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D5.1

Revised definition of requirements and preliminary definition of the iJOIN architecture

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Abstract

This deliverable recalls first the vision of the iJOIN project which embraces dense small cell deployments as a way to respond to the increasing data rate 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 for 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).

In particular, the present deliverable presents an overview of the activities carried out by the work package 5 (WP5) during the first twelve months of the project. The report gives an overall view of the current status of iJOIN project activities, definitions and system concepts, while specific aspects are contained in deliverables D2.1, D3.1 and D.41 coming from technical work packages. The aim is to provide a definition of iJOIN use cases and reference scenarios, plus preliminary assumptions and requirements, by integrating and harmonising at high level all technical findings coming from the other work packages Work Packages 2, 3 and 4. Starting from such information, an initial specification of the iJOIN architecture is provided, in its different views (logical, physical, and functional).

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Table of Contents

List of Figures

List of Tables

Abbreviations

3GPP	3rd Generation Partnership Project
ABS	Almost Blank Subframe
API	Application Programming Interface
bps	bit per second
BHaaS	Backhaul as a Service
BHRU	Baseband Hardware Resource Utilisation
BS	Base Station
BTS	Base Transceiver Station
BU	Bandwidth Utilisation
C&M	Control & Management
CA	Carrier Aggregation
CAPEX	Capital Expenses
CDF	Cumulative Distribution Function
CPRI	Common Public Radio Interface
CRE	Cell Range Extension
CRU	Cloud Resource Utilisation
CS	Common Scenario
CSG	Closed Subscriber Group
CT	Candidate Technology
C-RAN	Centralised RAN
D2D	Device-to-Device
DAS	Distributed Antenna System
DL	Downlink
DMM	Distributed Mobility Management
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
iveC	iJOIN virtual eNB 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 Functions Virtualisation
NGMN	Next Generation Mobile Networks
NIST	National Institute of Standards and Technology
NLM	Network Listening Module
NLOS	Non-Line-Of-Sight
OAM	Operation, Administration and Management
OBSAI	Open Base Station Architecture Initiative
OI	Overload Indicator
ONF	Open Network Foundation
OPEX	Operational Expenses
OSS	Operations Support System
PaaS	Platform as a Service
PDU	Protocol Data Unit
PGW	Packet Data Network Gateway
PLMN	Public Land Mobile Network
PRB	Physical Resource Block
QoE	Quality of Experience
QoS	Quality of Service
RA	Radio Access
RAB	Radio Access Bearer
RAN	Radio Access Network
RANaaS	RAN as a Service
RE	Radio Equipment
REC	Radio Equipment Control
RF	Radio Front-end
RN	Relay Node
RNC	Radio Network Controller
RNTP	Relative Narrowband Transmit Power
RP	Reference Point
RRH	Remote Radio Head
RRM	Radio Resource Management
RRU	Remote Radio Unit / Radio Resource Utilisation
RUE	Radio Utilisation Efficiency
SaaS	Software as a Service
SDN	Software Defined Networking
SDR	Software Defined Radio
S-GW	Serving Gateway
SISO	Single-Input Single-Output
SON	Self-Organising Network
TCO	Total Cost of Ownership
TD-LTE	Time Division Long Term Evolution
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication System
veNB	Virtual eNodeB
VM	Virtual Machine
WP	Work Package
XaaS	Anything as a Service

Definitions

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

Standard Terms

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

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 indoors or outdoors;
- can be within or outside of the coverage of a macro-cell.

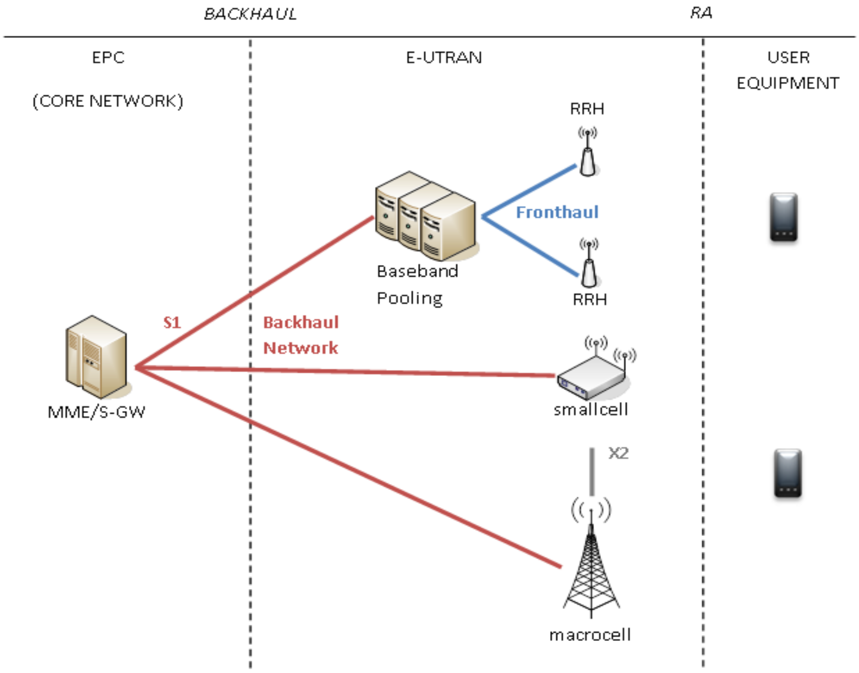
Radio Remote Head (RRH): Radio frequency processing unit without intelligence (e.g. optical to radio conversion), i.e. Radio-over-Fiber.

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

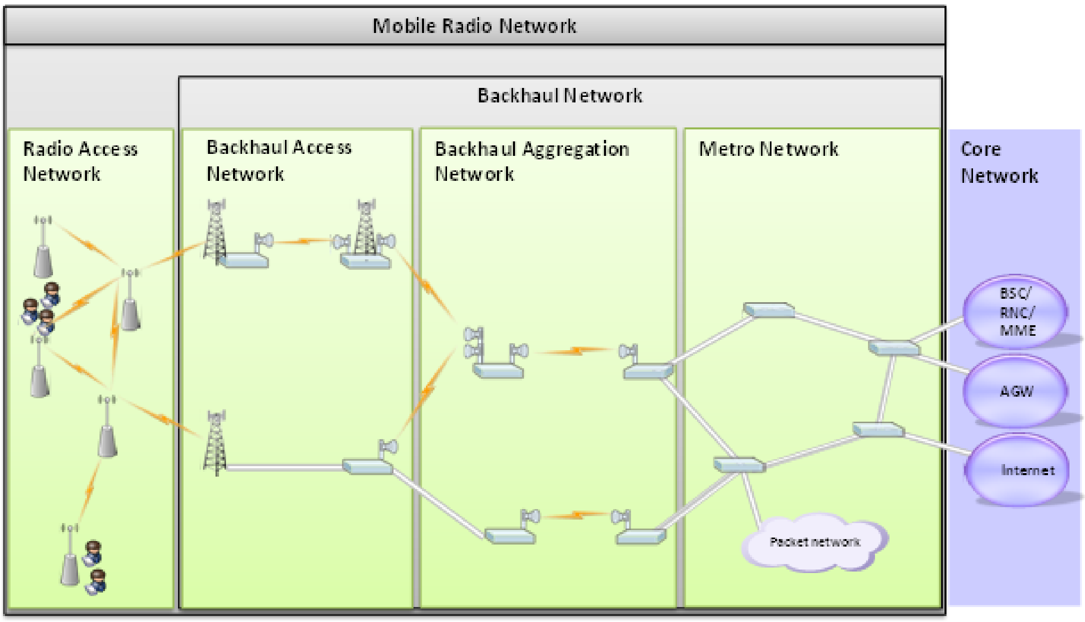
Backhaul Network: Network elements and functions required to support the backhaul operation.

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 for 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. They do not represent the final iJOIN architecture but 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): logical entity introduced by iJOIN. Cloud computing platform allowing for centralised processing and/or functional split of the lower OSI layer(s) (L1/L2/L3) usually processed in a base station. Functional split execution and configuration is done by RANaaS.

iJOIN Small Cell (iSC): logical entity introduced by iJOIN. Low power flexible radio access point implementing fully or partially the lower OSI layer(s) (RF/L1/2/3) of a base station while upper layers are handled by the RANaaS platform. It shares all other properties of a small cell. An iSC is connected to the RANaaS platform through the logical J1 interface and to another iSC through the logical J2 interface.

virtual eNB (veNB): The set of functions and interfaces which correspond to an implementation of an eNodeB according to 3GPP specifications. A veNB is composed by a RANaaS entity and one or more iSCs. Functions and interfaces are not necessarily executed or placed in the same physical or logical network entity.

iJOIN veNB Controller (iveC): : function located in the RANaaS platform and responsible for function placement, for coherent execution of the distributed functionalities, and for the management and configuration of veNB components.

iJOIN Network Controller (iNC): a functionality (or logical entity) for the control of joint RAN/BH operation. In order to minimise the impacts for the operator in terms of deployment cost and complexity, the iNC may be physically co-located with the RANaaS entity.

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 can be physically located somewhere in the RAN.

iJOIN Transport Node (iTN): entity located between iSC and RANaaS, or between RAN and core network. Each iTN is essentially a transport node operating at a different protocol stack layer depending on the particular functional split, and a set of iTNs is forming a backhaul network whose forwarding plane can be configured by an iNC.

1 Introdution

To cope with the exponentially growing traffic demand, small cells appear to be a relevant option for mobile network evolution. As radio access points are placed closer to the user, the same spectrum could be reused to increase tremendously the overall capacity of the network. 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 should be carefully considered when designing the overall system. The time of “infinite backhaul” is over, which is particularly true for small cell deployments where fibre-based backhaul will not always be present.

This deliverable recalls first the vision of the iJOIN project which embraces dense small cell deployments as a way to respond to the increasing data rate 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). It allows for classical functionalities which are usually processed within a small cell to be partially (or fully) deported in a cloud platform. Therefore, RANaaS benefits not only from the computing power but also from the centralisation gain. 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 network. The level of functional split in the RANaaS platform naturally takes into account the backhaul limitations. Other ways of optimisation may rely on the introduction of (local) network controllers which collect input from the small cells and the backhaul nodes to enhance the network management.

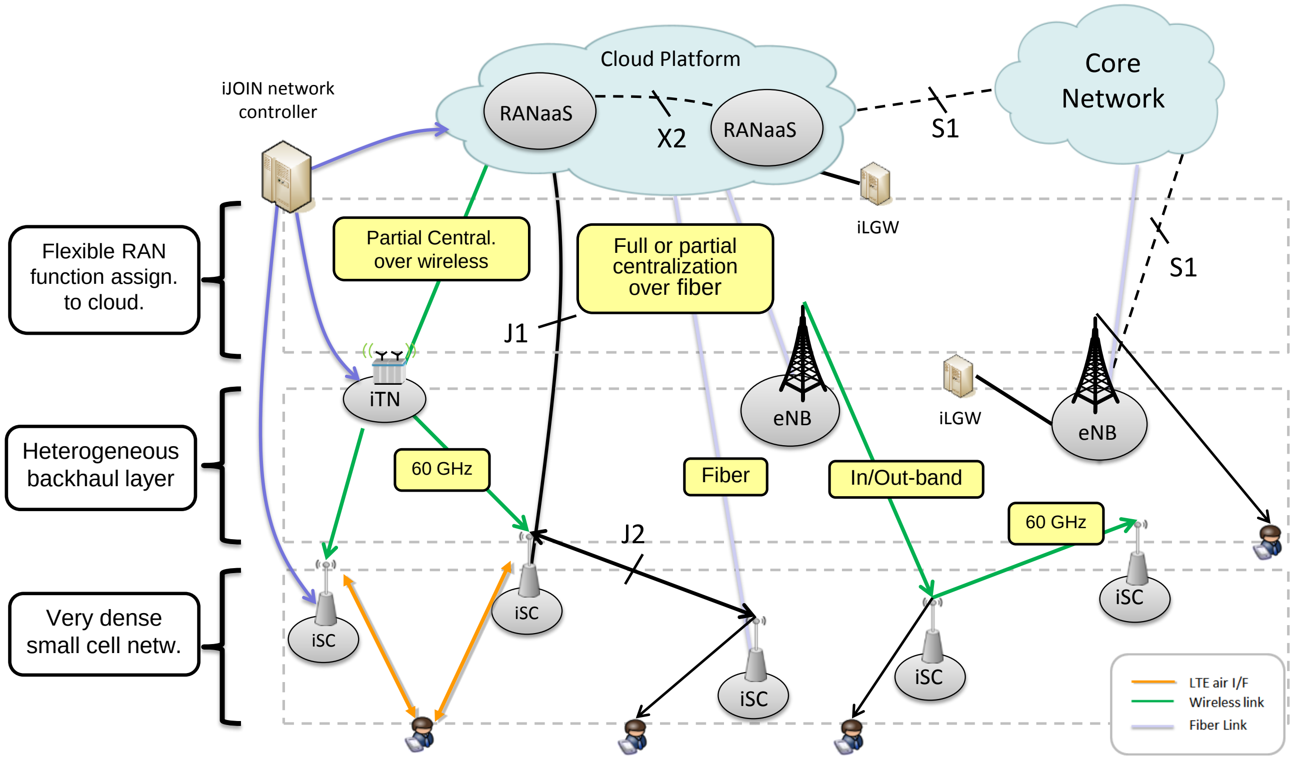


Figure 1-1: Overall View of the iJOIN System

The first part of this deliverable presents the current status of the 3GPP LTE Release 10 architecture upon which iJOIN will provide an evolutionary path. A special emphasis is paid for the main backhaul solutions (fibre and millimetre wave wireless technologies) which will support the iJOIN architecture. This architecture, geared toward dense small cell deployment, is designed with a special focus on two main iJOIN key enablers which were mentioned previously:

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

This deliverable further presents cloud computing classical concepts which will help defining the type of cloud architecture that fit best the requirements of iJOIN's 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 for defining the requirements on the backhaul in order to support the centralisation of a function and benefit from its potential gains.

One of the main goals of Work Package 5 is to serve as coordination point for the technical work packages (WP2, WP3 and WP4) and to ensure consistency between the related approaches which are under investigation (respectively at PHY, MAC/RRM and Network levels) and the proof-of-concept works in WP6.

An important role of WP5 is to define the global iJOIN system and architecture**.** Hence, this deliverable derives some preliminary assumptions and requirements in order to support the candidate technologies which are studied in WP2, WP3 and WP4[1], and (some of them) demonstrated in the test-beds produced by WP6. Some of these candidate technologies will address the use of the RANaaS platform, while others will benefit from the introduction of a network controller to jointly coordinate RAN and backhaul operation. Such initial inputs clearly impact the architecture of the system for which a first logical draft architecture is provided in this deliverable and which will be further refined as the project progresses.

Finally, to assess the benefits of using the two iJOIN key enablers, four metrics have been introduced upon which iJOIN will improve compared to the 3GPP Release 10 baseline system: area throughput, energy efficiency, utilisation efficiency, and cost efficiency. Their exact definitions are still subject of further investigations in progress.

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[1] Described in detail in the deliverables D2.1, D3.1 and D4.1

2 Executive Summary

The present deliverable is focused on the definition of iJOIN use cases and reference scenarios. Preliminary assumptions and requirements coming from the other work packages are also collected in order to draft a first architecture of the overall system.

Section 3 recalls the motivations of iJOIN, why we see 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 and heterogeneous backhaul networks.

Section 4 presents the 3GPP LTE Release 10 architecture upon which iJOIN will provide an evolutionary path. A special emphasis is dedicated to main backhaul solutions (fibre and millimetre wave wireless technologies) which will support iJOIN's 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 digs deeper into the functional split analysis. 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, Section 7 presents preliminary assumptions and requirements to support the investigated candidate technologies (CTs) studied in WP2, WP3 and WP4: some of them 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 8 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 3GPP 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 Motivation

3.1 The Still Increasing Traffic Demand in Mobile Networks

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 below:

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 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.

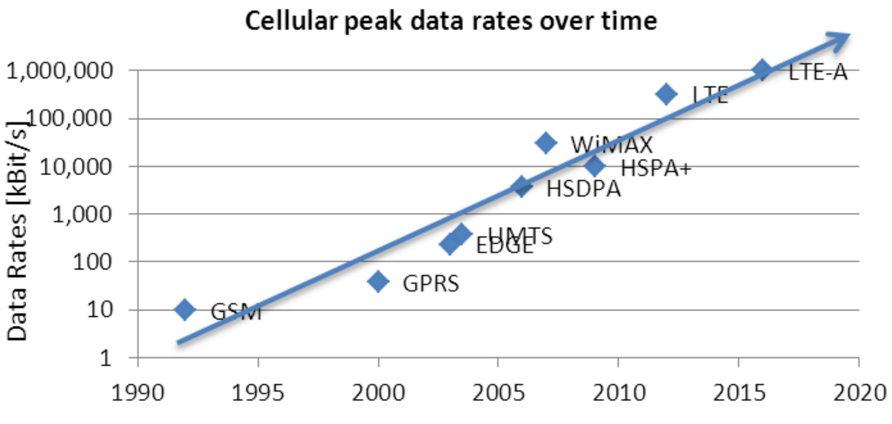


Figure 3-1: Cellular Peak Data Rates from Years 1990-2020

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].

A 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 for handling future data rate demands. Small cell networks 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 for 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 deployments are 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. Centralised-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 expensive. Hence, there is a trade-off between centralised processing requiring high-capacity front-haul links, and de-centralised processing which requires traditional backhaul 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 full 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.

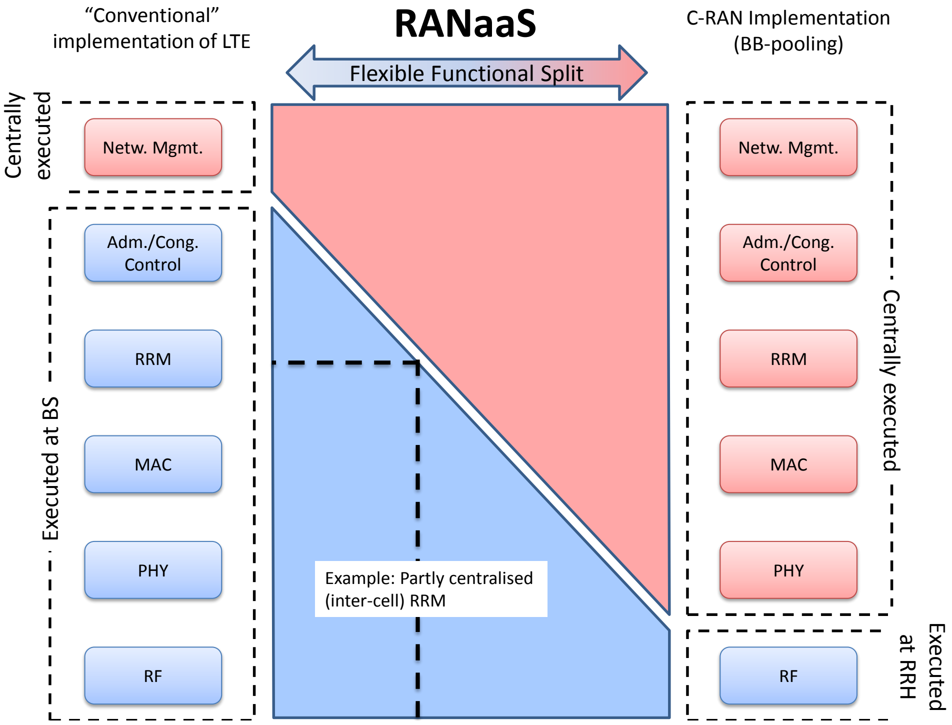


Figure 3-2: Illustration of the Flexible Implementation through RANaaS

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 (or entity). The RANaaS instance will control part of the 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 networks.

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 millimetre wave 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 this 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 is 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 millimetre wave wireless solutions with realistic parameters will also be considered.

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 presents the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) overall architecture which is further detailed in the next sections. The MME and S-GW are the connecting points of the E-UTRAN to the Evolved Packet Core (EPC). More details on the functional role of each depicted entity can be found in [22].

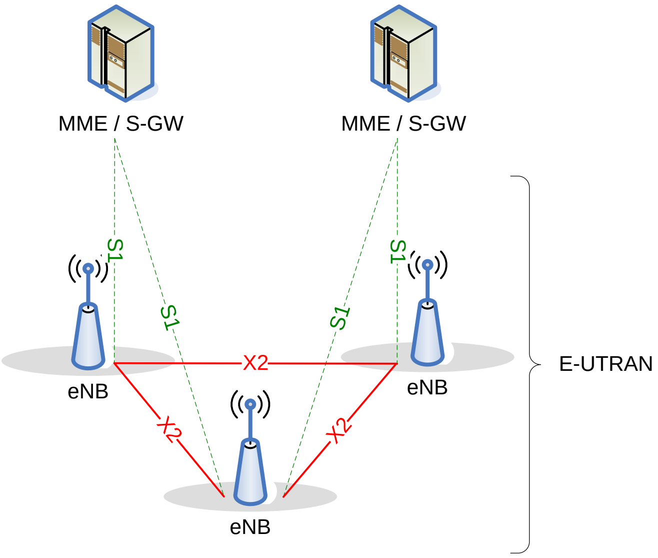


Figure 4-1: E-UTRAN Overall Architecture [22]

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 design principle of separating the handling of the control signalling from the user data traffic. According to this philosophy, the S-GW terminates the user plane interface towards the base stations (eNBs). 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 attached over the LTE RAN.

The S-GW terminates the interface towards E-UTRAN. Every UE that attaches to an EPS is associated with a single S-GW. Once a UE is associated with a S-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 S-GW will terminate the downlink (DL) path for data. If new packets arrive, the S-GW triggers paging towards the UE. The S-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 entity for control of the LTE access network. It selects the S-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 of 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, which handles 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 NodeB (eNB) includes all features needed in LTE systems to realise 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 the X2 interface. This interface has several uses 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. MME and 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, which is directly related to the maximum power they 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 per antenna port.

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 femto cell) 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.

