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iJOIN

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IR5.1- Preliminary definition of requirements and scenarios for the iJOIN architecture

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Abstract

This internal report is focused on the definition of iJOIN use cases and reference scenarios. Preliminary assumptions and requirements coming from the technical Work Packages 2, 3 and 4 are also collected in order to draft a first architecture of the overall system.

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Table of Contents

List of Authors ... 2
Table of Contents ... 3
List of Figures ... 6
List of Tables ... 7
Abbreviations ... 8
Definitions ... 10
1 Introduction ... 14
2 Executive Summary ... 16
3 Motivations ... 17
3.1 The Never-Ending Traffic Demand in Mobile Network ... 17
3.2 The Foreseen Key Enablers ... 18
3.2.1 Small Cell Deployment ... 18
3.2.2 Centralised Processing ... 18
3.3 iJOIN Concepts ... 19
3.3.1 Radio Access Network-as-a-Service (RANaaS) ... 19
3.3.2 Joint Access and Backhaul Design ... 20
3.4 iJOIN Vision ... 20
4 State of the Art ... 22
4.1 3GPP Architecture ... 22
4.1.1 General Description ... 22
4.1.1.1 MME / S-GW ... 22
4.1.1.2 Evolved Node B ... 23
4.1.1.3 S1 Interface ... 23
4.1.1.4 X2 interface ... 23
4.1.2 Support of Heterogeneous Network ... 24
4.2 Backhaul Solutions ... 25
4.2.1 Requirements for Small Cell Deployment ... 25
4.2.2 Wired Solutions ... 26
4.2.3 Wireless Solutions ... 29
4.3 Cloud Computing and Architecture ... 30
4.3.1 Cloud Computing Definition ... 31
4.3.1.1 The NIST Definition ... 31
4.3.1.2 Alternative Definitions ... 32
4.3.2 Service Models / IT enabled capabilities ... 33
4.3.3 Impact of Cloud Computing on Mobile Networks ... 35
4.4 Other European Projects / Initiatives ... 37
4.4.1 Small Cell ... 37
4.4.2 Backhaul Networks ... 38
4.4.3 Mobile Networks involving Cloud Architecture ... 39
4.4.4 Energy saving ... 40
4.4.5 Data Centre Energy Saving ... 40
5 iJOIN Reference Scenarios and Use Cases ... 43
5.1 Small Cell Definition ... 43
5.1.1 3GPP Definition ... 43
5.1.2 Small Cell Forum Definition ... 43
5.1.3 iJOIN Definition ... 43
5.2 Deployment Considerations ... 44
5.2.1 iJOIN Scenario Overview ... 44
5.2.2 Backhaul Considerations ... 45
5.2.3 Cloud Architecture Considerations ... 45
5.3 iJOIN Common Scenarios Description ... 45
5.3.1 CS1: Dense Hotspot in a Stadium ... 45
5.3.1.1 Use-Case Description ... 45
5.3.1.2 Use Case Mapping to Technical Realization ... 46

5.3.1.3 Technical Challenges ... 47
5.3.1.4 Candidate solutions and Architectural Considerations ... 48
5.3.2 CS2: Dense Hotpot in a Square ... 48
5.3.2.1 Use-Case Description ... 48
5.3.2.2 Use Case Mapping to Technical Realization ... 49
5.3.2.3 Technical Challenges ... 50
5.3.2.4 Candidate solutions and Architectural Considerations ... 50
5.3.3 CS3: Wide-area continuous coverage ... 51
5.3.3.1 Use-Case Description ... 51
5.3.3.2 Use Case Mapping to Technical Realization ... 52
5.3.3.3 Technical Challenges ... 53
5.3.3.4 Candidate solutions and Architectural Considerations ... 54
5.3.4 CS4: Dense Hotspot in an Airport / Shopping Mall ... 54
5.3.4.1 Use-Case Description ... 54
5.3.4.2 Use Case Mapping to Technical Realization ... 56
5.3.4.3 Technical Challenges ... 56
5.3.4.4 Candidate solutions and Architectural Considerations ... 57
6 Preliminary Considerations on System Requirements ... 58
6.1 RAN Functional Split ... 58
6.2 Preliminary Assumptions and Requirements ... 62
6.2.1 Candidate Technologies ... 62
6.2.2 Consolidated Assumptions ... 63
6.3 Preliminary Architecture Considerations ... 65
6.3.1 iJOIN Baseline System ... 65
6.3.2 Preliminary Draft of the iJOIN Logical Architecture ... 66
6.3.2.1 iJOIN Small Cell ... 66
6.3.2.2 iJOIN Network Controller ... 66
6.3.2.3 iJOIN Local Gateway ... 67
6.3.2.4 iJOIN Transport Node ... 67
6.3.2.5 iJOIN Draft Architecture ... 67
7 iJOIN System Performance Evaluation ... 68
7.1 Metrics ... 68
7.1.1 Area Throughput ... 68
7.1.1.1 Objective ... 68
7.1.1.2 Definition ... 68
7.1.2 Energy Efficiency ... 70
7.1.2.1 Objective ... 70
7.1.2.2 Definition ... 70
7.1.3 Utilization Efficiency ... 71
7.1.3.1 Objective ... 71
7.1.3.2 Definition ... 71
7.1.4 Cost Efficiency ... 72
7.1.4.1 Objective ... 72
7.1.4.2 Definition ... 72
7.2 Evaluation Methods ... 73
7.2.1 System-Level Simulation ... 73
8 Summary and Conclusion ... 76
9 Appendix A: High-Level Scenario Description ... 77
9.1 IMDEA ... 78
9.2 NEC ... 79
9.3 TI ... 81
9.4 SCBB ... 82
9.5 TID ... 83
9.6 IMC ... 84
9.7 CEA ... 86
9.8 UoB ... 87
9.9 UNIS ... 88

9.10 TUD 89
9.11 UC3M 90
Acknowledgements and Disclaimer 92
References 93

List of Figures

Figure 1-1: Overall View of the iJOIN System ... 14
Figure 3-1: Cellular Peak Data Rates from Years 1990-2020 ... 17
Figure 3-2: Illustration of the Flexible Implementation through RANaaS ... 19
Figure 4-1: E-UTRAN Overall Architecture [22] ... 22
Figure 4-2: Overall E-UTRAN Architecture with deployed HeNB GW [22] ... 24
Figure 4-3: Basic System Architecture of CPRI Interface [29] ... 27
Figure 4-4: Networking Topologies for the Interconnection of REs [29] ... 28
Figure 4-5: OBSAI Reference BTS Architecture [31] ... 29
Figure 4-6: Communication/Processing/Storage Dependency ... 30
Figure 4-7: Service Models: XaaS ... 34
Figure 4-8: “Typical” Architecture of an IaaS Cloud Stack ... 34
Figure 4-9: Impact of Cloud Computing on Mobile Networks ... 35
Figure 4-10: Gap between Per-User and Per-Device Capabilities over Time ... 36
Figure 5-1: Small Cell Forum Definition [53] ... 43
Figure 5-2: iJOIN Envisaged Use Cases (links to central units are given as an example) ... 44
Figure 5-3: The Stadium Use Case ... 46
Figure 5-4: Dense Small Cell Deployment Example in a Stadium ... 48
Figure 5-5: Square Use Case ... 49
Figure 5-6: Dense Small Cell Deployment Example in a Square ... 50
Figure 5-7: Macrocell and Several Outdoor Micros in Madrid City Centre ... 52
Figure 5-8: Wide Area Continuous Coverage Deployment Example ... 54
Figure 5-9: Airport Use Case ... 55
Figure 5-10: Shopping Mall Use Case ... 55
Figure 5-11: Dense Small Cell Indoor Deployment Example ... 57
Figure 6-1: iJOIN Baseline System Logical Architecture ... 66
Figure 6-2: Preliminary Draft of the iJOIN Logical Architecture ... 67
Figure 7-1: The Four Objectives of iJOIN in Relation to the 3GPP LTE State-of-the-Art ... 68
Figure 7-2: Tri-Sector Hexagonal Cellular System Model ... 69
Figure 7-3: Heterogeneous Deployment Example ... 74

List of Tables

Table 4-1: Categorization of Non-Ideal Backhaul [24] ... 25
Table 4-2: Categorization of Good to Ideal Backhaul [24] ... 25
Table 4-3: NGMN Requirements for Small Cell Backhaul ... 25
Table 4-4: Overview over wireless backhaul technologies ... 30
Table 6-1: RAN Functional Split ... 59
Table 6-2: WP2 Candidate Technologies ... 62
Table 6-3: WP3 Candidate Technologies ... 62
Table 6-4: WP4 Candidate Technologies ... 63
Table 6-5: Architectural and Technology Deployment Common Assumptions ... 64
Table 6-6: WP2 Implementation Assumptions ... 64
Table 6-7: WP3 Implementation Assumptions ... 65
Table 6-8: WP4 Implementation Assumptions ... 65
Table 7-1: Preliminary mapping of resource types to network entities ... 71
Table 9-1: High-Level Scenario Template ... 77

Abbreviations

3GPP	3rd Generation Partnership Project
ABS	Almost Blank Subframe
bps	bit per second
BHRU	Baseband Hardware Resource Utilization
BS	Base Station
BTS	Base Transceiver Station
BU	Bandwidth Utilization
C&M	Control & Management
CA	Carrier Aggregation
CDF	Cumulative Distribution Function
CPRI	Common Public Radio Interface
CRE	Cell Range Extension
CRU	Cloud Resource Utilization
CS	Common Scenario
CSG	Closed Subscriber Group
CT	Candidate Technology
D2D	Device-to-Device
DAS	Distributed Antenna System
eICIC	enhanced Inter-Cell Interference Coordination
eNB	evolved Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
ETSI	European Telecommunications Standards Institute
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
feICIC	further enhanced Inter-Cell Interference Coordination
FSO	Free Space Optics
Gbps	Gigabits per second
GPON	Gigabit Passive Optical Network
HE	Hardware Elements
HeNB	Home evolved Node B
HII	High Interference Indicator
HSS	Home Subscriber Server
IaaS	Infrastructure as a Service
ICIC	Inter-Cell Interference Coordination
iJOIN	Interworking and JOINt Design of an Open Access and Backhaul Network Architecture for Small Cells based on Cloud Networks
iLGW	iJOIN Local Gateway
iNC	iJOIN Network Controller
IP	Internet Protocol
iSC	iJOIN Small Cell
iTN	iJOIN Transport Node
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
LOS	Line-Of-Sight
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
NAS	Non-Access Stratum
NFV	Network Function Virtualization
NGMN	Next Generation Mobile Networks
NIST	National Institute of Standards and Technology
NLOS	Non Line-Of-Sight
OBSAI	Open Base Station Architecture Initiative
OI	Overload Indicator
PaaS	Platform as a Service

PLMN	Public Land Mobile Network
PRB	Physical Resource Block
QoE	Quality of Experience
QoS	Quality of Service
RA	Radio Access
RaaS	RAN as a Service
RAB	Radio Access Bearer
RAN	Radio Access Network
RAP	Radio Access Point
RE	Radio Equipment
REC	Radio Equipment Control
RF	Radio Front-end
RN	Relay Node
RNTP	Relative Narrowband Transmit Power
RP	Reference Point
RRU	Remote Radio Unit / Radio Resource Utilization
RUE	Radio Utilization Efficiency
SaaS	Software as a Service
SDR	Software Defined Radio
S-GW	Serving Gateway
SISO	Single-Input Single-Output
SON	Self-Organising Network
TCO	Total Cost of Ownership
UE	User Equipment
VM	Virtual Machine

Definitions

This section presents the concepts and definitions used within iJOIN to guarantee a common understanding of all the partners.

Classical Terms

Radio Access (RA): Wireless link (RF) between the User Equipment (UE) and the Radio Access Network (E-UTRAN).

Radio Access Network (RAN): Network elements and functions required to support the Radio Access operation (E-UTRAN).

Small Cell (SC): Low power base station with intelligence, part of the Radio Access Network. A Small Cell

- is an operator-controlled equipment;
- supports the same functionalities as an evolved Node B (eNB);
- can be deployed indoor or outdoor;
- can be within or outside of the coverage of a macrocell.

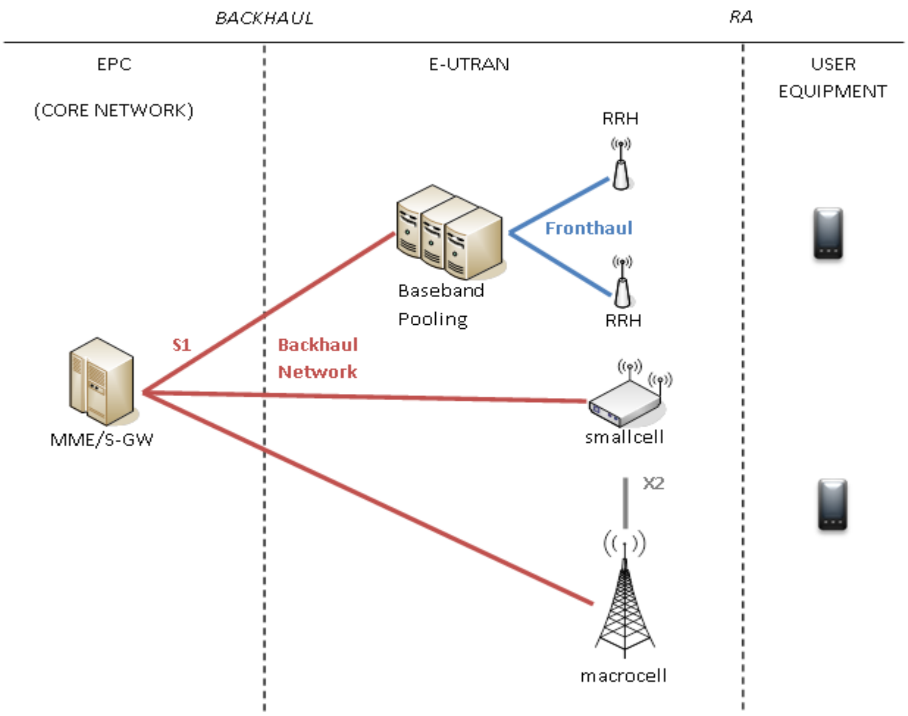
Radio Remote Head (RRH): Radio frequency processing unit without intelligence (e.g. optical to radio conversion), i.e. Radio-over-Fiber.

Backhaul (BH): Link connecting the Radio Access Network (E-UTRAN) and the Core Network (EPC).

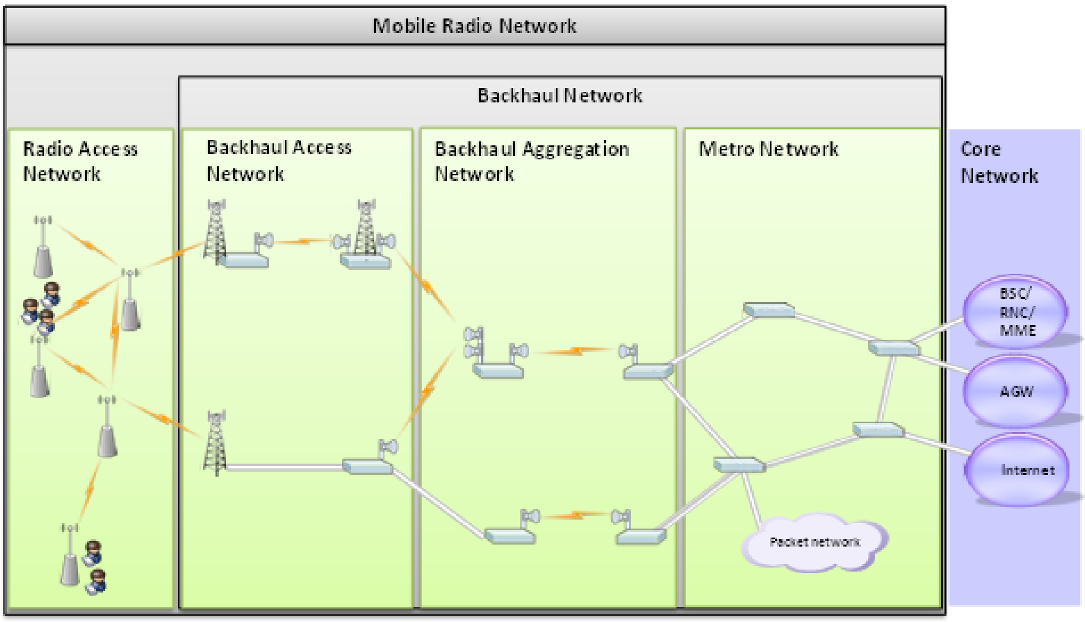
Backhaul Network: Network elements and functions required to support the backhaul operation.

Fronthaul (FH): Link within the Radio Access Network allowing a distributed implementation of the RF layer of a base station (e.g. optical link between baseband processing units and RRHs). As a convention in iJOIN, all links within the Radio Access Network allowing a distributed implementation of the upper OSI layer(s) (L1/L2/L3) will be referred as backhaul.

Figure (a) illustrates the mapping of the previous generic definitions on the 3GPP architecture and Figure (b) describes the backhaul network. Obviously, they do not represent the final iJOIN architecture but rather the existing solution upon which iJOIN will provide an evolutionary path.



(a) "Generic" Mobile Network Architecture



(b) Mobile Radio Network Definition

iJOIN-Specific Terms

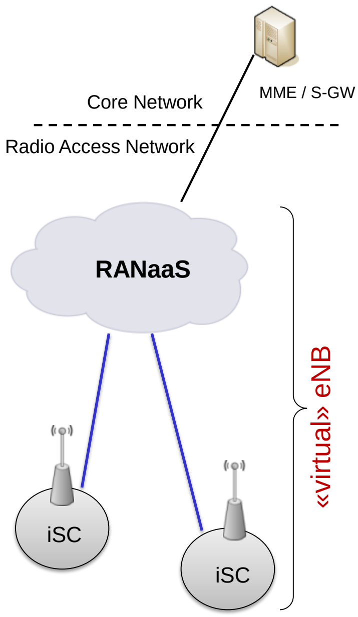
RAN as a Service (RANaaS): Cloud computing platform allowing centralisation processing and/or functional split of the lower OSI layer(s) (L1/L2/L3) usually process in a base station.

iJOIN Small Cell (iSC): Low power flexible radio access point implementing fully or partially the lower OSI layer(s) (RF/L1/2/3) of a base station (upper layers being handled by the RANaaS platform for partial implementation). It shares all other properties of a small cell. There may be different implementations of an iSC, e.g.:

- L0-iSC (or RF-iSC) only handles the RF transmission (equivalent to an analogue or digital RRH);
- L1-iSC handles all functionalities below Layer 1 and part or all functionalities of Layer 1;
- L2-iSC handles all functionalities below Layer 2 and part or all functionalities of Layer 2;
- L3-iSC handles all functionalities below Layer 3 and part or all functionalities of Layer 3 (if all Layer 3 functionalities are handled, then the L3-iSC is equivalent to a classical SC).

An iSC is connected to the RANaaS platform through the logical J1 interface and to another iSC through the logical J2 interface.

Virtual eNB: It includes all Small Cell functionalities. A virtual eNB can (logically and physically) coincide with an eNB or can be implemented as a split between RANaaS and iSC.



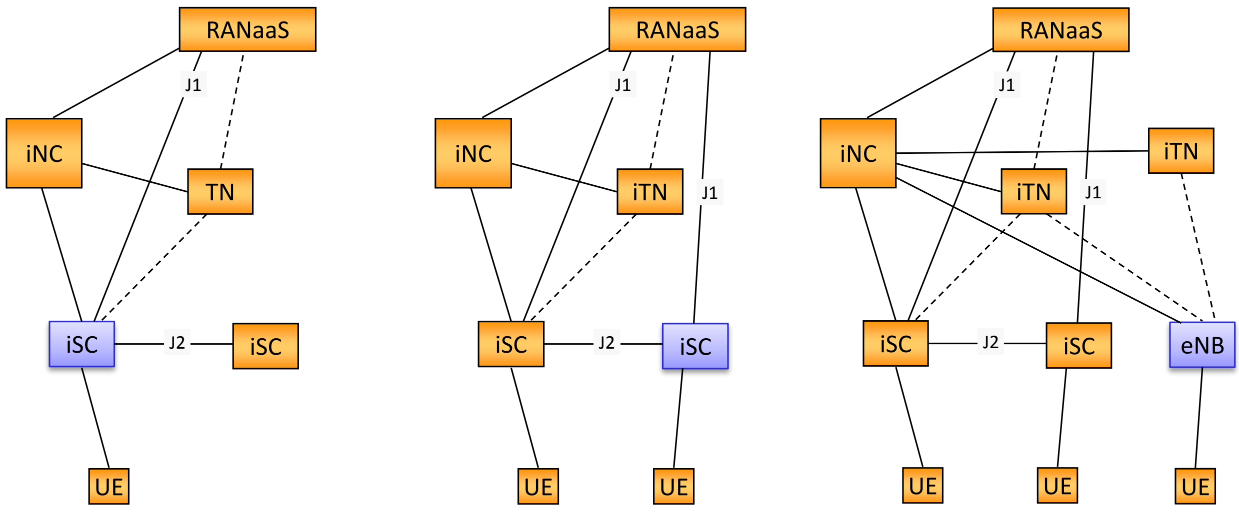
(c) Virtual eNB and Functional Split of a Small Cell

iJOIN Network Controller (iNC): a functionality (or logical entity) for the control of joint RAN/BH and/or RANaaS/iSC split. In order to minimize the impacts for the operator in terms of deployment cost and complexity, the iNC should preferably be physically co-located with the RANaaS entity. The iJOIN Candidate Technologies can be classified in three groups as shown in Figure (d):

(1) CT dealing with Joint RAN/BH and RANaaS

(2) CT dealing with RANaaS

(3) CT dealing with Joint RAN/BH (where the iSC coincides with a complete eNB)



(d) Classification of iJOIN Candidate Technologies

iJOIN Local Gateway (iLGW): an entity implementing a subset of the logical functions of a P-GW, it is logically connected with the eNB, but that can be physically located somewhere in the RAN.

iJOIN Transport Node (iTN): entity between iSC and RANaaS, or eventually between RAN and core network (possibly connected as a mesh network). In the case of considering a transport node connecting RAN and core network, another acronym (different from iTN) should be used (different protocol stack on board, different level of mesh functionalities …).

1 Introduction

To cope with the exponentially growing traffic demand, small cells appear to be a relevant option for mobile network evolution. As the radio access point is placed closer to the user, the same spectrum could be reused to increase the overall capacity of the network in tremendous ways. With high consumption of data in “limited” geographical places, successful dense small cell deployments will greatly benefit from smart interference management solutions, where centralisation could play a major role. However, centralisation means that the backhaul of the small cells, i.e. its link to the outside world, should be carefully considered when designing the overall system. The time of “infinite backhaul” is behind us, which is particularly true for small cell deployments where fibre-based backhaul will not always be present.

This internal report recall first the vision of the iJOIN project which embraces dense small cell deployment as a way to respond to the increasing demand but always with realistic backhaul limitation in mind. Relying on the progress in **cloud computing**, iJOIN introduces the concept of “Radio Access Network as a Service” (**RANaaS**) to allow classical functionalities usually processed within a small cell to be partially (or fully) deported in a cloud platform, in order to benefit, not only from computing power, but also from centralisation (coordination with other small cells). Obviously, this new paradigm is highly dependent on the RANaaS platform resource availability and also on the small cell backhaul properties. Thus, a specific attention is given to a **joint design of the radio access and the backhaul**. The level of functional split in the RANaaS platform naturally takes into account the backhaul limitations, while other optimisations may rely on the introduction of (local) network controller collecting inputs from the small cells and the backhaul nodes to enhance the network management.

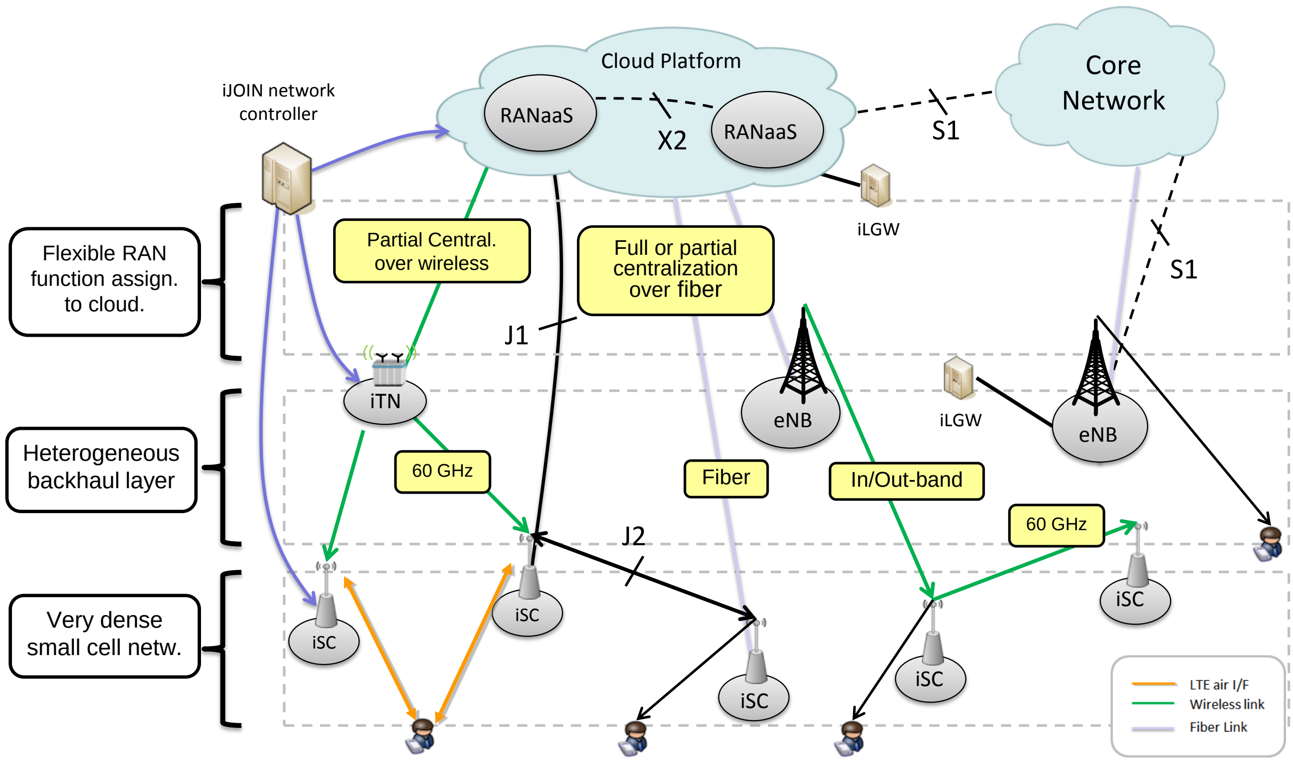


Figure 1-1: Overall View of the iJOIN System

This internal report presents the 3GPP LTE Release 10 architecture current status upon which iJOIN will provide an evolutionary path. A special emphasis is dedicated to the main backhaul solutions (fibre and 60 GHz wireless technologies) which will support iJOIN architecture. This architecture, geared toward **dense small cell** deployment, is designed with a special focus on two main concepts previously mentioned:

- The **RANaaS** platform for enabling advanced RAN features, benefiting from centralisation and functional split.
- A **joint RAN/backhaul design**.

Cloud computing classical concepts are presented which will help defining the type of cloud architecture devoted to the RANaaS platform.

The main iJOIN reference scenarios are also introduced representing realistic use cases. With **outdoor/ indoor dense hot-spot deployment** and **wide-area continuous coverage** scenarios, the project will cover use cases where the small cells will play a key role in providing enhanced capacity and coverage for an improved quality.

Since centralisation will be a major topic, a preliminary evaluation of the functionalities processed within the RAN has been conducted, mainly in terms of centralisation benefit and bandwidth/latency requirements. This on-going process will allow the definition of the requirements on the backhaul to support the centralisation of a function if a gain has been identified.

As one of the Work Package (WP) 5's roles is to derive the global **iJOIN system and architecture**, preliminary assumptions and requirements to support the candidate technologies investigated have been gathered from WP2, WP3 and WP4: some will address the use of the RANaaS platform, while others will benefit from the introduction of a local controller to jointly coordinate RAN and backhaul operation. Such initial inputs clearly impact the architecture of the system (for which a first logical draft is provided in this report) and will be clearly refined as the project progresses.

