



## COST Action CA15104 IRACON Reference Scenarios

COST Action CA15104 (IRACON) aims to achieve scientific networking and cooperation in novel design and analysis methods for 5G, and beyond-5G, radio communication networks. This report outlines the reference scenarios established within Working Group 3, whose goal is to develop new techniques and solutions and their performance for certain scenarios and use cases, in dynamic and complex scenarios oriented to beyond 4G and 5G networks.

This deliverable is the first step to establish a flexible common framework that enables the deployment of rather complex networks, which can be exploited to analyse a wide range of management techniques, solutions and, even, novel architectural approaches. These scenarios have been validated by the authors through their research activity being the next step the possibility for other IRACON members to use them for their own research. All the TDs presented so far are analysed, selecting those scenarios that could be used and asking the authors their agreement to share them.

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## 1. Introduction

In 5G networks it is expected a prominent role of the so called small-cell densification strategy, since it will yield a remarkable capacity increase. This, combined with the exploitation of virtualization techniques and Software Defined Networks (SDN) leading to the Network Function Virtualization (NFV) paradigm, would facilitate cooperation strategies between base stations, if some of their core functions are moved to the cloud.

IRACON WG3 members are working in dynamics and complex scenarios oriented to Beyond 4G and 5G, advocating new techniques and solutions, assessing their performance for certain scenarios and use cases.

It is of high interest for IRACON community to make available a flexible common framework that allows the deployment of rather complex networks which can be exploited to analyse a wide range of management techniques, solutions and, even, novel architectural approaches. These scenarios have been validated by the authors through their research activity being the next step the possibility for other IRACON members to use them for their own research.

This deliverable is the first step to facilitate this common environment. All the TDs presented so far have been analysed, selecting those scenarios that could be used and asking the authors their agreement to share them. In the following pages a short description of the reference scenarios, classified by realistic and synthetic, but also attending to their usability is given.

Other scenarios suitable for IoT have been also proposed by WG3 researchers, but as there is a specific Experimental Working Group on IoT (EWG-IoT) oriented to the definition and analysis of IoT platforms and applications, we did not include them in this deliverable. They can be introduced later if it is considered of interest for the Action.

## 2. Scenarios for C-RAN and Virtual RAN

Several scenarios have been identified.

### 2.1 Implementation analysis of Cloud Radio Access Network Architectures in Small Cells, TD(17) 03073 IST-Lisbon

This reference scenario allows us to analyse the performance parameters of a C-RAN in an already deployed LTE-A network of a mobile operator in the central area of Porto (Portugal). Current macro base station location is given as well as RRHs location.

Scenario characteristics:

- Urban environment.
- Radius of 20 km from Porto city centre.
- 614 RRHs, with cells classified based on their traffic profile. Classification is done automatically by comparing the traffic periods 9h-16h and 17h-24h. If the difference is not bigger than 15% the cells are classified as mixed, otherwise the dominance of the time periods define the classification type between Office or Residential site.
- 19 possible pools.
- Maximum distance between RRH and the corresponding pool is 15 km corresponding to a latency requirement of 150  $\mu$ s (round trip delay considering a fibre propagation delay of  $2 \times 10^8$  m/s).
- Downlink LTE real traffic measures in GBph and GOPS