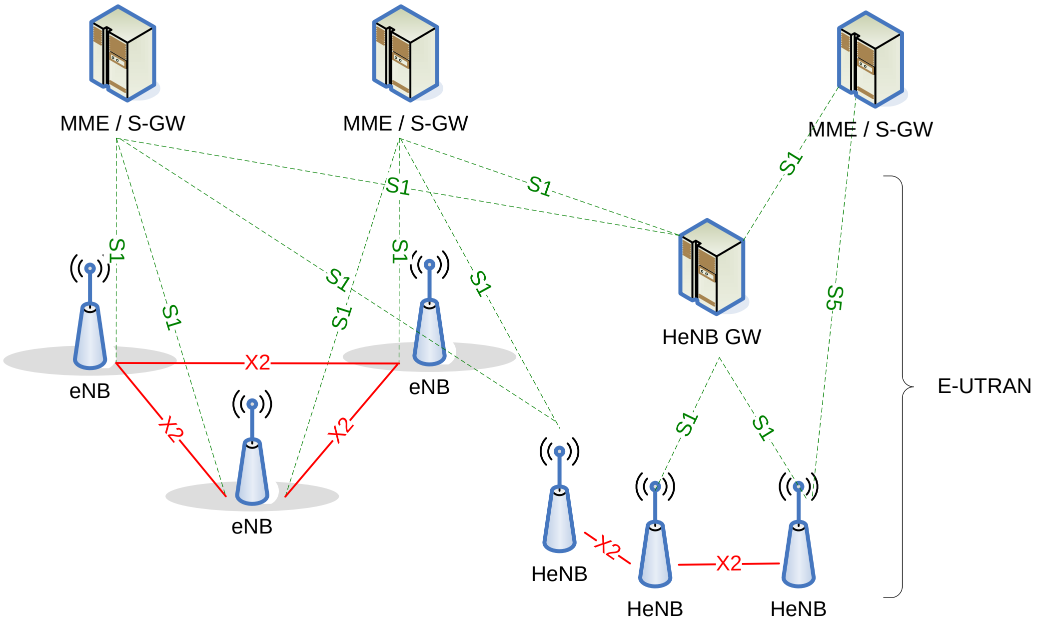


Figure 4-2: Overall E-UTRAN Architecture with deployed HeNB GW [22]

HeNBs are envisaged for residential and corporate deployment. They 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 access only to a selected group of users while denying or lowering the priority to other users. HeNBs use the end-user Internet connection (e.g. 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 networks. To deal with the interference that may come with such a deployment, Inter-Cell Interference Coordination (ICIC) methods have been defined. 3GPP LTE Release 8 and 9 saw the use of frequency domain solutions to protect the data channels with an 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 the following 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 deployments (split of control channels between primary and secondary cell/carrier).

4.1.3 Network Sharing

Network sharing between different operators has been widely used in the mobile industry, facilitated by a range of capabilities developed both in 3GPP standards and by vendors. Most of the early network sharing agreements establish a “passive” sharing where network operators achieve savings by sharing basic resources such as sites, masts, accommodation, power and air conditioning. On the other hand, although supported by standards, “active” sharing, in which operators share network equipment and potentially radio resources, has not been used widely because of the involved technical, commercial and regulatory complexities.

The interest of operators in network sharing is justified by a number of reasons: it can substantially reduce both CAPEX and OPEX, speed up network roll-outs, improve coverage and help to meet the capacity demands of increased data traffic. On top of this, in some cases the external limitations on the deployment of network elements (e.g., municipal regulations) make it mandatory to share the infrastructure between operators. However, despite its potential advantages, a drawback is the fact that sharing makes more difficult to differentiate technical aspects between cooperating operators. Operators must agree on a common technical solution, must coordinate on network growth, must share the same vendors and adopt similar practices, etc. It can be said that these limitations are responsible of the lack of success of network sharing.

This means that more flexibility is required to fully realise the advantages provided by network sharing. In the future, new details will be incorporated in the standards in order to allow for more flexible sharing that supports pooling spectrum, sharing resources asymmetrically and dynamically based on financial considerations and load, and the capacity of managing and controlling the use of resources independently by each sharing operator.

The proposed iJOIN architecture allows for additional flexibility that may help to achieve a more flexible network sharing that supports different technical solutions for the cooperating operators. It may also help to open new opportunities, e.g. the support of Backhaul as a Service (BHaaS) solutions.

4.2 Backhaul Solutions

Operators are currently considering the deployment of small cells for offering higher capacities in hotspot areas as well as better coverage in selected areas. The purpose of a backhaul network 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, and security. 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 the input of operators. For each technology, high level parameters are given as well as a priority. 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: Categorisation 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: Categorisation of Good to Ideal Backhaul [24]

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

The NGMN group also issued various white papers [25]-[27] where the requirements of wired and wireless backhaul are defined in order to support small cell deployments. The conclusions of these white papers 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 millimetre wave technologies, respectively.

4.2.2 Wired Solutions

Among wired backhaul technologies, optical fibre provides a very high performance connection with multi Gigabits per second (Gbps) throughput, for example using Gigabit Passive Optical Network (GPON) architectures. The transmission on the fibre is at present based on specific protocols such as Common Public Radio Interface (CPRI) [28], [29] and Open Base Station Architecture Initiative (OBSAI) [30]. Also ETSI is involved in standardisation activity, in particular 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].

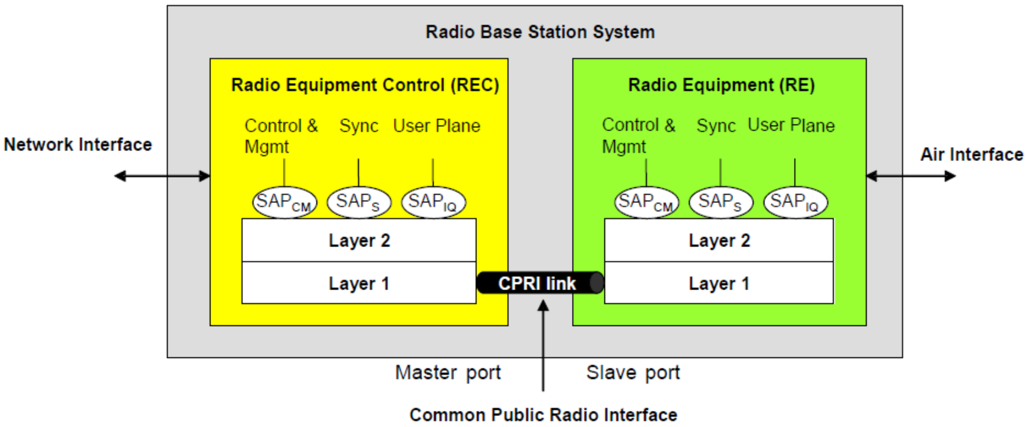


Figure 4-3: Basic System Architecture of CPRI Interface [29]

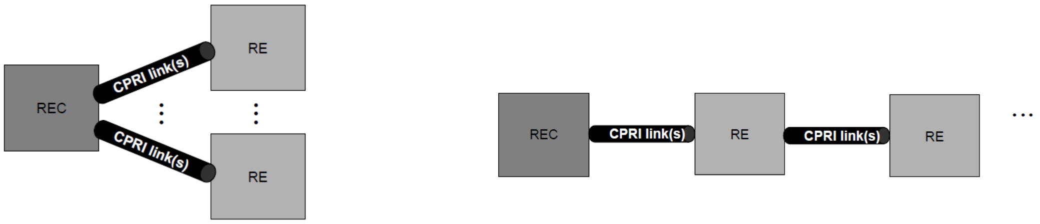
CPRI defines the Layer 1 and Layer 2 protocols for the transfer of user plane, control and management (C&M) as well as synchronization information between REC and RE as well as between two REs. The interface supports the following types of information flows:

- 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.

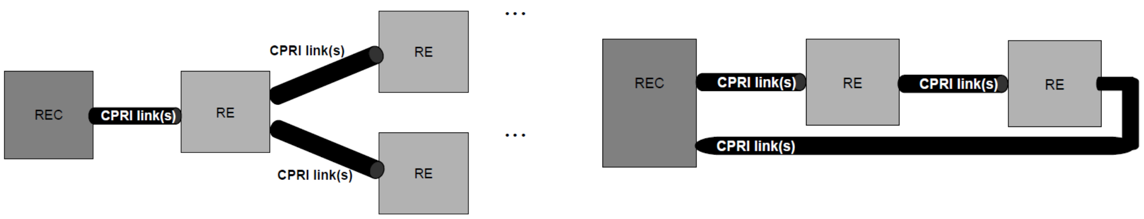
The basic configuration, shown in Figure 4-3, is composed of one REC and one RE connected by a single CPRI link. The basic configuration can be extended in several ways. For example, several CPRI links may be used to enhance the system capacity as required for large system configurations involving many antennas and carriers. It is required that an I/Q data flow of a certain antenna and a certain antenna-carrier[2] 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)
- 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)



a) Start Topology b) Chain Topology



c) Tree Topology d) Ring Topology

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[3] 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.

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[2] 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.

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

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 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;
- RP4 provides the DC power interface between the internal modules and DC power sources.

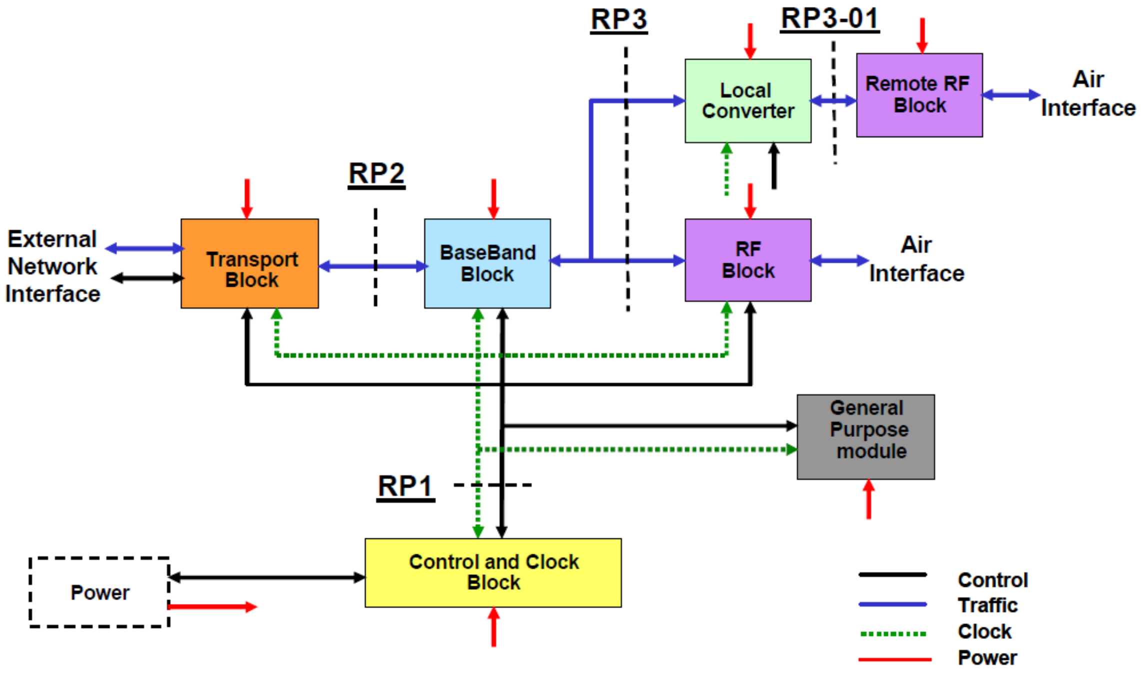

Figure 4-5: OBSAI Reference BTS Architecture [31]

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 data 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 interfaces 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 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 rates and lower availability. However, the different wireless systems have quite different characteristics [34]:

- Free space optics offers high data rates of multiple Gbps due to the very high available bandwidth and usually it operates in unlicensed spectrum which lowers cost and deployment time. However, it suffers heavily from snowfall and fog, limiting either range or availability. Due to their very narrow beamwidth, is also has to be carefully aligned and is susceptible to thermal expansion, building sway and vibration. When they is facing east to west, it 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 to 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 system with the highest frequency, hardware design is also most challenging.

To increase reliability, different wireless backhaul technologies 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 less favourable conditions.

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.

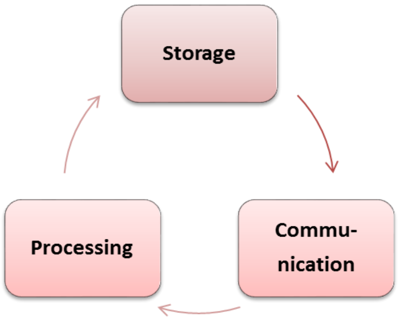

Figure 4-6: Communication, processing, and storage dependency

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 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 NIST (National Institute of Standards and Technology) definition [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.".

Full detail about the NIST definition is available in the aforementioned reference. Here, we just recap some main pillars. For NIST, the cloud computing model is done by 5 *basic characteristics*, 3 *service models*, and 4 *deployment models*.

The essential characteristics are:

- *On-demand self-service*: states that any cloud user can self-provision the needed computational resources, through a direct service entry point into the cloud platform (no human assistance, the provisioning is automated), at the time and in the amount best fitting its specific needs;
- *Broad network access*: the computational resources are accessed and used uniquely through a standard network connection (no other types of connection are viable);
- *Resource pooling*: the computational resource pool is unique and shared among all the users, according to a multi-tenancy model. The user has no way to influence the mechanisms according to which the assigned resource location is selected by the cloud platform;
- *Rapid elasticity*: the resources are supposed to be seamlessly scalable to the user, and anyhow must be able to dynamically adapt to the real time demand;
- *Measured service*: the cloud platform must have a metering capability[4], using abstraction levels peculiar to each provisioned service, supporting monitoring and accounting of resource request and usage from all the involved consumers.

The Service Models are:

- *Software as a Service (SaaS)*: consumers directly access and use an application running in multi-tenancy mode on a cloud infrastructure[5], without particular constraints on the client device and interface. The application is a black box to its users, which have no control on the resources used by the application, and can in the best case modify few selected configuration parameters;
- *Platform as a Service (PaaS)*: the cloud provider offers a platform where the user may run through the whole development and deployment cycle for his/her application. The user doesn't control the actual computational resources, in the best case he/she can modify some selected parameters of the development and deployment environment;

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

[5] 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.

- *Infrastructure as a Service (IaaS)*: the user may directly access basic computational resources, duly virtualised through an underlying hypervisor, and has full control of what he/she can install and run on top of such resources (CPU, storage, memory, network).

Finally, the Deployment Models are:

- *Private cloud*: the cloud environment is only accessible to users inside a single organization, although its physical location and operation could be hosted outside the organization itself;
- *Community cloud*: the cloud environment is only accessible to users inside a shared community of organizations, although its physical location and operation could be hosted out of any of the participating organizations;
- *Public cloud*: the cloud environment is accessible to any user, regardless the organizational affiliation; its physical location and operation is hosted by a single private, public or whatsoever provider;
- *Hybrid cloud*: this model is actually the union of two or more different platforms, private, public or community clouds themselves, which don't merge into a single super-organization, but share the technical features needed to enable data and application portability across them.

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 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 virtualised 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 are 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 are Google Application Engine, Microsoft Azure, and few other minor ones. PaaS should not be confused with IaaS resources containing a preinstalled platform (such as 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 and Salesforce.com.

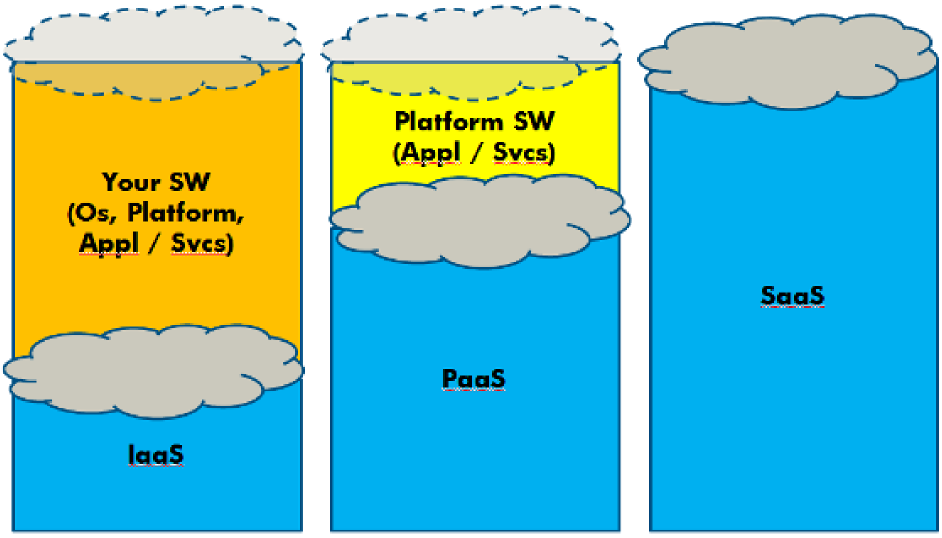

Figure 4-7: Service Models: XaaS

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

End users have a service interface (typically both an API and a user operation portal) through which they can manage virtual resources, e.g. create VMs, attach virtual disks, and configure virtual networks. 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.

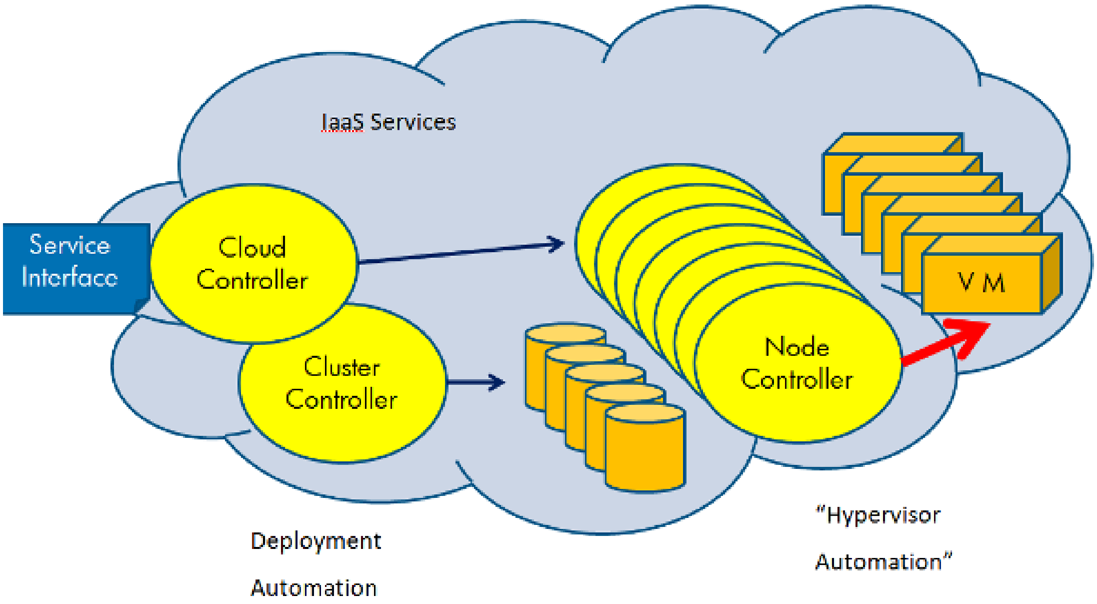

Figure 4-8: "Typical" Architecture of an IaaS Cloud Stack

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 specialised hardware, which reduces CAPEX and OPEX of EPC implementations. The next step in this development is Network Function Virtualisation (NFV) where individual network functions are virtualised and therefore become scalable and manageable [39][40]. NFV can also be applied to the EPC such that individual EPC elements are virtualised, 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].

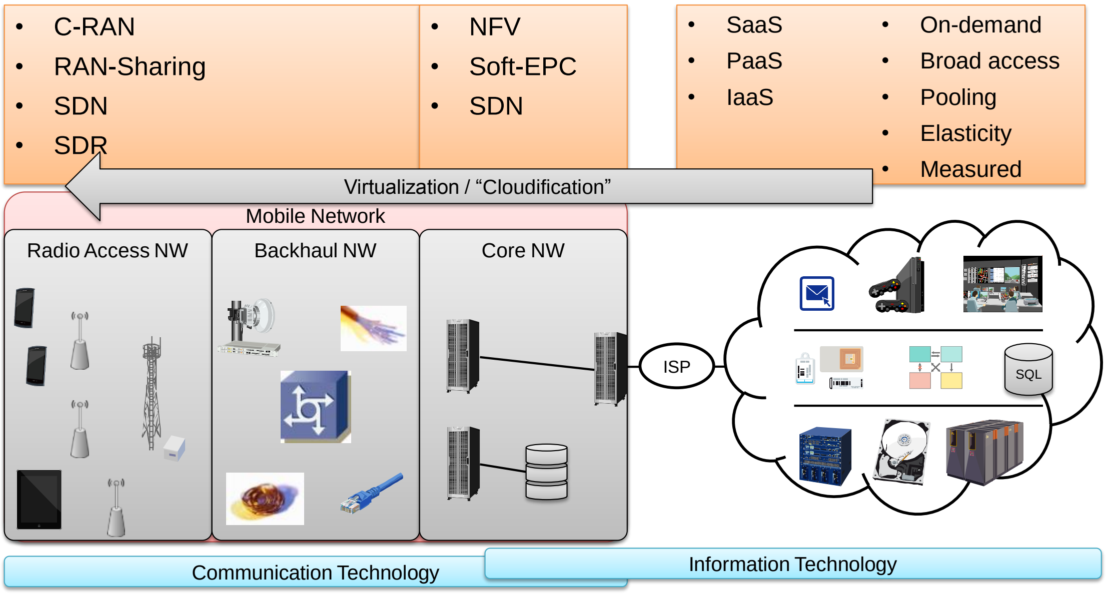

Figure 4-9: Impact of Cloud Computing on Mobile Networks

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 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 currently 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.

Another example for this development is RAN sharing [49] where resources in the radio access network are virtualised 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 virtualised 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 the deliverable D4.1). 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.

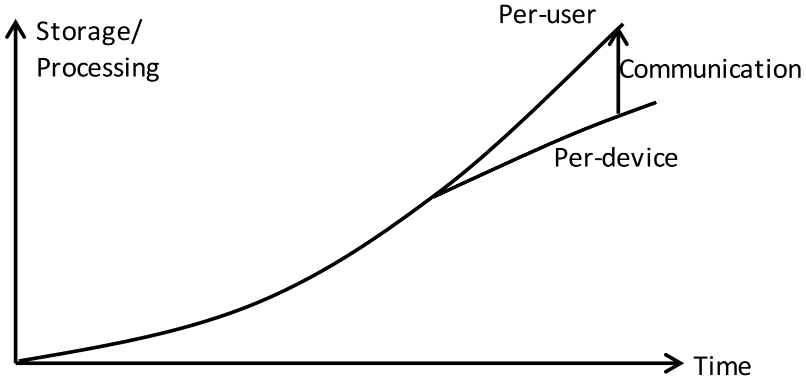

Figure 4-10: Gap between per-user and per-device capabilities over time

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 utilised. 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 the 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, hence, an optimisation 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

There exist other initiatives with similarities and differences w.r.t. iJOIN. In the following, some of the main EU projects are shortly described in order to highlight the added value provided by iJOIN, and also in some cases to identify potential synergies with other projects on topics of common interest. The projects listed below are divided in several categories in order to facilitate the reading: Small Cells, Backhaul Networks, Mobile Networks involving Cloud Architecture, Energy saving in mobile networks and finally Energy saving in data centers.