Finally, to assess the benefit of using a RANaaS platform and the joint RAN/backhaul approaches dedicated to the small cells, four metrics have been introduced upon which iJOIN will bring improvement compared to the Release 10 baseline system: **Area Throughput**, **Energy Efficiency**, **Utilisation Efficiency** and **Cost Efficiency**. Their exact definitions and how to evaluate them are still in progress, but iJOIN's intention is clearly to provide through those four objectives a simple yet accurate way to demonstrate in dense small cell deployment the merits of a system design oriented toward the already mentioned two concepts: RANaaS and joint RAN/backhaul design.

2 Executive Summary

This internal report is focused on the definition of iJOIN use cases and reference scenarios. Preliminary assumptions and requirements coming from the other Work Packages (WPs) are also collected in order to draft a first architecture of the overall system.

Section 3 recalls the motivations of iJOIN, why we see the small cells as a promising solution to cope with the increasing traffic demand, how we could benefit from the cloud computing emergence to enable advanced RAN features through flexible centralisation and why a joint RAN/backhaul design is necessary when dealing with small cells.

Section 4 presents the 3GPP LTE Release 10 architecture current status upon which iJOIN will provide an evolutionary path. A special emphasis is dedicated to main backhaul solutions (fibre and 60GHz wireless technologies) which will support iJOIN own architecture. This architecture, geared toward **dense small cell** deployment, will be designed focusing on two main concepts:

- The use of **cloud computing**, known within the project as a RAN as a Service (**RANaaS**) platform, for enabling advanced RAN features thanks to centralisation and functional split.
- A **joint RAN/backhaul design**.

Classical concepts of cloud computing are also presented which will help defining the type of cloud architecture devoted to the RANaaS platform.

Section 5 introduces the main iJOIN reference scenarios representing realistic use cases. With **outdoor/ indoor dense hot-spot deployment** and **wide-area continuous coverage** scenarios, the project will cover use cases where the small cells will play a key role in providing enhanced capacity and coverage for an improved quality.

Section 6 describes the preliminary system requirements. Since centralisation will be a major topic, a preliminary evaluation of the functionalities processed within the RAN has been conducted, mainly in terms of centralisation benefit and bandwidth/latency requirements. This on-going process will allow the definition of the requirements on the backhaul to support the centralisation of a function if a gain has been identified.

As one of WP5's roles is to derive the global **iJOIN system and architecture**, preliminary assumptions and requirements to support the candidate technologies investigated have been gathered from WP2, WP3 and WP4: some will address the use of the RANaaS platform, while others will benefit from the introduction of a local controller to jointly coordinate RAN and backhaul operation. Such initial inputs clearly impact the architecture of the system (for which a first logical draft is provided in this report) and will be clearly refined during the project's lifetime.

Finally, Section 7 presents the metrics which will be used for the system performance evaluation. To assess the benefit of using a RANaaS platform and the joint RAN/backhaul approaches dedicated to the small cells, four metrics have been introduced upon which iJOIN will bring improvement compared to a Release 10 baseline system: **Area Throughput**, **Energy Efficiency**, **Utilisation Efficiency** and **Cost Efficiency**. Their exact definition and how to evaluate them is still in progress, but iJOIN's intention is to provide through those four objectives a simple yet accurate way to demonstrate in dense small cell deployment the merits of a system design oriented toward the already mentioned two main concepts: RANaaS and joint RAN/backhaul design.

3 Motivations

3.1 The Never-Ending Traffic Demand in Mobile Network

Future mobile networks will have to provide an exceptionally greater traffic volume with diverse data rates from machine-to-machine (low data rates) to 3D applications (high data rates). The four main drivers of this development are listed in the following:

1. The **number of mobile Internet users** has **grown exponentially** during the last five years. The percentage of EU residents who access the Internet through a mobile device has increased from less than 2% in 2006 to almost 8% in 2010 [1]. In addition, the number of autonomously operating devices that communicate directly with each other without user-interaction (machine-to-machine (M2M) communication) is increasing continuously.
2. **Internet content** has become **more data-rich** over the years and features more multimedia content today. Websites constitute one of the drivers. During the last five years the average size of websites has tripled. Further, 90% of all websites today use multi-media content. Another driver of today's higher volume is the increased usage of video services. A recent report [2] predicted that 75% of all online videos will be HD by 2015, in addition to the ever-increasing length of videos. Already, video content accounts for more than 40% of overall mobile data traffic and Cisco forecasts that by 2015 this increases to 66% [3].
3. Furthermore, **mobile devices are used more frequently for more diverse services**. The number of mobile applications and services (apps) is still rising. Apple's iTunes offers more than 845,000 apps at present and about 25,000 apps are added each month [4]. Apple's iTunes has reported that they have had more than 15 billion app downloads to date. Similarly, Android's app market offers about 680,000 apps for downloading and between 12,000 and 30,000 apps are added each month. More than 10 billion Android app downloads have been reported [5], [6].
4. **End-user devices** become **more powerful** and have **greater screen-resolution** due as more tablets and laptops are in use to access the mobile Internet. The percentage of the EU population that uses a laptop and a wireless access at home or work to access the Internet has doubled from less than 10% in 2007 to almost 20% in 2010.

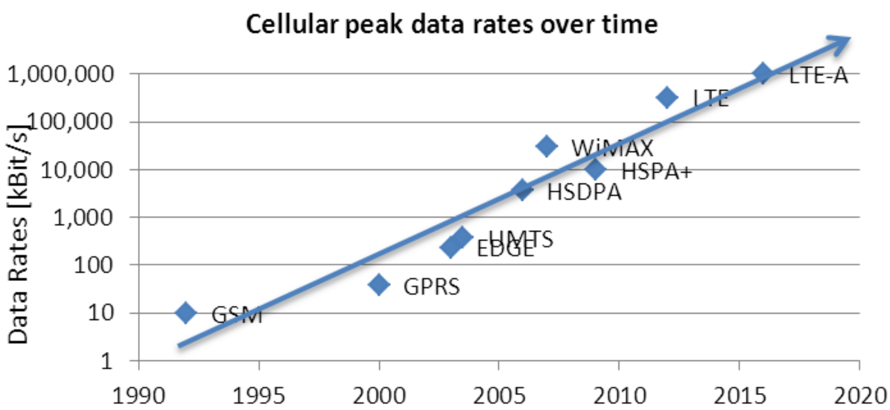


Figure 3-1: Cellular Peak Data Rates from Years 1990-2020

The trend of exponentially increasing data volumes is confirmed by [7] which forecasts that traffic will double every year. This implies an increase of about 1000 times over the next 10 years. According to [8], per-user data rates are expected to grow by a factor of up to 50-100 and the density of mobile Internet users is expected to increase by a factor of up to 10. This implies a 1000-fold increase in demand by 2020. Hence, the throughput carried by a mobile network (system throughput) must grow correspondingly [8], [9] to sustain the data rate development that has been observed during recent decades (see Figure 3-1). The Digital Agenda of the EC [10] reflects this development by setting a goal of providing data rates of at least 30 Mbit/s to all EU citizens by 2020 with 50% of them accessing the Internet with at least 100Mbit/s. These goals cannot be achieved by adding fixed lines only. They require a significant extension of mobile access because more users are accessing the Internet solely through mobile networks [1].

Very high system throughput of up to 500-1000 times today's throughput will be required by 2020 due to an increasing number of mobile Internet users, more frequent mobile Internet usage, increasingly complex content, and more powerful devices.

3.2 The Foreseen Key Enablers

3.2.1 Small Cell Deployment

Since 1950 the system throughput of cellular networks rose by a factor of 1600 simply by increased spatial reuse, i.e., denser networks and smaller cells [11]. In contrast, the per-link throughput improvement by physical layer techniques is of the order of 25 [11]. Therefore, the use of very dense, low-power, **small cell networks** and very high spatial reuse appear to provide a promising option to allow handling future data rate demands. Small cell network became possible through flat, IP-based architectures, and new and highly compact base station technologies. They exploit two fundamental effects. Firstly, the distance between the radio access point and users is reduced and the data rate increases super-linearly by the inverse of the distance. Secondly, the spectrum is used more efficiently because each radio access point uses the same spectrum. Small-cells complement existing macro-cellular deployments which are still required to provide coverage for fast-moving users and in areas with low user-density.

Small-cells are capable of enabling new services, increasing energy-efficiency, and reducing the costs of handling explosive data growth. As reported in [12], the Total Cost of Ownership (TCO) savings through small-cells as a percentage of revenue will be between 50% (Germany) and 350% (Singapore) compared to macro-cell deployments. Another report [13] showed that the three-year TCO can be lowered by 45% compared to macro-cell deployments.

A report by In-Stat [14] predicts a worldwide, four-fold increase in small-cell devices between 2009 and 2014. Hence, small-cell devices constitute a quickly growing market that becomes increasingly important tor European vendors. Another report [12] forecasts that the small-cell marketplace could be worth 6.1 milliard Euros by 2014 and that more than 50% of European mobile subscribers will be served through small-cells by 2017.

Small cell deployment is a promising way to cope with the rising need for very high data rates as they promise better per-link quality and a better reuse of the spectral resources.

3.2.2 Centralised Processing

As networks become denser, inter-cell interference increases and interference scenarios become more complex due to multi-tier interference. Furthermore, the higher the deployment density is, the higher is the chance that a certain radio access point will carry no traffic or only a low traffic-load due to spatial and temporal traffic fluctuations. Currently, 15-20% of all sites carry about 50% of the total traffic [15]. This implies that a considerable number of sites consume energy and computational resources, even though they carry no traffic or only a negligible level of traffic. For instance, China Mobile reports that 72% of its overall energy consumption is attributable to base station (BS) cell sites even though only parts of the network are active.

Centralised processing [16], [17] permits the implementation of efficient interference avoidance and cancelation algorithms across multiple cells. It provides the means to selectively turn RAPs on and off in order to load-balance traffic in scenarios that have high traffic fluctuations. Cloud-RAN (C-RAN) recently attracted a great deal of attention as one possible way to efficiently centralise computational resources, to balance throughput fluctuations, and to implement inter-cell coordination. In C-RAN, multiple sites are connected to a central data centre where all baseband processing is performed. The next generation of mobile networks alliance (NGMN) is investigating C-RAN in more detail in the "Project Centralised processing, collaborative radio, real-time cloud computing, clear RAN system (P-CRAN)". C-RAN will also permit energy savings of up to 50% as reported for a test-bed implementation in [18]. Furthermore, C-RAN is expected to reduce the OPEX of cellular systems by between 20% [15] and 50% [18], whereas CAPEX is expected to be reduced by 15% [18].

In C-RAN, transmitted and received radio signals are exchanged over fibre transmission lines (called front haul) between Remote Radio Heads (RRHs) and the data centre. At present, only fibre-links are capable of supporting these data rates, e.g., of about 10 Gbps for TD-LTE with 20 MHz bandwidth. This constitutes the main drawback of C-RAN which is the need for a front haul link that supports very high data rates. Due to the use of optical fibre, C-RAN deployments are less flexible as only spots with existing fibre-access may be chosen or fibre-access must be deployed, which is very cost-intense. Hence, there is a trade-off between centralised processing requiring high-capacity front-haul links, and de-centralised processing which requires traditional back-haul to transport the user and control data to and from the BS.

Centralised processing will be required to **handle the increasing interference in very dense networks,** to **reduce energy-consumption**, and to **deploy and manage cellular networks cost-efficiently**.

3.3 iJOIN Concepts

3.3.1 Radio Access Network-as-a-Service (RANaaS)

The trade-off between centralisation (C-RAN) and decentralisation ("traditional" implementation) can be exploited by the novel concept "Radio Access Network-as-a-Service" (RANaaS) proposed by the iJOIN project, which is illustrated in Figure 3-2. The left side of the figure exemplifies a traditional LTE implementation where all functionality in the protocol stack up to Admission/Congestion Control is locally implemented at the BS. The right side illustrates the C-RAN approach where only the Radio Front-end (RF) is locally implemented and all other functionality is centralised, including digital baseband processing. By contrast, RANaaS does not fully centralise all functionality, but rather flexibly centralises part of the RAN functionality and offers this as a service. This implies that operators may use a RANaaS platform and adapt, configure and extend it to their needs depending on the backhaul and access network structure.

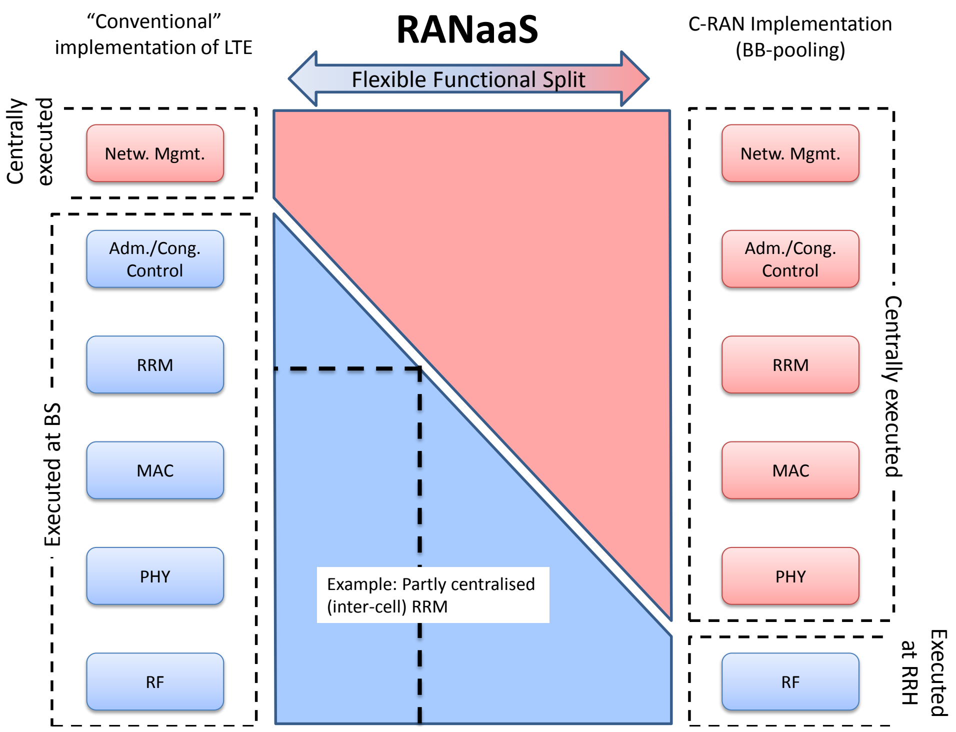


Figure 3-2: Illustration of the Flexible Implementation through RANaaS

RANaaS is an application of the XaaS-paradigm which indicates that any kind of service may be centralised by a cloud-platform. Services are provided on demand. Resources are scalable, can be better controlled and optimised, and may be pooled independently of the location and transparently to the user. In RANaaS, the Radio Access Network (RAN) is implemented through virtualisation on a cloud-infrastructure. Interfaces and network entities are virtual instances that permit more scalable and flexible resource usage. Furthermore, RANaaS will provide new possibilities to manage the mobile network. It improves the throughput by centralised processing and inter-cell coordination, improves the network scalability, and increases reliability through a cloud-computing infrastructure. RANaaS further allows third parties, e.g. IT companies, to implement parts of mobile networks on an open IT platform. An implementation of RANaaS on open IT-platforms within a cloud-infrastructure permits rapid product development, improved inter-operability, and more scalability. In addition, it opens a new market for cloud-providers.

Consider again Figure 3-2 where an example is shown for partly centralised inter-cell RRM. This is of interest for regional clusters of small-cells that are controlled by a RANaaS instance. The RANaaS instance will control part of the Radio Resource Management (RRM) in order to avoid and mitigate interference between multiple cells. All lower layer functions are still executed in a decentralised fashion. Alternatively, the RANaaS platform may only provide enhanced mobility functionality or provide the possibility to partly centralise PHY processing for the purpose of inter-cell coordination. Hence, the RANaaS concept is much more flexible and scalable than C-RAN due to the varying degree of centralisation and flexibility of implementation. Although RANaaS is a generic concept for any future mobile network, iJOIN mainly targets on small-cell deployments and therefore will focus on the application of RANaaS to very dense network.

RANaaS is a novel concept to flexibly centralise RAN operations, but it imposes new challenges on the access and backhaul network design, which are described below.

3.3.2 Joint Access and Backhaul Design

Small-cells may be deployed where it is difficult or too expensive to deploy fixed broadband access for backhaul or Line-Of-Sight (LOS) based microwave solutions. The Broadband Forum [19] reported that 30% of a mobile operator's OPEX today is spent for backhaul networks. Recently, wireless backhaul has received more attention due to its higher deployment flexibility and lower costs. The report [20] shows that the expenditures for wireless backhaul will increase by 41% from 2009 to 2014. Hence, small-cell deployments must be connected by heterogeneous backhaul technologies that consist of fibre, microwave solutions, as well as wireless backhaul [21].

So far, most radio access designs (including 3GPP architecture) consider the backhaul network to be sufficiently dimensioned (over-provisioned). While this is already challenging in today's backhaul networks, the backhaul requirements will increase correspondingly as we move towards small cells and more centralised operation. Therefore, the limited backhaul resources must be considered when operating the radio access network. However, the 3GPP LTE mobile network architecture provides no means to take into account the underlying physical transport network and functional split of the physical implementation. By contrast, RANaaS provides the possibility by co-designing and co-optimising access and backhaul network functionalities. Standardised interfaces will allow for optimising the mobile network operation based on the backhaul network by flexibly centralising functionality towards RANaaS. This co-design will be a key enabler to support the high diversity of QoS and data rates in future networks as outlined earlier.

As an example, consider again the partly centralised inter-cell RRM as explained before. The amount of data that needs to be exchanged between the RANaaS instance and the small cells as well as between different small cells largely depends on the number of users per cell and the amount of traffic per cell. For instance, if backhaul-resources are limited, it will not be useful to spend significant resources for inter-cell coordination as this would leave few backhaul resources for the actual user traffic. However, if backhaul resources are virtually unlimited, inter-cell coordination may operate on a finer grain with more frequent updates. Hence, the operation on the access network layer may depend greatly on the backhaul network layer and can be jointly optimised with it.

Small-cell deployments, particularly as they use **centralised processing**, will rely on a **novel and advanced co-design, and interworking of access network and a heterogeneous backhaul network**.

3.4 iJOIN Vision

Within iJOIN's overall vision, small-cells provide a high degree of flexibility to dimension the required computational and energy resources within the access network. The RANaaS concept further provides the means to efficiently mitigate and cancel interference, to dynamically balance the computational needs of individual base stations, and to deploy networks cost-efficiently. In addition, macro-cells may still provide coverage for users who are moving at high speed or in areas without small cells. Such a mobile network will require novel approaches for network operation and management that must adapt to the dynamic needs of the network, changes to the design of access and backhaul network, and possibly changes to architecture.

To support this vision, the iJOIN system and architecture will be carefully designed with the two previous concepts. To ease the adoption, the idea will be to provide an evolutionary path from the 3GPP Release 10 architecture which will enable the key candidate technologies investigated within iJOIN to demonstrate their potential in enhancing dense small cell deployment. Backhaul technologies such as fibre or 60 GHz wireless solutions with realistic parameters will also be considered as their characteristics.

4 State of the Art

4.1 3GPP Architecture

The iJOIN project intends to provide an evolutionary path of the current 3GPP architecture for LTE/LTE-A which will support the innovations developed within this collaborative project. For that purpose, it is of interest to recall the classical architecture defined by the 3GPP for LTE/LTE-A. By the time of this report, the Release 10 of the standard [22] has been chosen as the base line architecture.

4.1.1 General Description

Figure 4-1 represents the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) overall architecture. E-UTRAN is connected to the Evolved Packet Core (EPC). More details on the functional role of each depicted entity can be found in [22].

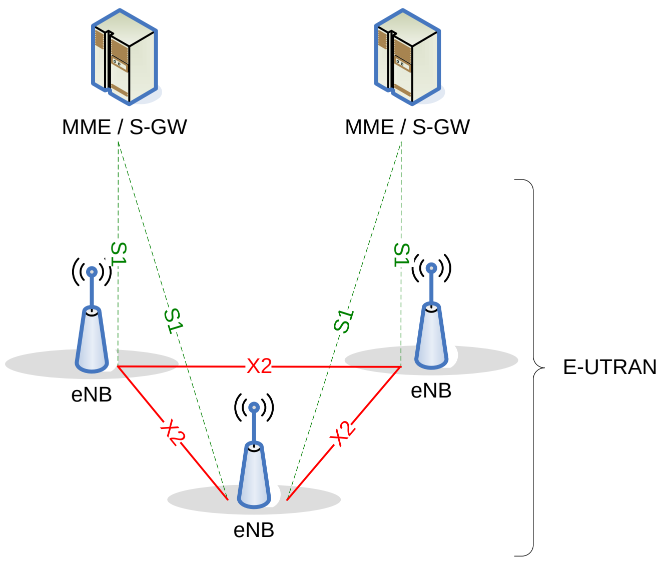


Figure 4-1: E-UTRAN Overall Architecture [22]

4.1.1.1 MME / S-GW

The distinction between EPC's Mobility Management Entity (MME) and Serving Gateway (S-GW) is due to the LTE designing principle of separating the handling of the control signalling from the user data traffic. According to this philosophy, the Serving GW terminates the user plane interface towards the base stations (eNBs, see more details below). It constitutes the anchor point for intra-LTE mobility, as well as (optionally) for mobility between GSM/GPRS, WCDMA/HSPA and LTE. The MME, on the other hand, handles all LTE-related control plane signalling, including mobility and security functions for devices and terminals attaching over the LTE RAN.

The Serving GW terminates the interface towards E-UTRAN; every UE that attaches to an EPS is associated with a single Serving GW. Once a UE is associated with a Serving GW, it handles the forwarding of end-user data packets and also acts as a local anchor point when required for inter-eNB handover. When a UE is in idle state, the Serving GW will terminate the downlink (DL) path for data. If new packets arrive, the Serving GW triggers paging towards the UE. The Serving GW is also responsible for the reproduction of user traffic in the case of lawful intercept.

From a Core Network perspective, the MME is the main node for control of the LTE access network. It selects the Serving GW for a UE during the initial attachment and also during handover, if necessary, between LTE networks. It is responsible for the tracking and paging procedure for UEs in idle mode and also the activation and deactivation of bearers on behalf of a UE. The MME, via interaction with the Home Subscriber Server (HSS), is responsible for authenticating the end-user. The MME also ensures that the UE has authorization to use (camp on) an operator's Public Land Mobile Network (PLMN) and also enforces any roaming restrictions that the UE may have. In addition, the MME provides control-plane functionality for mobility between LTE and 2G/3G access networks. The MME is also responsible for Non-Access

Stratum (NAS) signalling, which terminates at the MME; the MME also acts as the termination point in the network for the security of NAS signalling, handling the ciphering protection and management of security keys. Finally, the MME also handles lawful intercept related to signalling.

4.1.1.2 Evolved Node B

The functionality of the evolved Node B (eNB) includes all features needed to realize the actual wireless connections between user devices and the network. The eNB provides the radio interface and performs radio resource management, including radio bearer control, radio admission control, and scheduling of uplink and downlink radio resources for individual UEs. The eNB also supports IP header compression and encryption of the user-plane data. eNBs are interconnected to one another via an interface called X2; this interface has several uses, e.g. handover, that are described below. eNBs are also connected to the EPC via the S1 interface, which is split up into the user plane and the control plane, as indicated in the next section. The S1 interface also supports network sharing (S1-Flex). This allows operators to share the radio network, i.e. the eNBs, while maintaining their own EPC networks.

4.1.1.3 S1 Interface

The S1 interface is the logical interface between eNB and core network, i.e. Mobility Management Entity (MME) and Serving Gateway (S-GW). 3GPP LTE distinguishes the S1 User Plane (S1-U) and S1 Control Plan (S1-MME) interface. S1-U is established between eNB and S-GW and carries user plane PDUs over GTP-U. S1-MME is established between eNB and MME, and it uses S1-AP signalling carried over SCTP.

Among others, the following functions and interface signalling procedures are supported by S1-MME (a complete list is given in [22]):

- E-RAB management: A Radio Access Bearer (RAB) is established between eNB and S-GW. It carries the user data traffic of UEs;
- Mobility functions, e.g. handover preparation, resource allocation, and status transfer;
- eNB configuration update procedure;
- NAS signalling transport;
- LTE Positioning Protocol A (LPPA) signalling transport and location reporting;
- Network sharing functions;
- MME load balancing and overload function;
- RAN information management function.

4.1.1.4 X2 interface

Similar to the S1 interface, the X2 interface can be distinguished in X2 User Plan (X2-U) and X2 Control Plan (X2-CP) interface. Again, X2-U delivers user plane PDUs over GTP-U and X2-CP uses the X2 Application Protocol (X2-AP) carried over SCTP. An X2 interface is established between two eNBs and allows for directly exchanging information between eNBs. Of particular interest is the mobility support which allows for direct handover of UEs without involving S1 as well as interference coordination capabilities (load management). Among others, the X2 interface supports the following functionality and interface signalling procedures [22]:

- Mobility support (intra-LTE), e.g. context transfer between eNBs, user plane tunnelling between eNBs, handover management, and RLF indication for root cause analysis;
- Load management;
- Information exchange in support of inter-cell interference coordination;
- Information exchange in support of handover settings negotiation;
- Energy saving procedures, i.e. information relevant for cell activation and deactivation.

4.1.2 Support of Heterogeneous Network

The 3GPP specifications [23] define three base station classes according to their coverage area capability, directly related to the maximum power they can radiate:

- **Wide Area Base Station**: no maximum output power defined.
- **Local Area Base Station**: maximum output power of 24dBm for one transmit antenna port.
- **Home Base Station**: maximum output power of 20dBm for one transmit antenna port.

Each time the number of transmit antenna ports doubles (up to 8), -3dB should be subtracted from the maximum output power.

Wide and local area base stations are referred as evolved Node B (eNB) in the E-UTRAN architecture, while home base station (also known as femtocell) are tagged as Home evolved Node B (HeNB). Compared to eNB, HeNB may be connected to the EPC through a HeNB gateway (HeGW) as shown in Figure 4-2.

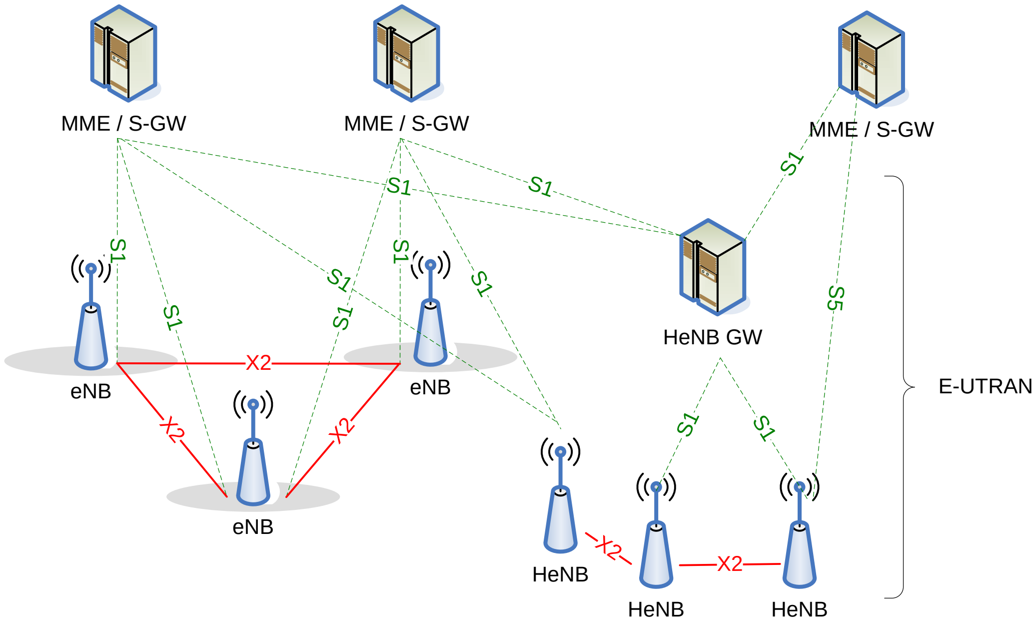


Figure 4-2: Overall E-UTRAN Architecture with deployed HeNB GW [22]

HeNBs are envisaged for residential / corporate deployment and are usually deployed by the end user and not the operator, making the Self-Organising Network (SON) procedure of primary importance. They can rely on a Closed Subscriber Group (CSG) policy to grant the access to a selected group of users while denying or lowering the priority to the rest of users. HeNBs use the end-user Internet connection (xDSL, cable …) to connect through a secured tunnel to the EPC.

By a native support of such base stations, LTE clearly supports all kinds of heterogeneous network. To deal with the interference that may come with such deployment, Inter-Cell Interference Coordination (ICIC) methods have been defined which are supported by the architecture. Release 8 and 9 saw the use of frequency domain solutions to protect the data channels with indicator exchange through the X2 interface:

- Uplink: Overload Indicator (OI) and High Interference Indicator (HII);
- Downlink: Relative Narrowband Transmit Power (RNTP).

