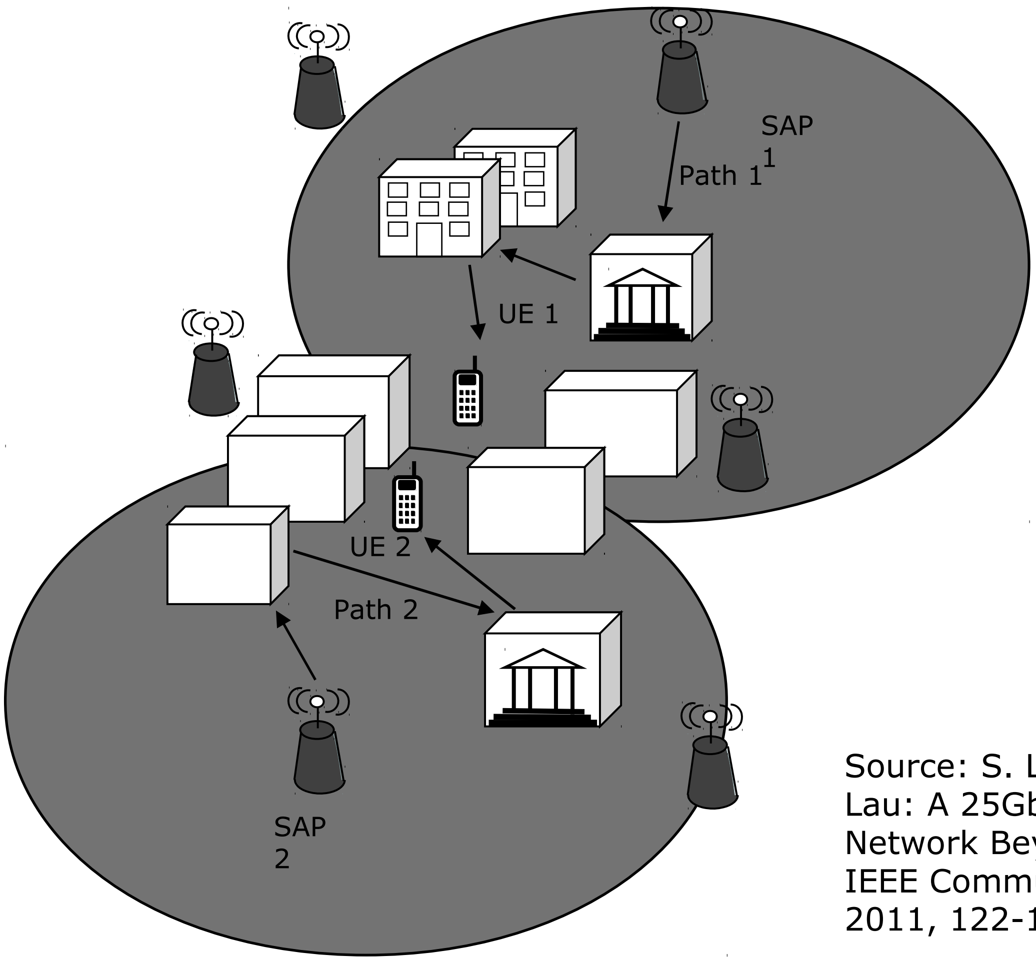


User Channel (may change to connect to BS/SAP)

Signaling Channel (remains the same within the macro cell between BS and UE)

Source: S. Liu, J. Wu, C. Ha Koh, V.K.N. Lau: A 25Gb/s(/km2) Urban Wireless Network Beyond IMT-Advanced. IEEE Communications Magazine, February 2011, 122-129

Dynamic Spatial Path/Beam Selection



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Conclusions

LTE-A (Rel.10) is the most complex mobile radio technology ever seen:

- OFDMA and MIMO/beamforming transmission on frequency channels of bandwidth of n*20 MHz.
- Relay Nodes (Fixed Wireless Routers) to increase cell edge capacity.
- Coordinated scheduling of beams of adjacent eNBs (expected to be introduced, soo)
- Joint processing (may be introduced, later).
- New technologies like network coding and CoMP have very high complexity and cost, which may delay introduction.
- Spectral efficiency target of LTE-A is 3,4 bps/Hz under certain conditions.

Other facts:

- Physical layer overhead is ~45% in FDD operation for typical load scenarios.
- Protocol overhead is >30%, resulting in overall efficiency of <35% of the spectral efficiency target, namely 1,1 bps/Hz.

Mobile broadband radio networks cannot keep pace with the exponential growth of Internet traffic that doubles about every 2-3 years.

New network architectures are required, e.g. centralized cloud or distributed self-organized networks

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Bernhard Walke, ComNets

Statements

LTE-A (Rel.10) will be the most complex mobile radio technology ever seen.

Relay Nodes (Fixed Wireless Routers) will be used to increase cell edge capacity.

Coordinated scheduling of beams of adjacent eNBs will be introduced, soon.

New technologies like network coding and Coordinated Multipoint transmission (CoMP) have very high complexity and cost, which may delay introduction.

Spectral efficiency target of LTE-A is 3,4 bps/Hz, but taking signaling and protocol overhead into account, efficiency will remain close to 1 bps/Hz.

Mobile broadband networks operating in licensed freqency spectrum have much difficulty to keep pace with the exponential growth of Internet traffic. High density deployment of eNBs and much more spectrum will be necessary for this (at much higher cost).

There is a great opportunity for IEEE 802 based wireless broadband systems operated in license exempt bands.

Overlay and coexistence techniques will enter the market.