4.4.1 Small Cells

- **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, eitherstandalone or networked femtocells, with a strong focus on interference management for CSG deployment, while iJOIN will tackle the small cell deployment mainly under the picocell umbrella which is operator controlled, allowing a better backhaul control in the joint RAN and backhaul 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 characterise cloud services. "*

  On the contrary, iJOIN aims at exploiting the cloud paradigm to enable centralised radio access/backhaul design 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 be integrated in such a system as iJOIN does not rely on a particular air interface between radio access point and terminal. iJOIN will rather provide 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. iJOIN's focus is rather on the implementation, coordination, and optimisation of radio access network functionality jointly with backhaul networks. This particular aspect is not a major part of METIS. iJOIN will well complement 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.* "

In comparison to the scope of CROWD, iJOIN will focus on small cell deployments, considering the RAN and backhaul constrains. The techniques proposed by iJOIN will cover physical layer, MAC layer and network layer aspects, rather than focusing on MAC optimisation in CROWD.

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 centralised. 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*
- *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*"

Both iJOIN and MCN aim at applying the concepts developed in the context of Cloud Computing to mobile networks. However, the focus of MCN (IP project) 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 in small cell deployments, and the application of partly centralised 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 in mobile networks

- **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 recognised 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 Energy saving in data centers

In the last years, the topic of data centre energy efficiency has gained more and more attention also in the research community. Accordingly, different FP7 research projects have successfully been launched, mostly concentrated in the FP7 objective 6.3.

These projects cover a wide range of data centre elements having an impact on energy efficiency. Some of these projects (CoolEmAll, and in part GAMES) address the intrinsic efficiency of hardware and data centre facilities. Others (FIT4Green, All4Green, ECO2Clouds) address operational efficiency of data centres [6] and their characteristics exploited to achieve the minimal global energy impact in terms of reducing consumption 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 for a consistent and significant assessment of the energy saving results enabled by the new technologies.

These projects can be relevant to iJOIN, because most of them have implemented, or are implementing, their energy optimisation functions also in cloud computing environments alike the one that is baseline of 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*

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[6] i.e. how the data centre assets, such as computing equipment and facilities, can be optimally employed

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 utilisation 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 minimise 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 reducing 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 optimised regarding their energy efficiency. Finally, the ECO2Clouds will evaluate the optimisations 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 kinds 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] defines 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 refers either to a Picocell or to 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:

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

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 small cells, defines on their website small cells 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.

Remote Radio Units are implicitly excluded from this definition due to their lack of “intelligence”.

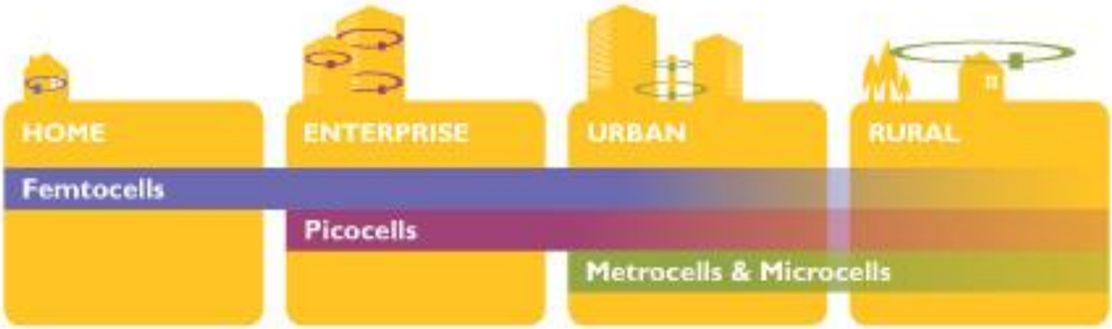

Figure 5-1: Small Cell Forum definition [53]

5.1.3 NGMN Definition

The NGMN proposes the classification showed in Figure 5-2 for 3G small cells, which is also applicable to LTE and takes as basic parameters the RF transmission power and the operational environment. The picture highlights how the different categories of small cell (microcell, picocell, femtocell) are actually defined.

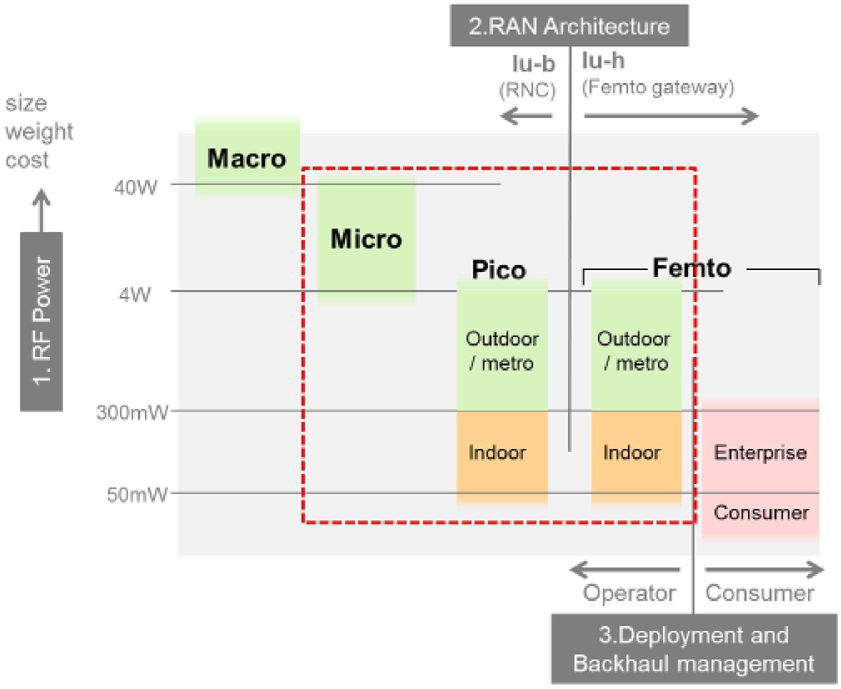

Figure 5-2: NGMN Definition

NGMN associates a number of additional characteristics to characterise a cell as "small cell", among them:

- Small cells will be located mainly outdoors at 50-300 meters apart, at about 3-6 meters above 'street level', although in some cases there is a possibility of a small cell being deployed on a rooftop or an indoor public space (sports arena or a shopping centre).

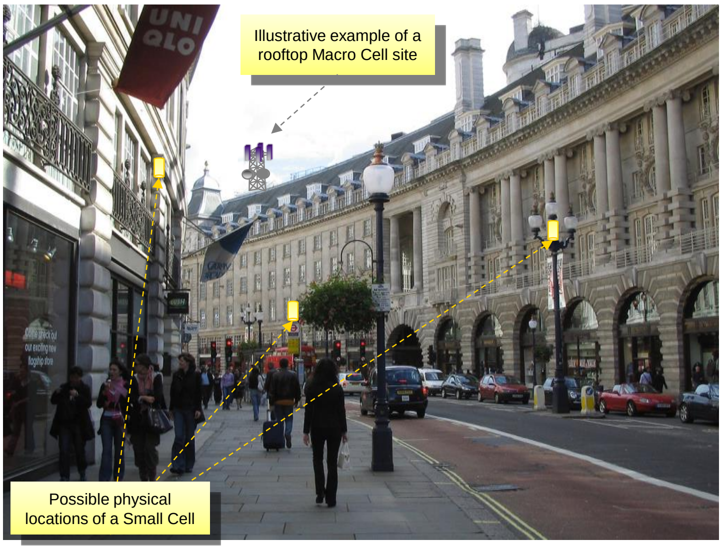

Figure 5-3: Small cell location example

- Its primary deployment motivation is to enhance capacity of data services, with a lower priority for voice services.
- Small cells are usually single cell (for the same technology) and their radio bandwidth is usually smaller.

5.1.4 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 outdoors but also indoors.

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. Femtocells could be part of the picture only if their backhaul is controlled by the same operator enabling joint optimisation of 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. 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 the joint optimisation of the RAN and the backhaul. This latter aspect may also be encompassed in pure RANaaS investigations as the degree of RAN centralisation and 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 elaborating iJOIN partners’ inputs, four main scenarios have been defined as iJOIN Common Scenarios (CS).

- Outdoor focus:
  CS1. Dense Hotspot in a Stadium
  CS2. Dense Hotpot in a Square
  CS3. Wide-Area Continuous Coverage
- Indoor focus:
  CS4. Dense Hotspot in an Airport / Shopping Mall

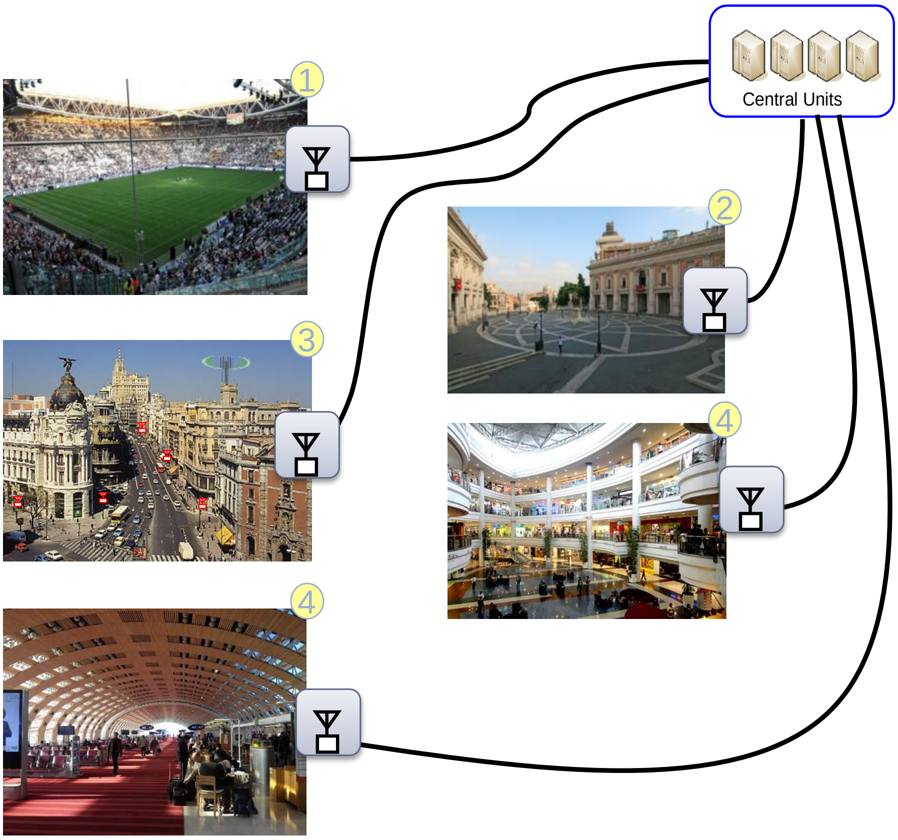

Figure 5-4: iJOIN envisaged use cases and corresponding CSs (links to central units are given as an example)

A more detailed description for each CS can be found in section 5.3. The baseline assumption is low user mobility, i.e. a speed about 3km/h, which reflects the fact that most small cells may be deployed in densely populated areas with mainly pedestrian users (as depicted in Figure 5-4). However, it can also be 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 dense 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.

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 (an iTN) with interfaces toward several small cells.

Backhauling technologies are mainly:

- Fibre based solutions: almost unlimited capacity but with high deployment costs.
- Wireless backhauling (e.g. millimetre wave 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 operators.

A current trend telecommunications is to deploy OSS and selected 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 5-5, 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 thousand 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 5-5: 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 Realisation

Even if in a stadium scenario it is possible to use other technological alternatives, like Wi-Fi, the support of high data rate services like HD video may rapidly deplete the radio resources. On the other hand, mobile solutions would allow not only for a higher spectral efficiency but also for a more consistent quality of experience.

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 may likely 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, the backhauling technology considered in this scenario could 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 wireless 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-fibre” 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 & Utilisation 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

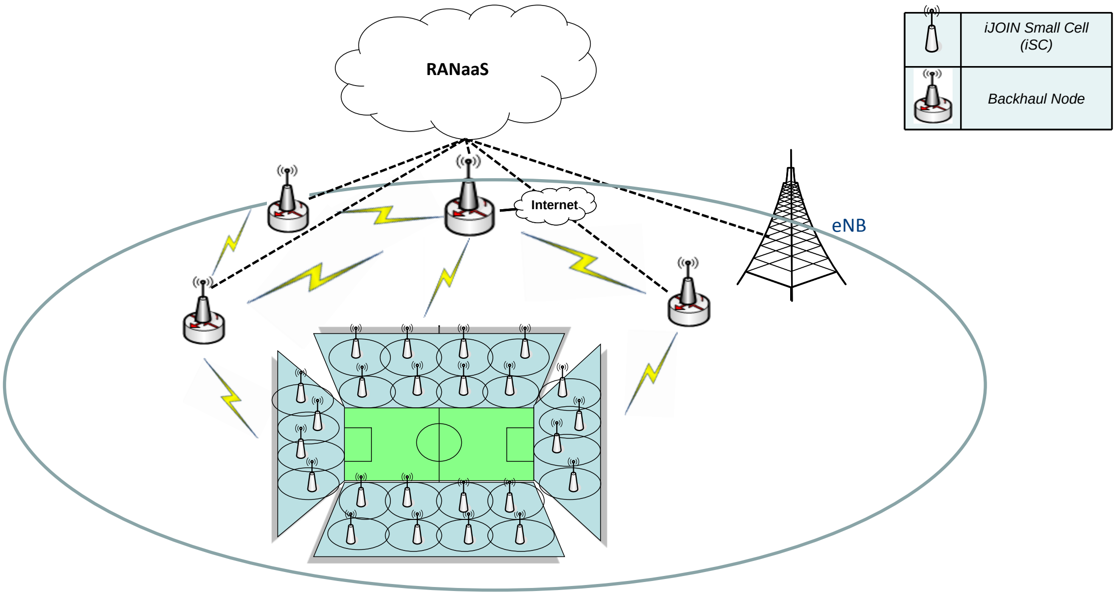

Figure 5-6: Dense Small Cell Deployment Example in a Stadium

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 iSCs illustrated in Figure 5-6:

- The optional deployment of a local gateway (backhaul node) which covers the stadium area is required to control traffic and facilitate interference management.
- Centralised Inter Cell Interference Coordination (ICIC) should be applied to avoid inter-cell interference at the edges of each iSC. 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 prioritise 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 5-6. 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 5-7: 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 Realisation

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 summarised 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 & Utilisation 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 characterised 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

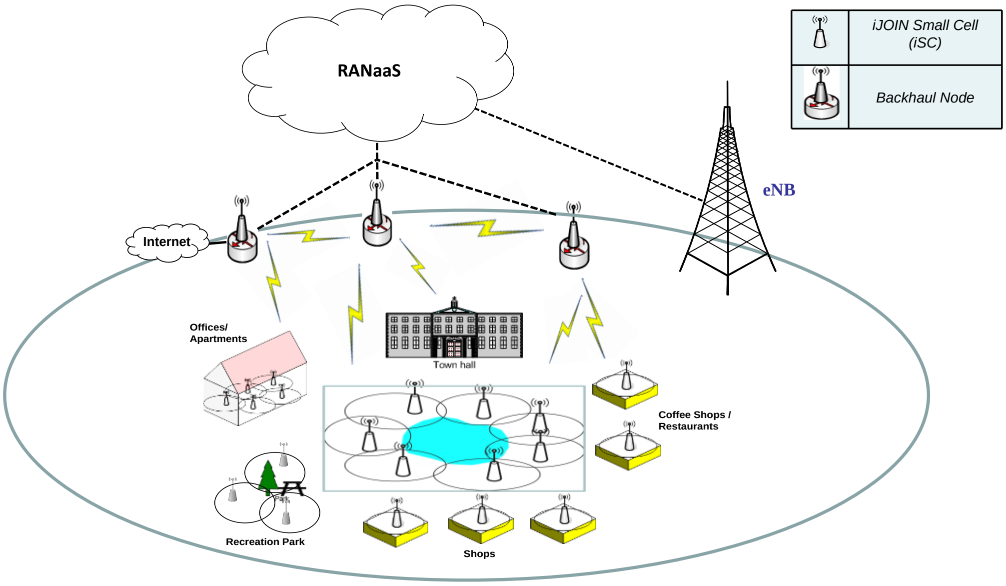

Figure 5-8: Dense Small Cell Deployment Example in a Square

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 5-8:

- The optional deployment of backhaul nodes for clusters of small cells can be defined to provide locally centralised 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 centralised 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 utilisation 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 5-9 (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)[7]. 60% of traffic is originated indoors, the rest outdoors. Propagation conditions would be characterised 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)
    - 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 5-9: Macrocell and Several Outdoor Micros in Madrid City Centre

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[7] These data are based on actual (obfuscated) activity statistics of Telefonica's network and are proposed only as an example.

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 characterised 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 utilisation 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 Realisation

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.
- **Utilisation & 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

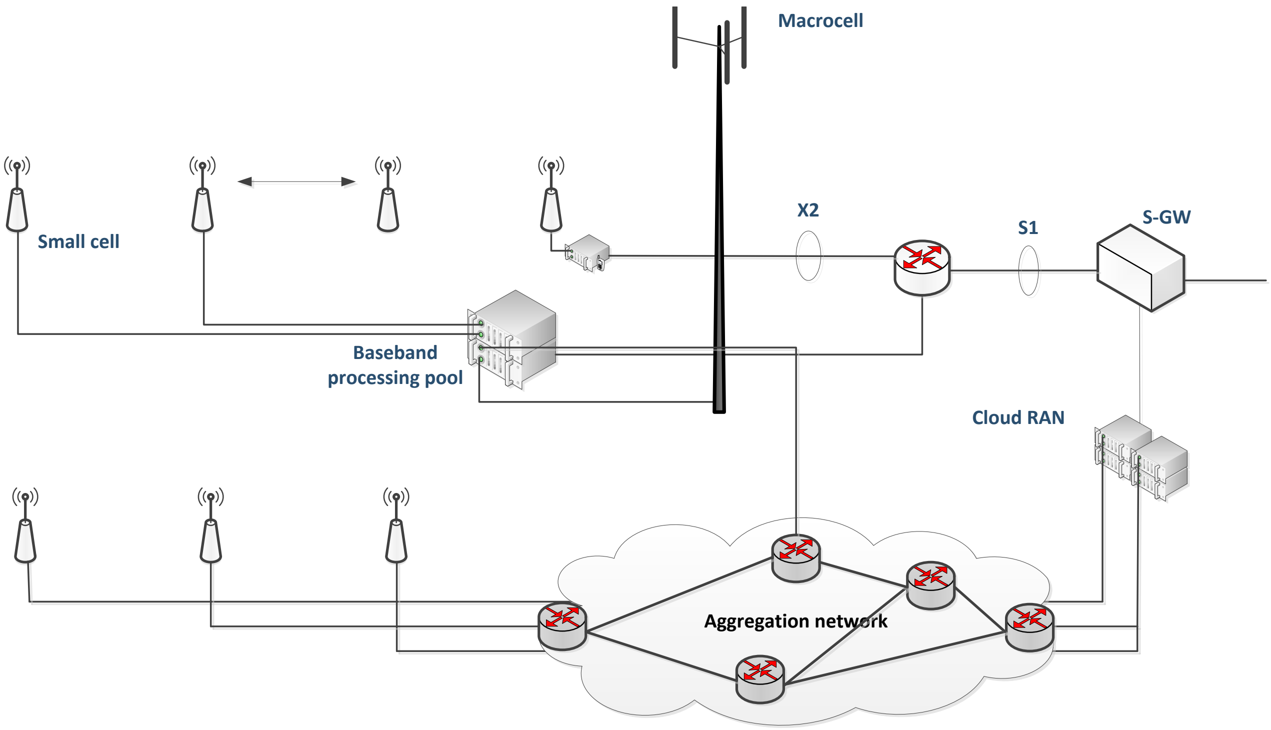


Figure 5-10: Wide Area Continuous Coverage Deployment Example

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 centralised 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 5-11, 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 5-12, 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 5-11: 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 5-12: 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 Realisation

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

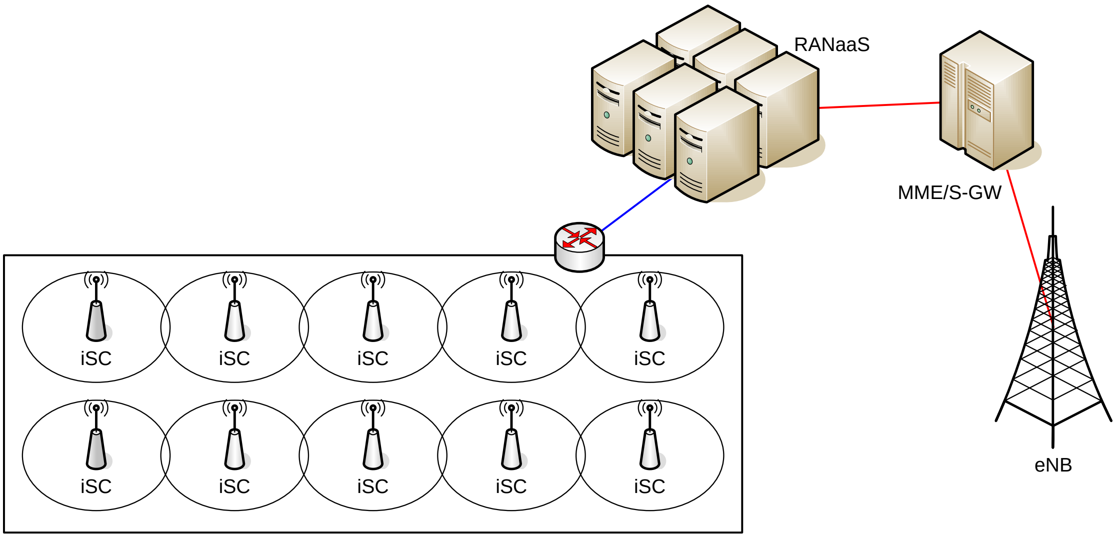


Figure 5-13: Dense Small Cell Indoor Deployment Example

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

- 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.
- Off-loading towards other radio access technologies, like Wi-Fi, or directly to Internet (LIPA, SIPTO).

6 Functional Split

One of the key ideas of iJOIN is to centralise some functionalities usually processed in an eNB into the RANaaS platform. Compared to the C-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, and computation requirements are also derived to facilitate the evaluation of the backhaul requirements in the case of centralisation.