Release 10 introduced enhanced ICIC (eICIC) mechanisms to protect the control channels for non-Carrier Aggregation (CA) scenarios with information:

- Downlink power control for HeNB based on Network Listen Module (NLM);
- Almost Blank Subframe (ABS) pattern in the time domain exchanged through the X2 interface when available or through Operations, Administration and Management (OAM) configuration otherwise;
- Cell Range Extension (CRE) introducing a strong bias for small cell selection (advanced receiver needed at the UE side).

Release 11 proposed further enhanced ICIC (feICIC) solutions for non-CA scenario (combination of previous solutions) and introduced ICIC for CA based deployment (split of control channels between primary and secondary cell/carrier).

4.2 Backhaul Solutions

Operators are currently considering deployment of small cells for offering higher capacities in hotspot areas as well as better coverage in selected areas. The purpose of backhaul is to provide connectivity between the small cells and the core network nodes with a desired Quality of Service (QoS) level in terms of data rate, packet delay, packet loss rate, delay jitter, connection availability, security, etc. Different backhauling technologies are foreseen, which can be basically divided in two main classes: wired solutions (e.g. fibre, copper, etc.) and wireless solutions (Microwave radio, Millimetre Radio, etc.).

4.2.1 Requirements for Small Cell Deployment

Recently, a study item on small cells was conducted by the 3GPP RAN Plenary group where the conclusions have been captured in the technical report TR 36.932 [24]. Among these, a backhaul categorisation has been proposed based on operator's inputs. For each technology, high level parameters are given as well as a priority for study. The categorisation can be summarised by Table 4-1 for the non-ideal backhaul and by Table 4-2 for the good to ideal backhaul.

Table 4-1: Categorization of Non-Ideal Backhaul [24]

Backhaul Technology	Latency (One way)	Throughput	Priority (1 is the highest)
Fiber Access 1	10-30ms	10M-10Gbps	1
Fiber Access 2	5-10ms	100-1000Mbps	2
DSL Access	15-60ms	10-100 Mbps	1
Cable	25-35ms	10-100 Mbps	2
Wireless Backhaul	5-35ms	10Mbps – 100Mbps typical, maybe up to Gbps range	1

Table 4-2: Categorization of Good to Ideal Backhaul [24]

Backhaul Technology	Latency (One way)	Throughput	Priority (1 is the highest)
Fiber	2-5ms	50Mbps -10Gbps	1

The Next Generation Mobile Networks (NGMN) group also issued various white papers [25]-[27] where the requirements of wired/wireless backhaul are defined in order to support small cell deployment. These conclusions are summarised in Table 4-3.

Table 4-3: NGMN Requirements for Small Cell Backhaul

Max backhaul traffic	One cell	178.5 Mbit/ peak 40.6 Mbit/s busy time avrg Should be prepared for up to 1Gbps/cell
	Aggregation of N small cells	max(peak, N*busy time avrg)
Availability	For hot-spot	Lower than macro 99-99.9%
	For not-spot	Same as macro 99.9-99.99%
QoS		Same as macro • for hot spots capacity more important, for not-spots availability/coverage

Physical connection	Wired (copper only up to 0.5 km, otherwise fibre): expensive/complicated deployment High data rate LOS wireless (<6 GHz): simpler deployment, medium data rate, high demand on antenna alignment/might not be available LOS/NLOS wireless (>6 GHz): simple deployment, low data rate • 'backhaul coverage' has to be considered
Interconnection	Can be separated in access/'last mile' (small cells to 'aggregators') and aggregation (aggregators to EPC) Multihop: Chain/Tree/Ring/Mesh for access, only ring or mesh for aggregation Access: massive point2point/p2mp/meshed with few p2p
Synchronisation	In case of centralised clock source distribution must be supported (frequency or phase/time sync) Multiple methods possible: physical, protocol-based, long term stable oscillator, GNSS
Security	IPsec must be always on because of easy access to tampering with small cells Compact, enclosed and obscured packaging preferred to reduce risk of tampering and injury
Cost	Must be lower than macro cell
Power consumption	Must be lower than macro cell, should be adaptive, on/off switching should be possible

Within iJOIN, wired and wireless backhaul solutions will be primarily investigated through fibre and 60GHz deployment, respectively.

4.2.2 Wired Solutions

Among wired solutions the optical fiber provides a very high performance connection with multi Gigabits per second (Gbps) throughputs, for example using Gigabit Passive Optical Network (GPON) architectures. The transmission on the fiber is at present based on specific protocols like Common Public Radio Interface (CPRI) [28], [29] and Open Base Station Architecture Initiative (OBSAI) [30]. Also ETSI is involved in standardization activity, and in particular in the ETSI ISG on Open Radio equipment Interface (ISG ORI) group, that was created for the specification of an open interoperable interface for radio equipment in distributed mobile cellular base stations. This group produced a first release of specifications (Rel.1) essentially based on CPRI, while now the second release of specifications is in a planning phase.

The CPRI specifies the internal interface of radio base stations between the Radio Equipment Control (REC) and the Radio Equipment (RE). The REC corresponds to the base station baseband unit that provides the access to the radio network, the control and management as well as the digital baseband processing. The RE corresponds to the base station RF unit (i.e., a local or remote radio head) that serves as air interface to the user equipment. The RE provides the analogue and radio frequency functions such as filtering, modulation, frequency conversion and amplification. The REC and RE communicate over a generic interface based on digital I/Q data transfer. In addition to the user plane data (I/Q data), control and management as well as synchronization signals are exchanged between the REC and the RE. All information flows are multiplexed onto a digital serial communication line using appropriate Layer 1 and Layer 2 protocols [29].

The different information flows have access to the Layer 2 via appropriate service access points. This defines the common public radio interface illustrated in Figure 4-3 [29].

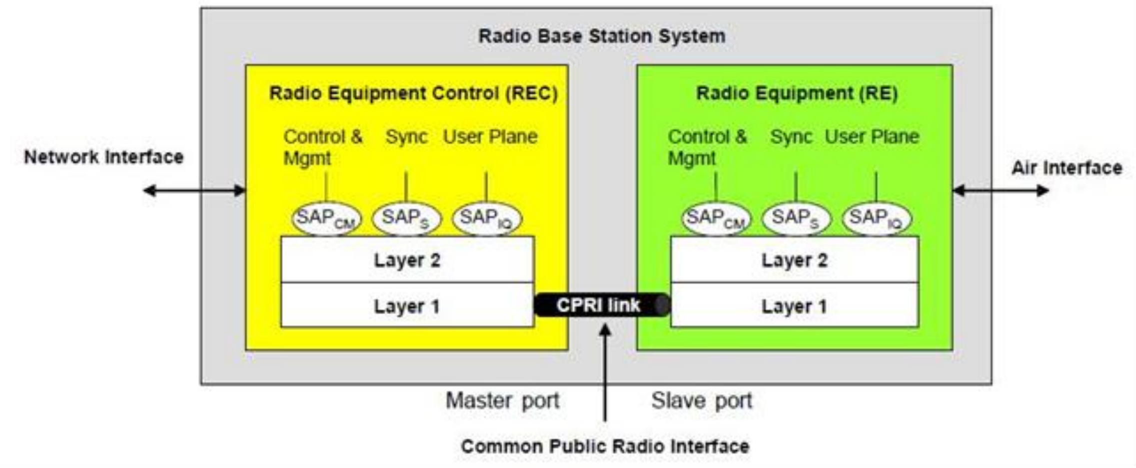


Figure 4-3: Basic System Architecture of CPRI Interface [29]

CPRI defines the Layer 1 and Layer 2 protocols for the transfer of user plane, Control & Management (C&M) as well as synchronization information between REC and RE as well as between two REs. The interface supports the following types of information flows:

- **I/Q Data**: User plane information in the form of in-phase and quadrature modulation data (digital baseband signals).
- **Synchronization**: Synchronization data used for frame and time alignment.
- **L1 in-band Protocol**: Signalling information that is related to the link and is directly transported by the physical layer. This information is required, e.g. for system start-up, Layer 1 link maintenance and the transfer of time critical information that has a direct time relationship to Layer 1 user data.
- **C&M data**: Control and management information exchanged between the control and management entities within the REC and the RE. This information flow is given to the higher protocol layers.
- **Protocol Extensions**: This information flow is reserved for future protocol extensions. It may be used to support, e.g., more complex interconnection topologies or other radio standards.
- **Vendor Specific Information**: This information flow is reserved for vendor specific information.

The basic configuration, shown in Figure 4-3, is composed of one REC and one RE connected by a single CPRI link. The basic configuration can be extended in several ways. For example, several CPRI links may be used to enhance the system capacity as required for large system configurations involving many antennas and carriers. It is required that an I/Q data flow of a certain antenna and a certain antenna-carrier[1] is carried completely by one CPRI link (however, it is allowed that the same antenna-carrier may be transmitted simultaneously over several links). Therefore, the number of physical links is not restricted by the specification. Second, several REs may be served by one REC using the so-called star topology. Third, one RE may be served by multiple RECs. Furthermore, three basic networking topologies may be used for the interconnection of Res: Chain topology, Tree topology and Ring topology, as shown in Figure 4-4.

In order to achieve the required flexibility and cost efficiency, several different line bit rates are defined. Therefore, the CPRI line bit rate at the physical layer (Layer 1) may be selected from the following list:

- CPRI line bit rate option 1: 614.4 Mbit/s
- CPRI line bit rate option 2: 1228.8 Mbit/s (2 x 614.4 Mbit/s)
- CPRI line bit rate option 3: 2457.6 Mbit/s (4 x 614.4 Mbit/s)
- CPRI line bit rate option 4: 3072.0 Mbit/s (5 x 614.4 Mbit/s)
- CPRI line bit rate option 5: 4915.2 Mbit/s (8 x 614.4 Mbit/s)

[1] Antenna-carrier (AxC): one antenna-carrier is the amount of digital baseband (I/Q) U-plane data necessary for either reception or transmission of only one carrier at one independent antenna element.

- CPRI line bit rate option 6: 6144.0 Mbit/s (10 x 614.4 Mbit/s)
- CPRI line bit rate option 7: 9830.4 Mbit/s (16 x 614.4 Mbit/s)

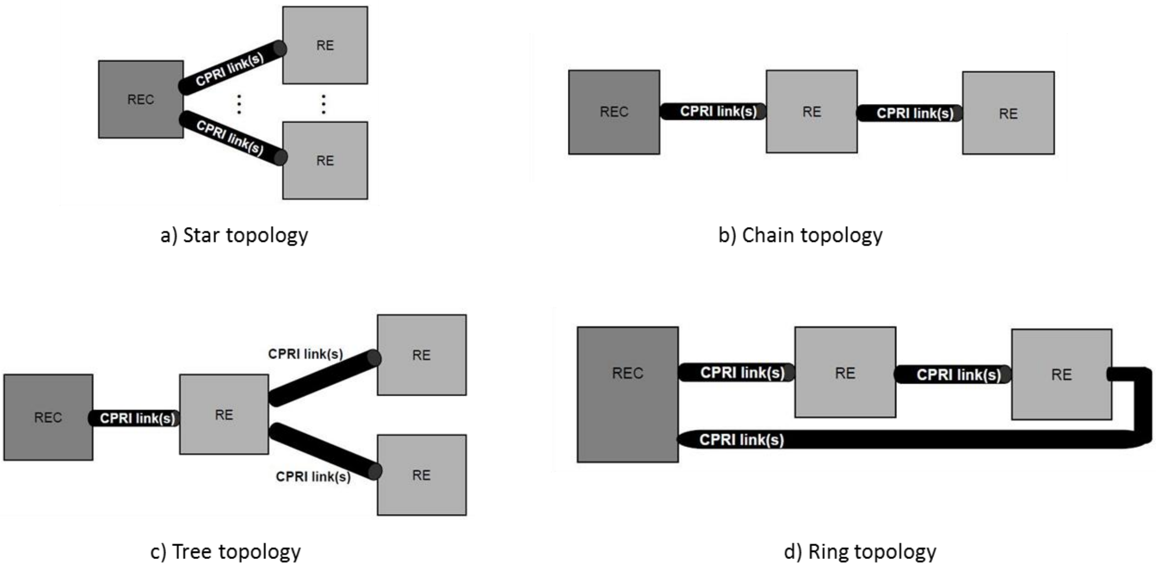


Figure 4-4: Networking Topologies for the Interconnection of REs [29]

It is mandatory that each REC and RE support at least one of the above cited CPRI line bit rates. All CPRI line bit rates have been chosen in such a way that the basic UMTS chip rate of 3.84 Mbit/s can be recovered in a cost-efficient way from the line bit rate.

In order to support efficient implementation of UTRA-FDD inner loop power control, the absolute round trip time[2] for U-plane data (I/Q data) on the interface, excluding the round trip group delay on the transmission medium (i.e. excluding the cable length), shall not exceed the maximum value of 5 µs.

- The CPRI standard supports transmission of data between the REC and RE in both directions for a radio base station consisting of one REC and one or more RE compliant to the following radio standards:3GPP UTRA FDD, Release 9, March 2010
- WiMAX Forum Mobile System Profile Release 1.5 Approved Specification (2009-08-01)
- 3GPP E-UTRA, Release 9, March 2010
- 3GPP GSM/EDGE Radio Access Network, Release 9, December 2009

The Open Base Station Architecture Initiative (OBSAI) standard is the results of an initiative created by some equipment vendors with the aim of creating an open market for cellular base stations [30]. The reference architecture for the OBSAI Base Transceiver Station (BTS) is shown in Figure 4-5.

The architecture elements consist of the following [31]:

- Functional blocks consisting of the Transport Block, Control and Clock Block, Baseband Block and RF Block
- External network interface. (example: Iub interface to the RNC for 3GPP systems)
- External radio interface (example: Uu or Um interfaces to the UE for 3GPP systems)
- Internal interfaces between BTS functional blocks designated as Reference Points (RPs)

There are four internal interfaces: the internal interface RP1 includes control data and clock signals to all blocks, RP2 provides transport for user data between Transport Block and Baseband Block, RP3 provides transport for air interface data between Baseband Block and RF Block and RP4 provides the DC power interface between the internal modules and DC power sources.

[2] Round trip time is defined as the downlink delay plus the uplink delay

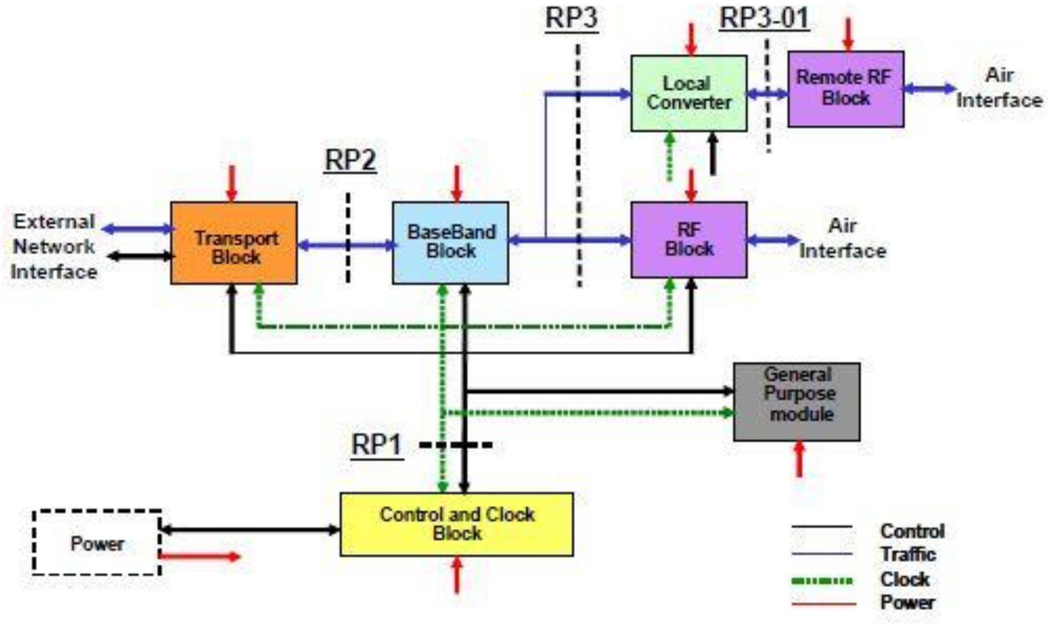


Figure 4-5: OBSAI Reference BTS Architecture [31]

The OBSAI RP3-01 interface [32] represents an extension of the Reference Point 3 protocol for Remote Radio Unit (RRU) use. The BS can support multiple RRUs connected in chain, ring, tree-and-branch topologies, which makes the interface very flexible.

The RP3-01 interface is a high speed serial interface for both uplink and downlink data and control transfer. The protocol stack is based on a packet concept using a layered protocol with fixed length messages. The transmitter Physical Layer is responsible for the line encoding, which provides a mechanism for clock recovery, and data serialization. The supported rates are 768 Mbps, 1536 Mbps, 3072 Mbps and 6144 Mbps and the supported radio interface include LTE, WCDMA, CDMA, GSM and WIMAX [32].

4.2.3 Wireless Solutions

For wireless backhauling, a number of frequency bands have been considered so far. Apart from in-band backhaul, the available solutions can be separated into traditional microwave (5-42 GHz), sub 6 GHz microwave, unlicensed (60 GHz) and licensed (70-80 GHz) millimetre wave systems. Furthermore, Free Space Optics (FSO) can also be considered as wireless backhaul [33].

Generally speaking, wireless backhaul has the advantage that it is easier, faster and cheaper to deploy than wired backhaul. On the other hand it usually offers lower data rate and lower availability. However, the different wireless systems have widely different characteristics themselves [34].

- Free space optics offer high data rates of multiple Gbps due to the very high available bandwidth and usually do not have to be licensed, lowering cost and deployment time. However, they suffer heavily from snowfall and fog, limiting either range or availability. Due to their very narrow beamwidth, they also have to be carefully aligned and are susceptible to thermal expansion, building sway and vibration. When they are facing east to west, they can also suffer from sunlight effects [34].
- Traditional microwave systems can only offer low data rates below 1 Gbps and use licensed spectrum, increasing costs and deployment time. The 5 GHz band is also used by many users as it is specified as a Wi-Fi band. This increases interference, which further limits data rates and decreases availability. The 5 GHz system is also more vulnerable to interception, because all other systems use highly directive beams that would require an interceptor be suspiciously deployed in the connection's line of site.
- The 60 GHz band offers up to 9 GHz of unlicensed spectrum, allowing for multi- Gbps data rates and fast deployment. However, 60 GHz faces a uniquely high attenuation through oxygen absorption and rain, limiting its range to below 2 km. In contrast, the oxygen absorption has the advantage that interference between 60 GHz links is very low, especially if combined with narrow antenna beams.

This also increases the security against eavesdropping. However, the small beamwidth limits the multipath effects, making spatial diversity multiplexing techniques more difficult and also requires line of sight.

- The 70- 80 GHz band combines the advantages of high bandwidth, long range and high availability. The spectrum is licensed, yet the licensing process is (at least in the US) easy and affordable. It also shares the advantages and disadvantages of narrow antenna beams with 60 GHz systems. However, since it is the highest frequency system considered, hardware design is the most challenging.

To increase reliability, different wireless backhauls can be combined, e.g. a 60 GHz system as main link and a 5 GHz link as backup in case of heavy rain. As in any communication system, effective data rates can be lowered in favour of a more robust coding, to ensure connectivity in suboptimal situations.

An overview of the different technologies is provided in Table 4-4.

Table 4-4: Overview over wireless backhaul technologies

Parameter	sub > 6GHz	6-42 GHz	60 GHz	70/80 GHz	FSO
Typical data rate	400 Mbps	400 Mbps	1 Gbps (commercial) 10 Gbps (demonstrator)	1 Gbps (commercial) 10 Gbps (demonstrator)	1 – 10 Gbps
Typical range	<5 km (interference limited)	5 km	0.5- 1 km	3 km	1 km
Licensing	Licensed/ unlicensed (5.8 GHz)	licensed	unlicensed	"lightly" licensed	unlicensed
Other	Multipath for spatial diversity High interference Easy to intercept		Very low interference Oxygen attenuation NLOS might not be possible	NLOS might not be possible	High degree of alignment required Only LOS possible high attenuation by snow, fog

4.3 Cloud Computing and Architecture

We are facing today an exponential increase of data rate demands. This is a continuation of a development which took place over the last decades. However, this development is tightly coupled with the exponential increase in available storage capacity and processing power. All three, as illustrated in Figure 4-6, depend upon each other, i.e. more processing power requires more storage in order to store the processed data.

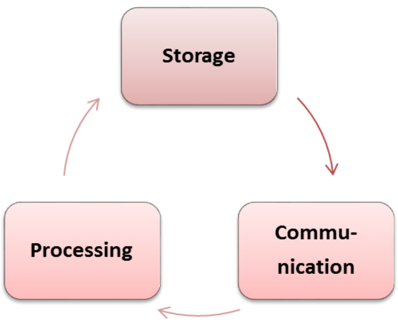


Figure 4-6: Communication/Processing/Storage Dependency

The communication capabilities have to increase likewise in order to transfer data from and to the storage devices. However, cloud computing and cloud storage are disruptive technologies which changed the development of IT platforms significantly. Communication technology needs to keep pace with this development in many ways, i.e., it needs to leverage cloud-technology to improve the network itself and it also needs to address user needs which are raised by the changing traffic demands. Therefore, we need to address two main issues:

- How to enable the access to cloud resources for users, depending on the service and service requirements?
- How to leverage the advanced state of cloud computing in order to benefit for the operation of mobile networks?

The rest of this section pays more attention on the definition of the cloud technology, its characteristics, and the way it is implemented. An overview on the challenges for cloud technology and communication technology is also described.

4.3.1 Cloud Computing Definition

4.3.1.1 The NIST Definition

According to the National Institute of Standards and Technology [35], cloud computing is *"a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.*

This cloud model is composed of five essential characteristics, three service models, and four deployment models.

Essential Characteristics

- ***On-demand self-service****. A consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed automatically without requiring human interaction with each service provider.*
- ***Broad network access****. Capabilities are available over the network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms (e.g., mobile phones, tablets, laptops, and workstations).*
- ***Resource pooling****. The provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand. There is a sense of location independence in that the customer generally has no control or knowledge over the exact location of the provided resources but may be able to specify location at a higher level of abstraction (e.g., country, state, or data center). Examples of resources include storage, processing, memory, and network bandwidth.*
- ***Rapid elasticity****. Capabilities can be elastically provisioned and released, in some cases automatically, to scale rapidly outward and inward commensurate with demand. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be appropriated in any quantity at any time.*
- ***Measured service****. Cloud systems automatically control and optimize resource use by leveraging a metering capability*[3] *at some level of abstraction appropriate to the type of service (e.g., storage, processing, bandwidth, and active user accounts). Resource usage can be monitored, controlled, and reported, providing transparency for both the provider and consumer of the utilized service.*

[3] Typically this is done on a pay-per-use or charge-per-use basis.

Service Models

- ***Software as a Service (SaaS)**. The capability provided to the consumer is to use the provider's applications running on a cloud infrastructure[4].The applications are accessible from various client devices through either a thin client interface, such as a web browser (e.g., web-based email), or a program interface. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user specific application configuration settings.*
- ***Platform as a Service (PaaS)**. The capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages, libraries, services, and tools supported by the provider[5].The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly configuration settings for the application-hosting environment.*
- ***Infrastructure as a Service (IaaS)**. The capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications; and possibly limited control of select networking components (e.g., host firewalls).*

Deployment Models

- ***Private cloud**. The cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed, and operated by the organization, a third party, or some combination of them, and it may exist on or off premises.*
- ***Community cloud**. The cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be owned, managed, and operated by one or more of the organizations in the community, a third party, or some combination of them, and it may exist on or off premises.*
- ***Public cloud**. The cloud infrastructure is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or government organization, or some combination of them. It exists on the premises of the cloud provider.*
- ***Hybrid cloud**. The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities, but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds).*"

4.3.1.2 Alternative Definitions

Other definitions are also found in the literature for cloud computing. For instance, according to Gartner [36], cloud computing is a *"style of computing where massively scalable (and elastic) IT-enabled capabilities are delivered 'as a service' to external customers using Internet technologies"*. It is worth to consider the five attributes highlighted by Gartner [37] to the cloud computing.

- *"**Service-Based**: Consumer concerns are abstracted from provider concerns through service interfaces that are well-defined. The interfaces hide the implementation details and enable a completely automated response by the provider of the service to the consumer of the service. The*

[4] A cloud infrastructure is the collection of hardware and software that enables the five essential characteristics of cloud computing. The cloud infrastructure can be viewed as containing both a physical layer and an abstraction layer. The physical layer consists of the hardware resources that are necessary to support the cloud services being provided, and typically includes server, storage and network components. The abstraction layer consists of the software deployed across the physical layer, which manifests the essential cloud characteristics. Conceptually the abstraction layer sits above the physical layer.

[5] This capability does not necessarily preclude the use of compatible programming languages, libraries, services, and tools from other sources.

service could be considered "ready to use" or "off the shelf" because the service is designed to serve the specific needs of a set of consumers, and the technologies are tailored to that need rather than the service being tailored to how the technology works. The articulation of the service feature is based on service levels and IT outcomes (availability, response time, performance versus price, and clear and predefined operational processes), rather than technology and its capabilities. In other words, what the service needs to do is more important than how the technologies are used to implement the solution.

- ***Scalable and Elastic**: The service can scale capacity up or down as the consumer demands at the speed of full automation (which may be seconds for some services and hours for others). Elasticity is a trait of shared pools of resources. Scalability is a feature of the underlying infrastructure and software platforms. Elasticity is associated with not only scale but also an economic model that enables scaling in both directions in an automated fashion. This means that services scale on demand to add or remove resources as needed.*
- ***Shared**: Services share a pool of resources to build economies of scale. IT resources are used with maximum efficiency. The underlying infrastructure, software or platforms are shared among the consumers of the service (usually unknown to the consumers). This enables unused resources to serve multiple needs for multiple consumers, all working at the same time.*
- ***Metered by Use**: Services are tracked with usage metrics to enable multiple payment models. The service provider has a usage accounting model for measuring the use of the services, which could then be used to create different pricing plans and models. These may include pay-as-you go plans, subscriptions, fixed plans and even free plans. The implied payment plans will be based on usage, not on the cost of the equipment. These plans are based on the amount of the service used by the consumers, which may be in terms of hours, data transfers or other use-based attributes delivered.*
- ***Uses Internet Technologies**: The service is delivered using Internet identifiers, formats and protocols, such as URLs, HTTP, IP and representational state transfer Web-oriented architecture. Many examples of Web technology exist as the foundation for Internet-based services. Google's Gmail, Amazon.com's book buying, eBay's auctions and Lolcats' picture sharing all exhibit the use of Internet and Web technologies and protocols."*

For Charles Brett, Principal Analyst for Forrester Research, the cloud is a "*pool of abstracted, highly scalable, and managed infrastructure capable of hosting end-customer applications and billed by consumption"* [38].

The common view of the iJOIN consortium is that cloud computing is a delivery model for technology enabled services that provides on-demand access via a network to an elastic pool of shared computing assets (e.g. services, applications, servers, storage, and networks) that can be rapidly provisioned and released with minimal service provider interaction. The entire value can be bi-directionally scaled as needed to enable pay-per-use.

4.3.2 Service Models / IT enabled capabilities

Figure 4-7 highlights the differences between IaaS, PaaS and SaaS. The lower blue portion represents the part offered by the provider and as such managed by the provider.

- In **IaaS** the provider is only responsible for keeping the virtualized resources up and running, and is not involved in the management of any software (operating system, platform, middleware, application or services) in execution on that infrastructure. End users are typically programmers and operators who need infrastructural resource to run their software and are ready to maintain all software layers they'll need. Examples of IaaS providers: Amazon WS, HP Cloud Services, and many others.
- **PaaS** providers are instead responsible for the management of all operating systems, platforms and middleware that constitute the offered platform: the target users are typically programmers who deploy their code on the platform - without caring on its operational details. Examples of PaaS providers: Google Application Engine, Microsoft Azure, and few other minor ones. PaaS should not be confused with IaaS resources containing a preinstalled platform (like a LAMP stack for instance, OpenShift or Stackato), because in this case the management of the platform is up to the user.

- **SaaS** providers offer fully fledged applications: End Users typically only "use" them. Administrative users will configure and upload basic data. Examples are Google Mail, Salesforce.com and many others.