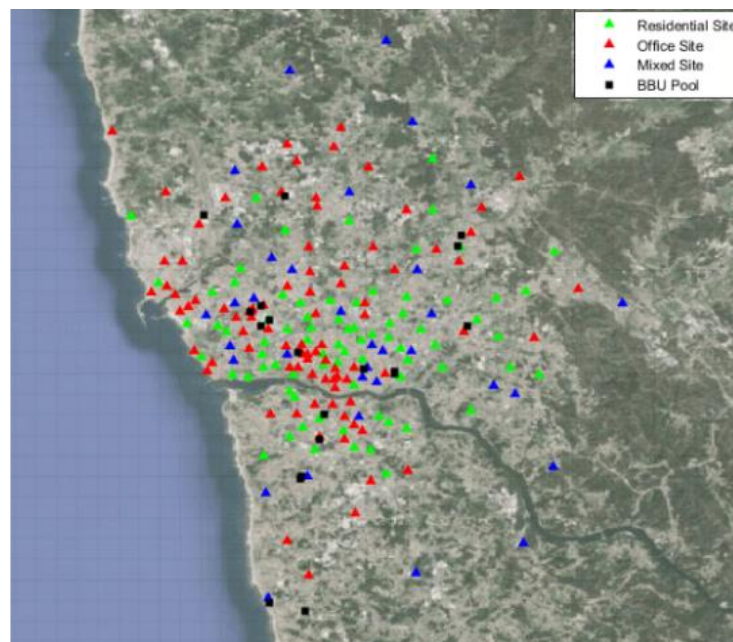


Figure 1. Scenario definition

Metrics to be analysed: optimum number and location of pools, optimization of fronthaul latency, optimal combination of fibre/microwave fronthaul links, pool capacity in traffic per hour, optimal load balancing and traffic offloading, processing power capacity, optimization of multiplexing gain, virtualisation factor (calculated as the inverse of the multiplexing gain measured for traffic curves in GBph), joint optimization of parameters (as fronthaul latency, load balancing and multiplexing gain), average capacity for different strategies (minimise delay, maximize MG, load balancing or combined strategies), cost savings in CAPEX and OPEX comparing with/without C-RAN deployments, future massive Scell deployment to handle traffic increase.

## 2.2 Design of C-RAN Fronthaul for existing LTE Networks, TD(17) 03074 IST Lisbon

This scenario is similar to the previous one but the geographical area is different. In this case a realistic Minho scenario with 374 cell sites, 1176 RRHs and 42 possible BBU Pools are used.

Traffic data is given and traffic patterns are classified slightly different from scenario 2.1 in three intervals: 00:00-8:00 (Dawn), 08:00-17:00 (labour) and 17:00-00:00 (night). This classification allows us to classify RRHs in Residential (night traffic is substantially higher compared with labour traffic), Commercial (labour traffic is substantially higher than night traffic) and mixed (differences between labour and night traffic are not significant).

RRHs are classified in dense urban, urban and rural depending on RRH density, analysing the number of neighbours in a 2 km radius.

## 2.3 A modified Proportional Fair RRM scheme in Virtual RAN, TD(17)03037 IST Lisbon

In this case a centralised Virtual Radio Access Network in a heterogeneous environment is given. Regarding access technologies, different options are considered, useful to test among others, heterogeneous 5G deployments optimising resource management among different access technologies.

The scenario considers Virtual Network Operators (VNOs). A VNO is a network operator that does not own the physical infrastructure and needs wireless connectivity to serve its subscribers. VNOs demand VRRM for the total required capacity of each service, according to their service priority and contracted Service Level Agreements (SLAs). SLAs are categorised into three types of contract: Guaranteed Bit Rate (GBR), Best Effort with minimum Guaranteed (BG) and Best Effort (BE). Services classes considered are conversational, streaming, interactive and background.

This scenario is uniformly covered by all the existing cellular access technologies with end users capable to connect to any available RAT. RRHs can support OFDMA (LTE), CDMA (UMTS), FDMA/TDMA (GSM). Additionally Wi-Fi (OFDM) coverage is provided by means of IEEE802.11ac standard access point at the centre of each LTE cell site to boost the capacity with only 25% of users have access to that.