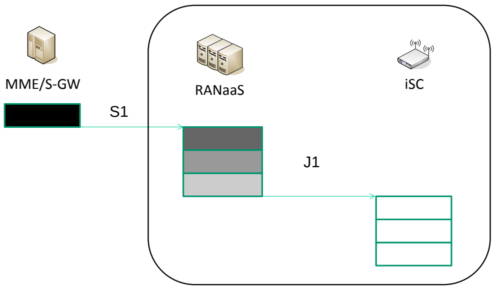
In order to derive a coherent architecture, WP2, WP3 and WP4 have also gathered and provided a consolidated set of assumptions and requirements of the specific Candidate Technologies (CTs) which are investigated in the individual WPs. Such a consolidated view is used to derive a preliminary draft logical architecture based on the 3GPP LTE architecture.

6.1 RAN Functional Split

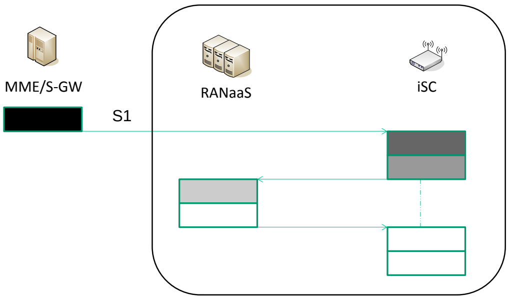
6.1.1 High Level Split Options

Given a certain functionality subject to split and centralisation (single functionality drill-down will be provided in Section 6.1.2), there are in general different possible options in terms of processing flow going from and to backhaul into the RANaaS subsystem. The possible models are as follows:

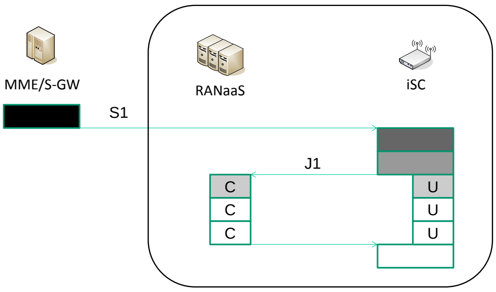
1. Straight flow: taking the downlink case as an example, the packets from EPC go into the RANaaS layer, which performs its own processing, then forwards the packets to iSCs. This option can be used when higher layer functionalities are centralised, while lower layers are implemented in iSCs.

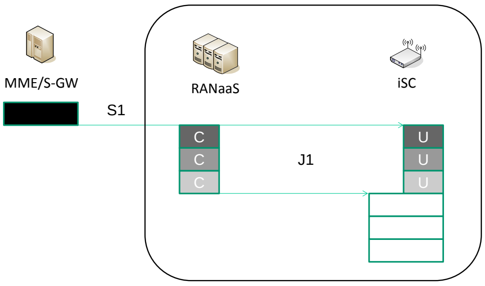


2. Forward-backward flow: the packets coming from EPC are sent to iSCs, which decide what must be sent back into the RANaaS, centrally processed and finally returned again to iSCs. This option can be used when higher layer functionalities are still implemented in iSCs (e.g. chyphering), while intermediate radio protocol functionalities are managed by RANaaS (lower layers, e.g. PHY, are still implemented in iSCs).



3. Control/user plane separation: the models 1 and 2 can be modified by assuming a strict separation between user data and control planes, whereas the RANaaS can only process in the control plane.





iJOIN project investigates and evaluates the applicability of these general models to realise the targeted functional split.

6.1.2 Functionality Analysis

Table 6-1 provides an overview of the considered functionality which may be centralised in the RANaaS platform. A more detailed description of the individual functionality is given in D2.1, D3.1, and D4.1. Table 6-1 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 identifies in which parameters the computational needs scale.
- Centralisation benefits: defines whether the RAN functionality provides gains if it is centralised or not. Note that in WP2 and WP3, centralisation usually applies to pushing PHY and 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 centralisation of network management functionalities at higher levels of the protocol stack, and is 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 or 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, D2.1, D3.1, and D4.1 describe how the proposed CTs make use of the functional split, i.e., whether a technology may be partly centralised. 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: Centralisation of different network functionalities

Functionality	WP scope	Computational Needs	Centralisation Costs/Impact	Centralisation 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 centralisation. High gains due to centralisation. 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 centralisation. High gains due to centralisation	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 centralisation. High gains due to centralisation	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 centralisation. High gains due to centralisation	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 centralisation. High gains due to centralisation	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 Optimisation	WP4	O(#backhaul nodes)	Moderate cost to implement centralisation. High gains due to centralisation	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 realise.	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 iJOIN Candidate Technologies

D2.1, D3.1, and D4.1 provide a detailed description of Candidate Technologies (CTs) which are investigated within iJOIN. Each report is targeted to a restricted set of layers, i.e. D2.1 deals with PHY layer CTs, D3.1 addresses MAC and RRM CTs, and D4.1 handles network management CTs.

These CTs are built around at least one of the two main pillars of iJOIN, namely the RANaaS concept and joint RAN/backhaul operation. They provide assumptions and requirements which will impact the iJOIN architecture (described in next sections). As an evolution of the 3GPP architecture, new entities and associated interfaces are introduced.

The three following tables regroup the CTs presented in D2.1, D3.1, and D4.1 with an emphasis on the primary (but not necessarily only) iJOIN concept which is targeted.

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 Centralised Inter-Cell Interference Cancellation	RANaaS
CT2.6	Data compression over RoF	RANaaS joint RAN/BH design
CT2.7	Millimetre wave 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 decentralised mechanisms for joint RAN and backhaul optimisation 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 utilisation 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 Optimised 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
CT4.2	Network Wide Energy Optimisation	joint RAN/BH design
CT4.3	Joint Path Management and Topology Control	joint RAN/BH design
CT4.4	Routing and Congestion Control Mechanisms	joint RAN/BH design
CT4.5	Network Wide Scheduling and Load Balancing	joint RAN/BH design
CT4.6	Backhaul Analysis based on Viable Metrics and “Cost” Functions using Stochastic Geometry	joint RAN/BH design

7 Preliminary iJOIN Architecture Definition

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

7.1 Baseline Architecture

The baseline system considered by iJOIN relies on 3GPP LTE Rel.10 specifications [22], and it represents the starting point for performance comparisons, potentially used by all CTs as a reference for gain evaluations during the project lifetime. Its logical architecture is depicted in Figure 7-1.

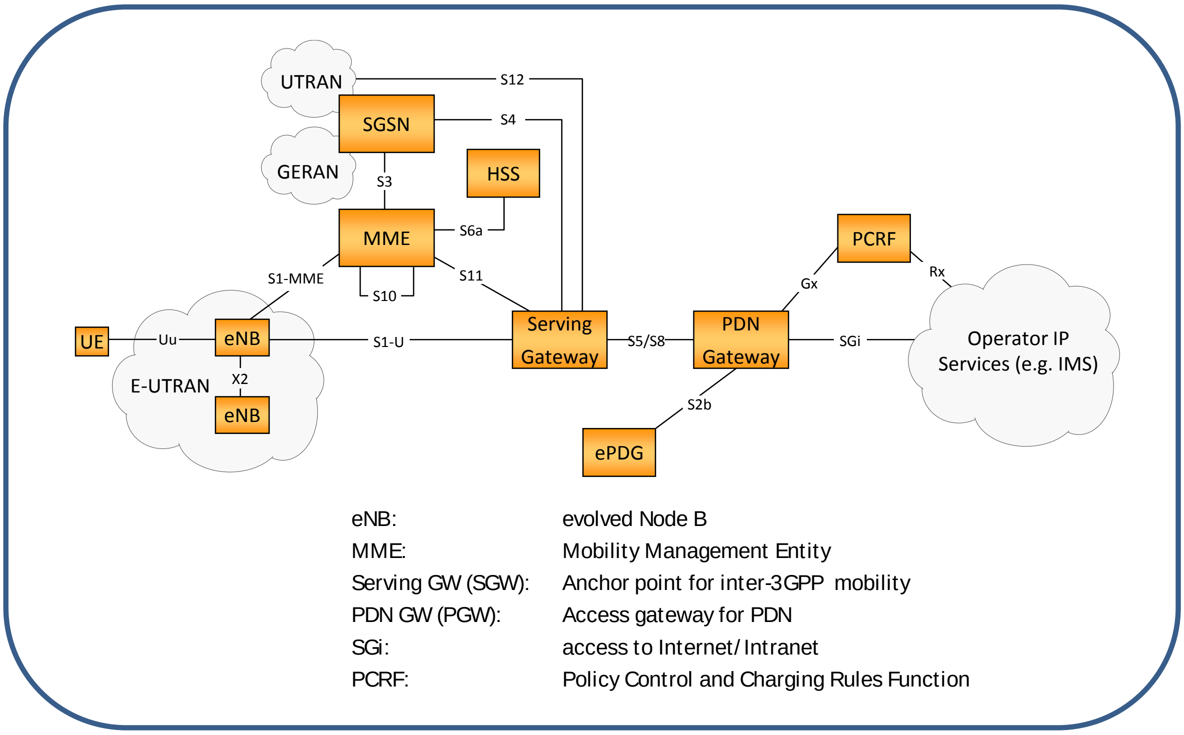


Figure 7-1: iJOIN Baseline System Logical Architecture

Figure 7-2 and Table 7-1 further describe the functional split in the baseline architecture, as reference information to move forward to specify the iJOIN architecture.

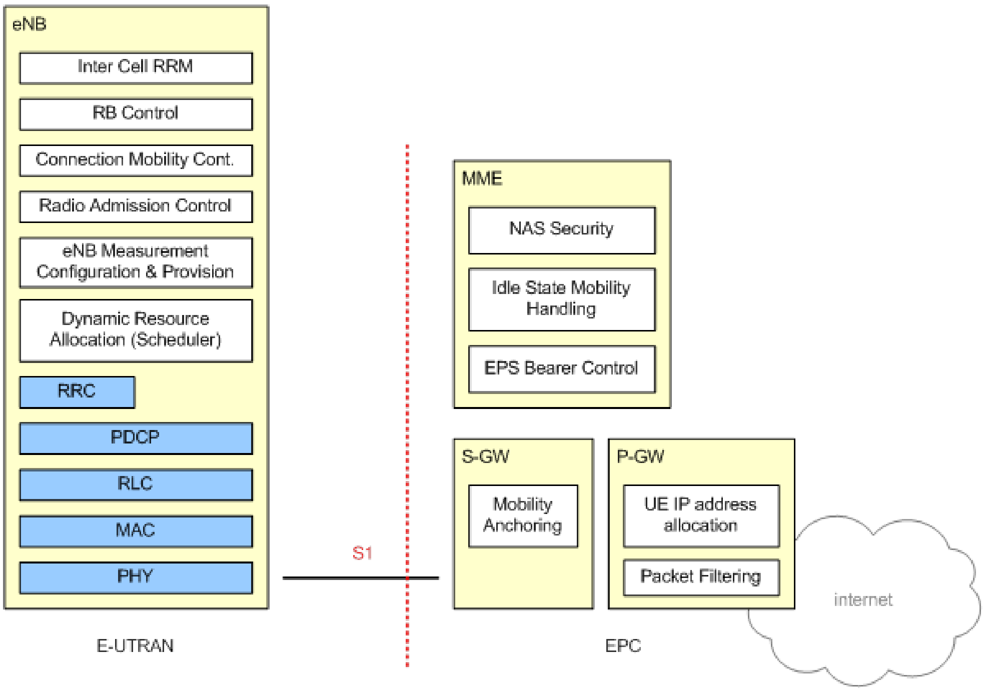


Figure 7-2: Functional Split between E-UTRAN and EPC [22]

Table 7-1: Functions Hosted by the E-UTRAN / EPC Logical Entities [22]

eNB	• **Radio Resource Management**:
	  • Radio Bearer Control
	  • Radio Admission Control
	  • Connection Mobility Control
	  • Dynamic allocation of resources to UEs in both uplink and downlink
	• **Measurement** and measurement reporting configuration for mobility and scheduling
	• IP header compression and encryption of user data stream
	• **Selection of an MME at UE attachment**
	  • When no routing to an MME can be determined from the information provided by the UE
	• **Routing of User Plane data towards Serving GW**
	• Scheduling and transmission:
	  • Paging messages (originated from the MME)
	  • Broadcast information (originated from the MME or O&M)
	  • Public Warning System (PWS) messages (originated from the MME)
	• CSG handling
	• Transport level packet marking in the uplink

MME
(3GPP TS 23.401)
	• NAS signalling
	• NAS signalling security
	• Authentication
	• AS security control
	• Bearer management functions
	  • Including dedicated bearer establishment
	• Idle mode UE reachability
	  • Including control and execution of paging retransmission
	• Tracking Area list management
	  • UE in idle and active mode
	• PGW and Serving GW selection
	• MME selection for handovers with MME change

	• Inter CN node signalling for mobility between 3GPP access networks; • SGSN selection for handovers to 2G or 3G 3GPP access networks • Roaming • Support for PWS message transmission; • Optionally performing paging optimisation. ◦ The MME should not filter the PAGING message based on the CSG Identities towards macro eNBs.
Serving GW (S-GW) (3GPP TS 23.401)	• Local Mobility Anchor point for inter-eNB handover • Mobility anchoring for inter-3GPP mobility • E-UTRAN idle mode downlink packet buffering and initiation of network triggered service request procedure • Packet routeing and forwarding • Lawful Interception • Transport level packet marking in the uplink and the downlink • Accounting on user and QCI granularity for inter-operator charging • UL and DL charging per UE, PDN, and QCI
PDN Gateway (P-GW) (3GPP TS 23.401)	• UE IP address allocation • Per-user based packet filtering (by e.g. deep packet inspection) • Lawful Interception • Transport level packet marking in the uplink and the downlink • UL and DL service level charging, gating and rate enforcement • DL rate enforcement based on APN-AMBR

7.2 iJOIN Logical Architecture

To support the two key concepts of iJOIN, the architecture given in Figure 7-3 has been defined. While still a work-in-progress at this stage of the project, the iJOIN architecture seamlessly extends the 3GPP LTE Rel.10 architecture, which represents our baseline system as stated previously. The logical entities and interfaces in this architecture will be defined in the following subsections.

In the picture, the leftmost side represents a standard 3GPP LTE eNodeB-based topology, whereas the right side shows the evolutionary iJOIN architectural model. The picture highlights how 3GPP LTE and iJOIN topologies can be interconnected entities in a unique composite architectural scenario.

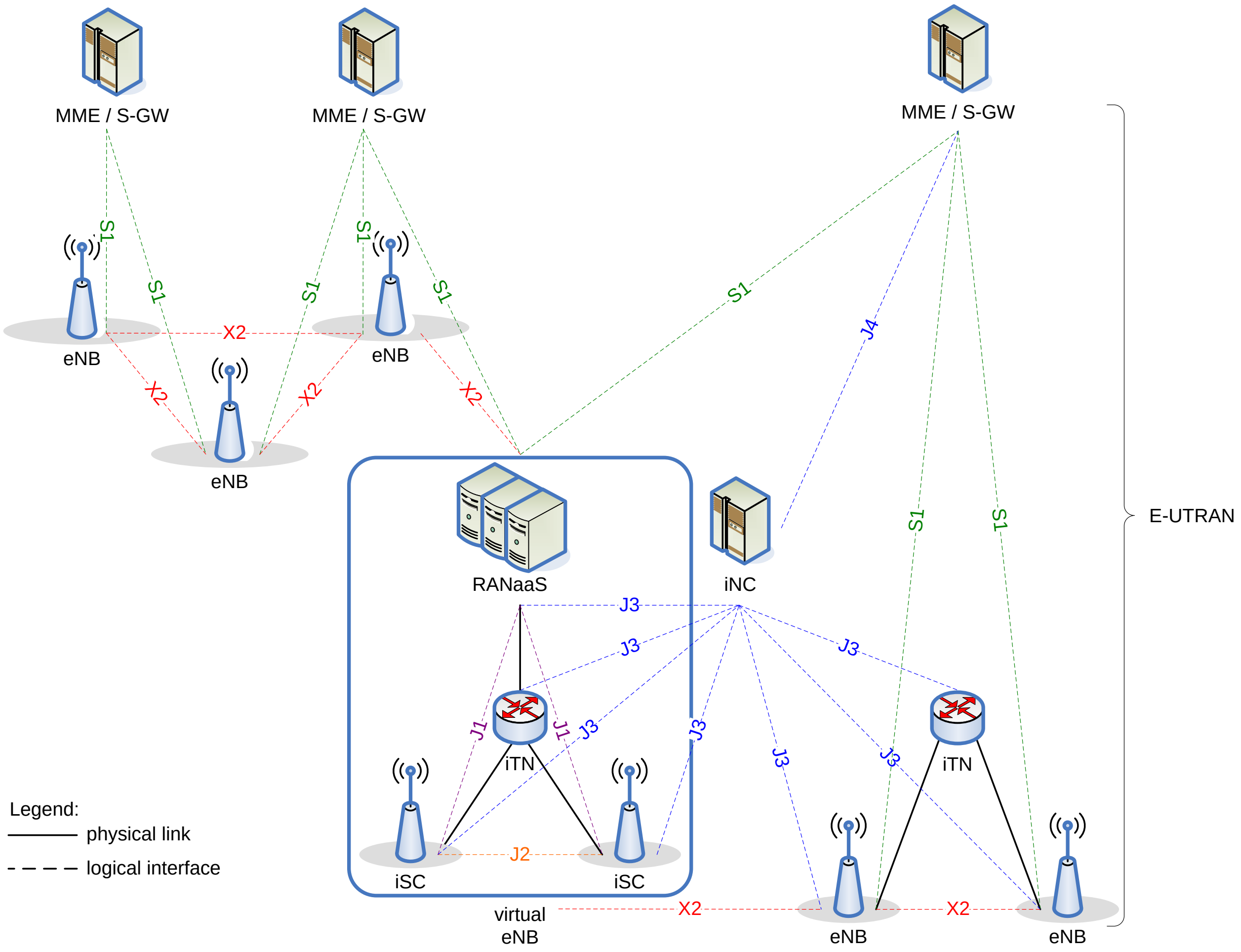


Figure 7-3: Preliminary Definition of iJOIN Architecture

7.2.1 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 are 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.

The iSCs are connected to the RANaaS platform through the logical J1 interface (see Figure 7-3), a new interface introduced by iJOIN, which is defined in 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. The J2 interface introduced by iJOIN may extend the current X2 interface. In Figure 7-3 the iNC is also depicted; it communicates with iSCs (and all the modules except MME/S-GWs) through the logical J3 interface (while J4 interface is introduced for the communication between iNC and MME/S-GWs). J3 and J4 interfaces will be introduced at a future stage.

7.2.2 iJOIN virtual evolved Node B

The main step forward from the 3GPP LTE architecture towards the iJOIN architecture is the evolution of the LTE eNB into the new logical entity called virtual evolved Node B (veNB). A veNB is composed of one or more iSCs combined with the RANaaS platform. A veNB maintains the same external interfaces as a 3GPP LTE eNB in order to maximise backwards-compatibility, i.e., X2 between eNBs and veNBs as well as S1 between veNBs and EPC (see subsection 4.1.1.3) as shown in Figure 7-3.

However, the veNB allows for a flexible distribution of RAN functionalities between the RANaaS platform and the iSCs through the two new interfaces J1 and J2. A first evaluation of the potential centralisation gains and challenges per functionality can be found in Table 6-1. This RAN functional split is controlled by the iJOIN veNB Controller (iveC). Figure 7-4 shows the main differences between physical eNB and virtual eNB.

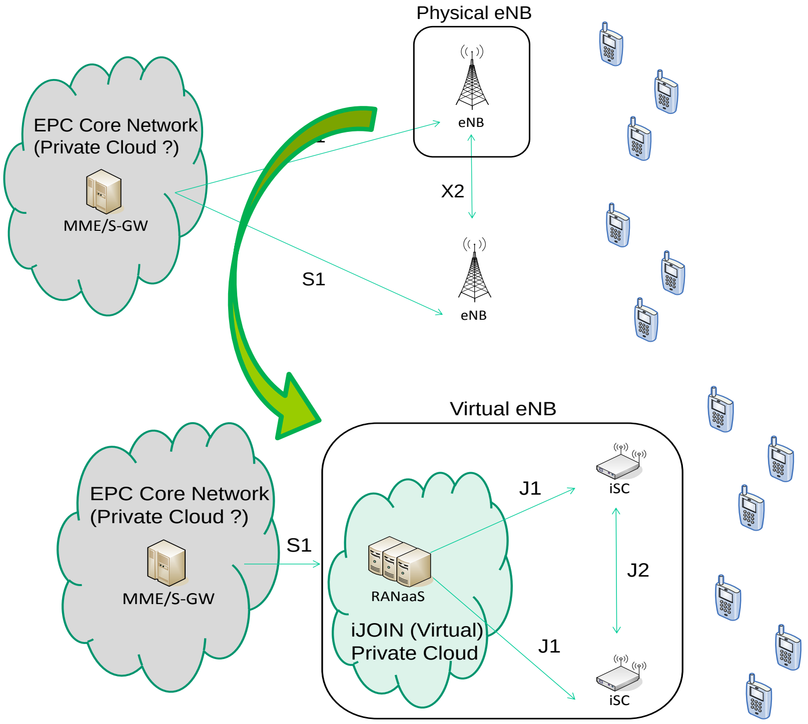


Figure 7-4: Evolutionary step from physical eNB to virtual eNB

The main characteristics of a veNB are:

- **Functional decomposition**: The functionality executed by a veNB can be decomposed in modules. Each module implements a functionality of the RAN protocol stack such as PHY layer, MAC layer, or RRC layer procedures.
- **Functional split**: Each of the modules may be located either locally at the iSCs or centrally at the RANaaS entity. Furthermore, only a subset of all modules may be executed at the iSCs while another subset is implemented at the RANaaS entity. The interaction between modules, the placement of modules, and the interaction of modules with other logical entities is controlled by the iJOIN virtual eNB controller (iveC).
- **Functional interworking (C-Plane)**: iJOIN defines interfaces that are used for the coordination and control of functional split in order to transparently configure which modules are executed at the iSC and which modules are executed in the RANaaS entity.
- **Logical unity**: On a black-box view, e.g. from the core network perspective, the veNB appears as a standard eNB in order to ensure compatibility with 3GPP specifications, hence:

  - veNB external interfaces (S1, X2) terminate towards the EPC or other eNBs/veNBs;
  - each veNB has only one instance of the S1 or X2 interfaces.

The main differences between eNB and veNB are summarised by Table 7-2:

Table 7-2: Comparison of 3GPP LTE eNB and iJOIN veNB

eNB	**veNB**
Physical "box"	Multiple distributed "boxes"
Either fully centralised (C-RAN) or fully decentralised	Partially centralised
Running on special HW	Partially running on general purpose HW (ISS – Industry Standard Servers)
Embedded SW	Mix of embedded and virtualised software
Full embedded RAN stack	Part of the RAN software executed on the RANaaS

The following subsections provide a more detailed description of the virtual eNB concept and its integration in the iJOIN logical architecture.