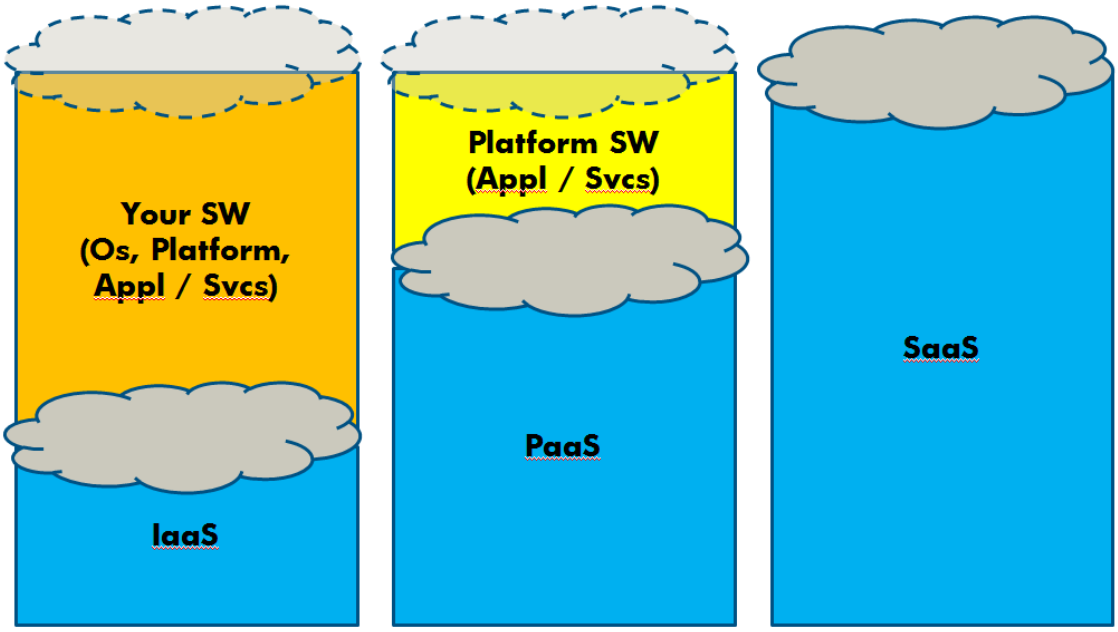


Figure 4-7: Service Models: XaaS

As an example, Figure 4-8 represents the typical architecture of an IaaS cloud stack like OpenStack (open source powering also HP Cloud Services), Eucalyptus (open source and commercial), OpenNebula (open Source) and very likely the model applies to AmazonWS (commercial).

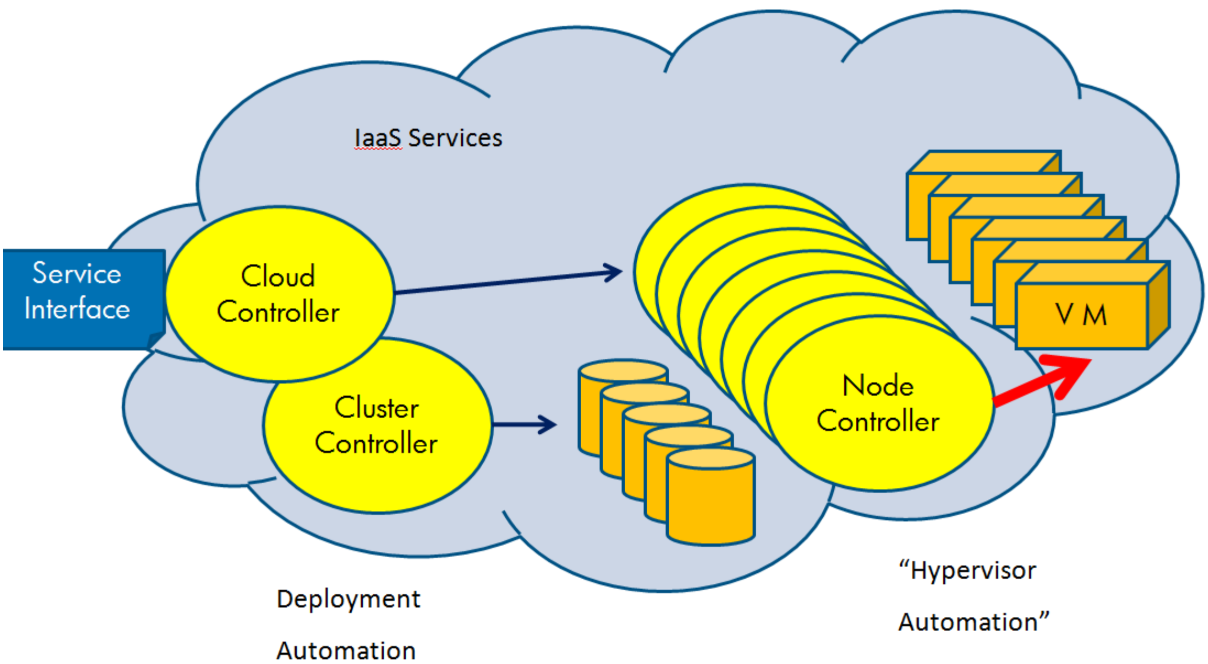


Figure 4-8: "Typical" Architecture of an IaaS Cloud Stack

End users have a service interface (typically both an API and a user operation portal) through which they can manage virtual resources (create VMs, attach virtual disks, configure virtual networks, etc). The Cloud Controller Module (managing the full cloud) will dispatch to the Cluster Controller (typically managing a single data centre) that will use the Node Controller to host virtual resources. Storage can also be duplicated in different sites to increase availability.

The process is fully automated and takes only minutes to complete virtual resource setup. The different providers offer a catalogue of system images (containing Operating Systems, and sometimes additional preinstalled software packages) where the user typically selects the initial contents of the virtual machine configuration.

4.3.3 Impact of Cloud Computing on Mobile Networks

The impact of cloud technology on the mobile network is illustrated in Figure 4-9. Cloud-technology already has a significant impact on the core network. For instance, Soft-EPC allows for the implementation of core-network functionality on standard IT platforms such that EPC elements do not require specialized hardware, which reduces CAPEX and OPEX of EPC implementations. The next step in this development is Network Function Virtualization (NFV) where individual network functions are virtualized and therefore become scalable and manageable [39], [40]. NFV can also be applied to the EPC such that individual EPC elements are virtualized, e.g. MME, S-GW, P-GW, PCRF. This is part of the investigations carried out in the FP7 Call 8 project "Mobile Cloud Networking" [41].

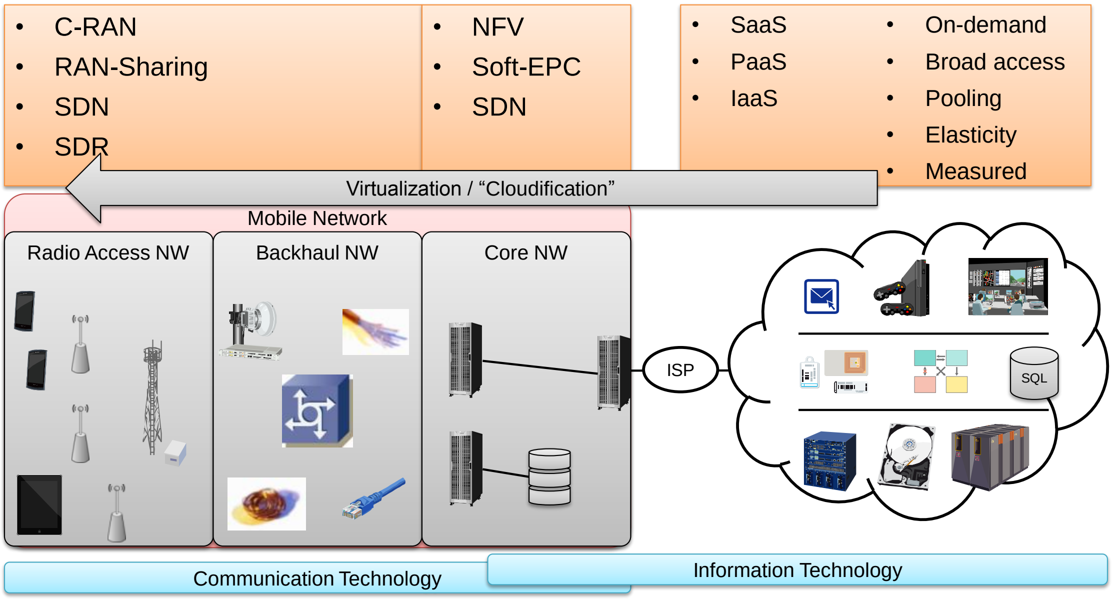


Figure 4-9: Impact of Cloud Computing on Mobile Networks

This application of cloud technology in mobile networks is pushed from the EPC towards backhaul network and radio access network. An example of the application is C-RAN. The C-RAN ("cloud"-RAN) approach (e.g., [42]-[44]) implies full centralisation of baseband processing of a mobile communication system with a cloud-infrastructure. In C-RAN, base stations (BSs) are replaced by Remote Radio Heads (RRHs) that are connected to the BS pool by fibre links. This permits processing power to be shifted from the radio access points to the BS pool, where it can be employed more efficiently. Instead of BSs being provisioned on the basis of their maximum loads, C-RAN permits provisioning based on the maximum overall load of the entire network. Furthermore, the processing power in the BS pool can be adapted to the instantaneous load, a common practice in cloud computing. Recently, different vendors have presented products based on this philosophy [45], [46] and have demonstrated the successful deployment of C-RAN installations [47], [48]. However, C-RAN's most important drawback is its reliance on high-capacity fibre links between the RRHs and the baseband pool. For interfacing of RRHs to the network, the CPRI has been defined [28] and the

OBSAI has been formed [30]. The large bandwidth requirement of the backhaul links can be satisfied only with fibre links. This complicates the application of C-RAN in small cells.

In contrast to C-RAN, iJOIN envisions a scalable function shift between the radio access points and the central processor, taking into account the backhaul network and the computational complexity of the different network entities. In contrast to IaaS, RANaaS also considers the networking infrastructure and part of the middleware, but unlike PaaS, RANaaS will not offer the full application stack to provide operators an opportunity to fine-tune their systems. The following paragraphs describe further the present state-of-the-art with respect to iJOIN's two major concepts - joint access/backhaul design and optimisation, and RAN-as-a-Service (RANaaS). Both concepts are approached on different layers (i.e., PHY, MAC, RRM, and system/network management).

Another example for this development is RAN sharing [49] where resource in the radio access network are virtualized and offered towards multiple operators. This principle needs to be equally applied to backhaul networks which usually are shared on the last hop. Furthermore, Software Defined Networking (SDN) [50] introduced a new way of operating networks. SDN allows for a separation of control and data plane, and it allows for a simplified and configurable management of the underlying network. Therefore, the network becomes a virtualized resource which can be adapted to the needs of the applications using this network. In radio access and backhaul networks, this approach may be useful to perform traffic engineering jointly for radio access and backhaul network (which is outlined in more detail in Work Package 4 IR4.1 document). A key enabler for the application of cloud-technology to mobile networks is Software Defined Radio (SDR) [51] as well as the possibility to implement the radio stack on standard IT platform which allows for cost-efficient implementation and the flexibility required by the iJOIN architecture.

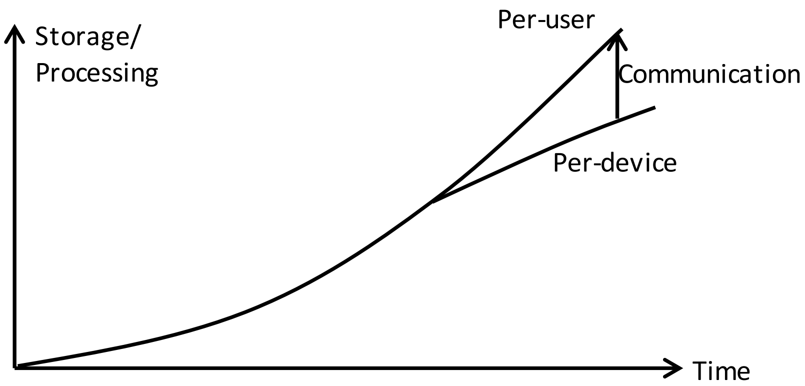


Figure 4-10: Gap between Per-User and Per-Device Capabilities over Time

On the user side, cloud technology also impacts the mobile network. For instance, the per-user storage and processing capabilities will continue to increase exponentially. However, the per-device capabilities will not grow with the same pace as shown in Figure 4-10 as more computing and storage in data centres is utilized. Therefore, communication networks, and in particular mobile networks, need to close the gap between per-user and per-device capabilities in order to allow for envisioned service diversity enabled through cloud-technology. Because more services will be executed in data centres, also the traffic diversity in mobile networks will increase an optimization of radio access and backhaul network based on service characteristics is required. Finally, the type of traffic will change, e.g., more internet traffic is concentrated within data centres while mobile network traffic will serve mainly the purpose to upload acquired data (photos, videos, etc.) and to download processed data.

4.4 Other European Projects / Initiatives

4.4.1 Small Cell

- **BeFEMTO**

  http://www.ict-befemto.eu

  "*The BeFEMTO project is an FP7 IP project, investigating innovative solutions to develop evolved femtocell technologies based on LTE-A that enable a cost-efficient provisioning of ubiquitous broadband services and support novel usage scenarios like networked, relay and mobile femtocells. The project targets both near-term and long-term solutions. With its strong industry consortium, the BeFEMTO project aims to have a real impact on the standardisation of the next generation Femtocell technologies based on LTE-A in the near term. In the long-term, the project focuses on novel concepts and usage scenarios such as self-organizing and self-optimizing Femtocell Networks, Outdoor Relay Femtocells as well as Mobile Femtocells.*

  The project started in January 2010 and finished its work in June 2012. Among the major results reached during the project, BeFEMTO developed a set of solutions for limiting the impact of both cross-tier and co-tier interference. Moreover, to enable the integration of such solutions, BeFEMTO has extended the 3GPP Evolved Packet System (EPS) architecture by introducing new entities and functionalities."

  Main focus on BeFEMTO was on femtocell deployment (standalone and networked) with a strong focus on interference management for CSG deployment, while iJOIN will tackle the small cell deployment mainly under the picocell umbrella (operator controlled) allowing a better backhaul control in the joint design envisaged.

- **TROPIC**

  http://www.ict-tropic.eu

  Tropic is an FP7 STREP project started in September 2012, which is currently investigating solutions to distribute the cloud architecture to local inter-connected femtocells, which are low-power and low-cost solution to offer radio coverage through a given technology. When femtocells are equipped with sufficient computational and storage resources, this new paradigm can lead to higher user experience by limiting latency and offering high data-rate. Resource consuming (in terms of computation, storage, latency, and energy) applications for mobile handsets can be distributed and run over cooperating femtocells, by leveraging on the virtualisation and the distribution paradigms which characterize cloud services.

  On the contrary, iJOIN aims at exploiting the cloud paradigm to enable centralized radio access and interference mitigation in dense small cell deployment. Although the two projects have complementary goals and will likely focus on different use cases, it is recommendable a strong cooperation between the two projects to follow each other's research activities especially in terms of architecture and radio access solutions.

- **DIWINE**

  http://www.diwine-project.eu/

  "*DIWINE considers wireless communication in a dense relay/node scenario where WNC (Wireless Network Coding) messages are flooded via dense massively air-interacting nodes in the self-contained cloud while the PHY air-interface between the terminals (sources/destinations) and the cloud is simple and uniform. A complex infrastructure cloud creates an equivalent air-interface to the terminal, which is as simple as possible. Source and destination air-interfaces are completely cloud network-structure-blind. The cloud has its own self-contained organising and processing capability.*"

  While iJOIN considers a cloud-platform that processes radio-access network information, DIWINE considers the set of radio access points itself as a cloud. This allows for an abstract but simple interface to the infrastructure while the complexity of the implementation is hidden from the terminal. This translates part of the paradigms which were introduced with "Cloud Computing" to the wireless network scope. iJOIN may integrate in such a system as iJOIN does not rely on a particular air interface between radio access point and terminal. iJOIN rather describes a possible way to implement a system as described by DIWINE.

- **METIS**

  https://www.metis2020.com/

  "*The main objective of METIS (Mobile and wireless communications Enablers for the Twenty-twenty Information Society) is to lay the foundation for, and to generate a European consensus on the future global mobile and wireless communications system. METIS will provide valuable and timely contributions to pre-standardisation and regulation processes, and ensure European leadership in mobile and wireless communications.*"

  METIS considers a perspective 5G system and aims to find new solutions with respect to network topologies, radio links, multi-node, and spectrum usage techniques. Furthermore, METIS focuses on different horizontal topics such as Device-to-Device (D2D) communications, massive machine communications, moving networks, ultra dense networks, and ultra-reliable communication. iJOIN, by contrast, does not focus on a particular horizontal application but on dense small-cell networks in general as well as four deployment use cases. Furthermore, iJOIN's focus is rather on the implementation, coordination, and optimization of radio-access network functionality jointly with backhaul networks. This particular aspect is not a major part of METIS. In that sense, iJOIN well complements METIS as it allows for applying its results to a novel 5G system concept developed by METIS.

- **CROWD**

  http://www.ict-crowd.eu/

  "*CROWD promotes a paradigm shift in the future Internet architecture towards global network cooperation, dynamic network functionality configuration and fine, on demand, capacity tuning. The project targets very dense heterogeneous wireless access networks and integrated wireless-wired backhaul networks. In this framework, CROWD pursues four key goals: i) bringing density-proportional capacity where it is needed, ii) optimising MAC mechanisms operating in very dense deployments by explicitly accounting for density as a resource rather than as an impediment, iii) enabling traffic- proportional energy consumption, and iv) guaranteeing mobile user's quality of experience by designing smarter connectivity management solutions.*"

  The architecture foreseen by CROWD comprises the following key functionalities:

  - Connectivity management mechanisms to exploit new opportunities due to the density of access points.
  - Energy efficient operation mechanisms, which are able to provide network-wide energy savings and traffic-proportional consumption.
  - MAC optimisation mechanisms for IEEE 802.11 to understand and solve performance misbehaviours due to the network density.
  - MAC optimisation mechanisms for 3GPP LTE, including inter-cell cooperation, scheduling, link adaptation and power control.
  - Backhaul optimisation mechanisms in order to dynamically configure it for optimal performance based on current load.
  - Global control framework able to configure the network for global optimal operation.

4.4.2 Backhaul Networks

- **E3Network**

  http://www.ict-e3network.eu/

  "*E3Network will design an E-band transceiver for the backhaul infrastructure of the future networks. It will work in the E-band, which enables highly focused "pencil beam" transmissions and huge bandwidth. The pencil-beam property facilitates a high degree of frequency reuse in the* *deployment of backhaul links and reduces EMF exposure of European citizens. The transceiver will use modern digital multi-level modulations to achieve high spectral efficiency. This together with the huge bandwidth will enable high capacities above 10 Gbps.*"

In contrast to E3 Network, iJOIN will not consider a new backhaul transceiver design but relies on existing and partly evolved 60GHz wireless backhaul technology as well as fixed line backhaul technologies, i.e. optical fibre.

- **BUNGEE**

  http://www.ict-bungee.eu/

  "*BuNGee's goal is to dramatically improve the overall infrastructure capacity density of the mobile network by an order of magnitude (10x) to an ambitious goal of 1Gbps/km2 anywhere in the cell – thereby removing the barrier to beyond next-generation networks deployment. To achieve this objective, the project will target the following breakthroughs:*

  - *unprecedented joint design of access and backhaul over licensed and license exempt spectrum;*
  - *unconventional below-rooftop backbone solutions exploiting natural radio isolations;*
  - *beyond next-generation networked and distributed MIMO & interference techniques;*
  - *protocol suite facilitating autonomous ultra-high capacity deployment.*"

  By contrast to BUNGEE, iJOIN makes the joint design and operation of radio access network and backhaul network for very dense small-cell deployments the main element of its research. Further beyond BUNGEE's research, iJOIN will apply RANaaS such that parts of the RAN functionality are centralized. However, iJOIN will be able to leverage existing results from the BUNGEE project, in particular with respect to backhaul technologies and deployment as well as radio access network cooperation strategies.

4.4.3 Mobile Networks involving Cloud Architecture

- **Mobile Cloud Networking (MCN)**

  https://www.mobile-cloud-networking.eu/

  "*Mobile Cloud Networking project will define and evaluate Europe's vision of mobile cloud computing. It will enable European Telco industry to take and sustain leadership in mobile cloud computing and thus a fundamental pillar of the Future Internet. One issue is that cloud computing is an invention of the software industry and frequently not well understood by Telco experts. Meanwhile cloud is too often turned into a buzzword to prettify old ideas, which rightfully poses questions on any cloud proposal. It is therefore important to understand the distinct concepts, both technological and economical, of Cloud Computing in order to penetrate the innovative vision of Mobile Cloud Networking, which establishes a sound vision driven by technological concepts and business drivers, clearly beyond the combination of two buzzwords.*

  The top-most motivations of the Mobile Cloud Networking project are to:

  - *Extend the Concept of Cloud Computing beyond data centres towards the Mobile End-User (as shown in the figure below)*
  - *One Service (atomic): Mobile Network + Computing + Storage*
  - *On-Demand, Elastic, and Pay-As-You-Go*
  - *Enable a Novel Business Actor, the Mobile Cloud Provider*
  - *The Mobile Network Architecture for Exploiting and Supporting Cloud Computing*
  - *Deliver and Exploit the Concept of an End-to-End Mobile Cloud for Novel Applications*"

  iJOIN and MCN aim for applying the concepts developed in the context of Cloud Computing to mobile networks. However, the focus of MCN is rather on the core network, network architecture, and business cases. iJOIN, by contrast, focuses on a much smaller scope, i.e. radio access and backhaul network, and the application of partly centralized RAN functionality. Both of them are not part of MCN, but the derived concepts and innovations may be integrated in the MCN concept by complementing the MCN system with the evolved radio access network concept derived by iJOIN.

4.4.4 Energy saving

- **EARTH**

https://www.ict-earth.eu/

The EARTH project is an FP7 IP project, investigating the energy efficiency of mobile communication systems. The goal of the project is to address the global environmental challenge by investigating and proposing effective mechanisms and to drastically reduce energy wastage and improve energy efficiency of mobile broadband communication systems, without compromising users' perceived "quality" of service and system capacity. In particular the overall goal was to derive solutions that together in an integrated solution will decrease the energy consumption by 50 %. The project started in January 2010 and finished its work in June 2012. Among the major results reached during the project, EARTH developed the methodology 'E3F' for the evaluation of energy saving gains on network level. It allows assessing which gains a solution or a combination of solutions yield in realistic scenarios of real networks, and allows for an objective and fair comparison of different concepts. To do that the project proposed different energy efficiency metrics. This methodology has been also adopted outside the project in other research initiatives, and provided foundations in standardisation towards characterising network energy efficiency in ETSI Eco-Environmental Product Standards.

The E3F methodology is deemed as highly appropriate also for the purpose on iJOIN, covering all the aspects of a possible estimation of the improvements in terms of Energy Efficiency of the proposed solutions. E3F refers indeed both to technological improvements (i.e. more efficient hardware) and to implementation and deployment improvements (i.e. more efficient software), aiming to an assessment of the overall network efficiency gains.

In E3F there are models of the power consumption within a radio equipment, encompassing macro-cellular base stations but also microcells and picocells. In this sense, E3F is appropriate for estimating power consumption from the RF power of a radio equipment.

On the other hand E3F is a reference also for estimating the gains of a RRM algorithm or a network planning solution with respect to a baseline (EARTH project considered LTE Rel. 8 as a baseline reference).

Considering that E3F has been the climax achievement in EARTH and has been recognized as acceptable by many other bodies, including some SDOs, it is recommendable that iJOIN will refer to it for the energy efficiency purposes within its innovative activities.

4.4.5 Data Centre Energy Saving

In the last years, the topic of datacentre energetic efficiency has gained more and more relevance also in the research community. Accordingly, different FP7 research projects have successfully been brought up, mostly concentrated in the FP7 objective 6.3.

These projects cover a wide range of datacentre elements having an impact on energy efficiency. Some of these projects (CoolEmAll, and in part GAMES) address the intrinsic efficiency of hardware and datacentre facilities. Others (FIT4Green, All4Green, ECO2Clouds) address operational efficiency of datacentres, i.e. how the datacentre assets (computing equipment and facilities) can be optimally employed, and their characteristics exploited, to achieve the minimal global energy impact (reducing consumption and/or greenhouse gas emissions) without any change or enforcement to the underlying equipment and to the operational constraints.

All these projects aim at enhancing the legacy set of performance indicators and metrics, to allow a consistent and significant assessment of the energy saving results enabled by the new technologies.

These projects are relevant to iJOIN, since most of them have implemented, or are implementing, their energy optimization functions also in cloud computing environments alike the one that is baseline to iJOIN RANaaS platform. Hence, the results of these projects can be included in the toolset to assess and improve the overall energy efficiency of the iJOIN architecture.

- **FIT4Green**

  www.fit4green.eu

  FIT4Green targeted to provide at least 20% savings in direct server and network devices energy consumption and induce an additional 30% savings due to reduced cooling needs. It created an energy-aware layer of plug-ins on top of current data centres' management tools to orchestrate the allocation of ICT resources, turning off unused equipment. The plug-ins enhance existing IT solutions' deployment strategies by moving computation and services around a federation of IT data centre sites, without giving up on compliance to Service Level Agreements (SLA) and Quality of Service (QoS). This approach is applicable to any data centre type. The project successfully terminated in June 2012.

- **ALL4Green**

  www.all4green-project.eu

  All4Green matches energy demand patterns of data centres and the energy supply patterns of energy providers and thus enables peak shaving, the reduction of inefficiencies in energy production, and the exploitation of renewable energy sources without endangering the stability of the grid. This is accomplished by designing new flexible contracts, revolving around the use of GreenSLAs between ICT users and data centres to enable new energy saving policies that can be tailored to different computing styles and can be used with all data centre monitoring and automation frameworks. All4Green will therefore allow avoiding:

  - high CO2 emissions by using inefficient peak energy sources,
  - energy losses tied up in inefficient peak energy sources,
  - additional energy transmission losses by using electricity produced elsewhere are avoided, and
  - a wasted surplus of renewable energy
  - using inefficient fossil fuels (through higher degree of utilization of renewable energy sources).

- **GAMES**

  www.green-datacenters.eu

  The GAMES project started out with the vision of a new generation of energy-efficient adaptive data centres in which energy efficiency is the primary issue to deal with, but also the quality of services delivered and IT resource utilisation and performance. This was done by directly combining and integrating the energy consumption measured at the three different levels of business/applications, IT components workload (processors, storage) and building in a real-time and rather fine granular monitoring framework. New metrics, Green Performance Indicators, aka GPI, were designed in order to grasp energy efficiency at all different levels. One main aspect is that the GAMES project built on aggregating several energy oriented indicators by assigning specific weights to them. The project combines metrics for facility resources, computing resources and application resources.

- **CoolEmAll**

  www.coolemall.eu

  The project CoolEmAll is developing a range of tools to enable data centre designers and operators to plan and run facilities more efficiently. These tools include blueprints of energy efficient IT hardware as well as a simulation, visualisation and decision support toolkit. Both of these tools especially focus on cooling models, application properties, and workload and resource management policies. Once developed, the tools should help to minimize the energy consumption of modular data centre environments. Additionally, CoolEmAll will contribute to existing energy-efficiency metrics and help define new metrics which will be used to evaluate the energy efficiency of the designed computing building blocks.

- **ECO2Clouds**

  www.ict-fire.eu/fileadmin/documents/call8_projects/FIRE_Call8_Projects.pdf

  ECO2Clouds will investigate strategies enabling an effective application deployment on cloud infrastructures and also reduce the resulting energy consumption and CO2 emissions. The project especially focuses on the case of applications spanning multiple clouds. The main goal of the project is the development of cloud API extensions to quantify the environmental impact on infrastructure and virtual machine level. Also, (multi-)cloud application deployment strategies will be optimized regarding their energy efficiency. Finally, the ECO2Clouds will evaluate the optimizations in the BonFIRE testbed.

5 iJOIN Reference Scenarios and Use Cases

5.1 Small Cell Definition

The word "small cell" can be used to name different kind of base stations, generally defined by their coverage distance, transmission power, and deployment location or purpose.

5.1.1 3GPP Definition

The 3GPP specifications [23] define three base station classes:

- *Wide Area Base Station*: equivalent to a Macrocell, no maximum output power defined;
- *Local Area Base Station*: equivalent to a Picocell, maximum output power of 24dBm (SISO);
- *Home Base Station*: equivalent to a Femtocell, maximum output power of 20dBm (SISO).