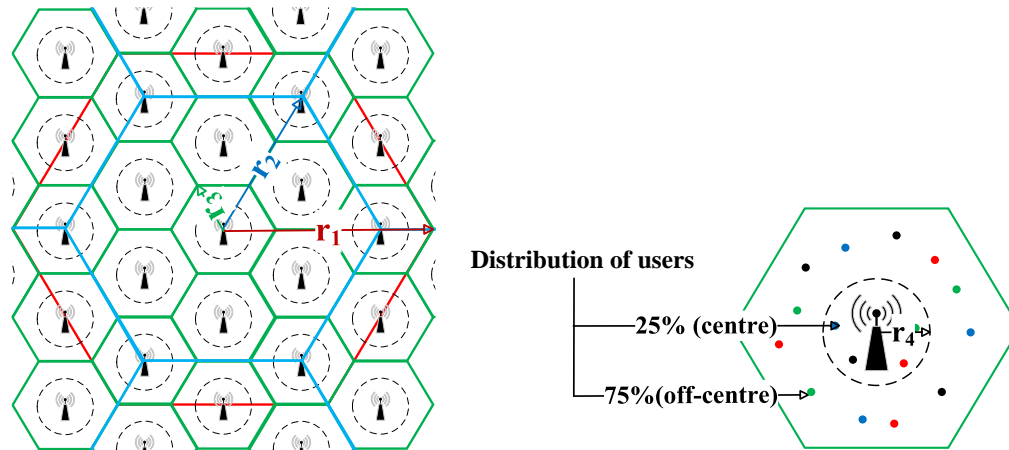


Figure 2: Network layout for the reference scenario

( $r_1=1.6$  km,  $r_2=1.2$  km,  $r_3=0.4$  km,  $r_4=0.05$  km)

RAT	Number of BSs,APs	Cell Radius [km]	RRU	Number of RRUs/BS	Data Rate/RRU [Mbps]	Data Rate/BS [Mbps]
OFDM (Wi-Fi)	16	0.05	Carrier	432 (108 sub-carriers × 4 SS)	0.97	419
OFDMA (LTE)	16	0.4	Resource Block	400 (100 Resource blocks × 4 SS)	0.75	300
CDMA (UMTS)	~ 1.7	1.2	Code	45 (3 carriers × 15 codes)	1.4	63
TDMA (GSM)	1	1.6	Time-slot	21 (3 carriers × 7 time-slots)	0.059	1.24

Table 1: Summary of RAT characteristics, extracted from [1]

VNO#	Service	Class	User mix [%]	Data rate [Mbps]	Serving weight	SLA
1	Video call	Conversational	15	[0.3, 5]	50	GB
	Voice		25	[0.032, 0.064]	50	
	Video stream	Streaming	45	[2, 13]	30	
	Music stream		15	[0.064, 0.32]	16	
2	File sharing	Interactive	50	$[1, R^{CRRM}]$	8	BG
	Web browsing		15	$[0.2, R^{CRRM}]$	6	
	Social networking		35	$[0.4, R^{CRRM}]$	4	
3	Smart metering	Background	50	[0, 0.1]	1	BE
	Email		50	$[0, R^{CRRM}]$	1	

Table 2: Assumptions for service parameters.

### 3. Scenarios for outdoor B4G and 5G (HetNets, macro + small cells)

#### 3.1 On the use of serious game engineering for 5G system performance evaluation, D(16)0216 ITeam UPV

UNITY 3D, created by Unity Technologies, offers a Madrid grid scenario as an extension of the Manhattan Grid model, containing blocks of buildings of different sizes and heights and an open park area with a grid of roads and sidewalks. Model also specifies traffic models for vehicles and pedestrians aiming at reproducing a typical European dense urban environment. Dimensions are 387 m x 552 m, with building heights between 8 and 15 floors with 3.5 m of height each. This model has been used by EU METIS-II [2] project ensuring that results and findings could be accessible and usable for other future purposes, as in next phase of 5G-PPP activities.

- 4 In the work a single three sectorial macro station operating at 800 MHz or 3.5 GHz with antenna elements positioned at the edge of the top of a central building is considered with antenna gains of 17 dBi. Additionally 12 micro/pico cells working at 2.6 or 25 GHz were positioned on lampposts 10 m above the ground.
- 5 A configurable number of cars, with dimensions 1.8 m x 4.3 m are uniformly distributed. Each car has a number of users inside chosen uniformly from the interval [1,5], being car maximum speed 50 km/h with car acceleration of 2.9 m/s<sup>2</sup> and deceleration 7.5 m/s<sup>2</sup>. Cars do not turn across streets but move always along the same street, driving along the opposite line when they reach the scenario border. Cars stop at red traffic lights and also when there is another vehicle less than 2.5 m in front. Traffic lights switch simultaneously every 90 s. with a giving pattern. Mobility traces were generated with a road traffic simulator (SUMO) [3].