7.2.2.1 veNB domain coverage and identification

In general, a veNB is made up by the combination of iSCs and RANaaS nodes. It's not immediate, however, to determine the exact boundary of a veNB in terms of covered cells and geographical areas. Such a choice is paramount to define the architecture and the functional distribution across it. In general, the most flexible choice is that a veNB can collect multiple geographical cells (sectors inside an eNB, according to LTE terminology). This means that a veNB can include more iSCs connected to one RANaaS module. Including multiple cells is a must-have in order to enable a RANaaS to control Coordinated Multipoint (CoMP) among different cells.

Clearly, each veNB must be individually tagged, and have its own unique veNB-ID. Less obvious is how unique veNB identifiers are associated to the IDs of the underlying RAN entities. In other words, since every single cell has its own ID, it must be defined if these cell IDs are maintained inside the containing veNB, and if the lower-level IDs are visible or hidden to UEs in the cell coverage. There has been some investigation about this matter. The most convincing conclusion seems to be a transposition of the 3GPP model to iJOIN: i.e., single iSCs inside a veNB become equipollent to sectors inside an eNB.

At a given instant in time, a UE can be connected to one veNB only. The information about the exact individual iSC connected to the UE is identified and traced as well. Routing of traffic to and from the correct cells is up to the veNB control functionality. Given the one-to-one UE-veNB association, the joint transmission and reception for a particular cell is performed within one veNB, and consequently the J1 and J2 interfaces are part of the veNB. This guarantees the lack of any conflict between the iJOIN model and the legacy 3GPP LTE specification.

7.2.2.2 Functional distribution inside veNB

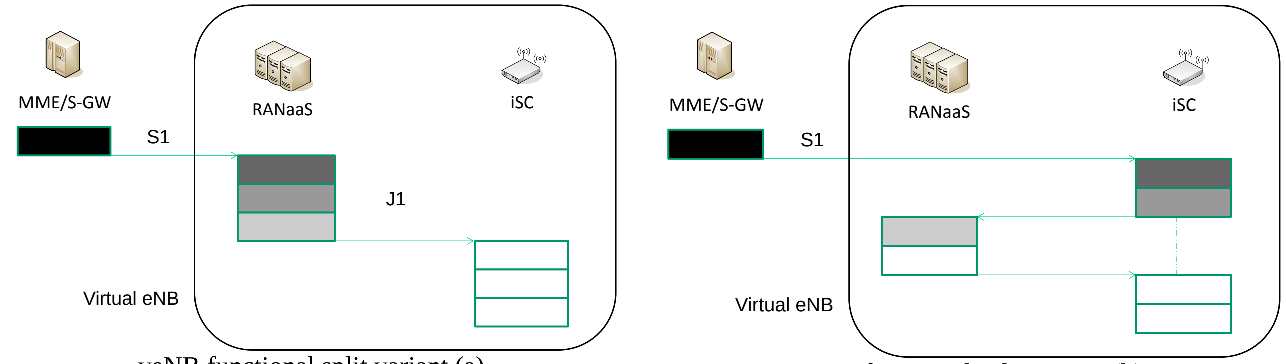
Being a "composite" element, the veNB needs to have a control and orchestration function, able to dispatch the different tasks inside the veNB according to the functional split policies and likely to some local parameters (backhaul limitations, RANaaS actual capacity, etc.). The related questions are:

- Where in the veNB is this control function located?
- What are the (static and dynamic) control policies applied by the controller?

The latter question is clearly tied to the details of functional split on the involved CTs. As far as the first point, the control of functional split should basically be located in the RANaaS element, unless later design considerations drive to different decisions. A centralised control, if viable, is far simpler and reliable than more complex distributed control models.

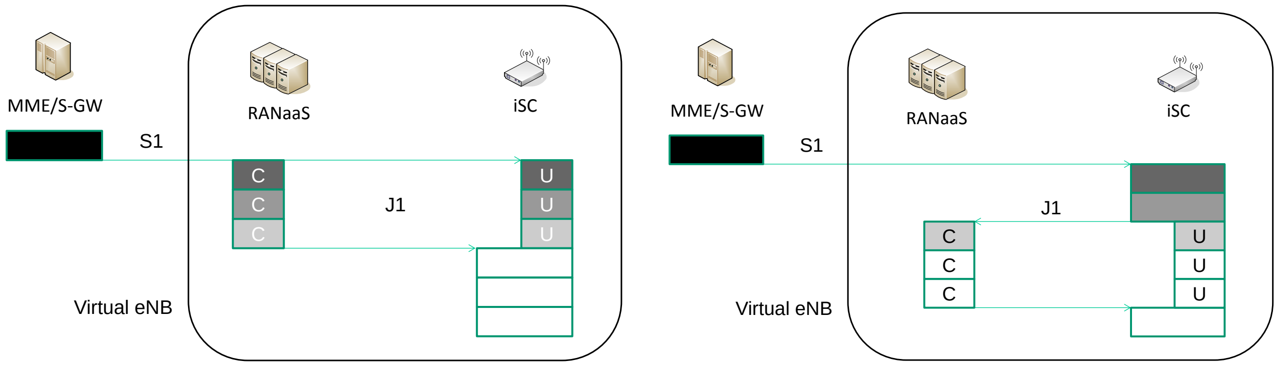
Different CTs consider different possible functional split solutions. In some cases in principle one can foresee even a flexible functional split of RAN functionalities. Based on the different functional split solutions applied to individual CTs as well as the necessity to operate joint transmission and reception mechanisms, the iJOIN architecture will require a control and orchestration function, able to dispatch and manage the functional split. In order to implement such a control function (called iveC, i.e., iJOIN virtual eNB controller), it is necessary to first determine where the control function is located and what the control policies are. The control of the functional split and in general of the veNB is located within the RANaaS element itself. It interacts with the iNC (see its description in 7.2.3) to get RANaaS-iSC route information at the backhaul level helping in the functional split decision. It also provides additional information to this network controller about required routes and QoS within the network.

Figure 7-5 shows in a non-exhaustive way the possible implementations of a veNB that were initially figured out for iJOIN. Not all of them will indeed be applied to iJOIN candidate technologies; however they are all showed here for the sake of completeness[8]. While in the first variant (a), functional split is implemented by centralising higher layers functionalities of the protocol stack, another possibility is given by the centralisation of intermediate layers (variant (b)), while variant (c) and (d) just centralize the related control plane functionalities.



veNB functional split variant (a)

veNB functional split variant (b)



veNB functional split variant (c)

veNB functional split variant (d)

Figure 7-5: Different implementations of functional split within veNB

Please notice that the four variants above are showing in general the principle of functional split, and the different boxes depicted in the protocol stacks are not necessarily entire ISO/OSI layers, but can be even sublayers or single functions of the radio chain. This general concept can be applied to the iJOIN perspective, by considering PHY and MAC/higher layers functionalities and their respective mapping in terms of possible centralisation options within a veNB.

As a potential example, Figure 7-6 below is showing CT2.6 (data compression over RoF) consisting of a decentralised part of the PHY layer functionalities (low levels in the protocol stack), while the rest of the processing is performed in the RANaaS (corresponding to variant (a) in Figure 7-5.

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[8] In particular, as highlighted by Table 7-3, the option (b) is at the current stage not considered viable by any CT.

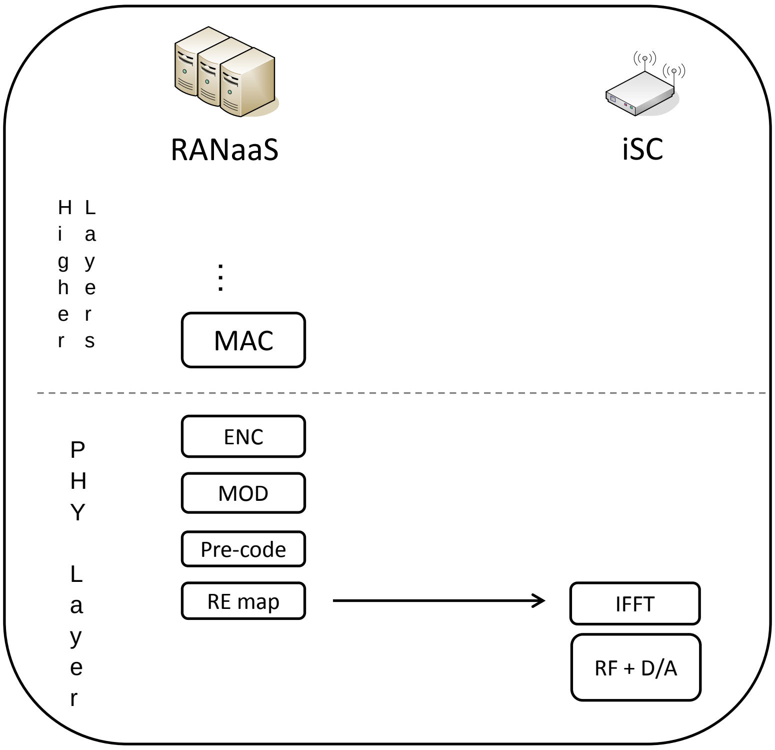

Figure 7-6: Example of veNB functional split variant (a), considered by CT2.6 (DL data compression over RoF)

Table 7-3 shows the iJOIN candidate technologies and preferred implementations in terms of possible functional split variants. Only CTs from WP2 and WP3 are listed because WP4 is not relevant for the functional split within a veNB. While CTs from WP2 are mainly focused on PHY layer aspects, CTs from WP3 are considering higher level functionalities (RRM, Scheduling, RRC …). The options listed below are some first educated guesses performed by iJOIN partners in order to give a first categorisation of preferred veNB implementations considered by the project (in principle, for every CT even more than one option is permitted, e.g. because the CT is foreseeing different deployment options).

Table 7-3: iJOIN veNB functional split variants (CTs from WP2 and WP3)

CT	Topic	Abbreviation	veNB functional split variant			
			a	b	c	d
2.1	In-Network-Processing	INP	x			
2.2	Multipoint Turbo Detection	MPTD	x			
2.3	Joint Network-Channel Coding	JNCC	x			
2.4	Sum-Rate and Energy-Efficiency Metrics of DL COMP with backhaul constraints	CoMP	x			
2.5	Partially Centralised Inter-Cell Interference Coordination	ICIC	x			
2.6	Data Compression over RoF	RoF	x			
2.7	Millimeter wave backhauling	mmWave	x			
3.1	Backhaul Link Scheduling and QoS-aware Flow Forwarding	BH Manager			x	
3.2	Partly decentralised mechanisms for joint RAN and backhaul optimisation in dense small cell deployments	Coordinated Cell Selection				x
3.3	Energy-Efficient MAC/RRM at Access and Backhaul	EE RRM			x	
3.4	Computational Complexity and Semi-Deterministic Scheduling	SD Scheduler			x	
3.5	Cooperative RRM for Inter-Cell Interference Coordination in RANaaS	Coop. RRM			x	
3.6	Assess and Increase Utilisation and Energy Efficiency	n.a.	n.a.	n.a.	n.a.	n.a.
3.7	Radio Resource Management for Scalable Multi-Point Turbo Detection	MPTD RRM	x		x	
3.8	Radio Resource Management for In-Network-Processing	INP RRM				x
3.9	Hybrid local-cloud-based user scheduling for interference control	HL Scheduler			x	

7.2.2.3 Operational constraints

The veNB must be designed and implemented to guarantee functional resilience and avoid becoming a critical point of failure for the RAN. It must ensure for instance resilience against link failures, packet drops, and possible hardware faults. These aspects must keep the same resilience level granted by the 3GPP E-UTRAN architecture.

Also configuration and management must be possible with adequate efficiency. The design must for instance specify how the collection of state information from different veNB functions occurs, or reconfigurations are triggered and enacted when needed.

7.2.2.4 External interfacing

The outside parts of the network must have a way to ensure that the correct entity inside the veNB is addressed. This point is under investigation, SDN capability in the iJOIN backhaul could be one of the solutions to dive deeper in.

In general, it’s possible that a veNB API turns out to be needed, to allow proper interfacing form the outside world to configure a veNB, request or instantiate functional modules in a correct way.

7.2.3 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, load balancing operation or mobility management. Moreover, some module in the system must be able to determine the actual functional split of RANaaS oriented CTs, as the variants will depend on the instantaneous backhaul conditions. 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. A SDN approach is being explored for the measurement, monitoring and control of the backhaul and RAN from the iNC. In order to minimise the impacts for the operator in terms of deployment cost and complexity, the iNC might be physically co-located with the RANaaS entity, though the feasibility of this approach will be evaluated as the final architecture is designed.

7.2.4 iJOIN Transport Node

Some CTs will assume multi-hop links from an iSC toward the RANaaS platform, the core network or another iSC, inferring 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.

7.2.5 iJOIN Local Gateway

The use of a local breakout point, to offload the core network, will also be investigated by some CTs (especially in WP4). For traffic selection and offloading needs, the **iJOIN Local Gateway** (iLGW) is introduced. This entity implements a subset of the logical functions of a P-GW and it is logically connected with the (v)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 purposes.

7.3 iJOIN Functional Architecture

The two key concepts of the iJOIN framework are RANaaS and joint RAN/backhaul optimisation in dense small cell deployments. In this section, we discuss the functional architecture of iJOIN. The functional architecture defines the interaction of functional blocks implemented in the iJOIN architecture. In particular, the functional defines the required input information for CTs and defines the output information provided by CTs. Furthermore, it allows for identifying the interaction across work package within the project which are of particular interest but also require special care to avoid inconsistencies. The deliverables D2.1, D3.1, and D4.1 provide a detailed overview of the functional architecture from each individual WP perspective. In this section, we provide a brief summary of the functional architecture considered by each WP's point of view.

7.3.1 WP2: Holistic PHY Layer Design for Backhaul and Access

WP2 aims to develop novel PHY technologies which implement the RANaaS concept and the concept of joint optimisation of RAN and backhaul transmission. In the D2.1 deliverable (chapter 4) we present seven promising CTs with the potential of enabling the envisaged performance improvements by iJOIN. These CTs are listed in the Table 7-4.

Table 7-4: iJOIN PHY Candidate Technologies (CTs)

CT	Topic	Abbreviation
2.1	In-Network-Processing	INP
2.2	Multipoint Turbo Detection	MPTD
2.3	Joint Network-Channel Coding	JNCC
2.4	Sum-Rate and Energy-Efficiency Metrics of DL COMP with backhaul constraints	CoMP
2.5	Partially Centralised Inter-Cell Interference Coordination	ICIC
2.6	Data Compression over RoF	RoF
2.7	Millimeter wave backhauling	mmWave

In order to implement these technologies based on the iJOIN architecture, they may have to interact with each other and other functionalities on PHY and MAC layer as well as mobile network functions. In D2.1 Section 5, the interfaces between the individual functions are detailed, i.e. the type of exchanged information, the logical interface (J1 or J2), and source/sink of the information. Figure 7-7 summarises these interactions by providing the functional architecture from a WP2 perspective.

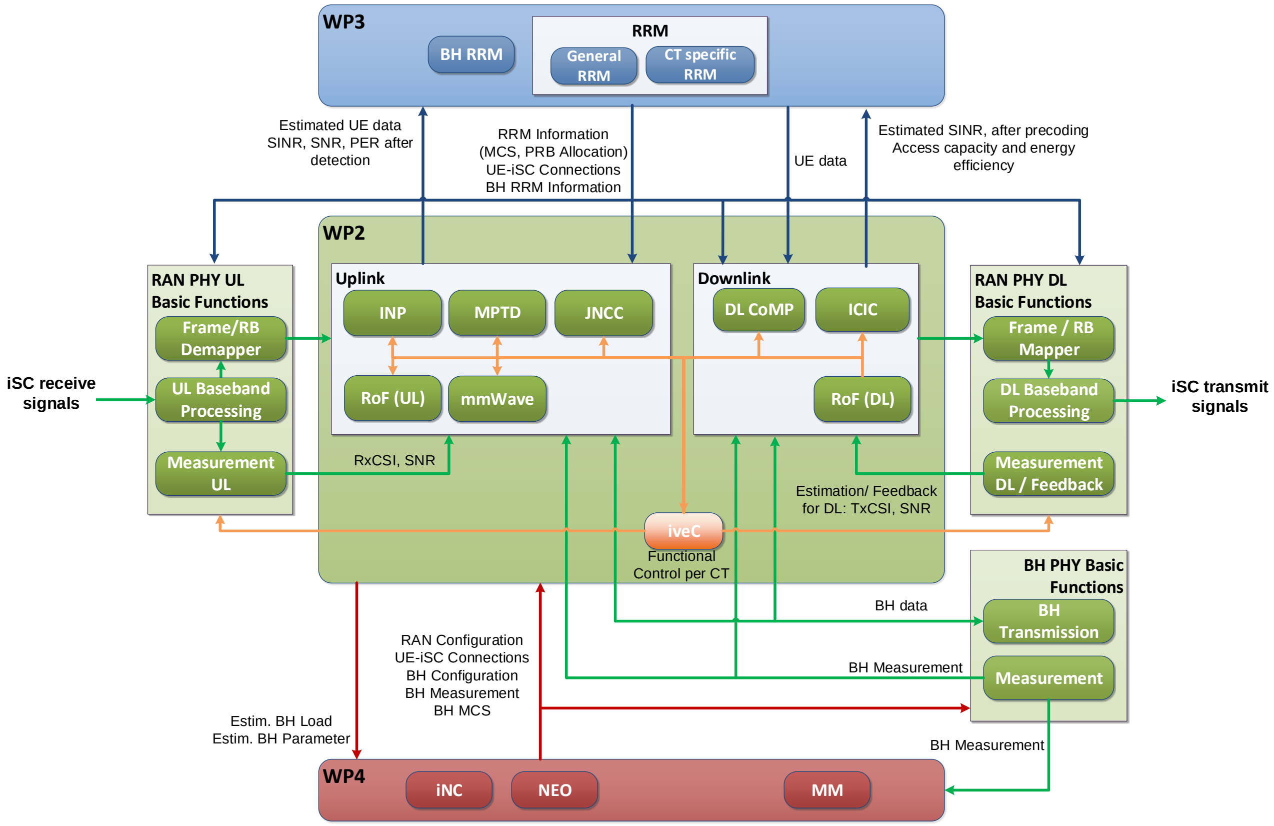

Figure 7-7: Functional Architecture from WP2 perspective

Basic PHY functions such as baseband processing, (de-)mapping of resource blocks and channel estimation are not part of WP2 investigations. Thus, standard implementations are assumed as supporting blocks for the UL and the DL. However, the iveC function controls also some of these basic blocks, e.g. the location of channel estimation depends on the actual functional split, i.e. the measurement being handled in the iSC or in the RANaaS. Based on the de-mapper output signal and the channel state information on the UL, alternative CTs for UL detection are considered. Based on the functional split approach determined by the CT-specific iveC, messages have to be exchanged with other MAC functions or network-control functions over the BH links. As output, WP2 UL CTs provide the estimated user data quality indicators such as SINR after UL detection to WP3 in order to optimise the RRM. Correspondingly, alternative CTs are investigated for joint DL transmission across multiple iSCs of a veNB. Based on the CSI estimation for the DL, the transmission strategy is determined and estimated SINR after pre-coding is delivered to the RRM in WP3. Based on the determined RRM information and the user data, the transmit signals of the iSCs are generated.

7.3.2 WP3: Holistic MAC/RRM Design for Backhaul and Access

WP3 focuses on the design of MAC and RRM algorithms for optimizing jointly the radio access and the backhaul of future cellular networks. Accordingly, in deliverable D3.1, we propose nine CTs, which are relevant for the iJOIN framework [61]. These CTs are listed in Table 7-5 and are classified accordingly to their specific objectives. In particular, CTs 3.1, 3.2, and 3.3 are seen as enablers for adapting the system configuration to changes in the cellular network state, due for instance to the network load, energy constraints, mobility, etc. CTs 3.4, 3.5 and 3.9 mainly focus on improving performance of downlink transmissions by increasing spectral efficiency, mitigating inter-cell interference, and coordinated RRM.
Finally, CTs 3.7 and 3.8 enhance uplink performance by inter-cell cooperation and exploiting spatial diversity. CT3.6 is devoted to investigate the novel metric Utilisation Efficiency in order to assess the improvements of iJOIN’s CTs. Hence, it is not a technology as such and therefore not represented in Figure 7-8.

Table 7-5: iJOIN RRM/MAC Candidate Technologies (CTs)

CT	Topic	Abbreviation	Functional Block
3.1	Backhaul Link Scheduling and QoS-aware Flow Forwarding	BH Manager	SON
3.2	Partly decentralised mechanisms for joint RAN and backhaul optimisation in dense small cell deployments	Coordinated Cell Selection	SON
3.3	Energy-Efficient MAC/RRM at Access and Backhaul	EE RRM	SON
3.4	Computational Complexity and Semi-Deterministic Scheduling	SD Scheduler	DL
3.5	Cooperative RRM for Inter-Cell Interference Coordination in RANaaS	Coop. RRM	DL
3.6	Assess and Increase Utilisation and Energy Efficiency	n/a	n/a
3.7	Radio Resource Management for Scalable Multi-Point Turbo Detection	MPTD RRM	UL
3.8	Radio Resource Management for In-Network-Processing	INP RRM	UL
3.9	Hybrid local-cloud-based user scheduling for interference control	HL Scheduler	DL

In addition to the three main WP3 blocks discussed above, we identified basic functions that include standard functionalities for the BH and RAN management, which support the iJOIN RRM/MAC enablers (similar to WP2). In particular, the RRC includes all procedures related to mobility management and measurements such as RSRP, the serving cell information and other information. The scheduler function is devoted to map available radio resources to service requests according to a given policy. The MAC function is responsible for the data management on individual radio bearers such as block size, QoS management and buffer management. Finally, the eICIC function allows for alleviating the effect of co-channel interference on both data and signalling by means of inter-cell coordination.

Figure 7-8 depicts the interaction of the four main blocks which are under investigation in WP3 (the blue box) as well the exchange of information between with WP4 (in red) and WP2 (in green). From WP2, we take into account input and output information from the two main blocks, namely UPLINK and DOWLINK. The exchange of information between WP3 and WP4 can be divided across two iJOIN logical entities: the iNC and the iTN. As discussed in Section 7.2, the iNC has the role to collect information from both the RAN and the backhauling on the network status. The iTN enables multi-hop connection between the RANaaS and the iSCs.