Within the 3GPP specifications, a small cell referred then to either a Picocell or a Femtocell. The growth in interest for heterogeneous networks has led the 3GPP to define the notion of "*low power node*" but only in their technical report [52]. These low power nodes can be seen as small cells as they encompass:

- *Radio Remote Head* (RRH): open to all UEs, placed indoor or outdoor;
- *Pico eNB* (Picocell for Hotzone): open to all UEs, placed indoor or outdoor (planned deployment);
- *HeNB* (Femtocell): open to set of selected UEs, placed indoor (consumer deployed)
- *Relay* nodes: open to all UEs, placed indoor or outdoor.

5.1.2 Small Cell Forum Definition

The Small Cell Forum (formerly known as the Femto Forum), an industry group devoted to the promotion of the small cells, defines on their website the small cell as "*low-power wireless access points that operate in licensed spectrum, are operator-managed and feature edge-based intelligence*" [53]. Under this term, small cells are classified to three categories as illustrated in Figure 5-1:

- *Femtocells*: for home deployment;
- *Picocells*: for enterprise deployment;
- *Metrocell* and *Microcell*: for urban and rural deployment.

Radio Remote Headers are implicitly excluded from this definition due to their lack of "intelligence".

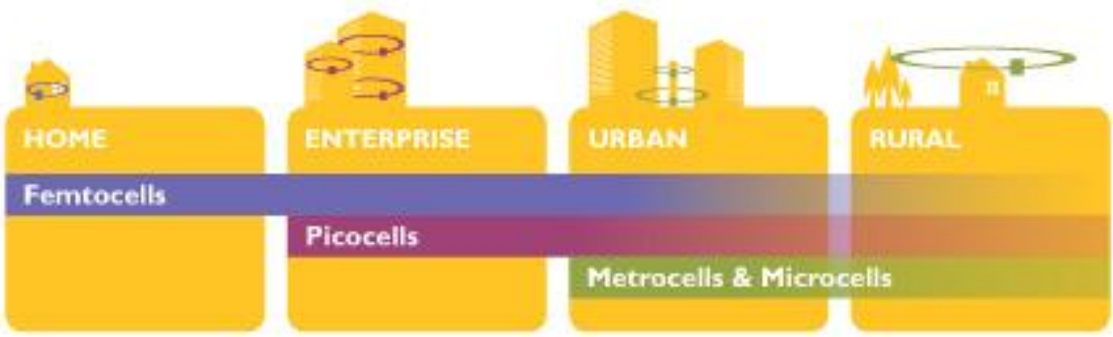


Figure 5-1: Small Cell Forum Definition [53]

5.1.3 iJOIN Definition

With such disparity in what lies behind the term "small cell", it is of a primary importance to define the "small cell" concept in iJOIN. To come up with a common understanding of the "small cell" concept through the life of the project, key requirements have been derived amongst partners.

For the iJOIN consortium:

- **Small cells** have to be in any case **operator controlled**, including their backhaul link;
- **Small cells** are intended mainly **for data** and deployed **for capacity**;
- **Small cells** can be deployed **outdoor** but also **indoor**.

Based on these requirements, a small cell in iJOIN is fully equivalent to a 3GPP picocell including the low power nodes such as relay and RRH. Femtocell could be part of the picture only if their backhaul is also controlled by the same operator enabling joint optimisation of both accesses (RAN and backhaul).

5.2 Deployment Considerations

5.2.1 iJOIN Scenario Overview

In the project, small cells will be mainly deployed with dense scenarios (see Appendix A). To stay within the scope of the project, investigations will target the use of the "RAN as a Service" (RANaaS**)** platform for RAN functional split and/or the joint optimisation of the RAN and the backhaul. This later aspect may also be encompassed in pure RANaaS investigations as the degree of RAN centralisation / functional split is highly dependent of the backhaul capability in addition to the cloud resource availability. Indeed, the backhaul link will be the physical media conveying the logical interfaces from a small cell toward the RANaaS platform.

After the process of iJOIN partners' inputs provided in Appendix A, four main scenarios have been defined as iJOIN Common Scenarios (CS).

1. Outdoor focus:
   - Dense Hotspot in a Stadium
   - Dense Hotpot in a Square
   - Wide-Area Continuous Coverage
2. Indoor focus:
   - Dense Hotspot in an Airport / Shopping Mall

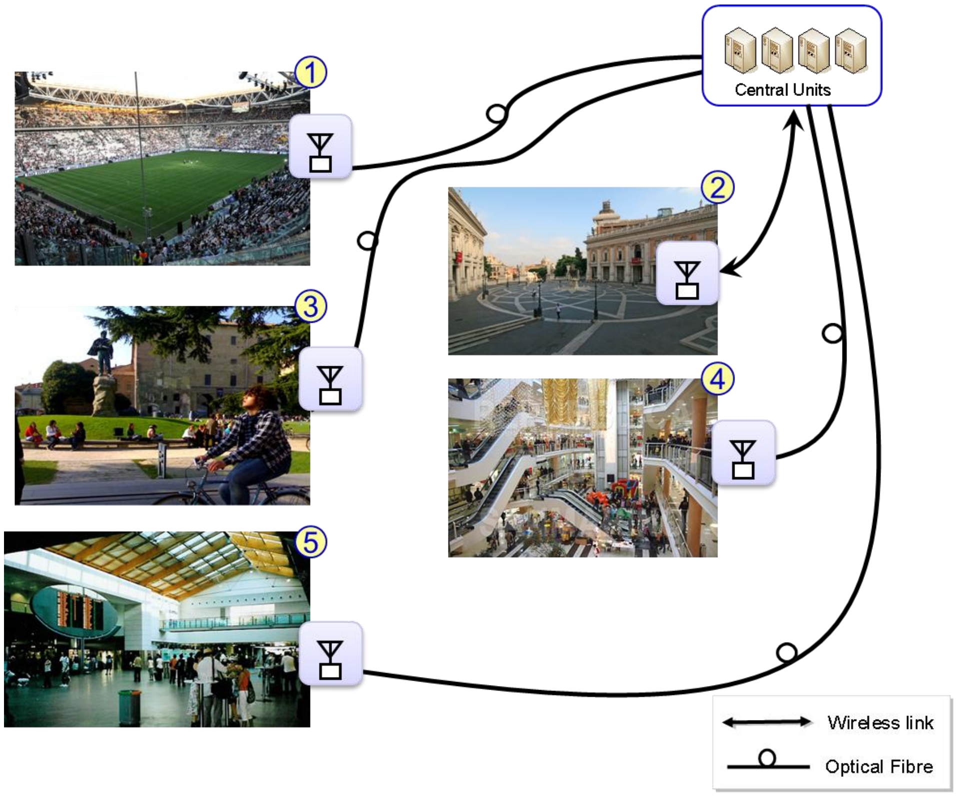


Figure 5-2: iJOIN Envisaged Use Cases (links to central units are given as an example)

A more detailed description for each CS can be found in section 5.3. The baseline assumption is low user mobility, i.e. about 3km/h, which reflects the fact that most small-cell may be deployed in densely populated areas with mainly pedestrian users (as depicted in Figure 5-2). However, it is also in scope of iJOIN to investigate users at medium speed of up to 50km/h as well as the impact of medium speed users on the performance of slowly moving users. It might be possible that hotspots are close to roads where users (voice and data) at medium velocity may create considerable interference.

5.2.2 Backhaul Considerations

The backhauling will be of primary importance since this link will limit the overall network capacity in case of densed small cell deployment. Indeed, more small cells means more capacity effectively provided at the radio access level only if the backhaul can cope with it. This is particularly true if the backhaul is shared between small cells. Therefore, a special attention should be given to a "joint" design between the access and the backhaul which should not compromise the overall QoS.

For the backhauling in a small cell deployment, there are mainly two cases:

- Direct connection of each small cell to the backhauling.
- Connection by means of a local concentrator with interface toward several small cells.

Backhauling technologies are mainly:

- Fibre based solutions: almost unlimited capacity but with high deployment costs.
- Wireless backhauling (e.g. 60 GHz link): usually used only in LOS conditions but with low costs. The limitation in link length may also be an issue
- Mixed fibre and copper connections: with lower bandwidth but also lower costs with regard to fibre-only solutions.

5.2.3 Cloud Architecture Considerations

The requirements of iJOIN in terms of guaranteed performance, network throughput and QoS can be managed only in a private cloud, where resource allocation is more deterministically controlled, users are limited in number and capabilities, and peaks of load can be managed in a more predictable way.

Moreover, the software that iJOIN plans to run in the cloud is not generally available "off-the-shelf" as in the typical public cloud provider service catalogue. In addition, the deployment and operation of this software need to be under strict control of the telco/service provider operators.

A current trend in telcos is to deploy OSS and some EPC components in IaaS private clouds. The challenge for iJOIN is to further extend the cloud boundary to selected E-UTRAN functionality.

5.3 iJOIN Common Scenarios Description

For each one of the main common scenarios, a more detailed description is given in the following subsections covering the type of deployment and services offered, with a basic set of assumptions, for instance, macrocell coverage, spectrum usage, user mobility and backhaul technology deployed.

5.3.1 CS1: Dense Hotspot in a Stadium

5.3.1.1 Use-Case Description

Synopsis: This scenario considers a stadium as in Figure 5-3, where tens of thousands of people gather to watch a special event (i.e. football match or a music concert). To capture and share these unique moments, the crowd will want to post videos and pictures in social networks like facebook and twitter) or to send instant messages through their smartphones. Therefore, a full featured communication network comprising a multitude of small cells is required at the stadium to support a complete range of broadband multimedia services.

Use case: The seats at the stadium are sold out for the football match and more than fifty thousands of people are awaiting the opening of the event. This football match is the final game between two of the most reputable football teams in Europe. The fans are excited about the atmosphere and start to take photos and videos from the stadium using their smartphones. Some unique moments will even trigger the desire of the fans to communicate to the outer world, i.e. when the team they support scores or as the last shot clinches victory for their team. These unique moments trigger similar reactions to the crowd, as they want to cheer, to embrace the people around them and post pictures, videos or comments to the internet through their smartphones. Even before the match has started, some fans, instead of waiting idly, spend their time on the Internet e.g. browsing the experts' view about the match or watching YouTube videos about previous encounters between the two teams.

Figure 5-3: The Stadium Use Case

The large number of mobile devices and the huge volumes of data traffic during the match are threatening to overload parts of the mobile network and can even lead to loss of connectivity thus reducing customer satisfaction. Being aware of the complaints that were reported by many customers during previous football matches, the network operator has already come up to a solution. The solution that the network operator considers is to install additional small cell base stations along the stadium to shrink cell sizes and thereby increase the network's capacity. The deployment of a multitude of small cells in the stadium seems an attractive solution to cope with the increasing capacity demands in such cases. However, this requires the deployment of an efficient backhaul network which can be complemented by a central entity that operates as an aggregation point between small cells and the core network. By this, users in different parts of the stadium can be served by different small cell base stations which are deployed arbitrarily throughout the stadium to increase the total capacity.

5.3.1.2 Use Case Mapping to Technical Realization

Deployment scenario	Type of deployment?	**Hotspot**
	Outdoor / Indoor?	**Outdoor**
	Small cell/user density?	**High cell and user densities**
	User mobility considered?	**No (possible nomadic in time, but at session granularity)**
	Planned or unplanned deployments?	**Planned**
	Overlapping small-cell coverage regions or rather well separated through natural shadowing?	**Overlapping small-cell coverage with macro layer**
	Operation on the same or orthogonal frequencies?	**Same frequency for all small cells, could be orthogonal to the macro layer**
	Local Breakout?	**Yes**

	Traffic?	**Bursty, web-browsing, non-buffered video streaming, real-time (possibly strongly correlated traffic (content and time).**
Het-Net	Macrocell considered?	**Yes**
	Macrocell/small-cell interaction envisaged?	**Yes**
Small cell	Picocell-like?	**Yes**
	Femtocell-like?	**No. Femtocells can be part of the baseline system.**
	Direct small cells connections considered (X2 or X2-like)?	**Yes**
	“Local” gateway/Backhaul node envisaged?	**Yes**
RAN	Frequency?	**2GHz, also 3.5 GHz**
	Bandwidth?	**10 MHz or more**
Backhauling	Specific backhaul?	**Wireless/Fiber**
	Heterogeneity of backhaul?	**Homogeneous but in an evolutionary approach could be Heterogeneous (along the years)**

5.3.1.3 Technical Challenges

The key technical challenges in such scenario are the following:

- **Inter-cell Interference**: The most significant factor in very dense deployments is the need to serve a large number of fans packed very close together. The large number of people and smartphones requires large number of small cells within the stadium. The dense small cell deployments in the stadium will provide critically increased levels of inter-cell interference since the scarcity and high cost of the spectrum resource can inevitably lead to intense spectrum reuse.
- **Backhaul Requirements**: In the dense small cell network which is located at the stadium backhaul network can be seen as a bottleneck that needs to be tackled. Here, one of the key challenges is the design of the backhaul network to cope with the increasing signalling overhead between small cells and the core network. For this scenario cost-efficiency is a very important factor for the operator due to the high installation and operation costs. In fact, for some reason, the backhauling technology considered in this scenario can be “all-wireless”, because, for example, the wireless infrastructure is added in a second moment w.r.t. the building of the stadium. In this case, traffic aggregation using multipoint microwave backhaul from multiple small cells towards the central entity should be further investigated as a potential solution to reduce transport and operation costs. On the other hand, also the “all-fiber” is a possible option (at least for the baseline), consisting in a wired infrastructure foreseen since the stadium design phase (in an evolutionary approach iJOIN can consider the addition of new small cells along the years, connected by wireless backhauling.
- **Providing minimum QoS to very high demand**: The dense small cell deployment in a stadium is implemented to meet the very high customer demands during the football match. Therefore, the operator’s major challenge is to ensure that all customers are going to experience seamless connectivity in terms of acceptable Quality of Experience (QoE) during the event.
- **Energy & Utilization Efficiency**: Small cell deployment in the stadium is dimensioned to deal with major entertainment events, which likely attract thousands of people and may generate data rate that are unaffordable for the macrocell. However, when the stadium is not overcrowded, load due to service requests may be extremely lower, and capacity at both the radio access and the backhaul network underutilised. Self-organising mechanisms should be integrated at the small cell network to configure transmission parameters and ISC activity according to the load variations. This approach

will enable to notably reduce the network energy consumption by dynamically matching available capacity and service request.

5.3.1.4 Candidate solutions and Architectural Considerations

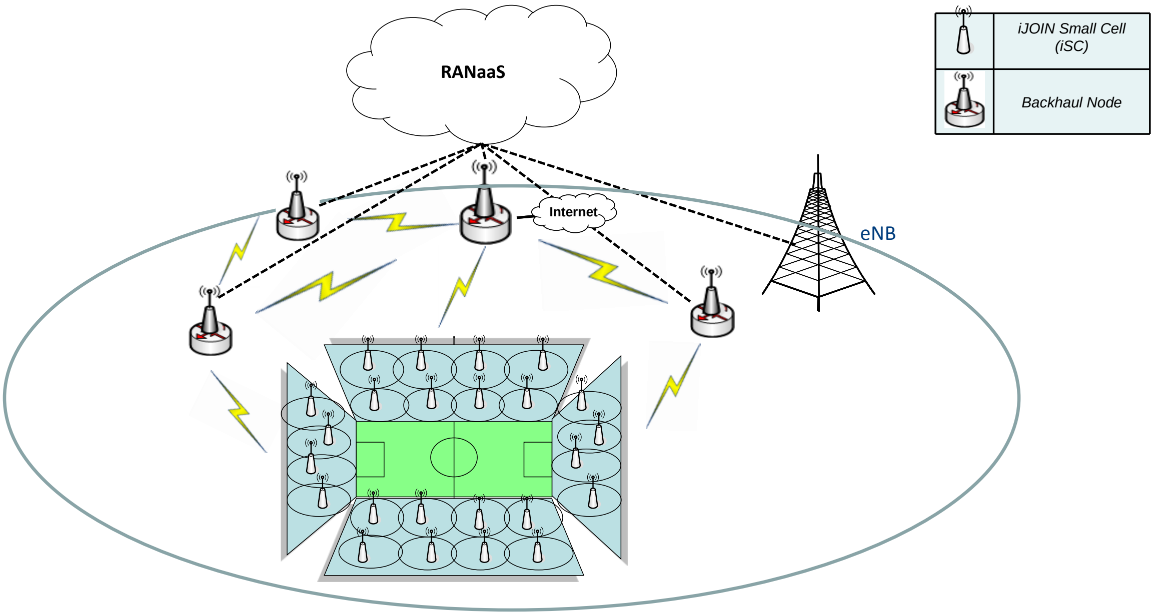


Figure 5-4: Dense Small Cell Deployment Example in a Stadium

These challenges need to be carefully considered by the operator to meet the customers' expectations. Therefore the following solutions can be provided together with the employment of a multitude of small cells as illustrated in Figure 5-4:

- The optional deployment of a local gateway (backhaul node) which covers the stadium area is required to control traffic and facilitate interference management.
- Centralized Inter Cell Interference Coordination (ICIC) should be applied to avoid inter-cell interference at the edges of each small cell. This can be done by dynamic resource partitioning between small cells (under the Backhaul Node coordination) to enhance spectral efficiency.
- Joint Routing and Scheduling should be performed at the backhaul node in both access and backhaul network to prioritize different traffic types, i.e. video streaming.

5.3.2 CS2: Dense Hotpot in a Square

5.3.2.1 Use-Case Description

Synopsis: This use case involves a square area which is visited every day by thousands people, as illustrated in Figure 5-4. The square encloses a mixture of dense outdoor and indoor environments, i.e. Coffee Shops, pubs, enterprise buildings, shops and recreation parks. Considering the variety of dense environments and the users' requirement for multimedia broadband services, the massive deployment of small cells is necessitated to provide a uniform broadband experience to the users.

Use case: Almost every city has some squares which can serve an important purpose as a social and commercial meeting place. A square is usually surrounded by shops, restaurants, and a city hall. For this dense area, the mobile network operator has decided to upgrade the mobile network to enhance the broadband services to the customers within the square using dense small cell deployments. In this use case, the following dense deployments can be considered:

- Outdoor network of small cells covering the square, in order to serve the high number of users who use their smart-phones while relaxing, waiting or traversing this square.
- Indoor network of small cells to serve enterprise (offices, town-hall) or domestic environments (apartments) which are located at the edges of the square.

- Indoor/Outdoor small cells to provide broadband services to the recreation facilities offered in the area surrounding the square (i.e. coffee shops, restaurants, shops, recreation parks).

Figure 5-5: Square Use Case

Therefore, the square and the surrounding buildings can be seen as a general case which encapsulates a set of domestic, enterprise and public access outdoor and indoor environments. In this use case, the small size of cells is going to provide better coverage and capacity. However, some challenges on inter-cell interference and the user mobility need to be taken care of.

5.3.2.2 Use Case Mapping to Technical Realization

Deployment scenario	Type of deployment?	**Hotspot**
	Outdoor / Indoor?	**Outdoor / Indoor**
	Small cell/user density?	**High cell density and medium-to-high user density**
	User mobility considered?	**Yes (medium)**
	Planned or unplanned deployments?	**Planned**
	Overlapping small-cell coverage regions or rather well separated through natural shadowing?	**Overlapping small-cell coverage with macro layer**
	Operation on the same or orthogonal frequencies?	**Same frequency for all small cells, could be orthogonal to the macro layer**
	Local Breakout?	
	Traffic?	**Full buffer, Real time**
Het-Net	Macrocell considered?	**Yes**
	Macrocell/small-cell interaction envisaged?	**Yes**
Small cell	Picocell-like?	**Yes**
	Femtocell-like?	**No. Femtocells can be part of the baseline system.**
	Direct small cells connections considered (X2 or X2-like)?	**Yes**
	“Local” gateway/backhaul node envisaged?	**Yes**

RAN	Frequency?	**2GHz, also 3.5 GHz**
	Bandwidth?	**10 MHz or more**
Backhauling	Specific backhaul?	**Wireless/Fiber**
	Heterogeneity of backhaul?	**Homogeneous but in an evolutionary approach could be Heterogeneous (along the years)**

5.3.2.3 Technical Challenges

The deployment of numerous small cells in a square is going to place some challenges regarding the interference, energy efficiency and mobility management. These challenges can be summarized as follows:

- **Inter-cell Interference Management**: One key challenge is the inter-cell interference which is created by the surrounding small cells and can significantly affect the user's performance. Due to the high density and the small size of cells, dynamic interference management is required in order to achieve high spectral efficiency in such networks.
- **Mobility Management**: Another key challenge that can also impact the ICI management concerns user's mobility in the square network. Small cells, due to their small coverage and the dense deployment, might experience frequent users' handovers from/to neighbouring small cells. Therefore, mobility management, in terms of handover and location management, is required to provide seamless connectivity to users all over the square network. Cell selection is also a relevant challenge, as many potential candidates might be visible by a terminal, and not all of them can provide the same QoE.
- **Energy & Utilization Efficiency**: Small cell deployment is dimensioned to deal with peak load requirements for both indoor and outdoor users. However, service request profile in the square is generally characterized by regular variations with low load periods early in the morning, medium loads mainly generated from indoor users during work-time, and higher loads in the evening when people enjoy recreation facilities nearby the square or relax at home. Whenever, the network operates under peak-load its resources are under-utilised, which turns in poor energy efficiency. To avoid excessive energy wastage, flexible mechanisms should be integrated in the candidate small cell architecture that dynamically adapts transmission parameters and ISC activity with respect to service requests.

5.3.2.4 Candidate solutions and Architectural Considerations

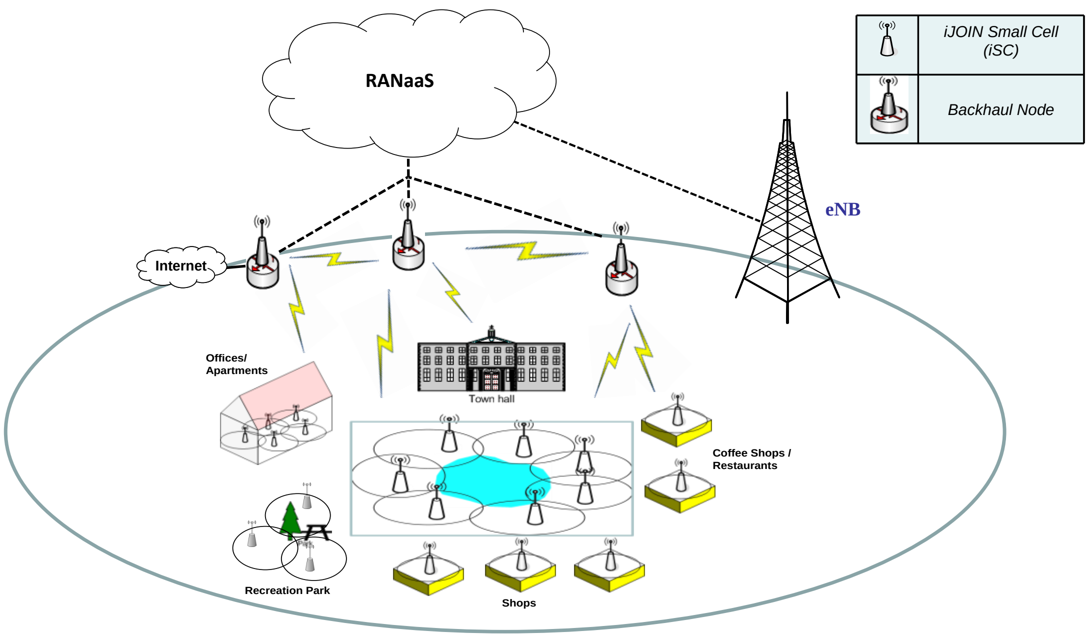


Figure 5-6: Dense Small Cell Deployment Example in a Square

The aforementioned challenges necessitate the employment of the following candidate solutions together with the employment of a multitude of small cells as can be seen in Figure 5-6:

- The optional deployment of backhaul nodes for clusters of small cells can be defined to provide locally centralized control for dense scenarios.
- The design of dynamic Interference Management mechanisms in terms of Interference Coordination and/or Cooperation between small cells is required to mitigate ICI and enhance spectral efficiency throughout the network. Here the optional deployment of the Backhaul Node for clusters of small cells could serve as a centralized coordinator to facilitate this process.
- User mobility management mechanisms should be applied to ensure fast and lossless handovers between small cells or small-cell clusters. In this context, intelligent mechanisms should be designed to support the cell switch of mobile users in connected mode with on-going sessions during their movement (handover management) and track the locations of the mobile users in idle mode to facilitate the fast incoming service delivery (location management).
- Joint Routing and Scheduling should be performed in both access and backhaul network taking into account the resource utilization and load balancing between small cells.

5.3.3 CS3: Wide-area continuous coverage

5.3.3.1 Use-Case Description

Synopsis: The objective of this use case is to evaluate the impact of the deployment of a small cell layer designed for coverage, rather than attending traffic hotspots (i.e., locating the small cells in areas where the traffic demand is very high). The purpose of the layer would be to provide as far as possible homogeneous small cell layer coverage for a range of services in an area of several square kilometres.

The reasons for studying this scenario are:

- Hotspots are not easy to locate, because of their change in time and space, and moreover an area may become hotspot only after data coverage has been established. Hence, there may be hotspots which are not obvious (cafes, squares, etc) but rather appear randomly.
- Small cell layer is expected to be used also to improve indoor coverage, complementing the macro-cell layer, e.g., in lower floors.
- Due to high demand (or any other reason, like lack of spectrum), it may be the best option for the operator to deploy the small cell layer as an alternative to the macro-cell layer.
- It may be easier to negotiate global arrangements with city councils or other providers of the small cell deployment infrastructure. The model of growing as required, used for macro-cells, may not be adequate for small cells.

Use case: The idea is to focus on a model representing a city-centre with high user density as in Figure 5-7 (4000 users in active state per square kilometre during the busy hour, 20% of them sending or receiving information in an active way – background traffic, like notifications from applications are not considered)[6]. 60% of traffic is originated indoors, the rest outdoors. Propagation conditions would be characterized as dense urban. Ideally, it should be possible to distinguish between areas with different average buildings density, street width, building height, etc.

Users can be divided into two groups and several subgroups:

1. Indoor users (static/low mobility users).
2. Outdoor users, with different mobility levels:
   - Low mobility (pedestrian users)
   - Medium/high mobility (vehicular users)

[6] These data are based on actual (obfuscated) activity statistics of Telefónica’s network and are proposed only as an example.

- Mix of both: in city-centre areas it is common to have both kinds of outdoor users. The percentage of mix depends on the particular case considered.

Figure 5-7: Macrocell and Several Outdoor Micros in Madrid City Centre

Indoor users are expected to require higher bandwidth services and applications like video services, whilst outdoor users will use lower bandwidth applications like voice, navigation, etc. Moreover, low mobility outdoor users have a longer permanence in the cells compared to medium/mobility outdoor users, which are characterized by a higher handover rate implicating a single data session spanning over different small cells.

Small cells are operator-deployed, are connected through operator-controlled backhaul and will support open access only.

The proposed use case needs to consider a number of trade-offs. For example, low power small cells may help to provide more homogeneous coverage, but they would require a higher capillarity backhaul network and would be prone to interference issues with the macro-cell layer. On the other hand, significant overlapping between small cells coverage area may facilitate the mobility, but at the expense of reduced overall capacity. Finally, there is a trade-off with respect to expenditures, i.e. deployment costs for small-cell in comparison to higher costs for spectrum required by macro-cells. Also, the utilization of small-cells may vary and may be non-homogeneous which should be considered for the evaluation and design of approaches.