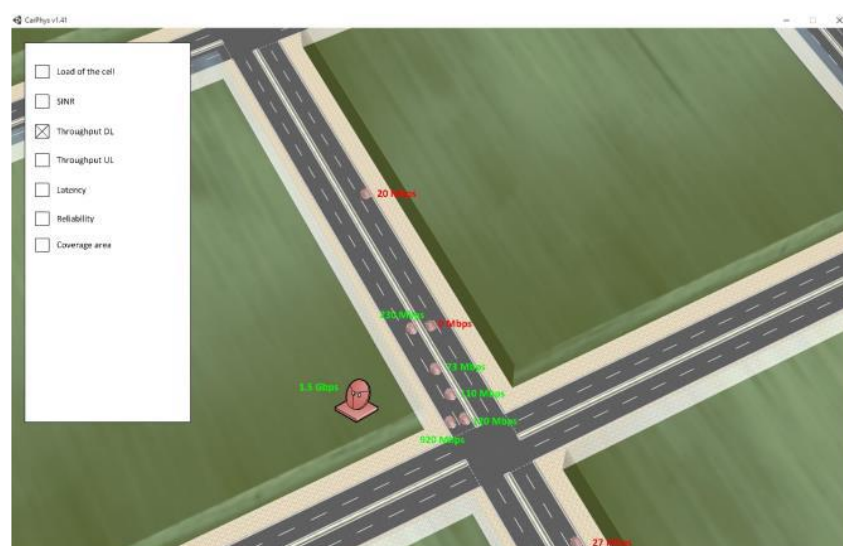


Figure 3: example of information display

The visualization tool is able to show the scenario with a set of pedestrians, cars and buses moving around, as well as showing other information as

coverage areas by transmitter in different colours, service area analysis, throughput distribution, user throughput distribution, QoS distribution, and connectivity links between UEs and BSs allowing to distinguish D2D links, moving network and cellular links.

Simulation results include the following items: mobility traces, loss maps, packet generation/reception files, per mobile entity KPIs file, per station KPIs file, global KPIs file.

### 3.2 Balancing the load in LTE urban networks via inter-frequency handovers. TD(17)03075 , IST Lisbon

A realistic scenario used to study the impact of load balancing via inter-frequency handovers in the performance of an LTE network. The reference scenario is the city of Lisbon considering that the whole city is a dense urban environment. Each district has a different population density, hence, a different generated traffic, which means that they have different coverage and capacity requirements. The total coverage area is 84.88 km<sup>2</sup>.

Seven type of services are considered, each with QoS priorities associated to it, as well as minimum, average and maximum throughputs as is represented in table 3. The maximum throughput of Web Browsing, File Sharing and E-Mail were changed to the theoretical maximum DL data rate of LTE, because they are services with no specific GBR.

Service		Bit Rate (Mbps)					Service Mix (%)
		Min	T_lo	Avg	T_hi	Max	
<b>VoLTE</b>		0.005	0.009	0.022	0.036	0.064	22
<b>Video</b>	<b>Calling</b>	0.064	0.231	0.384	0.422	2.048	8
	<b>Streaming</b>	0.5	4.158	5.12	6.304	13.000	28
<b>Music</b>		0.016	0.176	0.196	0.294	0.320	20
<b>Web browsing</b>		0.384	4.096	5.12	7.68	300.000	10
<b>File sharing</b>		0.384	4.096	5.12	7.68	300.000	8
<b>E-Mail</b>		0.384	0.819	1.024	1.536	300.000	4

Table 3: Service parameters

For users, 3 categories (3 to 5) are considered, wherein each one has a different maximum DL data rate associated to it: 3-100 Mbps, 4-150 Mbps and 5-300 Mbps. A 2x2 MIMO has been considered. Through the simulations the total number of covered users goes from 800 up to 19600.

Three frequency bands have been considered:

1. 800 MHz with a bandwidth of 10 MHz, dimensioned to offer the highest possible coverage area and consequently suffering more from inter-cell interference.
2. 1800 MHz with a bandwidth of 20 MHz, designed to offer capacity
3. 2600 MHz with a bandwidth of 20 MHz, designed to offer capacity.

Antenna parameters are different depending on the frequency band.

The number of BSs connected for each frequency band is given in Table 4. Each BS has three sectors.

Parameter Description	Value		
Frequency band (MHz)	800	1800	2600
Maximum bandwidth (MHz)	10	20	20
Number of BS	128	206	244
DL Transmission power (dBm)	43	42	43
BS maximum antenna gain (dBi)	16,4	17,8	17,5
Vertical half-power beamwidth (°)	7.4	5.5	4.2
Horizontal HP beamwidth (°)	65	62	63
Electrical downtilt (°)	12	8	6
Sidelobe attenuation (vertical) (dB)	20		
Front-to-back attenuation (horizontal) (dB)	50		

Table 4: BS characteristics

Propagation model used to calculate path loss is the COST-231 Walfish-Ikegami, choosing the parameters for a dense urban environment. The UE height corresponds to the average holding height of the UEs for both data and voice usages (1.2 m).