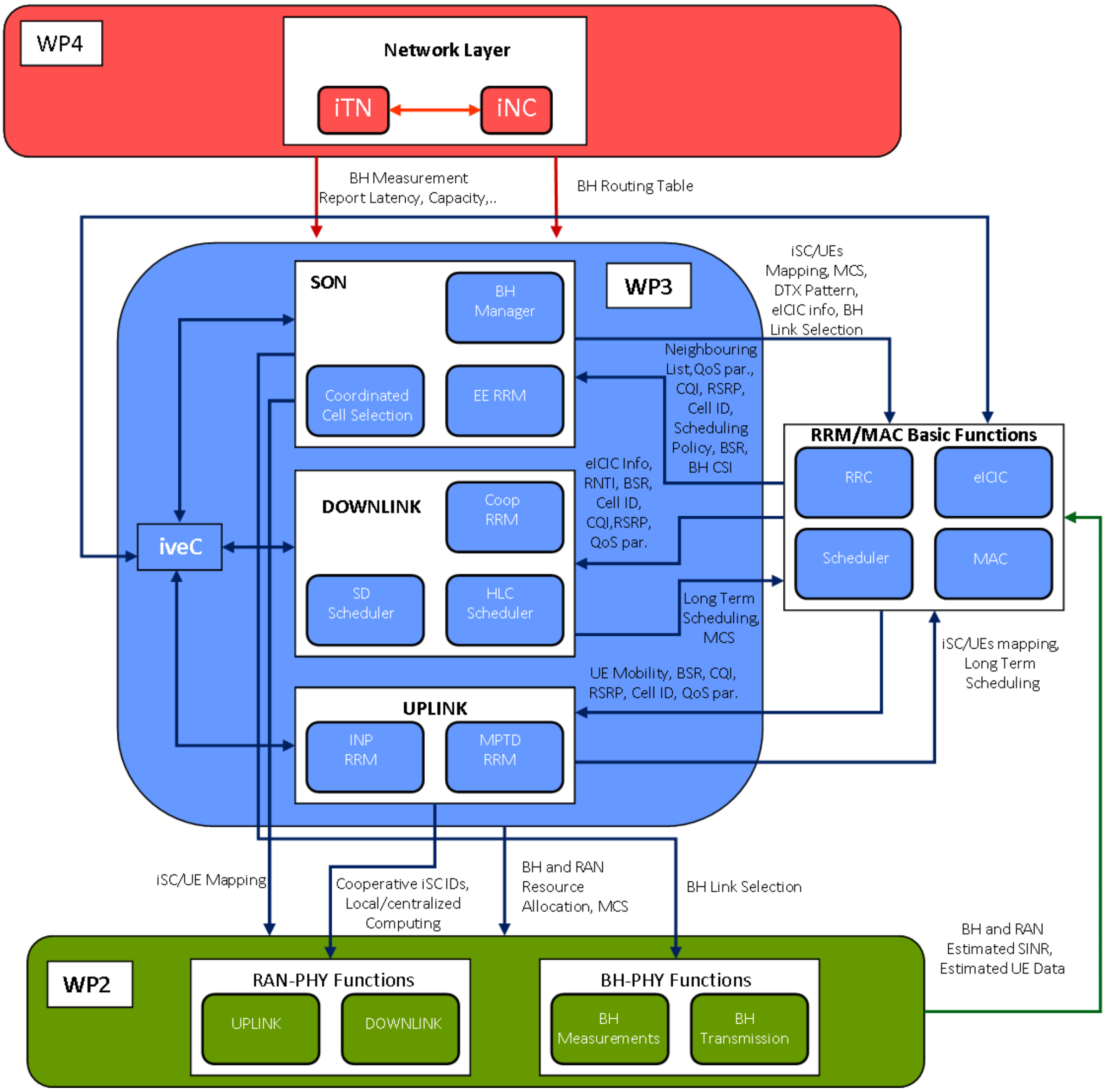

Figure 7-8: Functional interactions from WP3 perspective.

7.3.3 WP4: Network-Layer Solutions and System Operation and Management

WP4 deals with network layer functions to support the RANaaS concept as well as to implement the joint optimisation of RAN/backhaul transmission. In addition, WP4 also works on network wide mechanisms to ensure proper mobility management, energy optimisation, load balancing and congestion control in the RAN and backhaul network. In order to achieve these goals, the deliverable D4.1 (chapter 5) introduces and describes six CTs, which are listed in Table 7-6.

Table 7-6: iJOIN NET Candidate Technologies (CTs)

CT	Topic	Abbreviation
4.1	Distributed IP anchoring and Mobility Management	DMM
4.2	Network Wide Energy Optimisation	NWEO
4.3	Joint Path Management and Topology Control	JPMTC
4.4	Routing and Congestion Control Mechanisms	RCCM
4.5	Network Wide Scheduling and Load Balancing	NWSLB
4.6	Backhaul Analysis based on Viable Metrics and “Cost” Functions using Stochastic Geometry	BASG

The implementation of the functionality provided by each of these concepts requires interactions with other WP4 CTs, but also with PHY and MAC layer functions. Analogously, some of the NET functions provided by WP4 CTs are used by WP2 and WP3 CTs in order to be able to provide their intended functionality. The details of the internal interactions among the modules implementing the WP4 CTs are detailed in D4.1 (chapter 6), and this document explains the interactions between WP4 CTs and WP2 as well as WP3 CTs.

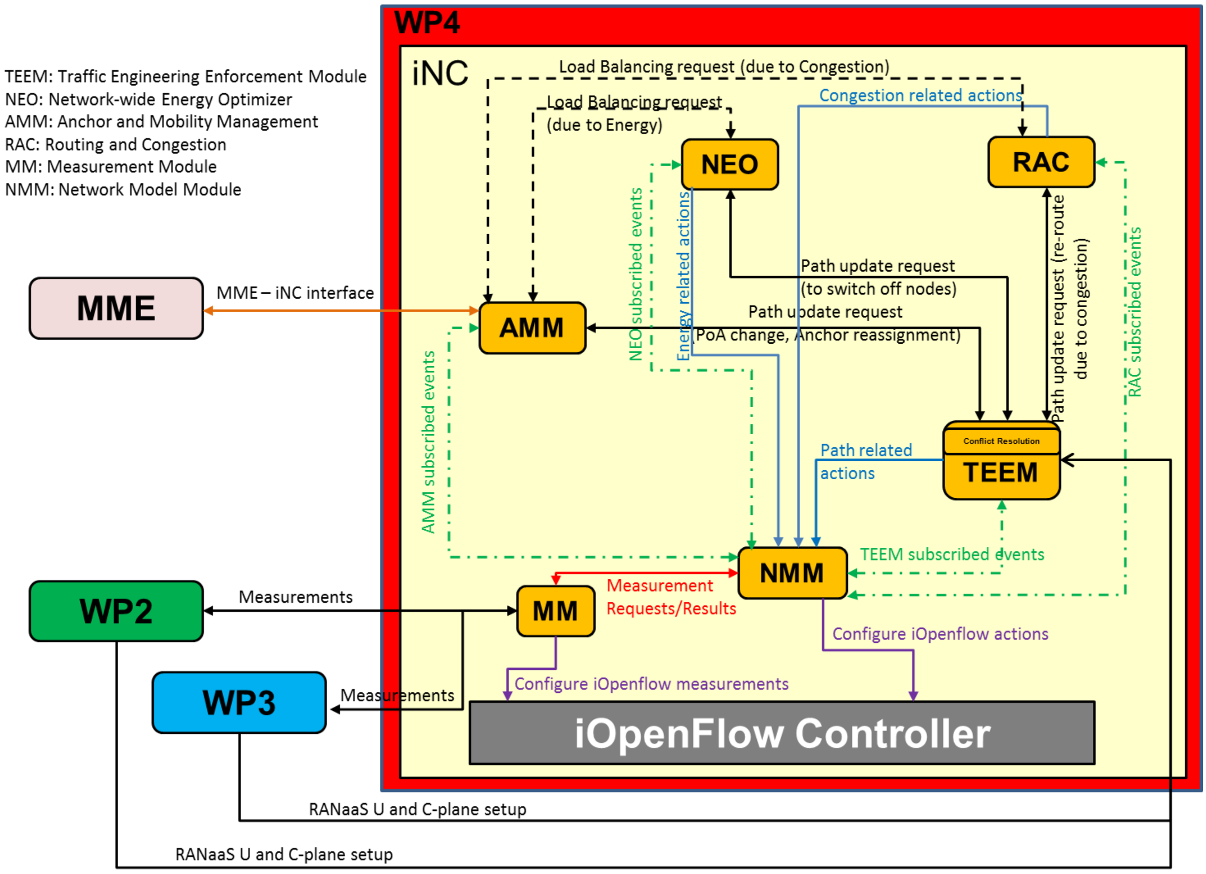

Figure 7-9: Functional Architecture from WP4 perspective

Figure 7-9 summarises the functional architecture from a WP4 perspective. The WP4 internal architecture is strongly influenced by SDN approach that has been adopted. This is reflected in Figure 7-9, which focuses on the iNC internal architecture. The iNC is in charge of configuring, monitoring and driving the operation of the RAN and backhaul network entities. At that purpose, an extended OpenFlow controller (iJOIN OpenFlow controller) resides on the iNC, which takes care of all protocol interactions with other network entities (not shown in the figure). These entities only need to support OpenFlow using the so-called Southbound protocol interface. Note that some extensions to the current OpenFlow protocol specification are foreseen at this stage, which are necessary to achieve iJOIN's objectives. In the future, WP4 will contribute to Open Networking Foundation (ONF) in order to propose extensions which allow for implementing the CTs proposed by WP4.

Within the iNC, different WP4 modules are running. There is basically one module per WP4 CT, except CT4.6, which does not deal with runtime functions but develops techniques that are used at the network planning stage. Wp4 covers the following modules:

- The AMM (Anchor and Mobility Management) module deals with the selection of the proper anchors on a per application and UE basis. It further ensures that those sessions needing mobility support are provided with it.
- The NEO (Network-wide Energy Optimiser) module monitors the network status and load, optimising the overall energy consumption while ensuring that the network wide performance is not compromised.

- The RAC (Routing and Congestion) module is in charge of avoiding network congestion in the RAN and backhaul network by properly configuring the network.
- The TEEM (Traffic Engineering Enforcement Module) hosts all the intelligence required to compute the best path within the backhaul network to satisfy the different traffic and network-wide requirements. It further provides the necessary conflict resolution functions, e.g. to ensure that a request from the NEO module does not introduce congestion or contradicts a previous request from the RAC module.

There are the two additional WP4 modules MM (Measurement Module) and NMM (Network Model Module). These modules are in charge of the initial acquisition of the topology and functional view of the network, i.e., which nodes are up and running and how they are interconnected, as well as which capabilities they have, for example, in terms of energy configurability of IP anchoring support. Both modules build a model of the network that reflects the status and that is kept up-to-date by continuously monitoring the status and load. This is not only used to trigger the different WP4 modules but also to assist WP2/WP3 CTs. WP2 and WP3 CTs may request different information or configure measurement thresholds to trigger back a notification, e.g., load of the backhaul links and signal quality measurements on the iSCs.

Additionally, WP4 and WP2 as well as WP3 need to interact during the setup of the user and control plane forwarding for the RANaaS functional split. WP2 and WP3 CTs may support different levels of functional split depending on the characteristics of the connectivity between the iSC and the RANaaS, e.g., bandwidth, delay, and jitter. Therefore, an objective metric of possible connectivity should be provided from WP4 to WP2 and WP3 modules, so they can internally decide and select which operation mode would be used. In addition, WP2 and WP3 CTs should coordinate with WP4 to ensure that the various types of traffic from different CTs and different levels of functional split are correctly set up and managed by the network under the control of the iNC.

7.3.4 Summary

Figure 7-10 shows an overview of the previously discussed functional architecture from a project perspective focusing on the interaction of the individual WPs. The interaction of WP2 and WP3 focuses on the exchange of estimated channel information such as SNR and user data after detection and decoding. WP3 mainly provides RRM and MAC information such scheduling maps, link adaptation parameters, and block sizes. Furthermore, the user data needs to be provided. WP4 provides to both WPs information about the backhaul configuration and measurements such as expected throughput, routing information, and mobility information. WP2 and WP3 provide details about the U/C plane split to WP4 which needs this information for an appropriate routing through the backhaul network. This functional architecture will serve as basis for further cooperation within iJOIN and will be used to define the actual data exchange in a physical architecture by combining functional and logical architecture.

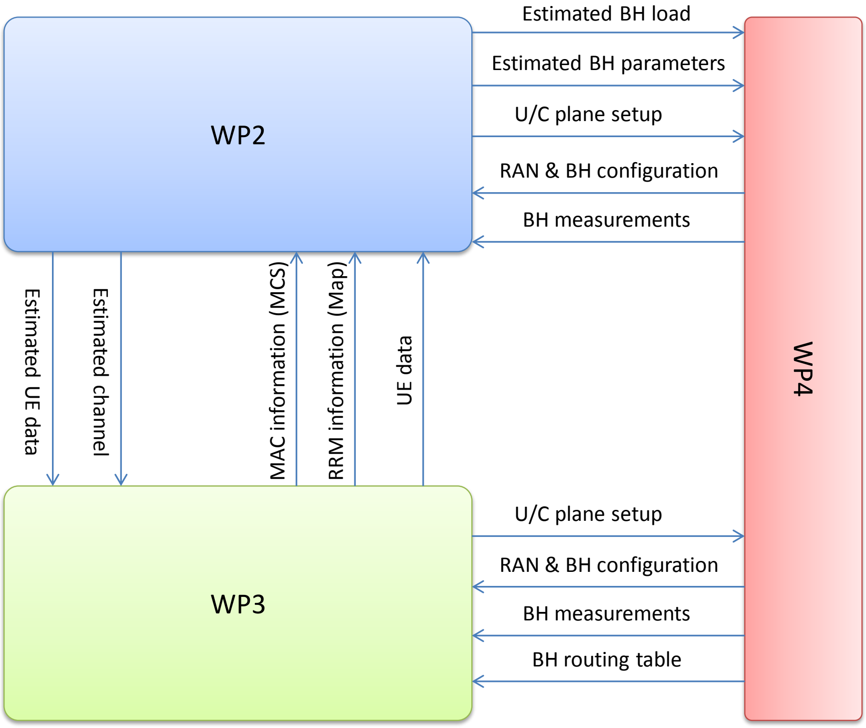

Figure 7-10 - Overview of functional architecture and interaction of WPs

7.4 iJOIN Physical Architecture

This section shoes how the logical and functional architecture concepts presented in Sections 7.2 and 7.3 are mapped on the four real use cases specified in Section 5.3.

7.4.1 CS1: Dense Hotspot in a Stadium

This scenario considers a stadium, 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.

A typical stadium covers a wide area, in the order of 50.000 m^2, and can contain several thousands of spectators. The average number of spectators that can be taken into account is 40000. By assuming to guarantee an average DL/UL throughput of 1.5Mbps during peak of traffic with 90% of active UEs, the network should be able to manage a DL/UL throughput over 50Gbps. The main parameters of the scenario are listed in Table 7-7.

Table 7-7: Stadium main parameters values

General Parameters	Value
UE density	~1 UE/m2
Small Cells Number	50 - 300
Experienced UE DL+UL Throughput	1.5 – 10 Mbps
Traffic density	0.5 – 10 Mbps/m2

The stadium scenario can be represented as one or multiple rings of Small Cells under a macro layer coverage, as represented in Figure 7-11.

Figure 7-11: stadium small cell deployments under an external macro layer

Different aspects need to be taken into account in the scenario description, such as number of small cell rings, inter-rings distance, downtilt of each ring, etc. in Figure 7-12 it is supposed to deploy 2 rings of small cells under the stadium rooftop.

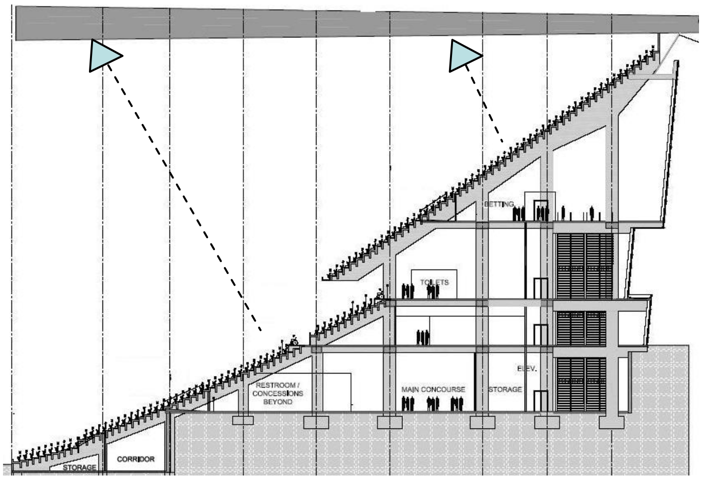

Figure 7-12:: small cell placement under the stadium rooftop (2 rings)

The number of iSC depends on the required performance and should be properly selected in order to compromise the required capacity and increased interference in the system.

Each ring has a backhauling interface toward the EPC (iTN). Fiber or millimetre wave connection for each iSC is supposed to provide the needed bandwidth even if other possible technologies are not excluded. All the rings and the Macro eNB are coordinated by the iNC node in the RANaaS. The physical connections between the involved nodes are illustrated in Figure 7-13.

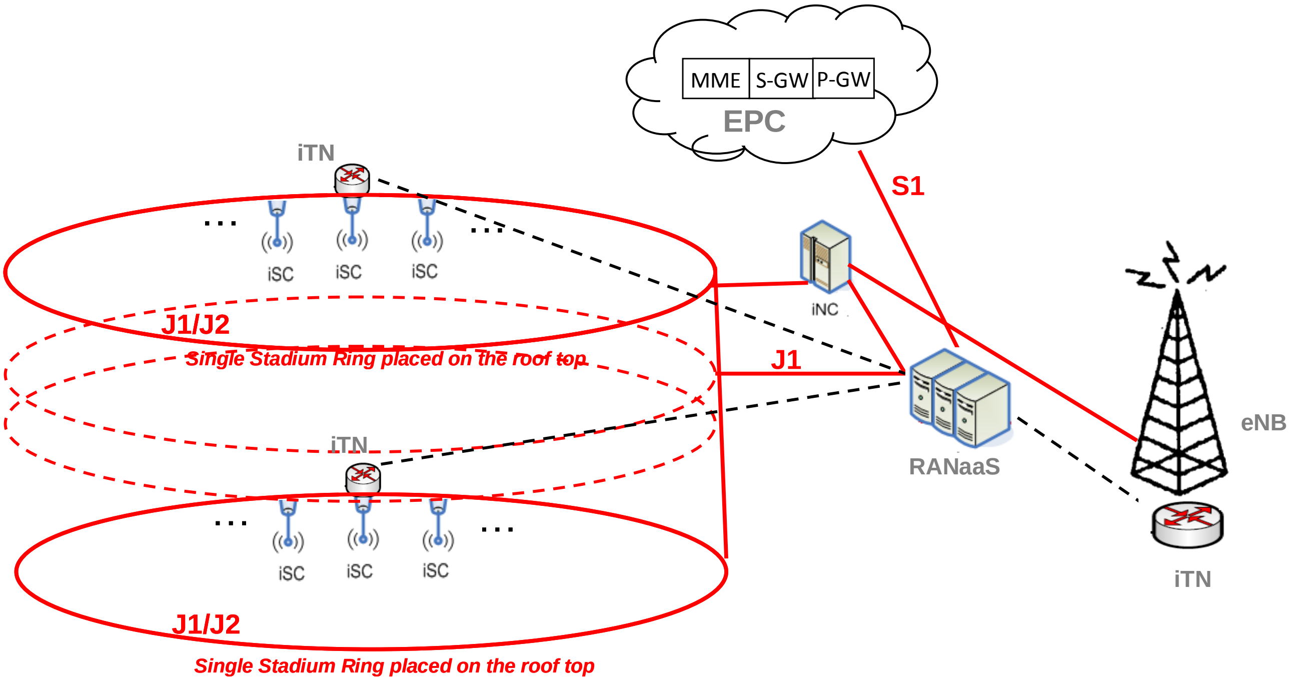

Figure 7-13: physical interconnections between the nodes in the stadium scenario

7.4.2 CS2: Dense Hotpot in a Square

This scenario considers a square, where hundreds of people can simultaneously found at almost any given moment of the day (e.g., shopping, relaxing taking a cup of coffee, spending time with friends on a pub while watching a sport event, or just walking around). In many of these situations, people will want to access to the Internet, to talk to friends, post media on social networks, watch videos or even work with their laptops. Therefore, also in this scenario it is needed to deploy a full featured communication network comprising a multitude of small cells to continuously support a complete range of broadband multimedia services.

The size of a square might vary, and with that also the number of people that might be requiring connectivity. We can however assume an average area coverage in the order of 8.000 m^2, which can contain hundreds or even a few thousands of visitors, though we can take 1000 as an average.

Since some of the people at the square may be using laptops/tablets in addition to the more common smartphones, the average DL/UL throughput that we assume needs to be maintained is about 4Mbps during peak of traffic with 90% of active UEs, the network should be able to manage a DL/UL throughput around 4Gbps. The main parameters of the scenario are listed in Table 7-8.

Table 7-8: Dense square main parameters values

General Parameters	Value
UE density	~0.125 UE/m2
Small Cells Number	50 - 300
Experienced UE DL+UL Throughput	4 – 20 Mbps
Traffic density	0.5 – 2.5 Mbps/m2

The physical deployment of small cells of a square depends of its shape, but we can assume that small cells will be deployed inside the different shops/stores, as well as in some lampposts of the square. One characteristic that is highly probable in this scenario is the presence of iLGWs that provide local connectivity at some small cells. This local connectivity can provide access to the public Internet, or to local services, such as servers to offer personalised services or offers.

The number of iSC depends on the required performance and should be properly selected in order to compromise the required capacity and increased interference in the system.