5.3.3.2 Use Case Mapping to Technical Realization

Deployment scenario	Type of deployment?	**Wide area continuous coverage**
	Outdoor / Indoor?	**Cells deployed only outdoors, coverage provided both indoors and outdoors.**
	Small cell/user density?	**Between 5 and 15 small cells per square kilometre;**
	User mobility considered?	**Yes**
	Focus on control / user plane?	**Both**
	Planned or unplanned deployments?	**Planned**

	Overlapping small-cell coverage regions or rather well separated through natural shadowing?	**Overlapping regions between small cells, overlapping also with macro-cells**
	Operation on the same or orthogonal frequencies?	**Same frequency**
	Local Breakout?	
	Traffic?	**Bursty, web-browsing, non-buffered video streaming for indoors; bursty traffic and interactive traffic for outdoors.**
Het-Net	Macrocell considered?	**Yes**
	Macrocell/small-cell interaction envisaged?	**Yes**
Small cell	Picocell-like?	**Yes**
	Femtocell-like?	**No**
	Direct small cells connections considered (X2 or X2-like)?	**Yes**
	“Local” gateway/concentrator envisaged?	**Yes**
RAN	Frequency?	**2.6 GHz/800 MHz**
	Bandwidth?	**10 MHz or more**
Backhauling	Specific backhaul?	**Yes**
	Heterogeneity of backhaul?	**Yes**

5.3.3.3 Technical Challenges

The key technical challenges in such scenario are listed as follows:

- **Coexistence with macro-cell layer**. Mechanisms in order to ensure ‘peaceful’ coexistence between macro-cell layer and small cell layer can range from deployment limitations (e.g., minimum distance between the macro-cell and the small cell) to the implementation of eICIC mechanisms.
- **Coexistence with small cell hotspots**.
- **Growth model**. How the network should evolve in order to accommodate new small cells.
- **Small cell layer optimal density**. Depending on a number of factors (antenna height, transmission power, orography, etc.), the maximum number of small cells that can be deployed before incurring in significant intra-layer interference will be different.
- **Mobility estimation**. For a smoother user experience, it would be convenient to assign high mobility users to the macro-cell layer. Rescue mechanisms should also be supported. The interference caused by medium mobility users on low-mobility users may impose a problem for the coordination efforts.
- **Load balancing**, taking into account not only radio capacity issues but also the capacity of the backhaul network.
- **Backhaul provision** over a non-homogenous infrastructure and different operational models (network sharing, backhaul as a service, etc.).
- **Network sharing issues**. Sharing infrastructures for small cells deployments by operators may be either the result of CAPEX/OPEX reduction efforts or the imposition of the infrastructure owners.
- **Utilization & Energy efficiency** with respect to capacity and computational resources; existing resources should be efficiently used, particularly if hotspots are time-variant and spatial variant.

5.3.3.4 Candidate solutions and Architectural Considerations

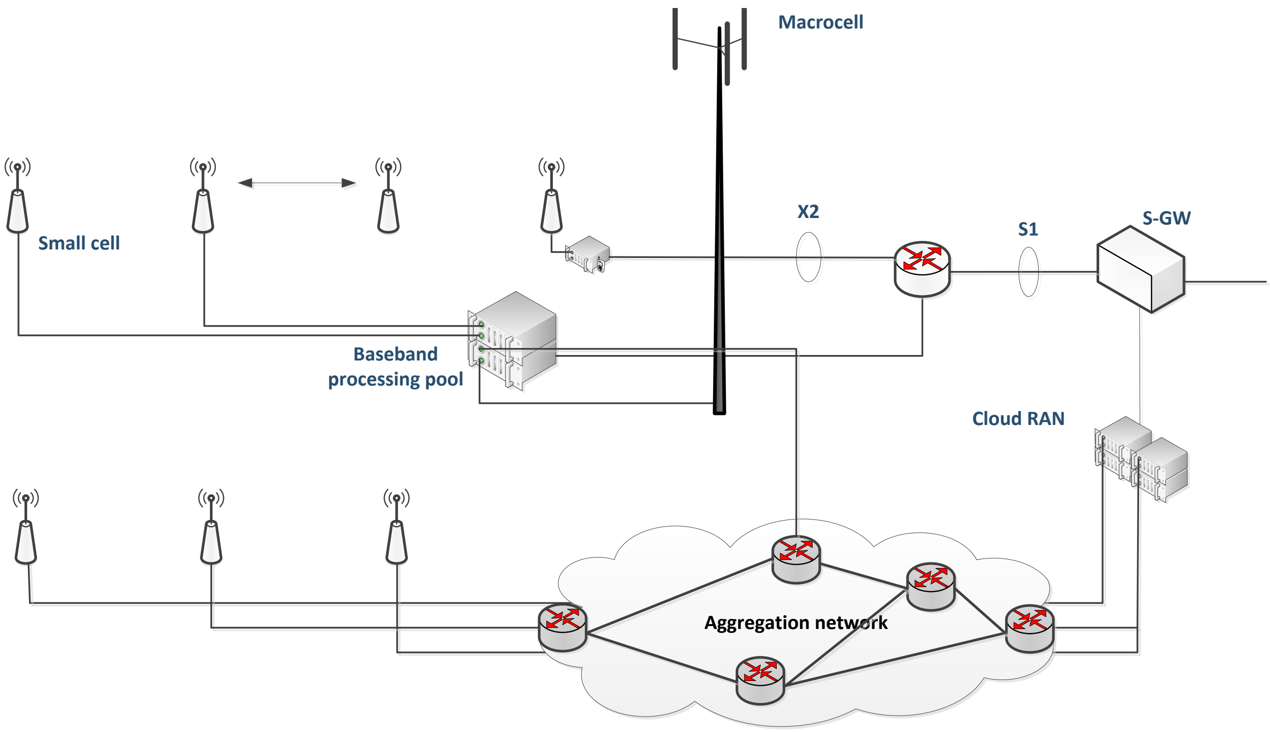


Figure 5-8: Wide Area Continuous Coverage Deployment Example

These challenges need to be carefully considered by the operator to meet the customers' expectations. Therefore the following solutions can be provided:

- Enhanced inter-layer coordination mechanisms, based in centralized processing of cells, for both macro and small cells. These coordination mechanisms need to be robust with regard to backhaul load, channel coherence, latency, and scalable in number of users and cells, and efficient. It must be shown that each invested coordination bit also implies a certain gain in capacity in order to avoid "useless efforts".
- Convergent fixed/mobile backhaul provision. Reusing, e.g., the fixed access network optical infrastructure may help to reduce costs. In an evolutionary approach, wireless backhauling provisioning can be considered in addition to existing fixed backhauling infrastructure.
- Enhanced mobility mechanisms in order to handle small cell layer mobility (e.g. forward handover) with excellent performances.
- SDN based backhaul network control that may allow for the support of different transport and security mechanisms based on, e.g., whether the backhaul is trusted or not.
- Traffic engineering for backhaul network exploiting a time-variant and non-homogeneous nature of the small-cell layer.
- Off-loading towards other radio access technologies, like Wi-Fi, or directly to Internet (LIPA, SIPTO).

5.3.4 CS4: Dense Hotspot in an Airport / Shopping Mall

5.3.4.1 Use-Case Description

Synopsis: Most of the traffic nowadays is originated indoor with a demand in capacity growing exponentially. If sub-gigahertz technologies provide efficient indoor coverage, they also come with a limited spectrum by nature which restricts the available capacity. Going with 2GHz (and above) carriers allows more spectrum to be used but at the cost of a stronger propagation loss leading to poor indoor coverage situations. Deployment of indoor small-cells is an efficient solution to benefit from higher spectrum availability and favourable propagation environment (no indoor loss), by reducing the gap between the entry point to contents and services (base station) and the consumer (user equipment). The objective of this use case is to evaluate the benefit of the RANaaS concept in hotspot-based dense small cell deployment. Indoor environment such as airport or shopping mall presents more identifiable hot-spot positions (e.g. in one shop, boarding room).

Use case: Waiting for their plane to take-off, users usually browse their smartphone/tablet/PC for traditional everyday usage (web browsing, video streaming …) in the waiting/boarding room leading to a high density of traffic demand in a concentrated area. In modern airports as shown in Figure 5-9, those "rooms" are often aligned in big open space leading to a natural dense small-cell deployment to cover all of them.

Similar use case with high user and small cell density can also be found in shopping mall environment as shown in Figure 5-10, where small cells can be deployed either by the shopping mall owner in a planned manner or by each shop to provide additional services to the customers in an unplanned manner.

Figure 5-9: Airport Use Case

Compared to the airport use case, mobility can be considered as well as additional traffic profiles relative to shopping, e.g., high number of price comparison/product detailed requests (short message, low latency appreciated), picture/video of a product send to friend/family for purchase advice (long message) ...

Figure 5-10: Shopping Mall Use Case

For both scenarios, macrocell coverage can be assumed but the main investigations will be on small-cell/small-cell interactions.

5.3.4.2 Use Case Mapping to Technical Realization

Deployment scenario	Type of deployment?	**Hotspot**
	Outdoor / Indoor?	**Indoor**
	Small cell/user density?	**TBD: Up to 8 small cells per floor. Floor could be 20x100m-(3GPP Dual-Stripes) 45x120m (ITU-R InH)**
	User mobility considered?	**Optional (slow user mobility by nature)**
	Focus on control / user plane?	**Both**
	Planned or unplanned deployments?	**Both**
	Overlapping small-cell coverage regions or rather well separated through natural shadowing?	**Overlapping regions between small cells, overlapping also with macro-cells**
	Operation on the same or orthogonal frequencies?	**Same frequency**
	Local Breakout?	**Yes**
	Traffic?	**High variety of traffic (video, web browsing …)**
Het-Net	Macrocell considered?	**Optional**
	Macrocell/small-cell interaction envisaged?	**Optional**
Small cell	Picocell-like?	**Yes**
	Femtocell-like?	**No (Optional)**
	Direct small cells connections considered (X2 or X2-like)?	**Yes**
	“Local” gateway/concentrator envisaged?	**Yes**
RAN	Frequency?	**2GHz – 3.5GHz**
	Bandwidth?	**10 MHz or more**
Backhauling	Specific backhaul?	**Wireless/Fiber**
	Heterogeneity of backhaul?	**Yes**

5.3.4.3 Technical Challenges

The key technical challenges in such scenario are the following:

- **Small-Cell coexistence**. Small cells deployed in a dense fashion will lead to the introduction of intelligent interference management mechanisms to increase the user/area throughput.
- **High QoS for a high QoE.** Particularly true for shopping mall scenario where response to short request should have a very low latency.
- **Load balancing.** Between small cells, taking into account not only radio capacity and traffic demand, but also the capacity/congestion of the backhaul network.
- **Backhaul deployment.** Fiber and wireless based backhaul could be jointly deployed.

5.3.4.4 Candidate solutions and Architectural Considerations

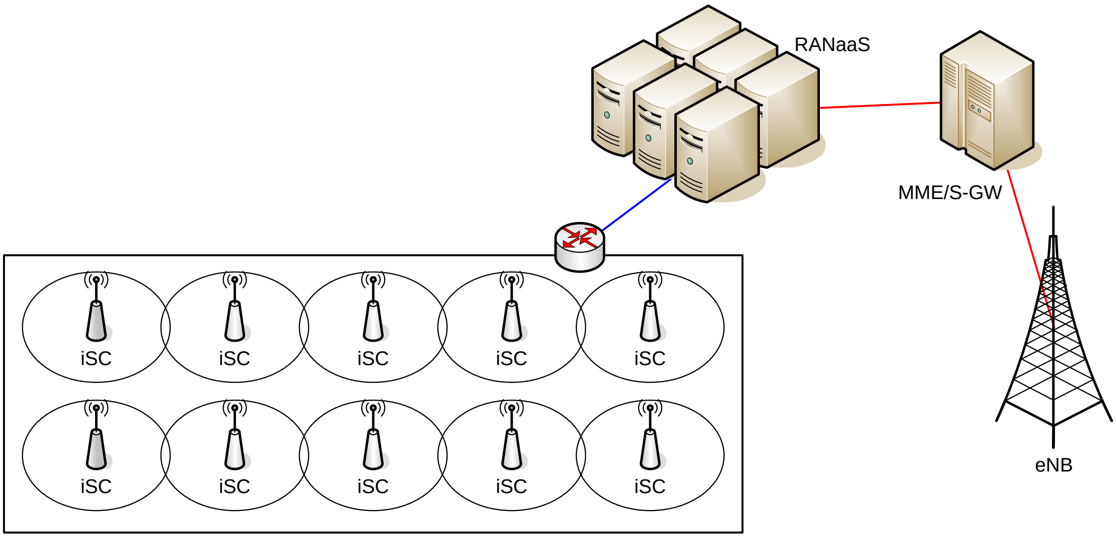


Figure 5-11: Dense Small Cell Indoor Deployment Example

The presence of a gateway concentrating the backhaul links toward the core network and also offering the ability to dissect the traffic and maybe offering centralised functionality for the RAN part, should be envisaged. This gateway could be either physically deployed in the indoor environment or virtually deployed in the RANaaS platform.

6 Preliminary Considerations on System Requirements

One of the key ideas of iJOIN is to centralise some functionalities usually processed in an eNB in the RANaaS platform. Compared to the Cloud-RAN approach, this split can be done at various layers in the OSI model and not only after the RF front-end. A first evaluation of the potential centralisation benefit is given for each RAN functionality which is usually performed at the eNB. Preliminary latency/bandwidth/computation requirements are also derived to facilitate the evaluation of the requirements needed over the backhaul in case of centralisation.

In order to derive a coherent architecture, WP2, WP3 and WP4 have also gathered and provided a consolidated set of assumptions and requirements dealing with the specific Candidate Technologies (CTs) the WP is handling. Such consolidated view is used to derive a preliminary draft logical architecture extending the 3GPP LTE one where key nodes are presented.

6.1 RAN Functional Split

Table 6-1 provides an overview of the considered functionality which may be centralized in the RANaaS platform. A more detailed description of the individual functionality is given in the respective IRX.1 documents. The table details the following properties for each functionality:

- **Computational needs**: defines whether the RAN functionality is computational intense or not. This is done using the O(X) notation which defines the growth rate of the computational complexity and identify in which parameters the computational needs scale.
- **Centralization benefits**: defines whether the RAN functionality provides gains if it is centralized or not. Note that in WP2/WP3, centralization usually applies to pushing some PHY/MAC functionality that is currently implemented in the protocol stack of the radio access network equipment (the eNB) towards the RANaaS platform, while in WP4 it usually refers to centralization of network management functionalities at higher levels of the protocol stack, and often applied to the control plane.
- **Computational diversity** specifies whether the complexity of a functionality may be time-variant (or varies with another parameter such as number of users, CSI …). In this case, it may be possible to exploit this diversity to load balance computational needs in the RANaaS entity.
- **Latency requirement** on interfaces specifies the latency requirements on the interfaces between the functionality and those functionalities that either deliver or receive data to/from the functionality.
- **Bandwidth requirement** on interfaces specifies the bandwidth requirements on the interfaces between the functionality and those functionalities that either deliver or receive data to/from the functionality.

Furthermore, the individual WPX will describe in DX.1 how the proposed CTs make use of the described functional split, i.e. whether a technology may be partly centralized. In addition, the impact of a shift of functionality towards the RANaaS entity will be investigated, e.g. required context transfer and whether the shift can be seamless.

Table 6-1: RAN Functional Split

Functionality	WP scope	Computational Needs	Centralization Costs/Impact	Centralization Benefit	Computational Diversity	Latency requirement on interface	Bandwidth requirement on interface
Backhaul routing (path management & topology control)	WP4	O(#backhaul links), O(#flows)	Moderate cost to implement centralization. High gains due to centralization. Changes apply on long-term scale	Global view of the RAN and BH allows for optimal routing and congestion avoidance.	Varies according to #backhaul links and #flows; Offline and online component	Depends on time scale of Traffic Engineering action. From Low to middle latency	Low to Medium (if high frequency of measurement reports)
Admission control	WP4	O(#backhaul links)	Moderate cost to implement centralization. High gains due to centralization	Global view of the network enables optimal routing decisions	Varies according to #backhaul links	Medium	Low/Medium
Congestion control	WP4	O(#backhaul links)	Moderate cost to implement centralization. High gains due to centralization	Global view of the network enables optimal routing decisions	Varies according to #backhaul links	Medium	Low/Medium
Mobility control (network)	WP4	O(#prefixes) O(#backhaul nodes)	Low cost to implement centralization. High gains due to centralization	Global view of the network enables optimal actions	Follows #prefixes #backhaul nodes	Low	Low
Mobility control (access)	WP4	O(#backhaul links), O(#flows)	Moderate cost to implement centralization. High gains due to centralization	Global view of the network enables optimal actions	Varies according to #attachment points and #flows	Depends on speed of the user terminal and size of the cell. From low to middle latency	Low

Network-wide Energy Optimization	WP4	O(#backhaul nodes)	Moderate cost to implement centralization. High gains due to centralization	Global view of the network enables optimal actions	Varies according to #backhaul nodes	Medium	Low/Medium
Split U-plane/ C-plane	WP3	O(#cells)	High (impact on eNB architecture)	High (e.g. central RRM)	TBD	High (if following frame creation)	Medium/high (control plane/ol option)
Cell selection	WP3	O(#UE)	Low	Low		Medium	Medium (control plane)
Ciphering/security	WP3	O(#bearers)	Medium	Medium (no need for additional security)	follows #bearers	Low	BW on PDCP layer
Quality of service management	WP3	O(#bearers)	Medium	High	follows #bearers	Medium (mostly applied to RT)	Medium
RRC connection handling	WP3	O(#bearers)	Low	medium	follows #bearers	Medium (RB control)	Low (control msg)
RoHC	WP3	O(#UE, #BS)	Low	Medium	Low-medium	Medium (during HO)	Low
In-sequence and duplication detection	WP3	O(#bearers)	Medium	Medium	follows #active QCI=1 bearers	Medium (mostly applied to RT)	BW on PDCP layer
ARQ	WP3	O(#buffer size)	Low	Low	-	Low	Low
Segmentation, Reassembly, … of SDUs	WP3	O(#retransmissions)	Low	Medium	depends on CQ	Medium	Medium
(QoS) Scheduling	WP3	O(#bearers)	Low	Low	follows #bearers	Low	BW on the RLC layer

Inter-cell RRM	WP3	O(network load)	High	High	High	High (TTI)	High
FFT / IFFT and up (cloud RAN): DL (CoMP using virtual MIMO)	WP2	O(#UE), O(#antennas) channel variation mechanism also important.	Very High	High but impossible to realize.	no	Low	High
All above FFT / IFFT (FD compression)	WP2	O(#PRB)	Medium	medium (enables “per user” operations)	With #users	Low	Reduced compared to cloud RAN
Detection & Decoding: UL	WP2	Detection: O(#transmit antenna) Decoding O(#code block)	High	High	Yes	Low (<4ms)	High (raw symbols)
Encoding & Modulation: DL (CoMP)	WP2	O(#users, CSIT)	High to Medium	High to Medium	With # of Users, nature of CSIT	Very Low	High to Medium

6.2 Preliminary Assumptions and Requirements

Each WP (2/3/4) investigates in the project numerous Candidate Technologies (CTs) targeted to a restricted set of layers which are all interconnected to each other. WP2 deals with physical CTs; WP3 addresses MAC/RRM CTs, while WP4 handles network management CTs.

These CTs are built around at least one of the two main pillars of iJOIN, namely the RANaaS concept and the joint RAN/backhaul optimisation. They have assumptions and requirements which will impact the iJOIN architecture. As an evolution of the 3GPP architecture, new entities and associated interfaces will be introduced.

6.2.1 Candidate Technologies

The three following tables regroup the CTs investigated within WP2, WP3 and WP4 with an emphasis on the **primary** (but not necessarily only) iJOIN concept targeted. More details on one CT can be found in its dedicated WP internal report. Some CTs are primarily relying on the cloud computing RANaaS platform to perform a functional split of a RAN feature, made possible only if the backhaul supports it, while other CTs target first a joint RAN/backhaul design, some even introducing "local" gateways or controllers possibly connected to the RANaaS platform.

Table 6-2: WP2 Candidate Technologies

CT	Title	Primary iJOIN Concept [RANaaS - joint RAN/BH design]
CT2.1	In-network processing	RANaaS
CT2.2	Multipoint turbo detection	RANaaS
CT2.3	Joint network-channel coding	joint RAN/BH design
CT2.4	Sum-Rate and Energy-Efficiency metrics of DL COMP with backhaul constraints	RANaaS
CT2.5	Cloud Based Joint-Processing and Partially Centralized Inter-Cell Interference Cancellation	RANaaS
CT2.6	Data compression over RoF	RANaaS joint RAN/BH design
CT2.7	60GHz backhauling	RANaaS joint RAN/BH design

Table 6-3: WP3 Candidate Technologies

CT	Title	Primary iJOIN concept [RANaaS - joint RAN/BH design]
CT3.1	Backhaul Link Scheduling and QoS-aware Flow Forwarding	joint RAN/BH design
CT3.2	Partly decentralized mechanisms for joint RAN and backhaul optimization in dense small cell deployments	joint RAN/BH design

CT3.3	Energy-efficient MAC/RRM at access and backhaul	joint RAN/BH design
CT3.4	Computation complexity and semi-deterministic scheduling	RANaaS joint RAN/BH design
CT3.5	Cooperative RRM for inter-cell interference coordination in RANaaS	RANaaS
CT3.6	Assess and increase utilization and energy efficiency	RANaaS joint RAN/BH design
CT3.7	Radio Resource Management for Scalable Multi-Point Turbo Detection	RANaaS
CT3.8	In-Network-Processing for RX cooperation	RANaaS
CT3.9	Rate adaptive strategies for Optimized Uplink Transmissions	RANaaS joint RAN/BH design

Table 6-4: WP4 Candidate Technologies

CT	Title	Primary iJOIN concept [RANaaS - joint RAN/BH design]
CT4.1	Distributed IP anchoring and Mobility Management	joint RAN/BH design (assume iJOIN Network Controller)
CT4.2	Network Wide Energy Optimization	joint RAN/BH design (assume iJOIN Network Controller)
CT4.3	Joint Path Management and Topology Control	joint RAN/BH design (assume iJOIN Network Controller)
CT4.4	Routing and Congestion Control Mechanisms	joint RAN/BH design (assume iJOIN Network Controller)
CT4.5	Network Wide Scheduling and Load Balancing	joint RAN/BH design (assume iJOIN Network Controller)
CT4.6	Backhaul Analysis based on Viable Metrics and "Cost" Functions using Stochastic Geometry	joint RAN/BH design
CT4.7	Use of Software Defined Networking in the iJOIN Network	joint RAN/BH design (assume iJOIN Network Controller)

6.2.2 Consolidated Assumptions

The following tables present the list of assumptions gathered from each CT and consolidated at the WP level. The general set of assumptions common to more than one WP is first presented in Table 6-5 and then the set of assumptions specific to each WP is provided in Table 6-6 to Table 6-8 for WP2 to WP4, respectively. As a consequence, one CT will assume a subset of the general list of assumptions and a subset of its WP-specific list.

Table 6-5: Architectural and Technology Deployment Common Assumptions

Assumption	Description
A.1	Large number of iSCs in local area
A.2	Availability of macro BS in same frequency band (co-channel deployment)
A.3	Availability of macro BS in different frequency band
A.4	J1 interface between all iSCs and RANaaS with known parameters
A.5	J1 interface between some iSCs and RANaaS with known parameters
A.6	J2 interface for interconnections of all iSCs
A.7	J2 interface for interconnections of some iSCs (direct neighbours, selection)
A.8	Wired inter-node links between iSCs (fibre)
A.9	Wireless inter-node links between iSCs (60GHz)
A.10	Wired connection of iSCs to RANaaS (fibre)
A.11	Wireless connection of iSCs to RANaaS (60GHz)
A.12	Availability of a logical network controller (iNC) for the joint RAN/BH optimization

Table 6-6: WP2 Implementation Assumptions

Assumption	Description
A.2.1	Global TxCSI at RANaaS
A.2.2	Local TxCSI at iSCs
A.2.3	Global RxCSI at RANaaS
A.2.4	Local RxCSI at iSCs
A.2.5	Global RxCSI at iSCs
A.2.6	LTE Modulation & Coding Schemes
A.2.7	Gaussian Input Signals
A.2.8	Perfect Channel Codes (infinite length)
A.2.9	Adaptive Coding and Modulation
A.2.10	Uplink Transmission
A.2.11	Downlink Transmission
A.2.12	FDD / TDD
A.2.13	Multiple Tx/Rx antennas in iSC

Table 6-7: WP3 Implementation Assumptions

Assumption	Description
A.3.1	Traffic bottleneck due to limited backhaul capacity
A.3.2	Traffic bottleneck due to limited cell capacity
A.3.3	FDD based small cells for channel feedbacks and data transmission
A.3.4	Protocol to transport scheduling/channel information between small cells and cloud
A.3.5	Logical interface between small cell eNB - iNC
A.3.6	Flexible RANaaS implementation
A.3.7	Dynamic capacity shifting in backhaul
A.3.8	Dynamic and fine granular resource allocation in the RANaaS platform
A.3.9	If a local gateway (i.e. the iLGW) is deployed, link between the gateway and the small cells should be high speed / low latency

Table 6-8: WP4 Implementation Assumptions

Assumption	Description
A.4.1	The leftover capacity in the current backhaul infrastructure used for the macro-network is reused to backhaul small cells
A.4.2	Heterogeneous backhaul (fibre and heterogeneous wireless)
A.4.3	The backhaul is a multi-hop IP network
A.4.4	Some nodes in the radio access network or in the backhaul might have local IP connectivity
A.4.5	Nodes providing local breakout have control interfaces with the mobility entities in the core
A.4.7	Small-cells are connected to the cloud through Backhaul Nodes (BNs)
A.4.8	Path diversity within the backhaul network
A.4.9	Reusability of existing backhaul technology

Based on these lists, the preliminary iJOIN architecture can be derived, while the specific requirement will be investigated/derived based on this architecture.

6.3 Preliminary Architecture Considerations

Starting from a 3GPP-compliant baseline system, iJOIN project will introduce new functionalities in the mobile network architecture, by exploiting the two technology enablers (RANaaS introduction and the joint RAN/BH design). The resulting system will have a potential impact on the 3GPP LTE RAN implementation.

6.3.1 iJOIN Baseline System

The iJOIN baseline system is based on Rel.10 3GPP LTE specifications, and it represents the starting point for performance comparisons, potentially used by all CTs as a reference for gains calculations during the lifetime of the project. The logical architecture of the iJOIN baseline system is depicted in Figure 6-1.

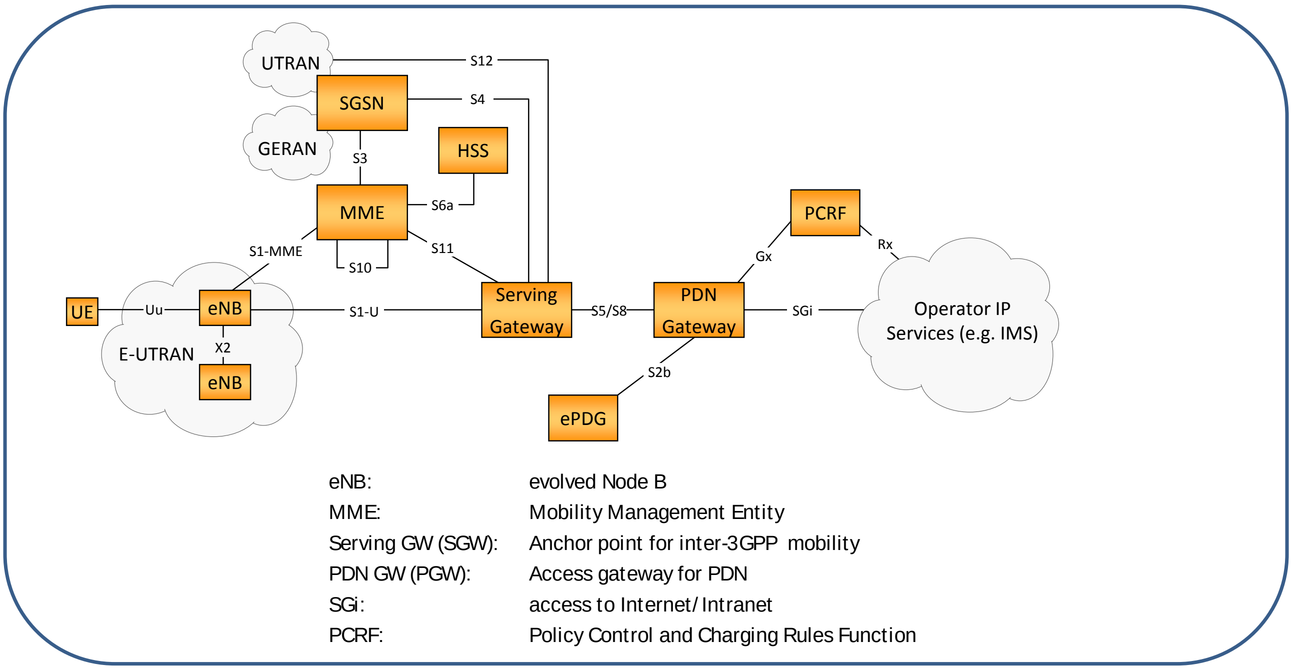


Figure 6-1: iJOIN Baseline System Logical Architecture

6.3.2 Preliminary Draft of the iJOIN Logical Architecture

A draft of the iJOIN architecture is planned for month 12 (D5.1), but according to current discussions among the partners, we envisage the introduction in the system of a set of new logical entities / functionalities.