### 3.3 Performance Comparison of UL and DL Techniques under DUDE Strategies for Heterogeneous Networks, TD(17)03014, UPC Spain

The advantage of this work is that proposes the use of a modified and improved version of the realistic Vienna Scenario that was used in a COST Action IC1004 [4], and therefore well known by many IRACON researchers, consisting in 51 macro eNBs and 221 pico eNBs. Path loss is obtained through a 3D ray-tracing algorithm.

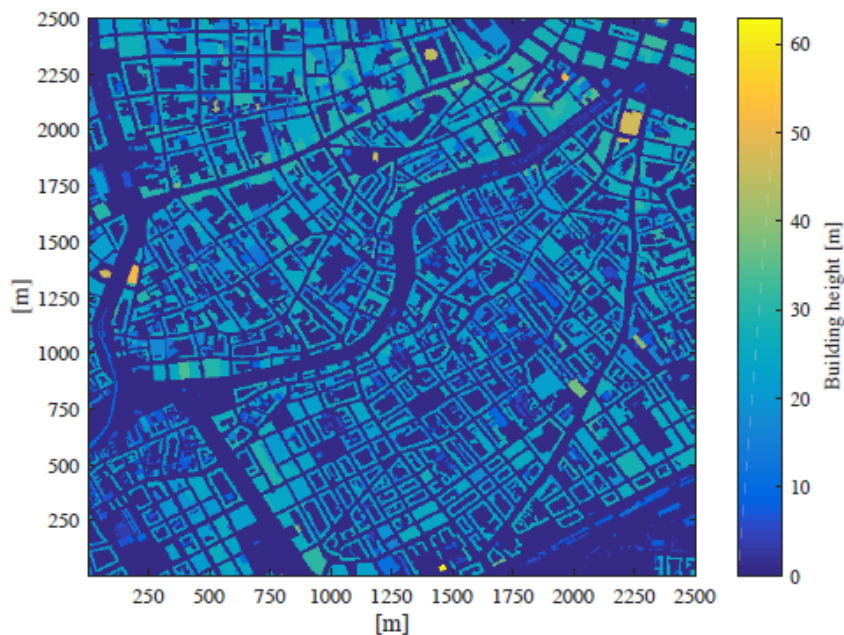


Figure 5: Minimum attenuation of the realistic Vienna Scenario

Synthetic scenario to compare performance with 54 macros and 221 picos with path loss calculated through the 3GPP LTE urban model. User cell association is closely depending on the distance from which the LoS is lost for the pico eNBs, and from the Inter-site Scells Distance among small cells. After several simulations the parameters that better adjust to the realistic scenario are  $D_{LoS}=100$  m and  $D_{ISD}=30$  m.

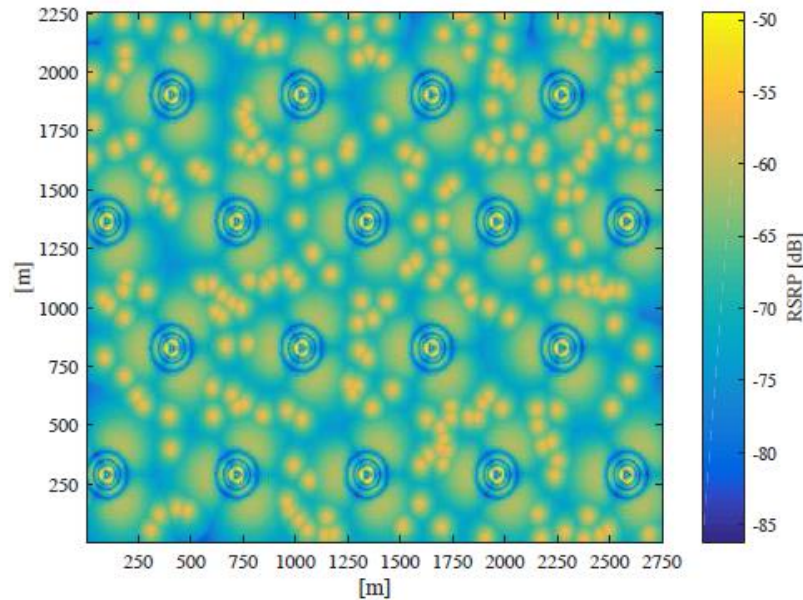


Figure 6: RSRP of the synthetic scenario

With 7000 pedestrian users randomly distributed (only outdoors for the realistic case) and full buffer traffic. A table with other parameters is given.