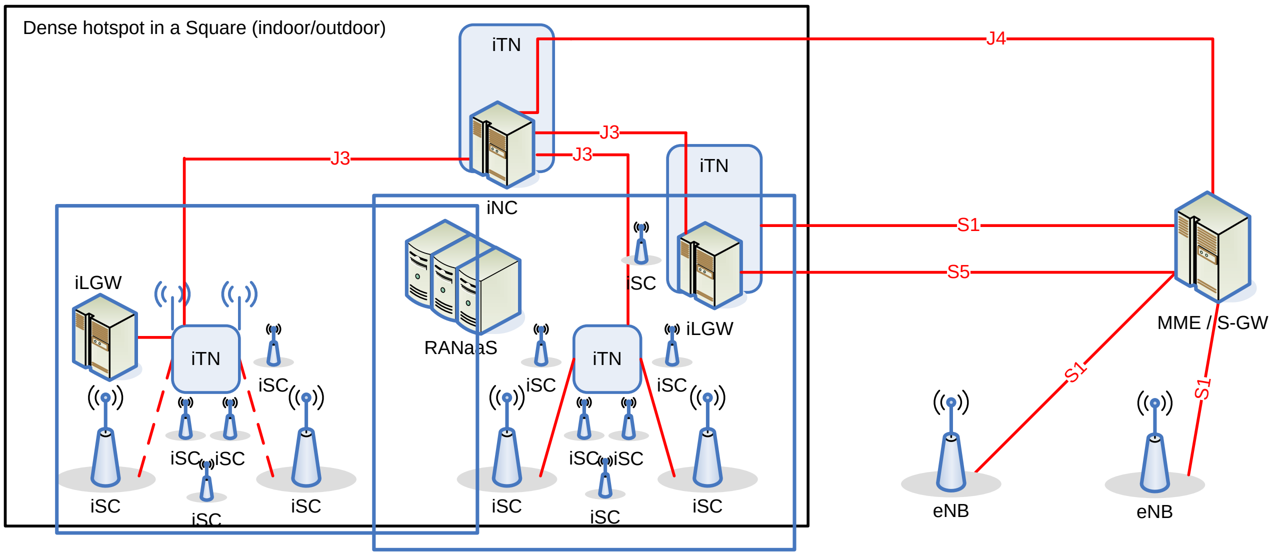

Figure 7-14: Physical interconnections between the nodes in the square scenario

There might be wireless or wired (fiber) connections towards the EPC (iTN). An example of physical deployment is illustrated in Figure 7-14.

7.4.3 CS3: Wide-Area Continuous Coverage

The case study CS3 (Wide area continuous coverage) considers a part of the city where the coverage objective, which is usually pursued at the beginning of the mobile network deployment process, is intended to be achieved by means of iSCs, instead of macrocells. So, it is not the case, as in the other CSs, that the iSCs should be deployed where there is a traffic hotspot, but rather as an alternative solution for providing the continuous coverage that users expect.

This deployment option implies a number of requirements that are rather specific to this CS:

- The TCO for this option should be favourable with respect to the option of deploying a macro layer, even in the case that the traffic demand is not so high as to impose a small cell solution.

  In order to be the case, it is important that the mobile network takes advantage of any potential synergy with the fixed network, sharing infrastructure whenever possible. Also, network sharing between operators should be supported.
- Mobility support should be comparable, in terms of QoE, to the one provided by the macrocell layer. This means that, for example, handover failure probability should be lower than for macrocells, as in a typical session/conversation the number of handovers a moving user will experience will be higher.
- As the use of high power small cells seems a likely option for this CS, higher level of cooperation between iSCs will be needed in order to overcome potential interference issues.
- It cannot be assumed that the deployment conditions will be homogeneous in all the area to be covered, neither in terms of propagation conditions nor in terms of the available infrastructure to deploy the cells or support the backhaul.
- Also, it can be expected that the capability of the operator to deploy the cells will be limited by a number of factors
- The network should support both indoors and outdoors users, with potentially different traffic profiles.

For these reasons, the solutions proposed by iJOIN may become enablers of CS3 feasibility from the technical and economic viewpoint. For example, the flexible functional split proposed by iJOIN allows the adoption of different cooperation strategies between different iSCs, as well as between iSCS and eNBs, to effectively comply with not homogeneous backhaul capacities. Also, a new functional split may be required in order to facilitate the coordination with new deployed cells that may interfere with already deployed ones. And the concept of virtual iSC may be useful in order to overcome mobility related issues and support faster handovers.

In terms of the area that may be considered representative of the CS, a real network in the centre of a big city has been analysed. The criteria that have been used are:

- The average inter site distance of the 3G macrocells deployed is lower than 400 meters.
- There are 2G microcells deployed in the area.
- Presence of natural boundaries, like highways, wide streets, parks, rivers …

The Figure 7-15 represents one of the areas analysed (9 km^2 in London), where the red-shaded area is the one that is considered adequate for wide area coverage:

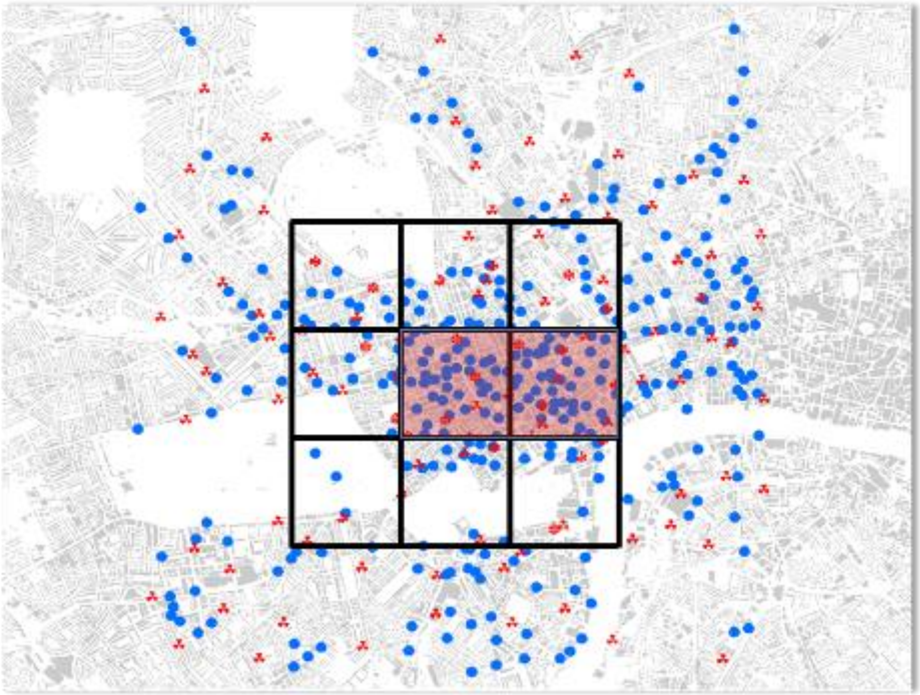

Figure 7-15 Example of wide area coverage

In this sense, an average area of 2 to 10 square kilometres is estimated as plausible. However applying the same criteria to other cities and networks may yield different results.

With respect to the number of iSCs, its number will depend on whether high or low power nodes are used for the deployment (in real world situations it may be a mixture of both of them). Again the following figures are provided as an indication.

- Low power nodes (less than 250 mW power per antenna port): 50- 150 iSCs per square kilometre.
- High power nodes (between 1 and 5 Watts per antenna port): 10 to 50 iSCs per square kilometre.

In terms of the iSCs location, it cannot be assumed that cells are placed opportunistically and that their locations are better modelled as a random process.

In this case, the split will depend on the functionalities intended to be supported (e.g., if cooperation between iSCs is required to cope with interference) and the backhaul capabilities. In this sense, e.g., if L1 is centralised in the RANaaS entity, J2 interface is not required between iSCs, but if L1 processing is kept in the iSC, the J2 can be used to exchange the PHY layer information required for supporting cooperative schemes.

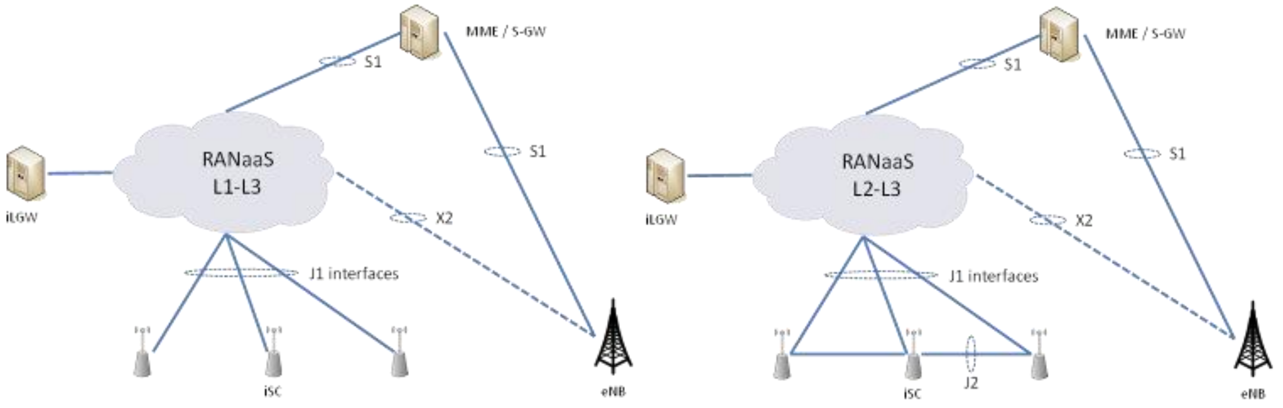

Figure 7-16 Dependence of the physical architecture on the functional split

In the Figure 7-16, the X2 interface is present between the macro eNodeB and RANaaS entity in order to allow for the support of procedures that may help to overcome load distribution and inter-layer interference issues, like MLB/MRO and ABS eICIC procedures.

One aspect that differentiates this CS from the others considered in iJOIN is the scale of the backhaul network required to support it (as to other aspects, like the traffic carried, other CSs may be more significant).

One feature that should be taken into account is the flexibility that the backhaul infrastructure should be able to support. It cannot be assumed that it will be possible to apply a single solution for all the iSCs in the deployment scenario.

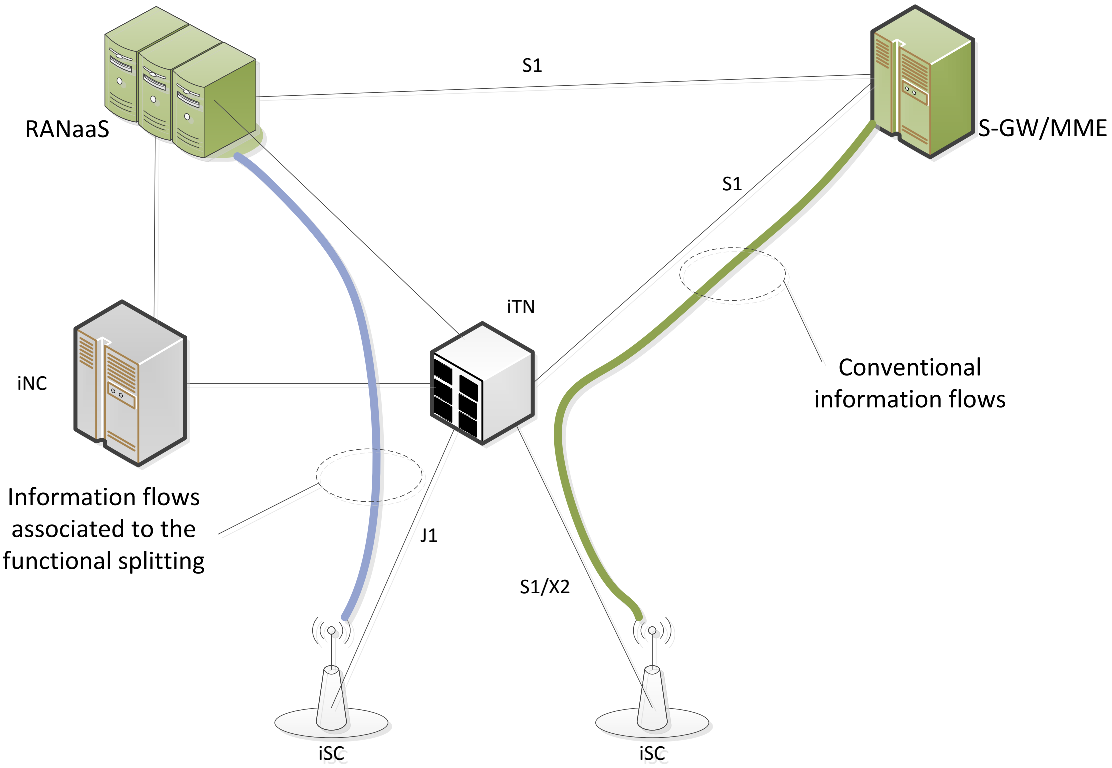

Figure 7-17 Flexible backhaul support

A second aspect that should be taken into account in terms of the backhaul design is the possibility of reusing the existing fixed access infrastructure, and fundamentally the FFTH infrastructure. Figure 7-18 represents a potential solution that may be adopted:

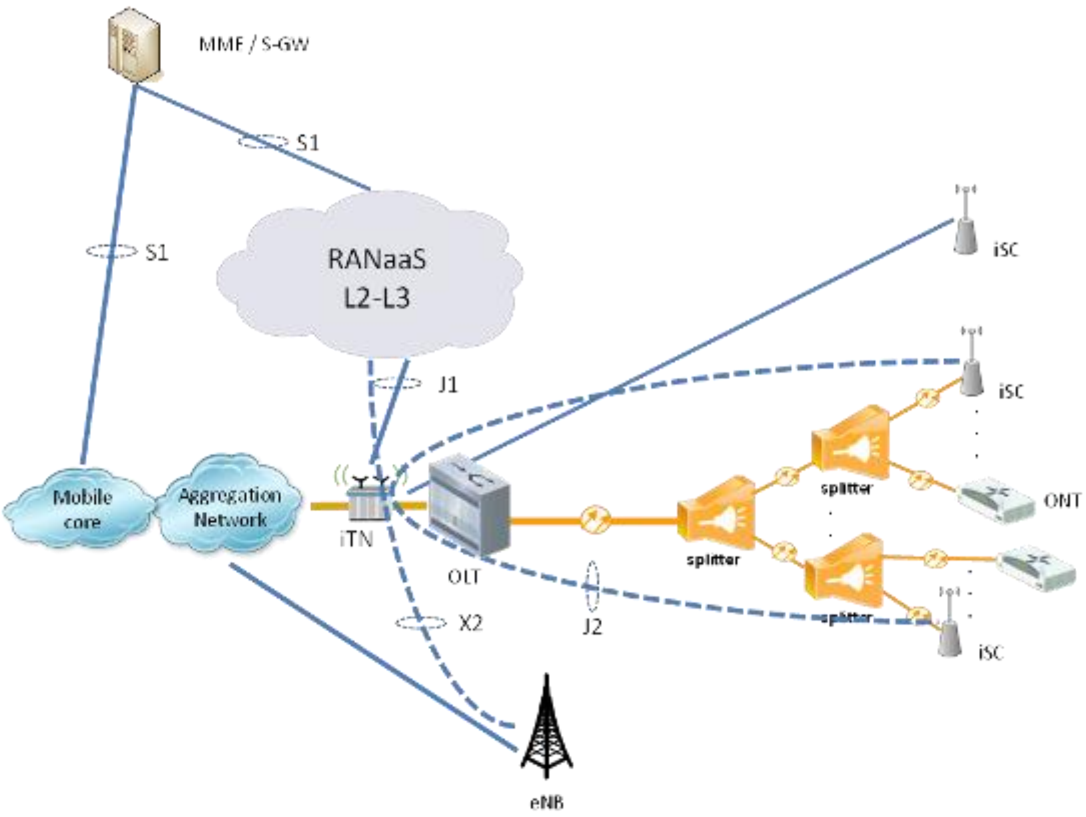

Figure 7-18 FTTH based backhaul support

Finally, in order to better cope with the scenario specific requirements, several enhancements of the architecture may be considered. Some of them may be feasible without major modifications of the architecture concept:

- Interconnection of the iTN with the iLGW.
- X2 interface between eNodeB and RANaaS. This interface may be useful to support mobility and load balancing optimisation between layers when RRC is located at the RANaaS, as SON procedures rely on X2 for information exchange. This interface may also facilitate the support of ABS based eICIC.

Other enhancements may be more difficult to assume:

- Interconnection of the macrocell to the RANaaS through the J1 interface, in such a way that the macrocell becomes in an iSC from the functional viewpoint. The support to the interface may be useful for implementing advanced inter-layer interference management/CoMP features.

iLGW implementing BRAS (instead of P-GW) functionalities. This feature would facilitate fixed-mobile convergence scenarios that may be relevant for this CS.

7.4.4 CS4: Dense Hotspot in an Airport/Shopping Mall

This scenario considers an airport where millions of people transit per annum. Waiting for their plane, they use their smartphones/tablet to do everyday life Internet usage (streaming, email, social networks…) using their operator contract instead of relying on over-crowded Wi-Fi hotspots. In the shopping mall scenario, mobility is also considered as thousands of people go from shops to shops doing price check comparison or taking HD picture to request family/friend purchase advice. The native mobility support and seamless authentication procedure (no email address to enter or user-driven authentication procedure to start to benefit from the Wi-Fi hotspot available) offered by the cellular network make it the communication network of choice for these scenarios. In both cases, the communication network should comprise several small cells to support the dense concentration of users in “small” areas (waiting room or shops).

We can assume that on average a waiting room can host up to 100 people, with a half of them requesting a network connection. Using the well-known indoor hotspot model defined in the ITU-R M.2135 shown in Figure 7-19, we may assume that each 15m x 15m block of this model is a waiting room. By assuming that two gates are associated per waiting room, our terminal can support 32 gates (medium terminal size). The same model could be used for the shopping mall scenario with less "static" users.

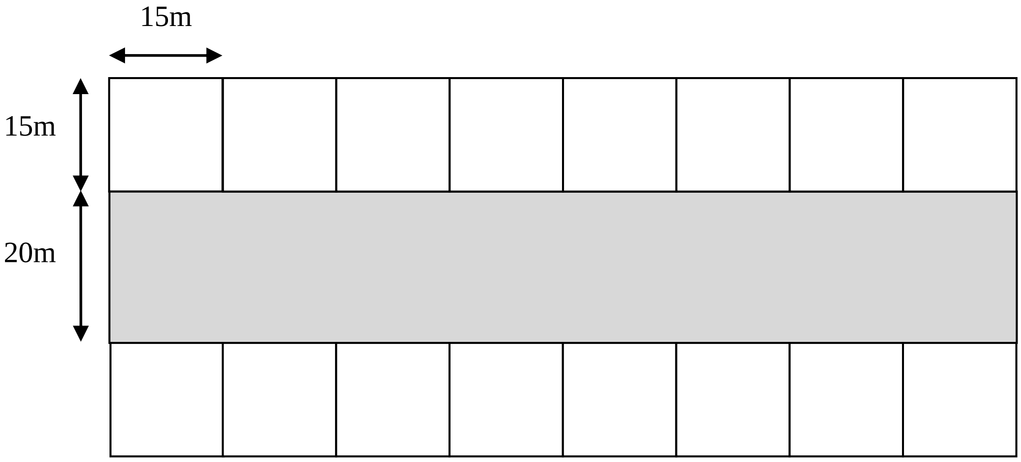

Figure 7-19: ITU-R InH Layout

Like the previous cases, the number of allocated iSCs depends on the required performance and should properly be selected based on the user's density. It's reasonable to assume that in an airport setup, fiber connects the iSCs to the core network (through an iTN concentrator node), while wireless backhaul is used in shopping mall where the internal shop disposition is more subject to change an year basis leading to new users density repartition and new iSC optimal placement.

Due to the indoor nature of the deployment and its natural isolation from the outer-world, macro coverage is not expected to play a major role in this common scenario on the contrary to the previous CSs. Figure 7-20 shows one physical instantiation of the iJOIN architecture in this common scenario, where there is only one iTN serving as a gateway toward the core network (or the RANaaS platform). The iNC could be implemented on the same cloud resources as the RANaaS platform as routing is quite straightforward with one iTN in this particular instantiation.

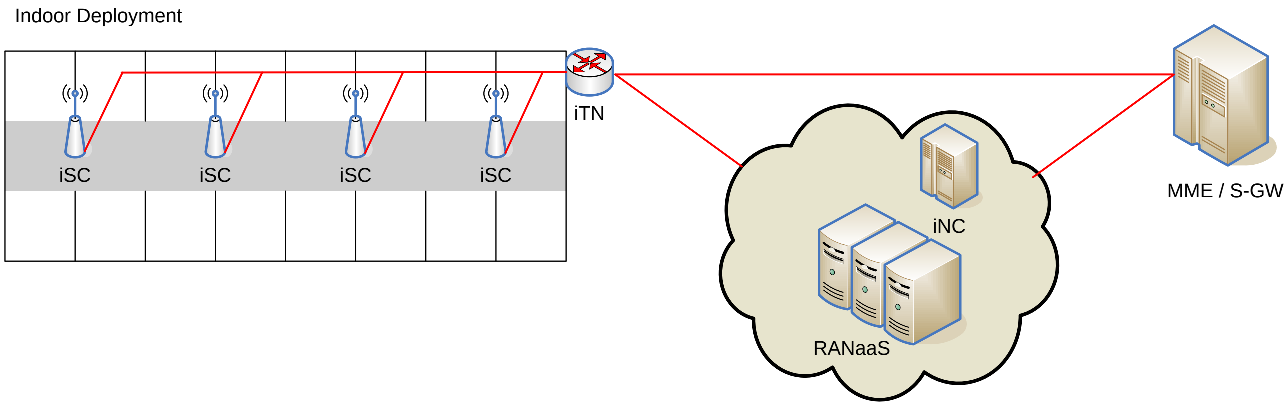

Figure 7-20: Example of one Physical Architecture Instantiation in the Airport/Shopping Mall Common Scenario

8 iJOIN System Performance Evaluation

8.1 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 8-1.