6.3.2.1 iJOIN Small Cell

To support the functional split envisaged within the project and shown in Figure 3-2, a new type of small cell is introduced: the **iJOIN Small Cell** (iSC). These low power flexible radio access points implement fully or partially the lower OSI layer(s) (RF/L1/2/3) traditionally executed at the base station, the upper layers being handled by a **cloud computing** entity, the "RAN as a Service" (**RANaaS)** platform, for partial implementation. It shares all other properties of a classical small cell. There may be different implementations of an iSC according to the CTs' needs, e.g.:

- L0-iSC (or RF-iSC) only handles the RF transmission (equivalent to an analogue or digital RRH);
- L1-iSC handles all functionalities below Layer 1 and part or all functionalities of Layer 1;
- L2-iSC handles all functionalities below Layer 2 and part or all functionalities of Layer 2;
- L3-iSC handles all functionalities below Layer 3 and part or all functionalities of Layer 3 (if all Layer 3 functionalities are handled, then the L3-iSC is equivalent to a classical SC).

The iSCs are connected to the RANaaS platform through the **logical J1 interface**, a new interface introduced by iJOIN, which definition and specification will be an on-going process closely related to the CTs.

As a natural continuity of the current trend in mobile network architecture, iSCs will be able to communicate and exchange information with each other directly through the **logical J2 interface**.J2 interface introduced by iJOIN may extend the current X2 interface.

6.3.2.2 iJOIN Network Controller

Some CTs which target a joint RAN/backhaul design assume the presence of a network controller which will be able to collect information from both the RAN part and the backhauling part and perform routing or load balancing operation. Such device will be particularly needed when dealing with multi-hop links between the RAN part and the core network or even between small cells. To this end, the iJOIN Network Controller (iNC) entity is introduced. In order to minimize the impacts for the operator in terms of deployment cost and complexity, the iNC should preferably be physically co-located with the RANaaS entity.

6.3.2.3 iJOIN Local Gateway

As breakout option will also be investigated by some CTs (especially in WP4) for traffic selection and offloading needs, the **iJOIN Local Gateway** (iLGW) is also introduced. This entity implements a subset of the logical functions of a P-GW. It is logically connected with the eNB, but it that can be physically located somewhere in the RAN domain. Its functionality is close to the local gateway (LGW) used in the femtocell for LIPA purpose.

6.3.2.4 iJOIN Transport Node

Many CTs will assume multi-hop links from an iSC toward the RANaaS platform, the core network or other iSC, inferring then the presence of a node between two hops. Such node is part of the backhaul network and it is usually not represented in a logical architecture. However, as we intend to design the RAN and the backhaul jointly, such node should be somehow introduced and logically connected to the iJOIN architecture. For this purpose, the **iJOIN Transport Node** (iTN) is introduced. Its exact connection to the iJOIN architecture is an on-going process. For the time being, this entity stands between iSC and RANaaS, or eventually between RAN and core network (possibly connected as mesh network). In case of considering a transport node connecting RAN and core network, another acronym (different from iTN) should be used with different protocol stack on board and different level of mesh functionalities.

6.3.2.5 iJOIN Draft Architecture

The real need of the previous entities is still to be verified, and consequently a coherent definition of the related interfaces will be introduced accordingly. Nevertheless, a first draft logical iJOIN architecture can be depicted (see Figure 6-2), by supposing that all these nodes will be introduced by iJOIN candidate technologies and will interact with all the existing entities in the baseline architecture.

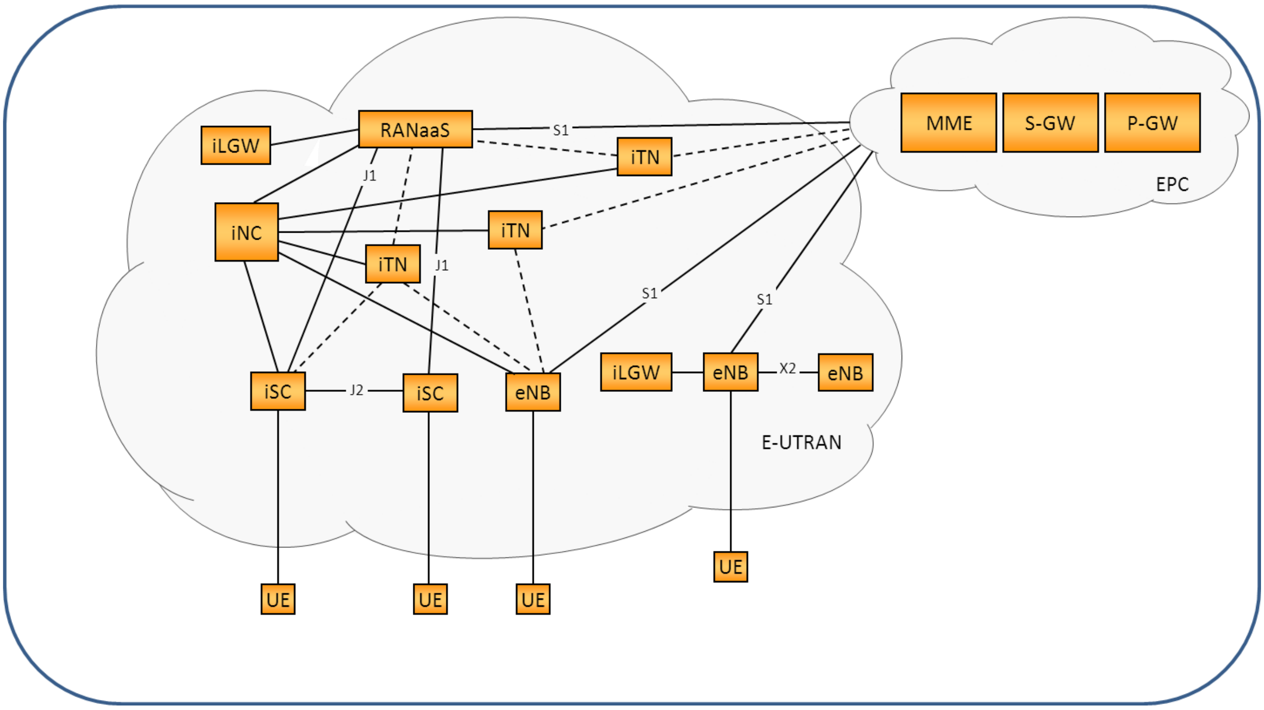


Figure 6-2: Preliminary Draft of the iJOIN Logical Architecture

7 iJOIN System Performance Evaluation

7.1 Metrics

The iJOIN project has defined four metrics to be improved by using a joint design of the radio access and the backhaul for small cells based on cloud network compared to a classical approach. The targeted improvement for each metric is given in Figure 7-1.

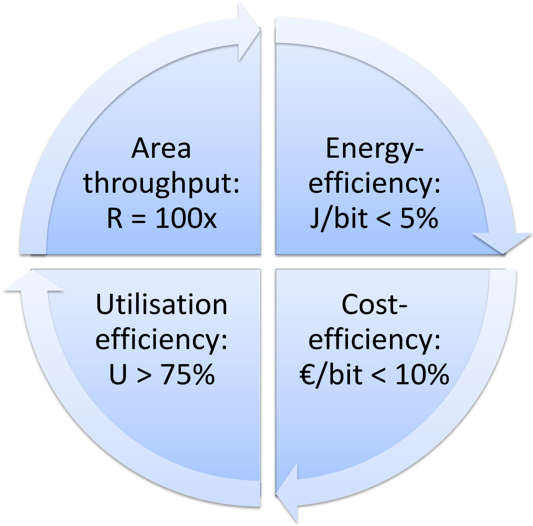


Figure 7-1: The Four Objectives of iJOIN in Relation to the 3GPP LTE State-of-the-Art

7.1.1 Area Throughput

7.1.1.1 Objective

Smaller sizes of cells and a suppressed impact of interference provides a robust platform to support versatile services, such as M2M Communications, 2D and 3D video streaming and other bandwidth-hungry applications. By 2020, spectral resources are expected to increase by a factor of 10 [8], which will enable the required increase of system throughput by a factor of 1000. However, iJOIN does not focus on challenges resulting from an increase of spectrum, but seeks improved system efficiency. Thus, in summary, iJOIN targets to **increase the system throughput within the same spectrum by a factor of 50-100** as a result of:

- High density of small cells, re-use of spectrum, and PHY / RRM improvements enabled by RANaaS to adequately address interference (≥10x)
- Shorter distances and increased LOS probability (5-10x)

7.1.1.2 Definition

A simplified description of a cellular network is a system comprising multiple sites and cells, which are distributed geographically in order to provide wireless access connectivity over a certain area. Figure 7-2 provides a schematic illustration of a nineteen sites system with three sectors per site in which a few users are present (representation largely adopted in cellular system-level simulations).

Observing the network over some time period T, one can measure the traffic flowing through the network (and also the network power usage). Denoting by $r_i(t)$ the rate by which bits are correctly delivered in cell i, the total information (number of bits) delivered in a network comprising N cells is calculated as:

$$I = \sum_{i=1}^{N} \int_{0}^{T} r_i(t)dt \qquad \text{[bit]}$$

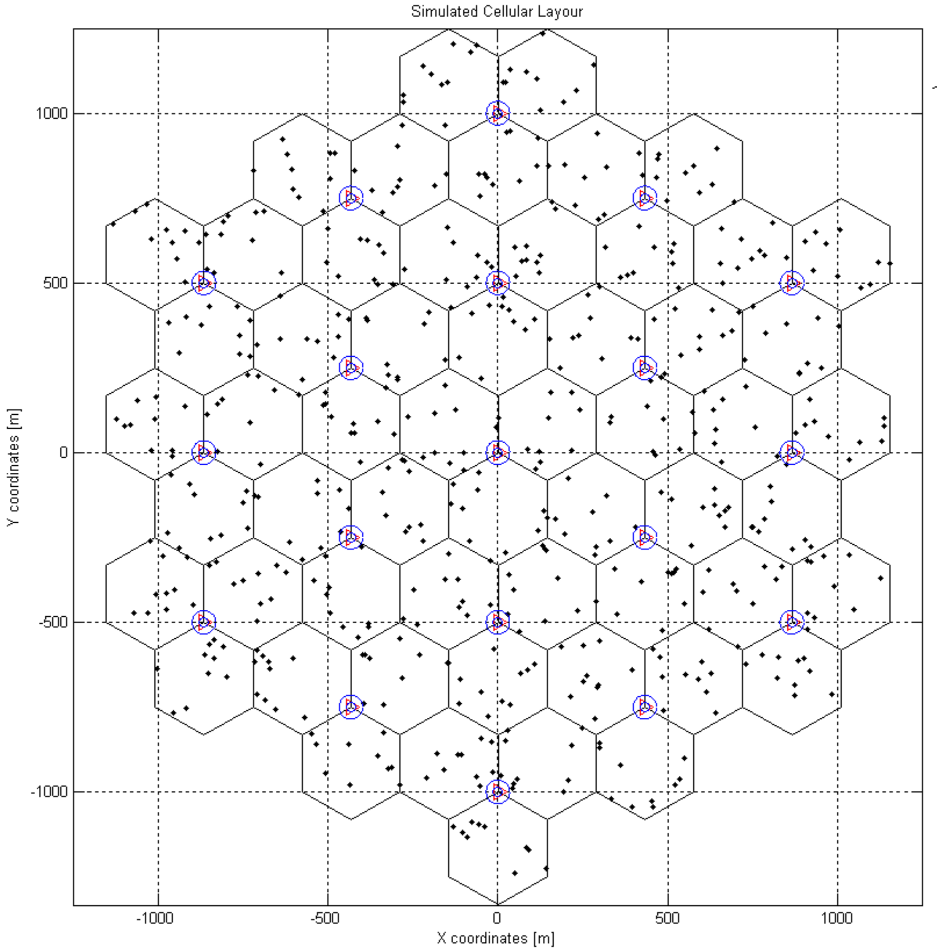


Figure 7-2: Tri-Sector Hexagonal Cellular System Model

The average rate *R* in the network is then simply *I/T*. It may often be helpful to normalize the rate *R* by either the number of cells or the network area. To make the normalized measures independent of the deployment, we choose here to work with rate per area unit expressed in square kilometres. **Area Throughput** is defined within iJOIN as the average rate per area unit R_A. It is then calculated as:

$$R_A = \frac{R}{A} = \frac{I}{A \cdot T} = \frac{1}{A \cdot T} \cdot \sum_{i=1}^{N} \int_0^T r_i(t)dt \qquad [\text{bps/km}^2]$$

- **Network Level Example:** Urban macro scenario for a 2-tiered cellular network (10+10 MHz, MIMO 4x2) with a typical cell spectral efficiency of 2.2 bit/s/Hz/cell in downlink and 1.4 bit/s/Hz/cell in uplink (simulation assumptions and IMT-Advanced requirements please refer to ITU reports [54] and [55]).

  Consider a system level simulation conducted in a measured time of observation (T = 10s) giving an average volume per cell equal to I_{DL} = 220 Mbit in downlink and I_{UL} = 140 Mbit in uplink. Note that the rate served by the cells in the area is usually calculated at MAC level (MAC PDU payload), and corresponds to the IP traffic provided by the LTE radio interface (corresponding also to the traffic to be transported by the backhauling network).

  Given the scenario (ISD = 500m corresponding to an area of 0.0722 km^2 per each hexagonal sector), the area throughput calculated from the simulation results (according to the above equation) is equal to 304.8 Mbps/km^2 in downlink and 194 Mbps/km^2 in uplink.

Simulations are often used to produce not only average values but also Cumulative Distribution Function (CDF) of the cell or user throughput, in order to give more complete information about the system behaviour. In particular an important metric that must be taken into account is the cell edge user throughput: a good system design should take into account also this statistic, so that also minimum radio performance is guaranteed in the covered area.

7.1.2 Energy Efficiency

7.1.2.1 Objective

In practice, reducing the size of the cells and shortening the communication distance enables higher data rates to be achieved at lower transmitted power than conventional cells. This leads to better power-efficiency in bits/Joule, i.e. the relative energy-consumption per bit decreases even though the overall energy-consumption may increase due to the densification of the network. On the other hand, smaller cells provide finer spatial granularity. Therefore, better energy management is possible by turning off under-loaded cells. Furthermore, RANaaS architecture paves the way to more computational energy saving. All of these factors contribute to energy efficiency that is intended to be achieved by iJOIN. Given an increase of system throughput by a factor of 100, **iJOIN aims to reduce energy-per-bit to less than 5%** of that of current systems, while also taking the backhaul-energy consumption into account. By applying novel architecture, approaches, and algorithms in iJOIN, this objective is achieved by reducing

- Transmission of energy through smaller cells and shorter distances between RAPs and terminals (down to 10-20% through up to 10dB lower transmitted power, while preserving the same SINR in the interference-limited regime),
- Average per-site energy by deploying small-cells (down to 25-50% [56]),
- Signal processing and computation energy by exploitation of diversity effects within RANaaS (down to 40-50% [18]),
- Network energy by jointly shutting down radio access and backhaul network nodes (down by 20-50%).

7.1.2.2 Definition

The main metric used for energy efficiency used in iJOIN is consumed energy per information bit. It was also successfully used in other projects like EARTH. **Energy Efficiency** is thereby measured as an **Energy Consumption Index** defined as:

$$\eta_{\text{energy}} = \frac{\text{energy consumed}}{\text{information delivered}} = \frac{\text{power consumption}}{\text{delivered data rate}} \qquad \text{[Joule/bit] = [Watt/bps]}$$

The metric normalizes the power consumed for information transmission by the actual information transmitted. It thereby decouples the energy consumption from the amount of delivered traffic. This is necessary because a higher traffic demand or larger network might require a higher total power consumption, which does not mean it cannot be more efficient than a smaller one.

The metric can be used for varying scenarios, as the following examples illustrate:

- **Link Level Example**: A backhaul link transmits 10 Gbps. All involved components (transmitter, receiver, power amplifiers, data processing ...) consume 1 kW during a sustained (full buffer) transmission. This results in an energy efficiency of 10 kW /10 Gbps = 1 µJ/bit.
- **Network Level Example**: A heterogeneous network can serve 100 users with a downlink data rate of 1 Mbps each. The power consumption of all involved components (small and macro cells, backhaul links, RANaaS) sums up to 10 MW. This results in an energy efficiency of 10 MW / (100 * 1 Mbps) = 0.1 J/bit.

It should be noted that as the information goes to zero, the metric goes to infinity, indicating an infinitely bad efficiency. This is important because a system usually consumes energy when it is not transmitting any information. This problem can be avoided by using time averaged values or assuming full buffer traffic.

Furthermore, the metric can depend on a number of other parameters, which have to be accounted in order to be able to compare two setups:

- Traffic demand or number of users
- Utilization or load of the network/link
- Number, deployment density and type of base stations

- Covered area
- Required QoS for user (e.g. minimum data rate)
- Uplink and/or downlink observed
- Set of appliances considered (cells, RANaaS, network switches, transceivers, data processing devices …)

If two different setups have to be compared, two other metrics can be used, depending on the context:

Power consumption per covered area

$$\eta_{\text{energy}} = \frac{\text{power consumption}}{\text{area covered}} \qquad [\text{Watt/km}^2]$$

This metric is for example useful to compare networks of different sizes or deployment densities.

Power consumption per satisfied users

$$\eta_{\text{energy}} = \frac{\text{power consumed}}{\text{number of (satisfied) users served}} \qquad [\text{Watt/user}]$$

This metric is useful because it includes QoS constraints and thereby ensures a certain degree of fairness. It also offers good insight for operators as to how efficient their network is compared to how many customers they can satisfy.

7.1.3 Utilization Efficiency

7.1.3.1 Objective

Currently, 15-20% of all cells carry 50% of the overall traffic [57]. Alternatively, we could say that less than 40% of the overall available throughput is actually utilised (i.e., the utilisation efficiency is lower than 40%). The main reason for this phenomenon is a wide deployment of macro-cells for high coverage, and the network dimensioning to peak traffic demands, meaning that a large fraction of deployed resources are underutilised. This can be increased significantly by concentrating traffic where it is actually needed, instead of ubiquitously and continuously providing peak throughput. iJOIN will **increase the Utilisation Efficiency in relevant scenarios to more than 75%,** i.e. 75% of the available throughput is also exploited by the network. This can be achieved by

- Counteracting the “always-on” paradigm,
- Flexibly moving computational resources towards a central entity (RANaaS), and
- More efficient load balancing concepts on both access and backhaul layers.

7.1.3.2 Definition

In the context of iJOIN, a holistic view on utilization is taken to cover the whole network architecture from the cloud platform to the iJOIN small cell. Correspondingly, relevant resources can be categorized along the two dimensions of resource type (e.g. radio, hardware …), and the network entity where the resource is provided and consumed (e.g. iSC, backhaul …).

Table 7-1: Preliminary mapping of resource types to network entities

Resource type \ network entities	eNodeB/RAP	Fronthaul	Backhaul	Cloud platform
Radio resources	e.g. PRBs	if applicable	if applicable	N.A.
Bandwidth	e.g. cell capacity	e.g. link capacity	e.g. link capacity	N.A.
Hardware/ computational resources	e.g. hardware elements	N.A.	N.A.	e.g. CPUs

Table 7-1 provides an overview of a preliminary mapping of resource types to network elements in the iJOIN architecture. Note that although the backhaul may be a wireless link, the applicability of radio resources as an input variable for utilization metrics depends on the employed technology. Only technologies which allow for dynamic allocation of radio resources (e.g. TDMA) can be considered here.

From the different resource types, utilization metrics can be derived. Some examples for utilization metrics are as following:

- In the eNB/iSC:
  - Radio Resource Utilization (RRU). In LTE, one common metric is the number of occupied Physical Resource Blocks (PRBs) compared to the total available PRBs [52].
  - Baseband Hardware Resource Utilization (BHRU): Common base station architectures comprise Hardware Elements (HEs) for baseband processing. The BHRU can be defined as the number of occupied HE compared to the total number of available HE.
- On the backhaul:
  - Bandwidth Utilization (BU): The total throughput compared to the capacity of a backhaul link.
- In the cloud platform:
  - Cloud Resource Utilization (CRU): For a public or private corporate cloud: the total virtual resource generated load on all hypervisors nodes compared to the maximum load that these servers (hypervisors node) can sustain.

Utilization efficiency is defined as a metric which expresses how well the utilized resources are used for a given performance metric. For example, if the cell throughput is the key performance indicator, the Radio Utilization Efficiency (RUE) can be expressed as the throughput divided by Radio Resource Utilization (RRU):

$$RUE = throughput/RRU$$

Utilization and utilization efficiency metrics which consider the whole iJOIN architecture is subject to on-going research and is covered in WP3.

7.1.4 Cost Efficiency

7.1.4.1 Objective

The iJOIN approach leads to less complexity in radio access points and a simplified network dimensioning by shifting RAN functionality to RANaaS, which provides the service when it is needed. This leads to a reduction in the total cost of ownership (TCO) for small-cells compared to conventional macro-cells. The revenue-per-bit of currently deployed systems is declining as the amount of traffic is increasing exponentially with the result that the overall revenue is rising only linearly. As previously outlined, the number of mobile Internet users is expected to rise by a factor of 10 within the next decade and mobile subscribers are not expected to pay higher data rates. Hence, iJOIN will counteract this development by **reducing the cost-per-bit to less than 10% of that of current systems** while enabling increased system throughput as previously described. In particular, the developed architecture reduces

- Backhaul expenditures due to lower density of fibre-links,
- Total CAPEX due to lower requirements on RAPs, lower density of macro-sites and therefore lower installation costs per site, HW costs, and rental costs per site,
- Total OPEX due to lower maintenance costs, lower upgrading costs (mainly done within RANaaS), and lower energy-consumption.

7.1.4.2 Definition

Cost-efficiency is hardly to define as it depends of a lot of parameters as coverage, area, performance, capacity and cost variations in time are important (market price and depreciation) and in conditions (urban, buildings sizes, rural…), and finally depends on countries ...

In [58], different iso-performance scenarios are investigated, i.e. combinations of relay nodes (RNs) or Pico eNBs and extended Inter-Site Distance (ISD) between the macro sites that provide the same performance in terms of coverage. The gain in an iso-performance scenario is defined by the corresponding ISD extension, which is in turn based on the coverage area of the small node. The exchange ratios give an indication on the cost savings when deploying RNs or Pico eNBs in contrary to eNB-only deployment.

In [59], prices are assumed for the base stations: a capital expenditure of a three-sector 2-by-2 MIMO LTE base station (including both hardware and software license) is assumed at 20,000 € while an enterprise small cell is estimated at 800 € with depreciation. In top of that, the backhaul cost is integrated to the Total Cost Ownership (TCO) based on its quality: low-cost backhaul corresponding to a leased line of 400 € per month; while high-cost backhaul corresponding to a leased line of 1,000 € per month.

In [60], the effect of cooperation between base stations on the backhaul cost is added. For comparison purpose of various heterogeneous infrastructures, this work introduces the notion of "cost per bit" of uplink and downlink and relates it to the area covered. They enumerate parameters having a direct impact on the cost, such as backhaul cost per bit, base station equipment cost, energy related base station costs per site and year …

Within iJOIN, the following parameters will be introduced to estimate the cost of the iJOIN system.

- C_{sc}: small cell cost (info on its maximal throughput/user capacity)
    - Hardware costs
    - Installation costs
    - Site rental costs
- $C_{sc,pwr}$: small cell power consumption cost
- Lifespan of small-cell eNB
- C_{bh}: backhaul cost (including node cost for wireless?) (info on its maximal throughput capacity - assuming proprietary backhaul since operator controlled, leasing otherwise?)
    - Hardware costs
    - Installation costs
    - Site rental costs
- $C_{bh,pwr}$: backhaul power consumption cost
- C_{RANaaS}: RANaaS platform cost (info on the data center?)
- $C_{RANaaS,pwr}$: RANaaS platform power consumption cost

Cost efficiency will be defined as a metric which will relate the cost of the system to a given key performance indicator. Based on this first set of parameters, the cost efficiency metric will be refined through the course of the project by getting input from the other WPs.

7.2 Evaluation Methods

7.2.1 System-Level Simulation

In order to assess the performances of the different proposed solutions, different methods can be applied. A theoretical or analytical approach can be considered for some specific solutions. However, due to the complexity of some of the considered scenarios, simulation approaches are necessary. In the second case, depending on the proposed solutions and required accuracy and analysed metrics, static or dynamic simulations can be considered. Taking into account the scenarios and simulation methodologies adopted for example in 3GPP, the following aspects must be defined to finalize the scenarios:

- 19 tri-sectorial macro sites as depicted in Figure 7-2 as a typical macro scenario. Depending on the complexity of the solutions, the number of macro sites can be decreased to 7 (i.e. central site and first tier of interfering sites).

- Wrap around: in order to remove edge effects in the scenario wrap around should be applied. If a small number of sites is considered and depending on the propagation models and inter-site distance, there could be some problems in the wrap-around application due to auto-interference problems. In this scenarios the wrap around should be avoided.
- Traffic distribution: both homogeneous and hotspot traffic distributions can be considered. To emulate traffic hotspot a variable percentage of users can be distributed in different hotzones.
- Heterogeneous networks: under the coverage of the macro cell one or more small cells can be placed to boost the system offered capacity, as illustrated in Figure 7-3. The small cell can be placed following a sparse o clustered distribution (depending on the size of the traffic hotspot the small cells are serving).

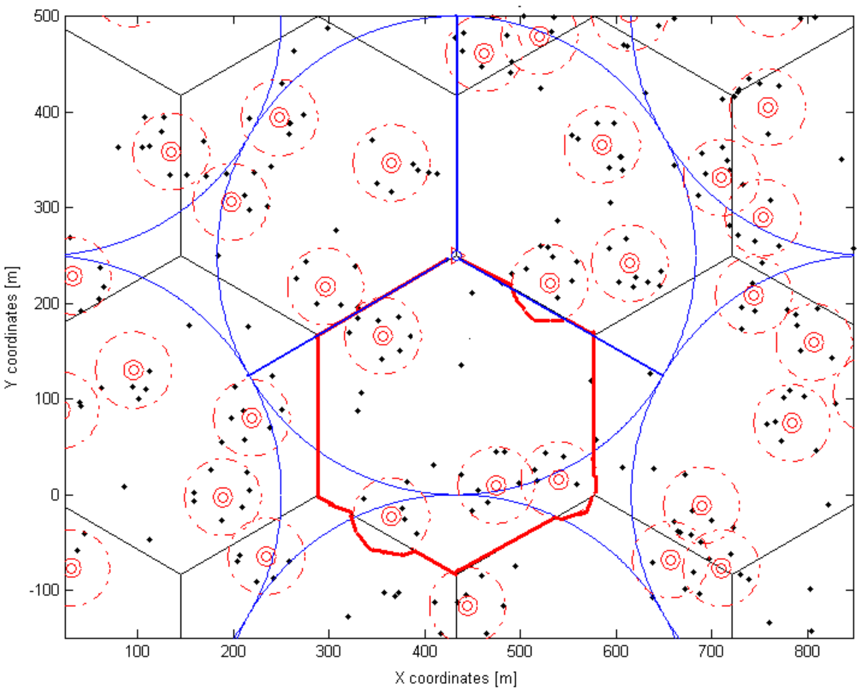


Figure 7-3: Heterogeneous Deployment Example

- Outdoor/indoor distribution: a percentage of users can be placed in indoor. While macro cell are installed outdoor, small cells can be placed both in indoor or outdoor. In current deployments the traffic is mainly generated by indoor users.
- Traffic models: first simulation campaign can be carried out considering full buffer traffic. Anyway, taking into account possible coordination techniques applicable to the heterogeneous scenarios more detailed traffic models should be considered.
- Carrier Aggregation: to boost the performance, both macro cells and small cells can use carrier aggregation. Depending on the backhauling performance carriers transmitted by different sites can be aggregated.

Depending on the analysed solutions explicit model for mobility of the users can be considered or not. In case the explicit mobility model is required, the relevant protocol and mobility procedures should be included in the simulator.

For the deployment, propagation models, traffic models, traffic spatial distributions the «official» references considered in literature (e.g. 3GPP, ITU …) and related parameters / assumptions should be reused as much as possible. For more details, the sources [52], [54] and [55] can be considered as a good starting point.

For comparison purposes it is important to consider a baseline system configuration: the baseline system can be assumed as heterogeneous deployment without heterogeneous backhauling and without RANaaS (or centralization of RAN functionality in C-RAN). From a standard point of view LTE Rel. 10 system can be a good baseline to introduce coordination algorithms in RANaaS architecture and with a joint access/backhauling design, while performances given by an ideal architecture can be given by Release 11 with CoMP. For the sake of comparison, all the solutions should consider the same number of macro and small cells in the area.