	<b>Synthetic Scenario</b>	<b>Realistic scenario</b>
Operation frequency	1.8 GHz	1.8 GHz
Bandwidth	20 MHz (100 PRBs)	20 MHz (100 PRBs)
Network deployment	54 macros and 221 picos	54 macros and 221 picos
User distribution	7000 (uniformly distributed)	7000 (uniformly distributed)
Scheduler	Round Robin	Round Robin
Simulation time	1000 ms	1000 ms
Traffic Model	Full Buffer	Full Buffer
Path loss calculation	3GPP LTE Urban Model	3D Ray Tracing
Maximum Tx Power	Macro=46 dBm Pico=30 dBm UE=20 dBm	Macro=46 dBm Pico=30 dBm UE=20 dBm
Antenna system	Macro 2x2 Pico: 2x2	Macro 2x2 Pico: 2x2
Antenna gain	Macro 18 dBi Pico 2 dBi	Macro 18 dBi Pico 2 dBi
UEs mobility	Pedestrian (3 km/h)	Pedestrian (3 km/h)

Supported UL modulation schemes	QPSK 16QAM 64QAM	QPSK 16QAM 64QAM
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Table 5: Simulation parameters

These scenarios have been used to analyse the performance of Down-link and Up-link decoupling (DUDe) compared with Cell Range Expansion (RE) combined with enhanced Inter-Cell Interference Coordination (eICIC) through Monte Carlo System level simulations.

3.4 Generic system level simulation for advanced resource management solutions: holistic approach for complex network deployments.  
TD(17)04062, University of Cantabria, Spain

This work defines a Generic Wireless Network System Modeler (GWNSyM), a flexible platform that allows easy-configuration and easy-analysis of rather large and complex system deployments specially focused on the evaluation of service performance when applying different network techniques. It also includes the synthetic scenario recommended by 3GPP, consisting of 7 macro-cells deployed following a hexagonal pattern, and a variable number of small cells deployed within the coverage range of the macro-cell. Main parameters are given in table 6.

The scenario is used to test different access selection policies (RSRP, CRE and DUDe) for different small-cell density and number of UEs (up to 6000).

<b>Deployment LTE</b>	<b>FDD 2x20MHz, 2.1GHz</b>
<b>Macro Layer</b>	ISD 500 m, 7 tri-sector sites Max Tx. Power 46 dBm Antenna Gain 15 dBi, 15° downtilt
<b>Small Layer</b>	Random deployment Max Tx Tower 37 dBm Omni Antenna
<b>UE</b>	DL NF 7 dB Rx Gain 7 dB Max Tx Power
<b>Deployment LTE</b>	L(dB) distance function d(m)
<b>Macro<sub>NLOS</sub></b> <b>Macro<sub>LOS</sub></b>	139.1033 + 39.0864*(log <sub>10</sub> (d)-3) 36.2995 + 22*log <sub>10</sub> (d) if d<328.42 40*log <sub>10</sub> (d) – 10.7953 if d>328.42
<b>Small<sub>NLOS</sub></b> <b>Small<sub>LOS</sub></b>	145.48 + 37.5*(log <sub>10</sub> (d) – 3) 103.8 + 20.9*(log <sub>10</sub> (d) – 3)
	LOS probability, distance function d(m)
<b>Macro</b> <b>Small</b>	$P_{LOS} = \min(18/d, 1) \cdot (1 - e^{-d/36}) + e^{-d/36}$ $P_{LOS} = 0.5 - \min(0.5, 5 \cdot e^{-156/d}) + \min(0.5, 5 \cdot e^{-d/30})$
<b>UE target SINR</b>	5 dB
<b>UL Tx power</b>	$P_{tx} \text{ (dBm)} = \min \{P_{max}, P_0 + 10\log_{10}(N_{RB}) + \alpha L\}$ $P_{max}=24 \text{ dBm}, P_0 = -80 \text{ dBm}, \alpha$ L propagation losses $N_{RB}$ number of RBs assigned

Table 6: Simulation configuration

### 3.5 Load balance performance analysis with a quality of experience perspective in LTE networks, TD(17)05003, University of Malaga, Spain

Dynamic synthetic scenario with regular 57 cell scenario with wrap-around. Traffic load and service distributions can be configured on a cell basis. The scenario is used by the authors to introduce a QoE perspective in SON algorithms oriented to load balance. Main simulation parameters are listed in table 7.