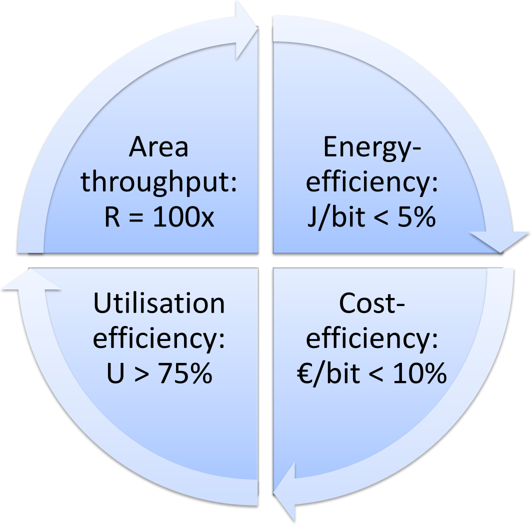

Figure 8-1: The Four Objectives of iJOIN in Relation to the 3GPP LTE State-of-the-Art

8.1.1 Area Throughput

8.1.1.1 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)

8.1.1.2 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 8-2 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, within the time period T, in a network comprising *N* cells is calculated as:

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

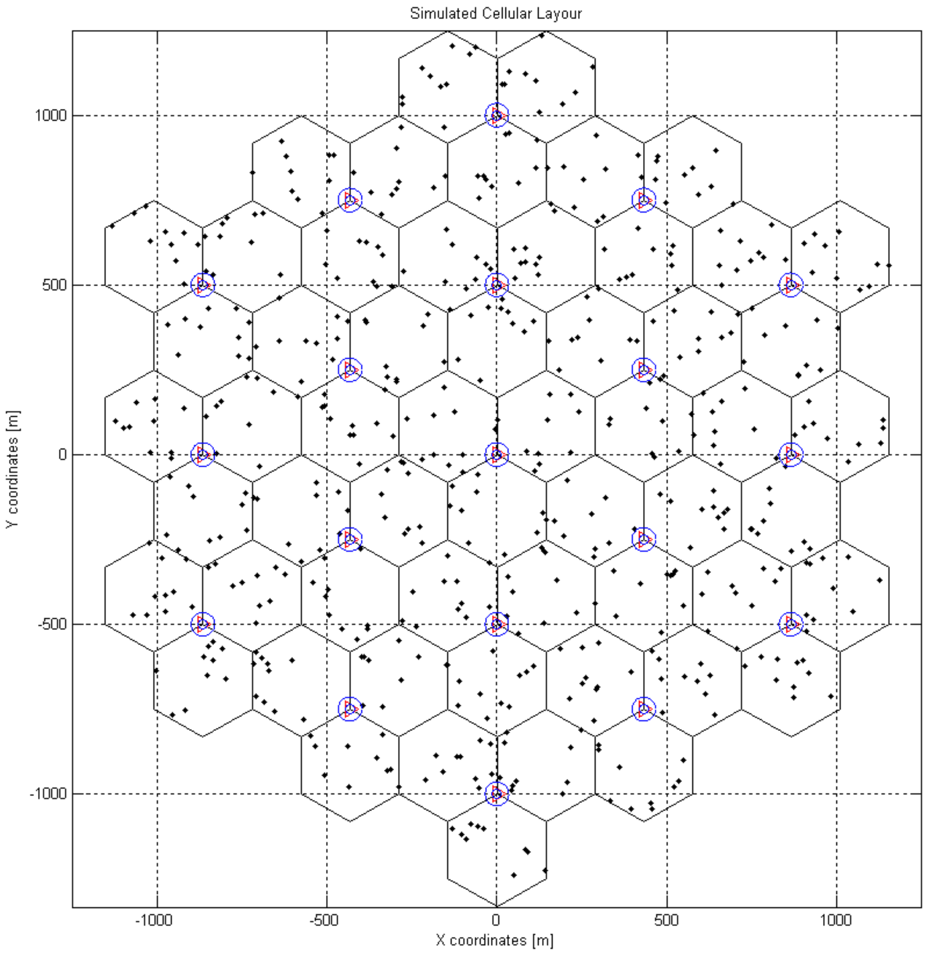

Figure 8-2: Tri-Sector Hexagonal Cellular System Model

The average rate R in the network is then simply I/T. It may often be helpful to normalise the rate R by either the number of cells or the network area. To make the normalised 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:** In can be considered an 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.

  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 the 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.

8.1.2 Energy Efficiency

8.1.2.1 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%).

8.1.2.2 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 [63]. 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 normalises 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, and 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 for in order to be able to compare two setups:

- Traffic demand or number of users
- Utilisation 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.

8.1.3 Utilisation Efficiency

8.1.3.1 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.

8.1.3.2 Definition

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

Table 8-1: Preliminary mapping of resource types to network entities

Resource type \ network entities	eNodeB	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 8-1 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 utilisation 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, utilisation metrics can be derived. Some examples for utilisation metrics are as following:

- In the eNB/iSC:
    - Radio Resource Utilisation (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 Utilisation (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 Utilisation (BU): The total throughput compared to the capacity of a backhaul link.
- In the cloud platform:
    - Cloud Resource Utilisation (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.

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

$$\mathrm{RUE} = \mathrm{throughput}/\mathrm{RRU}$$

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

8.1.4 Cost Efficiency

8.1.4.1 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 baseline system 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.

8.1.4.2 Definition

Cost-efficiency is hardly to define as it depends of a lot of variables. In fact network deployment options depend on many parameters like coverage, capacity, served area, radio performances, all often vary in time and space. Also the unitary cost of an equipment (CAPEX and OPEX) have important variations in time (market price and depreciation) and in conditions (urban, buildings sizes, rural…), and on countries.

Finally, all these parameters have a strong impact on network costs, and the consequent definition of an overall cost-efficiency metric appears to be quite complicated from the methodological point of view.

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. A similar investigation based on normalised cost has been performed in [1][62] for relay-based networks and multi-cell MIMO.

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 are identified 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 or a subset of them, the cost efficiency metric will be refined through the course of the project by getting input from the other WPs.

8.2 Evaluation Methods

In order to assess the performance of the proposed solutions, different methods can be applied, briefly described in the following. An analytical approach can be considered for some specific solutions. However, due to the complexity of some of the considered scenarios, simulation approaches will be necessary to draw precise conclusions on the benefits of the individual solutions. In addition, proof of concept implementations will be also considered.

All the evaluations performed by the different partners will 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 provide the gains measured with one or several of the four metrics illustrated above:

- Area throughput;
- Energy Efficiency;
- Utilisation Efficiency;
- Cost Efficiency

In the following sections different evaluation tools and/or approaches used in iJOIN are described.

8.2.1 Analytical approach

Some of iJOIN CTs are developing new approaches based on theoretical investigations, e.g. information theoretic derivations. In such cases where CTs are focused on radio techniques innovations, a detailed simulation environment could not be required in order to assess the benefits of the proposed features. For example in case of considering particular backhauling techniques over fibre, the detailed modeling of all the radio links between all the nodes involved in a multi cell environment would be too complex to analyse the performance (for example capacity and latency) of the backhauling link. In these cases a simpler behavioural model could be enough to obtain the relevant metrics to assess the CTs in iJOIN.

8.2.2 Link-Level Simulation

For some innovations, it is important to model in a very detailed way all the aspects related to the transmission at the physical layer. However, for iJOIN's purposes it is fully acceptable that common simplifications are applied, e.g. with respect to baseband modelling. The evaluation will be based on link-level simulations using transmission parameters (e.g. MCS, channel model) achieving BER or FER curves. Throughput will be based on FER analysis. Where a further extension of the model should be needed, additional functional blocks will be taken into account like, for instance:

- Source generator
- Channel encoder (for example LDPC turbo codes)
- Digital modulator
- Propagation channel (AWGN, Rayleigh fading)
- Channel estimation/equalization
- Digital demodulator
- Channel decoder
- BER/BLER/throughput counter

The simulator can be developed using different programming languages such as Matlab or C/C++. The BER, BLER, or throughput estimated by means of simulations can be the basis to elaborate other metrics such as Energy Efficiency or Area throughput (see section 8.1).

8.2.3 System-Level Simulation

Depending on the proposed solutions and required accuracy and analysed metrics, the whole system should be simulated. In these cases, static or dynamic system simulations can be considered. Taking into account the scenarios and simulation methodologies adopted for example in 3GPP, the following optional characteristics will be defined to finalise the scenarios:

- 19 tri-sectorial macro sites as depicted in Figure 8-2 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 these 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 hot-zones.
- 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 8-3. 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).

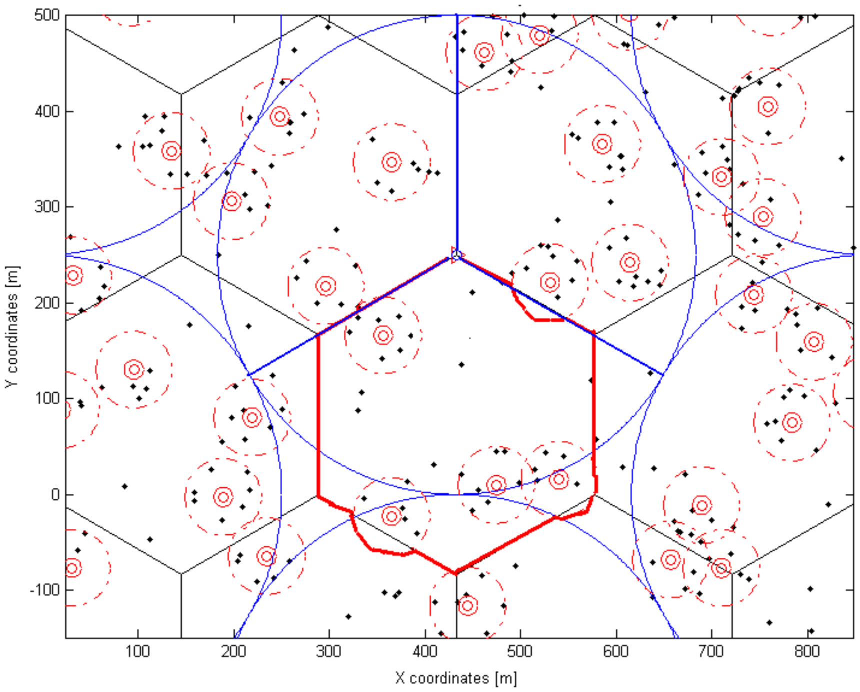

Figure 8-3: Heterogeneous Deployment Example

- Outdoor/indoor distribution: a percentage of users can be placed indoors. While macro cells are installed outdoors, small cells can be placed both in indoors and outdoors. In current deployments, the traffic is mainly generated by indoor users.
- Traffic models: first simulation campaign can be carried out considering full buffer traffic. 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 models 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 and assumptions will 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 centralisation 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 performance results 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 density of macro and small cells.

8.2.4 Proof of Concept

To prove the iJOIN concepts, iJOIN is preparing three demonstration platforms. First platform is a “RANaaS testbed” which is based upon a general purpose cloud computing platform of IaaS (Infrastructure as a Service) type. This testbed would demonstrate the flexible processing split between iSCs and RANaaS node. These flexible functional split possibilities would be demonstrated using the candidate technologies from WP2 and WP3.

The second testbed is a joint backhaul/RAN testbed which provides a reference implementation of a 60GHz backhaul following the principle of hardware-in-the-loop. This platform can be harnessed to demonstrate joint access-backhaul algorithms as envisioned in WP2 and WP3

The SDN testbed is the third demonstration platform for iJOIN. This testbed is based on OpenFlow technology that provides functions for reporting the status of the network and modifying the routing tables in the network nodes. These features will be used for implementing algorithms aimed to continuously monitor the network status, calculate the best path between nodes and re-configure the nodes’ routing tables in order to optimise network communications. The testbed is also able to demonstrate novel system-wide energy saving algorithms and many new load balancing and congestion control mechanisms.

Figure 8-4 gives a snapshot of how the different testbeds map into iJOIN’s logical architecture, and which modules are demonstrated by each of the testbeds.

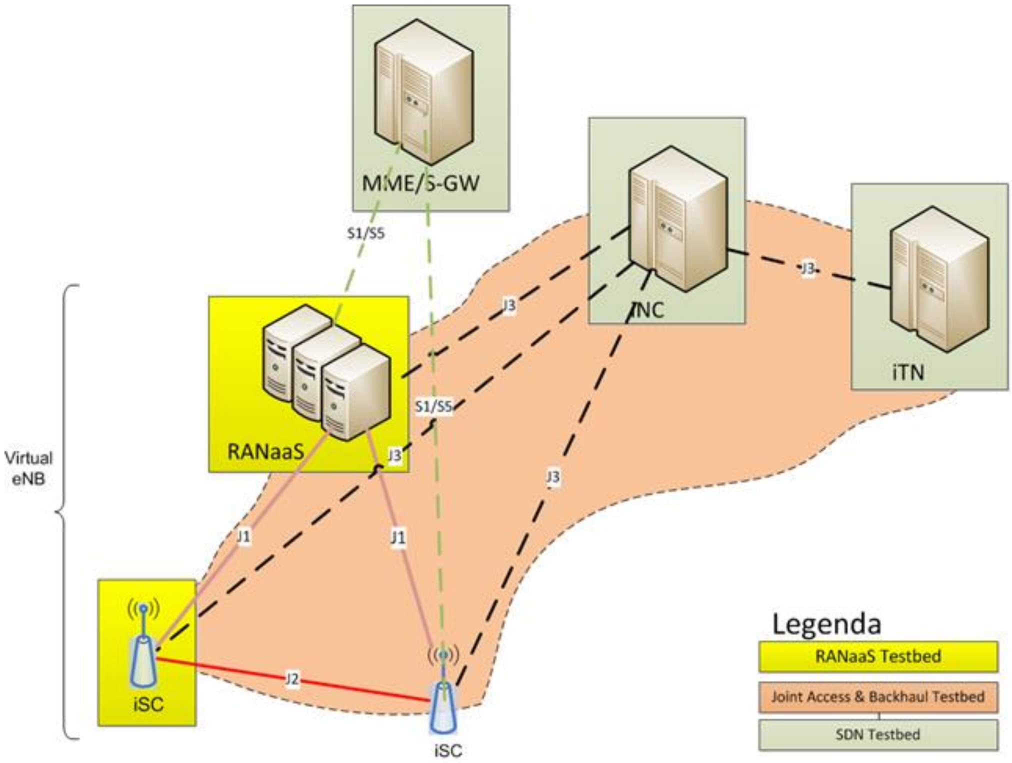

Figure 8-4 - iJOIN overall testbed coverage

9 Summary and Conclusion

This deliverable 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 which will support iJOIN's 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 for defining 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 3GPP 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.

10 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 10-1 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 10-1: 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 standardised 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 centralisation?”	*i.e. where is the “centralisation 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)	

The outcome of this preliminary work performed in the first phase of the project served as a basis for the definition of iJOIN scenarios and use cases (in section 5) and after project-internal elaboration has been summarised in the harmonised assumptions that served as a basis for the definition of logical architecture present in section 7.2 and functional architecture (section 7.3).

Acknowledgements and Disclaimer

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References

[1] European Commission, “Digital Agenda Scoreboard”, Brussels, May 2011

[2] Cisco, “Cisco Visual Networking Index: Forecast and Methodology, 2010–2015”, Jun. 2011

[3] Cisco, “Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2010-2015”, Cisco, February 2011

[4] 148Apps.biz, http://148apps.biz/app-store-metrics/. [Accessed 17 Apr. 2013].

[5] “Number of available Android applications – AppBrain”, http://www.appbrain.com/stats/number-of-android-apps. [Accessed 19 December 2011]

[6] “Android Market Hits 10 Billion Downloads, Kicks off App Sale”, http://www.wired.com/gadgetlab/2011/12/android-market-downloads/. [Accessed 19 December 2011].

[7] European Commission, “Digital Agenda Scoreboard 2011”, Brussels, 2011

[8] Nokia Siemens Networks, “2020: Beyond 4G, Radio Evolution for the Gigabit Experience”, Aug. 2011

[9] Net!Works European Technology Platform, “Broadband Wireless Beyond 2020”, May 2011

[10] European Commission, “Digital Agenda for Europe: key initiatives”, Brussels, May 2010

[11] M. Dohler, R. Heath, A. Lozano, C. Papadias and R. Valenzuela, “Is The PHY Layer Dead?”, IEEE Communications Magazine, no. 4, pp. 159-165, 2011

[12] Alcatel-Lucent, “Small Cells Technology Fuels New Consumer Market Opportunities - An overview of key research findings in five national markets”, Oct. 2010

[13] Alcatel Lucent, “Metro Cells: A Cost-effective option for meeting growing capacity demands”, White Paper, Jun. 2011

[14] In Stat, “Small Cells Will Play a Very Large Part in 4G: Worldwide Femto, Pico, and Microcell Market Analysis”, Jul. 2010

[15] H. Guan, T. Kolding and P. Merz, “Discovery of Cloud-RAN”, in Cloud-RAN Workshop, Apr. 2010

[16] eMobility NetWorld, “Deliverable D1.1, White Paper on Broadband Wireless Beyond 2020”, Jun. 2011

[17] eMobility NetWorld, “Deliverable D1.2, Strategic Applications, Research and Innovation Agenda”, Jul. 2011

[18] China Mobile Research Institute, “C-RAN - Road Towards Green Radio Access Networks”, in WWRF Meeting, Dusseldorf (Germany), Oct. 2011

[19] Broadband Forum, http://www.broadband-forum.org/

[20] In Stat, “Wireless Backhaul: The Network Behind LTE, WiMAX, and 3G”, Oct. 2010

[21] NGMN, “Next Generation Mobile Networks Optimised Backhaul Requirements”, Aug. 2008

[22] 3GPP TS 36.300 (v10.8.0), “Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2 (Release 10)”, Jul. 2012

[23] 3GPP TS 36.104 (v10.8.0), “Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Base Station (BS) radio transmission and reception (Release 10)”, Dec. 2012

[24] 3GPP TR 36.932 (v12.0.0), “Scenarios and Requirements for Small Cell Enhancements for E-UTRA and E-UTRAN (Release 12)”, Dec. 2012

[25] NGMN, “Small Cell Backhaul Requirements”, White Paper. [online] available on http://www.ngmn.org/nc/downloads/techdownloads.html

[26] NGMN, “Security in LTE backhauling”, White Paper. [online] available on http://www.ngmn.org/nc/downloads/techdownloads.html

[27] NGMN, “LTE Backhauling Deployment Scenarios”, White Paper. [online] available on http://www.ngmn.org/nc/downloads/techdownloads.html

[28] Common Public Radio Interface (CPRI), http://www.cpri.info

[29] CPRI, “Interface Specification”, v5.0 (2011-09-21), Sept. 2011

[30] Open Base Station Architecture Initiative (OBSAI), http://www.obsai.com/

[31] OBSAI, “BTS system reference document”, v2.0, 2006

[32] OBSAI, “Reference Point 3 Specification”, v4.2

[33] Ceragon, “Wireless Backhaul Solutions for Small Cells”, Solution Brief. [online] available on http://www.ceragon.com/files/library/Ceragon_Small_Cell-Solution_Brief.pdf (accessed Feb. 2013)

[34] J. Wells, “Faster than fiber: The future of multi-G/s wireless”, IEEE Microwave Magazine, vol.10, no.3, pp.104-112, May 2009

[35] P. Mell and T. Grance, “The NIST Definition of Cloud Computing. National Institute of Standards and Technology”. [online] available on http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf

[36] Gartner, http://www.gartner.com/it-glossary/cloud-computing/

[37] Gartner, http://www.gartner.com/newsroom/id/1035013

[38] C. Brett, “Grids, Clouds or Ultra Modular Computing for the Enterprise”, BEinGRID Industry Days, Barcelona, Jun., 2008. [online] available on http://www.ogf.org/OGF23/materials/1328/Charles+Brett+-+Forrester+-+BEinGRID+Industry+Days.pdf

[39] NEC Corporation, “NEC Corporation and Telefonica to collaborate in the development of network virtualisation,” Press Release, Feb. 2013. [online] http://www.nec.com/en/press/201302/global_20130221_02.html

[40] ETSI ISG NFV, “Network Functions Virtualisation: An Introduction, Benefits, Enablers, Challenges & Call for Action,” White Paper, Oct. 2012. [online] http://portal.etsi.org/NFV/NFV_White_Paper.pdf

[41] Mobile Cloud Networking (MCN) Project, https://www.mobile-cloud-networking.eu

[42] H. Guan, T. Kolding and P. Merz, “Discovery of Cloud-RAN”, Cloud-RAN Workshop, 2010

[43] P. Olanders, “Cloudification of RAN”, Wireless World Research Forum, Meeting 27 (WWRF 27), Düsseldorf, Germany, 2011

[44] Y. Lin, L. Shao, Z. Zhu, Q. Wang and R. Sabhikhi, “Wireless network cloud: Architecture and System Requirements”, IBM Journal of Research and Development, pp. 4:1-4:12, Jan 2010

[45] Nokia Siemens Networks Corporation, “Liquid Radio - Let traffic waves flow most efficiently”, White Paper, Espoo, Finland, 2011

[46] S. Kemp and T. Gruba, “lightRadio™ Technology Overview”, Alcatel-Lucent TechZine, 2011

[47] ZTE Corporation, “ZTE's C-RAN Progress in China”, Wireless World Research Forum, Meeting 27 (WWRF 27), Düsseldorf, Germany, 2011

[48] China Mobile Research Institute, “C-RAN - Road Towards Green Radio Access Network”, Wireless World Research Forum, Meeting 27 (WWRF 27), Düsseldorf, Germany, 2011

[49] A. D. Little, “The New Reality of Network Cooperation”, White Paper. [online] http://www.adl.com/uploads/tx_extthoughtleadership/ADL_RAN_Cooperation.pdf

[50] Open Networking Foundation, “Software-Defined Networking: The New Norm for Networks”, White Paper, Apr. 2012. [online] https://www.opennetworking.org/images/stories/downloads/white-papers/wp-sdn-newnorm.pdf

[51] J. Mitola, “Software radios-survey, critical evaluation and future directions,” National Telesystems Conference, Fairfax (VA), USA, May 1992

[52] 3GPP TR 36.814 (v9.0.0), “Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects (Release 9)”, Mar 2010

[53] Small Cell Forum, http://www.smallcellforum.org

[54] ITU-M2134, “Requirements related to technical performance for IMT-Advanced radio interface(s)”, 2008. [online] available on http://www.itu.int/pub/R-REP-M

[55] ITU-M2135-1, “Guidelines for evaluation of radio interface technologies for IMT-Advanced”, 2009. [online] available on http://www.itu.int/pub/R-REP-M

[56] O. Arnold, F. Richter, G. Fettweis and O. Blume, “Power consumption modeling of different base station types in heterogeneous cellular networks”, in Future Network and MobileSummit, Florence, Italy, 2010

[57] H. Guan, T. Kolding and P. Merz, “Discovery of Cloud-RAN”, Cloud-RAN Workshop, Apr. 2010

[58] A. Bou Saleh, S. Redana, B. Raaf and J. Hamalainen, “Comparison of Relay and Pico eNB Deployments in LTE-Advanced”, IEEE 70th Vehicular Technology Conference Fall (VTC 2009-Fall), 2009

[59] Zhen Liu, T. Kolding, P. Mogensen, B. Vejgaard and T. Sorensen, “Economical Comparison of Enterprise In-Building Wireless Solutions Using DAS and Femto”, IEEE Vehicular Technology Conference (VTC Fall), Sept. 2012

[60] P. Marsch, A. Fehske, G. Fettweis, “Increasing mobile rates while minimising cost per bit - Cooperation vs. denser deployment”, 7th International Symposium on Wireless Communication Systems (ISWCS), pp. 636-640, 2010.

[61] INFSO-ICT-317941 iJOIN, “Final report on MAC/RRM state-of-the-art, requirements, scenarios and interfaces in the iJOIN architecture and promising candidates for joint Access/Backhaul RRM design and novel backhaul solutions in RANaaS” October 2013.

[62] P. Rost, G. Fettweis, and J.N. Laneman, “Energy and cost-efficient mobile communication using multi-cell MIMO and relaying,” IEEE Transactions on Wireless Communications, vol 11, no 9, September 2012

[63] EARTH project, https://www.ict-earth.eu/