All the evaluations performed by the different partner should consider:

- Performance that can be obtained by the baseline system
- Performance that can be obtained by the system implementing the proposed features

Comparing the two configurations above, each proponent should (if possible) provide the gains measured with four metrics illustrated above:

- Area throughput;
- Energy Efficiency;
- Utilization Efficiency;
- Cost Efficiency.

8 Summary and Conclusion

This internal report has presented the 3GPP LTE Release 10 architecture current status upon which iJOIN will provide an evolutionary path. A special emphasis has been dedicated to main backhaul solutions (fibre and 60GHz wireless technologies) which will support iJOIN's own architecture. This architecture, geared toward **dense small-cell** deployment, will be designed around two main concepts:

- The use of **cloud computing**, known within the project as a RAN as a Service (RANaaS) platform, for enabling advanced RAN features thanks to centralisation and functional split.
- A **joint RAN/backhaul design**.

Cloud computing's classical concepts have also been presented which will help defining the type of cloud architecture devoted to the RANaaS platform.

The main iJOIN reference scenarios have also been introduced representing realistic use cases. With **outdoor/ indoor dense hot-spot deployment** and **wide-area continuous coverage** scenarios, the project will cover use cases where the small cells will play a key role in providing enhanced capacity and coverage for an improved quality.

As centralisation will be a major topic, a preliminary evaluation of the functionalities processed within the RAN has been conducted, mainly in terms of centralisation benefit and bandwidth/latency requirements. This on-going process will allow the definition of the requirements on the backhaul to support the centralisation of a function if a gain has been identified.

As one of WP5's roles is to derive the global **iJOIN system and architecture**, preliminary assumptions and requirements to support the candidate technologies investigated have been gathered from WP2 to 4: some will address the use of the RANaaS platform, while others will benefit from the introduction of a local controller to jointly coordinate RAN and backhaul operation. Such initial inputs clearly impact the architecture of the system (for which a first logical draft is provided in this report) and will be clearly refined during the project's lifetime.

Finally, to assess the benefit of using a RANaaS platform and the joint RAN/backhaul approaches dedicated to the small cells, four metrics have been introduced upon which iJOIN will bring improvement compared to a Release 10 baseline system: **Area Throughput**, **Energy Efficiency**, **Utilisation Efficiency** and **Cost Efficiency**. Their exact definition and how to evaluate them is still an on-going process, but iJOIN's intention is clearly to provide through those four objectives a simple yet accurate way to demonstrate for dense small cell deployment the merits of our system design oriented toward our two key concepts: RANaaS and joint RAN/backhaul design.

9 Appendix A: High-Level Scenario Description

In order to define the use cases to be adopted within the iJOIN project, partners filled a high-level scenario template given in Table 9-1 answering a simple set of questions. Those templates lead to the definition of the iJOIN primary use cases, a preliminary architecture and enable the use of a common wording amongst all partners.

Table 9-1: High-Level Scenario Template

Deployment scenario	Type of deployment?	*e.g. hotspot*
	Outdoor / Indoor?	
	Prior deployed fixed network infrastructure available?	*i.e. which scenarios of fixed network access are considered, what is the density of existing fixed network access, …*
	Small cell/user density?	
	User mobility considered?	*e.g. slow, fast, none*
	Focus on control / user plane?	
	Planned or unplanned deployments?	
	Overlapping small-cell coverage regions or rather well separated through natural shadowing?	
	Operation on the same or orthogonal frequencies?	
Specific details (optional)	Degree of required vendor cooperation?	*i.e. where do we assume standardized interfaces*
	Local breakout and traffic offload support?	*i.e. where can data be offloaded to CDN*
	Traffic?	*e.g. bursty, full buffer, FTP, web browsing*
	Point of centralization?”	*i.e. where is the “centralization break-out*
Het-Net	Macrocell considered?	
	Macrocell/smallcell interaction envisaged?	
Small cell	Picocell-like?	
	Femtocell-like?	*i.e. potentially, access through the core network could be done through an uncontrolled link (e.g. DSL)*
	Direct small cells connections considered (X2 or X2-like)?	*e.g. mesh network*
	“Local” gateway/concentrator envisaged?	*i.e.” geographically” close to a set of small cells*
	Gateway/concentrator envisaged?	*i.e device handling a lot of small cells not located close to each other*
RAN	Definition?	*e.g. link between EUTRAN and UE*

	Frequency? Bandwidth?	
Fronthauling	Definition?	*e.g. link between a baseband pooling and a RRH ("simple" optical to radio conversion)*
Backhauling	Definition?	*e.g. link between E-UTRAN equipment and the core network (EPC)*
	Specific backhaul?	*e.g. fiber, wireless (60GHz)? copper*
	Fronthauling functionality through backhauling envisaged?	*e.g. needed in PHY functional split*
	Heterogeneity of backhaul?	*i.e. is backhaul assumed to be homogeneous within a local area or do we assume that even adjacent small-cells may have different backhaul connection?*
Interface used	J1? J2? Other (specify between which entities)	

9.1 IMDEA

Deployment scenario	Type of deployment?	**Hotspot**
	Outdoor / Indoor?	**Both**
	Prior deployed fixed network infrastructure available?	
	Small cell/user density?	**High density of small cells, medium/high density of UEs**
	User mobility considered?	**No**
	Focus on control / user plane?	**Both**
	Planned or unplanned deployments?	**Planned**
	Overlapping small-cell coverage regions or rather well separated through natural shadowing?	**Overlapping**
	Operation on the same or orthogonal frequencies?	**Frequency reuse one**
Specific details (optional)	Degree of required vendor cooperation?	
	Local breakout and traffic offload support?	**Yes**
	Traffic?	**Full buffer, Real time**
	Point of centralization?"	
Het-Net	Macrocell considered?	**Yes**
	Macrocell/smallcell interaction envisaged?	**Partially**
Small cell	Picocell-like?	**Yes**

	Femtocell-like?	**Yes**
	Direct small cells connections considered (X2 or X2-like)?	**Yes**
	"Local" gateway/concentrator envisaged?	**Yes**
	Gateway/concentrator envisaged?	**No**
RAN	Definition?	**Link between EUTRAN and UE**
	Frequency?	
	Bandwidth?	
Fronthauling	Definition?	**Link between a baseband pooling and a RRH ("simple" optical to radio conversion)**
Backhauling	Definition?	**Link between E-UTRAN equipment and the core network (EPC**
	Specific backhaul?	**Wireless (potentially heterogeneous)**
	Fronthauling functionality through backhauling envisaged?	**No**
	Heterogeneity of backhaul?	**Heterogeneous Backhaul**
Interface used	J1? J2? Other (specify between which entities)	**J2 and maybe J1**

9.2 NEC

Deployment scenario	Type of deployment?	**Mainly focus on local clusters of small-cells, i.e. the density of small-cells follows the density of users/demand for high data rates**
	Outdoor / Indoor?	**Outdoor deployments**
	Prior deployed fixed network infrastructure available?	**We assume a mix of existing infrastructure (high capacity/low latency) and infrastructure dedicated to new small-cells; this mix will be overlapping, i.e. within the same geographical region you may have both types**
	Small cell/user density?	**Both high but not homogeneous**
	User mobility considered?	**Mix of slowly moving users and fast moving users**
	Focus on control / user plane?	**Both**
	Planned or unplanned deployments?	**We clearly prefer operator-deployed networks as a mix of planned and unplanned deployments, possibly also as a result of evolving deployments where capacity needs to be provided on a short time-scale which is complemented**

		afterwards.
	Overlapping small-cell coverage regions or rather well separated through natural shadowing?	**Mostly overlapping regions of small-cells and macro-cells even though small-cells may also be deployed for coverage extension**
	Operation on the same or orthogonal frequencies?	**Should be in general the same frequency, however, we should first show that there is a real gain from operating both on the same frequency compared to high-frequency (5+ GHz) small-cell layers**
Specific details (optional)	Degree of required vendor cooperation?	**Latest after the point of centralization, vendor-collaboration is required. The communication between "centralization break-out" and small-cells not necessarily needs to be "collaboration-ready" even though this may depend also on the size of the cluster which is centralized.**
	Local breakout and traffic offload support?	**I think this should be part of the "flexible centralization" component, i.e. depending on the back-haul, this should be possible at the eNB/Small-cell GW/…**
	Traffic?	**That's probably more of a simulator parameter but in general, I think we are going to face a high diversity of traffic types which need to be handled**
	Point of centralization?"	**At least for small-cells, this should be before the Backhaul Aggregation Network**
Het-Net	Macrocell considered?	**Yes**
	Macrocell/smallcell interaction envisaged?	**Yes**
Small cell	Picocell-like?	**May be, even though we will focus on outdoor deployments**
	Femtocell-like?	**No**
	Direct small cells connections considered (X2 or X2-like)?	**There should be a logical link between small-cells and in some cases even a physical**
	"Local" gateway/concentrator envisaged?	**Yes; it's determining the degree of centralization (both function-wise and geographically)**
	Gateway/concentrator envisaged?	**?**
RAN	Definition?	**Links eNB-UE and eNB-eNB; RAN should include all logical functionality and interfaces to control and operate these links**
	Frequency?	**2.x for macro-cells; possibly higher frequencies for small-cells**
	Bandwidth?	**High bandwidth**
Fronthauling	Definition?	**Any physical links towards the eNB which are part of the RAN**
Backhauling	Definition?	**See figure on Mobile Radio Network**

	Specific backhaul?	**Mix of optical, 60GHz, and possibly other high-latency/low-capacity backhaul technologies**
	Fronthauling functionality through backhauling envisaged?	**Sounds interesting because front-haul and back-haul should be orthogonal?**
	Heterogeneity of backhaul?	**Heterogeneous, even in small local areas**
Interface used	J1? J2? Other (specify between which entities)	**Scope of the project**

9.3 TI

Deployment scenario	Type of deployment?	**Hotspot, and more generally capacity driven**
	Outdoor / Indoor?	**Outdoor and in selected indoor hotspots**
	Prior deployed fixed network infrastructure available?	**Available in indoor hotspots**
	Small cell/user density?	**High cell density, moderate user density**
	User mobility considered?	
	Focus on control / user plane?	**Both, but mainly user plane**
	Planned or unplanned deployments?	
	Overlapping small-cell coverage regions or rather well separated through natural shadowing?	**Overlapping but also vertical handover to be considered**
	Operation on the same or orthogonal frequencies?	**Depends on RAT, but in general same frequency. RRM could be a driver in this context**
Specific details (optional)	Degree of required vendor cooperation?	**Vendor cooperation is highly recommended to define open interfaces**
	Local breakout and traffic offload support?	
	Traffic?	
	Point of centralization?”	**Depends strongly on the interfaces that will be defined**
Het-Net	Macrocell considered?	**Generally yes**
	Macrocell/smallcell interaction envisaged?	**Yes**
Small cell	Picocell-like?	**Yes**
	Femtocell-like?	**The question is how to make a joint project with access part?**
	Direct small cells connections considered (X2 or X2-like)?	**Yes, but only from an architectural point of view**
	“Local” gateway/concentrator envisaged?	**Optionally**
	Gateway/concentrator envisaged?	**Optionally**
RAN	Definition?	**Link between EUTRAN and UE**

	Frequency?	**LTE frequency allocation**
	Bandwidth?	**Open**
Fronthauling	Definition?	**Link between a baseband pooling/RANaaS and a RRH/small cell**
Backhauling	Definition?	**Link between E-UTRAN equipment and the core network (EPC)**
	Specific backhaul?	**Various options available and to be evaluated with pros and cons**
	Fronthauling functionality through backhauling envisaged?	**Depends on the boundaries to be defined, but generally yes**
	Heterogeneity of backhaul?	**In principle it could be heterogeneous, and this option should be investigated**
Interface used	J1? J2? Other (specify between which entities)	**The interfaces are still to be defined, and not necessarily iJOIN should stick on J1 or J2, but rather it should consider all the envisaged options**

9.4 SCBB

Deployment scenario	Type of deployment?	**Hotspot *(shopping mall)***
	Outdoor / Indoor?	**Indoor *(maybe outdoor)***
	Prior deployed fixed network infrastructure available?	**TDB**
	Small cell/user density?	**TDB**
	User mobility considered?	**None/Slow**
	Focus on control / user plane?	**User plane**
	Planned or unplanned deployments?	**Unplanned *(users will dropped near small cell)***
	Overlapping small-cell coverage regions or rather well separated through natural shadowing?	**Overlapping possible *(random drop)***
	Operation on the same or orthogonal frequencies?	**Same frequency**
Specific details (optional)	Degree of required vendor cooperation?	
	Local breakout and traffic offload support?	
	Traffic?	**Full buffer (heavy traffic)**
	Point of centralization?”	
Het-Net	Macrocell considered?	**Not specifically**
	Macrocell/smallcell interaction envisaged?	**No**
Small cell	Picocell-like?	**Yes**
	Femtocell-like?	**Maybe**
	Direct small cells connections considered (X2 or X2-like)?	**Yes**

	"Local" gateway/concentrator envisaged? Gateway/concentrator envisaged?	**Yes** **No**
RAN	Definition? Frequency? Bandwidth?	**Link between EUTRAN and UE** **Around 2GHz** **10MHz**
Fronthauling	Definition?	**Link between a baseband pooling and a RRH *(RRH="simple" optical to radio conversion device, no intelligence)***
Backhauling	Definition? Specific backhaul? Fronthauling functionality through backhauling envisaged? Heterogeneity of backhaul?	**Link between E-UTRAN equipment and the core network (EPC)** **TBD** **Yes** **Homogeneous *(at first)***
Interface used	J1? J2? Other (specify between which entities)	**J1 & J2 (or X2 with new messages)**

9.5 TID

Deployment scenario	Type of deployment? Outdoor / Indoor? Prior deployed fixed network infrastructure available? Small cell/user density? User mobility considered? Focus on control / user plane? Planned or unplanned deployments? Overlapping small-cell coverage regions or rather well separated through natural shadowing? Operation on the same or orthogonal frequencies?	**Hotspot, nospot and wide area continuous coverage** **Outdoor** **Small cell density:** **- 10 per sq. kilometre for high power small cell** **- 20 per sq kilometre for low power small cell** **Slow (mobility level estimation required to be supported by RAN)** **Both**
Specific details (optional)	Degree of required vendor cooperation? Local breakout and traffic offload support? Traffic? Point of centralization?"	

Het-Net	Macrocell considered?	**Yes**
	Macrocell/smallcell interaction envisaged?	**Yes**
Small cell	Picocell-like?	**Yes**
	Femtocell-like?	**Under consideration**
	Direct small cells connections considered (X2 or X2-like)?	**Direct connection yes, mesh network under consideration**
	"Local" gateway/concentrator envisaged?	**Yes**
	Gateway/concentrator envisaged?	**No**
RAN	Definition?	**Network elements and functions required to support the radio access operation**
	Frequency?	**2.6GHz**
	Bandwidth?	**20MHz**
Fronthauling	Definition?	**Link between baseband processing units and radio frequency processing units (BB pooling not mandatory)**
Backhauling	Definition?	**Under consideration (not clear that the MAN should be considered a part of the backhaul)**
	Specific backhaul?	**Fiber, wireless (60 GHz, 70-80 GHz)**
	Fronthauling functionality through backhauling envisaged?	**Yes**
	Heterogeneity of backhaul?	
Interface used	J1? J2? Other (specify between which entities)	

9.6 IMC

Deployment scenario	Type of deployment?	**Main square/avenue in the downtown or hotspot.**
	Outdoor / Indoor?	**Outdoor**
	Prior deployed fixed network infrastructure available?	**Our plan is to study the 2 cases (i) when conventional infrastructure is available and (ii) when deployment is only done with iJOIN access points.**
	Small cell/user density?	**High density of small cells.**
	User mobility considered?	**No**
	Focus on control / user plane?	**Mostly user plane.**
	Planned or unplanned deployments?	**Our study would focus on planned deployment.**
	Overlapping small-cell coverage regions or rather well separated through natural	**Overlapping regions**

	shadowing? Operation on the same or orthogonal frequencies?	 **Overlapping frequency deployment.**
Specific details (optional)	Degree of required vendor cooperation? Local breakout and traffic offload support? Traffic? Point of centralization?”	 **Full buffer traffic.** **Part of the problem.**
Het-Net	Macrocell considered? Macrocell/smallcell interaction envisaged?	**Plan is to study the network both with and without macrocells.** **Yes**
Small cell	Picocell-like? Femtocell-like? Direct small cells connections considered (X2 or X2-like)? “Local” gateway/concentrator envisaged? Gateway/concentrator envisaged?	**Yes** **Possible.** **We shall consider these connections but not from the design point of view but shall take advantage based upon the presence of these links.** **Most probably yes.**
RAN	Definition? Frequency? Bandwidth?	**Link between EUTRAN and UE** **Mostly frequency independent but close to LTE frequencies – 2 GHz** **Large but not specified.**
Fronthauling	Definition?	**Link between a baseband pooling and a RRH (“simple” optical to radio conversion)**
Backhauling	Definition? Specific backhaul? Fronthauling functionality through backhauling envisaged? Heterogeneity of backhaul?	**Link between E-UTRAN equipment and the core network (EPC)** **Most of the study would study backhaul independent of its physical implementation and under the requirements imposed by small cells and RAN functionality. Partial consideration of fibre and wireless backhaul.** **No.** **Heterogeneous backhaul, mostly in terms of high-level capabilities like capacity and latency.**
Interface used	J1? J2? Other (specify between which entities)	**Both J1 and J2 interfaces would be used in our study. Again like backhaul case, the main focus would be on the requirements and constraints of these interfaces rather their specific design.**

9.7 CEA

Deployment scenario	Type of deployment?	**Hotspot**
	Outdoor / Indoor?	**Outdoor**
	Prior deployed fixed network infrastructure available?	
	Small cell/user density?	**High density of small cells; medium density of UEs**
	User mobility considered?	**None**
	Focus on control / user plane?	**Both**
	Planned or unplanned deployments?	**Planned**
	Overlapping small-cell coverage regions or rather well separated through natural shadowing?	**Overlapping**
	Operation on the same or orthogonal frequencies?	**Frequency reuse one**
Specific details (optional)	Degree of required vendor cooperation?	
	Local breakout and traffic offload support?	
	Traffic?	**Full buffer; Real time**
	Point of centralization?”	
Het-Net	Macrocell considered?	**Yes**
	Macrocell/smallcell interaction envisaged?	**Partially**
Small cell	Picocell-like?	**Yes**
	Femtocell-like?	**No**
	Direct small cells connections considered (X2 or X2-like)?	**Yes**
	“Local” gateway/concentrator envisaged?	**Potentially**
	Gateway/concentrator envisaged?	**No**
RAN	Definition?	**Link between EUTRAN and UE**
	Frequency?	**2GHz**
	Bandwidth?	**10MHz**
Fronthauling	Definition?	**Link between a baseband pooling and a RRH (“simple” optical to radio conversion)*)***
Backhauling	Definition?	**Link between E-UTRAN equipment and the core network (EPC)**
	Specific backhaul?	**Wireless**
	Fronthauling functionality through backhauling envisaged?	**No**

	Heterogeneity of backhaul?	**Heterogeneous Backhaul**
Interface used	J1? J2? Other (specify between which entities)	**Both J1 and J2**

9.8 UoB

Deployment scenario	Type of deployment?	**Generally dense, e.g. hot spot**
	Outdoor / Indoor?	**Outdoor**
	Prior deployed fixed network infrastructure available?	**Is used if available**
	Small cell/user density?	**High cell density, moderate user density**
	User mobility considered?	**No to slow mobility**
	Focus on control / user plane?	**Both investigated, but focus on user plane**
	Planned or unplanned deployments?	**Planned preferred, unplanned accepted**
	Overlapping small-cell coverage regions or rather well separated through natural shadowing?	**Overlapping**
	Operation on the same or orthogonal frequencies?	**Same (Uplink only)**
Specific details (optional)	Degree of required vendor cooperation?	**High**
	Local breakout and traffic offload support?	**Yes**
	Traffic?	**Not relevant**
	Point of centralization?”	**Variable**
Het-Net	Macrocell considered?	**In general yes**
	Macrocell/smallcell interaction envisaged?	**Yes**
Small cell	Picocell-like?	**Yes**
	Femtocell-like?	**Potentially yes**
	Direct small cells connections considered (X2 or X2-like)?	**Yes**
	“Local” gateway/concentrator envisaged?	**Yes, optionally**
	Gateway/concentrator envisaged?	**Yes, optionally**
RAN	Definition?	**Link between EUTRAN and UE**
	Frequency?	**Open**
	Bandwidth?	**Open**
Fronthauling	Definition?	**Link between “dumb” remote radio head and baseband pool**
Backhauling	Definition?	**Any link between “intelligent” RAPs and controlling entities**

	Specific backhaul?	**Not specific, but heterogeneous in general**
	Fronthauling functionality through backhauling envisaged?	**Yes**
	Heterogeneity of backhaul?	**Yes**
Interface used	J1? J2? Other (specify between which entities)	**Both J1 and J2**

9.9 UNIS

Deployment scenario	Type of deployment?	**Hotspot**
	Outdoor / Indoor?	**Both**
	Prior deployed fixed network infrastructure available?	
	Small cell/user density?	**Both Dense and Sparse**
	User mobility considered?	**Yes, slow (0 - 3 km/h) and medium (upto 30 km/h) speeds**
	Focus on control / user plane?	**Both**
	Planned or unplanned deployments?	**Both planned and unplanned**
	Overlapping small-cell coverage regions or rather well separated through natural shadowing?	**Both**
	Operation on the same or orthogonal frequencies?	**Same frequency for small cells, could be orthogonal to the macro layer**
Specific details (optional)	Degree of required vendor cooperation?	
	Local breakout and traffic offload support?	
	Traffic?	**Full buffer**
	Point of centralization?”	
Het-Net	Macrocell considered?	**If there is co-channel deployment between macro and small cell layer**
	Macrocell/smallcell interaction envisaged?	**Potentially**
Small cell	Picocell-like?	**Yes**
	Femtocell-like?	**Yes (but with a low priority)**
	Direct small cells connections considered (X2 or X2-like)?	**Yes**
	“Local” gateway/concentrator envisaged?	**Yes**
	Gateway/concentrator envisaged?	**Maybe**
RAN	Definition?	**Link between EUTRAN and UE**
	Frequency?	**2GHz, also 3.5 GHz**
	Bandwidth?	**1.4 - 20 MHz**

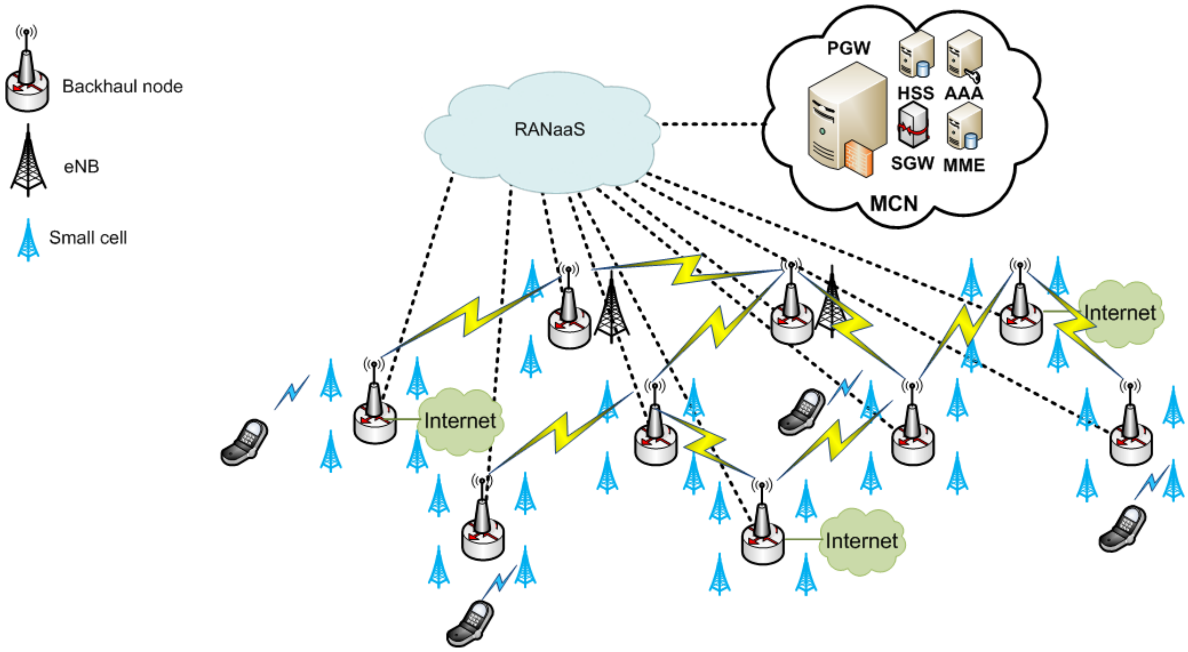
Fronthauling	Definition?	**Link between a baseband pooling and a RRH**
Backhauling	Definition? Specific backhaul? Fronthauling functionality through backhauling envisaged? Heterogeneity of backhaul?	**Link between E-UTRAN equipment and the core network (EPC)** **Microwave based** **Homogeneous but could be Heterogeneous**
Interface used	J1? J2? Other (specify between which entities)	**Both J1 and J2**

9.10 TUD

Deployment scenario	Type of deployment? Outdoor / Indoor? Prior deployed fixed network infrastructure available? Small cell/user density? User mobility considered? Focus on control / user plane? Planned or unplanned deployments? Overlapping small-cell coverage regions or rather well separated through natural shadowing? Operation on the same or orthogonal frequencies?	**Hotspot** **Outdoor** **Yes** **It will be an objective to increase the maximum number of users for a given deployment** **None** **User plane** **Planned** **Overlapping**
Specific details (optional)	Degree of required vendor cooperation? Local breakout and traffic offload support? Traffic? Point of centralization?”	**Full cooperation** **Full buffer (question can be removed)**
Het-Net	Macrocell considered? Macrocell/smallcell interaction envisaged?	**Yes** **Yes**
Small cell	Picocell-like? Femtocell-like? Direct small cells connections considered (X2 or X2-like)? “Local” gateway/concentrator envisaged?	**Yes** **No** **Yes**

	Gateway/concentrator envisaged?	
RAN	Definition? Frequency? Bandwidth?	**Link between EUTRAN and UE** **LTE@~2 GHz** **10 MHz**
Fronthauling	Definition?	**Link between a baseband pooling/RANaaS and a RRH/small cell**
Backhauling	Definition? Specific backhaul? Fronthauling functionality through backhauling envisaged? Heterogeneity of backhaul?	**Link between E-UTRAN equipment and the core network (EPC)** **Varying (homogeneous)** **Yes** **Homogeneous**
Interface used	J1? J2? Other (specify between which entities)	**J1, possibly J2**

9.11 UC3M



Network architecture

Key aspect to highlight here (from UC3M viewpoint): backhaul is potentially an IP network (multiple-hops) and local access to the Internet/operator services might be available in some locations.

Deployment scenario	Type of deployment? Outdoor / Indoor? Prior deployed fixed network infrastructure available? Small cell/user density?	**Hotspot** **Both** **Yes, fixed access allowing offloading might be available** **High density of small cells, medium/high density of UEs**

	User mobility considered?	**Yes, it has an impact on the anchoring mechanisms used**
	Focus on control / user plane?	**Both. From mobility management viewpoint, goal is to distribute user plane.**
	Planned or unplanned deployments?	**Planned**
	Overlapping small-cell coverage regions or rather well separated through natural shadowing?	**Overlapping**
	Operation on the same or orthogonal frequencies?	
Specific details (optional)	Degree of required vendor cooperation?	
	Local breakout and traffic offload support?	**Yes**
	Traffic?	**All types of user traffic should be considered, paying special attention to main ones present in today's and future's mobile networks**
	Point of centralization?"	
Het-Net	Macrocell considered?	**Yes**
	Macrocell/smallcell interaction envisaged?	**Partially**
Small cell	Picocell-like?	**Yes**
	Femtocell-like?	**Yes**
	Direct small cells connections considered (X2 or X2-like)?	**Yes**
	"Local" gateway/concentrator envisaged?	**Yes**
	Gateway/concentrator envisaged?	**No (to be further analysed)**
RAN	Definition?	**Link between EUTRAN and UE**
	Frequency?	
	Bandwidth?	
Fronthauling	Definition?	**Link between a baseband pooling and a RRH ("simple" optical to radio conversion)**
Backhauling	Definition?	**Link between E-UTRAN equipment and the core network (EPC)**
	Specific backhaul?	**Wireless (potentially heterogeneous)**
	Fronthauling functionality through backhauling envisaged?	**No**
	Heterogeneity of backhaul?	**Heterogeneous Backhaul**
Interface used	J1? J2? Other (specify between which entities)	**Hard to answer at this stage, potentially other might be needed**

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