Time resolution	10 TTI (10 ms)
Propagation model	Okumura-Hata, wrap-around, Slow fading (lognormal $\sigma = 8$ dB, correlation distance = 20 m), multipath fading (ETU model)
Bandwidth	1.4 MHz (6 PRB)
Base station model	Tri-sectorial, MIMO 2x2, EIRP <sub>max</sub> =62 dBm
Carrier Frequency	2 GHz
Cell Radius	500 m
Inter-site distance	1.5 km
Simulation scenario	Hexagonal grid with 57 cells ( 8x19 sites)
Scheduler	Classical exponential/Proportional Fair

Power Control	Equal transmit power per PRB
Link Adaptation	CQI-based
Transmission direction	DL

Table 7: Simulation parameters

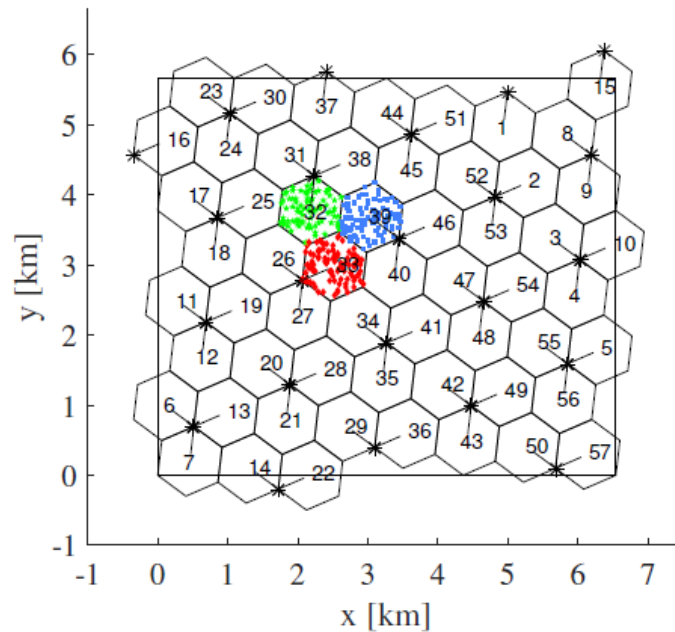


Figure 7: Synthetic scenario

Table 8 provides main information related with traffic models GBR (VoIP) and non-GBR or Best Effort (video and Web), Full buffer (FTP)

Service	Main features
<b>VoIP</b>	Coding rate 16 kbps Exponential duration (60 s) Call drop after 1s without resources
<b>Video</b>	H.264 (MPEG-4 AVC) VBR (Variable Bit Rate) 352x288 pixel resolution and 25 frames per second Video duration evenly distributed (11.2 s maximum) and random frame size according to real traces Connection drop when stalling for twice the video duration
<b>Web</b>	Random number of pages per session Lognormal, $\mu=2$ , exponential waiting time between pages ( $\mu=30$ s) Page size according to [5]

Table 8: traffic model parameters.

### 3.6 Effects of Hyper-Dense Small-cell network deployment on a realistic urban environment, TD(16)01024, Technical University of Braunschweig, Germany

The TD uses Urban Hannover Scenario which was published in COST Action IC1004. It also adds small cell deployment to the previous scenario.

This project presents compares a 3GPP- like deployment with a realistic urban scenario for a hyper-dense small cell network deployment. A realistic simulation environment has been set up, based on the “Urban Hannover Scenario” [1]. It defines a realistically planned macro-cell layer for the entire city of Hannover, Germany. Moreover, full 3D building information has been incorporated and used for the planning and prediction of a hyper-dense small-cell network. Organized in four consecutive extension stages, up to 1200 small cells in an area of 2 x 2 km<sup>2</sup>, which refers to 300 cells per km<sup>2</sup>, have been deployed. The environment is modelled at a carrier frequency of 2600 MHz, which is a plausible band for macro-cell and small cell deployments, even in the same band. In total, four expansion stages of small-cell deployments are considered for the environment, which range from a total small-cell count of 300 to 1200. Given a simulation area of 2 x 2 km<sup>2</sup>, this leads to 75 to 300 small cells per km<sup>2</sup>. The scenario also defines a realistically planned LTE macro-cell network in the city area of Hannover, Germany and consists of 195 cells (65 sites with 3 sectors per site) in an area of 20 x 24 km<sup>2</sup>.

Within the buildings, two different setups of small-cell deployments have been realised. First, a regular deployment on the ground floor along a grid. Second, a random 3D distribution inside the buildings. In the later one, the building dimensions are respected for the deployment as well. The probability of choosing a particular building for a small-cell deployment is proportional to its volume. The antenna is randomly placed inside the 3D building hull, while keeping a minimum distance of 3 m to other small-cells in the same building. In both setups the associated usage of the building decides on the transmit power of the small cell, i.e. 26 dBm for enterprise cells or 20 dBm for home cells.

### 3.7 EMF exposure assessment in a real femtocell environment under 5G paradigm, TD(16)01027, Fondazione Ugo Bordoni, Italy

This work introduces an implemented scenario which comprises two outdoor nodes and five indoor femtocell nodes. The nodes have been deployed in the premises of the Italian Ministry of Economic Development as the basis of the world’s first pilot on the Licensed Shared Access (LSA) approach.

During the project it has been assessed the Electromagnetic field exposure level (EMF) of a real dense indoor femtocell environment deployed for the Licensed Shared Access (LSA) pilot project. In this scenario a real LTE network operates in time division duplexing (TDD) mode. The network has two outdoor nodes and four indoor femtocells operating in the 2.3-2.4 GHz band and one indoor femtocell operating in the 2.6-2.7 GHz band.

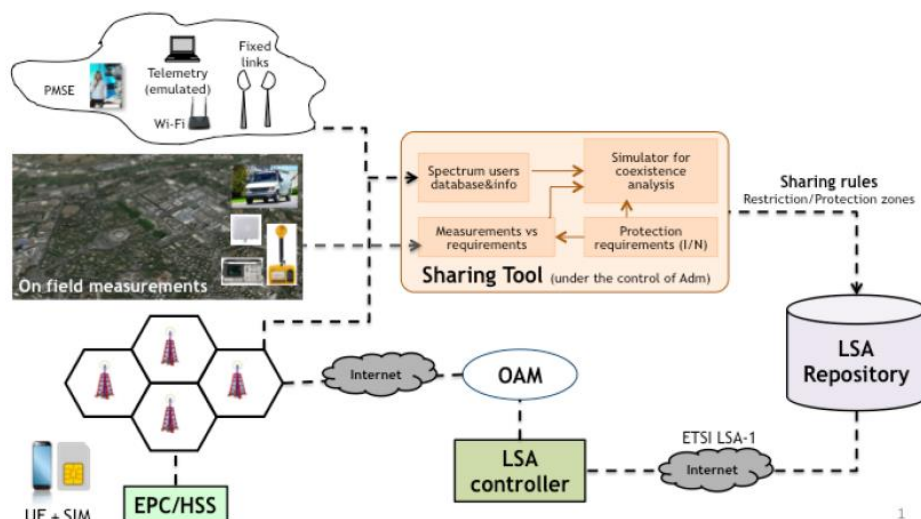


Figure 9: LSA pilot architecture

Figure 9 shows the LSA pilot architecture where the indoor and outdoor BSs are connected to the Evolved Packet Core (EPC), which allows the communication toward user equipment (i.e. commercial smartphones equipped with authenticated test SIMs). A network management system (OAM) communicates with the LSA controller and can manage the mobile network to cope with the requirements imposed by the sharing rules stored in the LSA repository. The different elements of the pilot are provided by different entities. Connections to these elements are granted through the internet.

The indoor femtocell layout of this architecture is shown in figure 10. This layout is composed of four LTE TDD base stations operating in the 2.3 – 2.4 GHz band and one LTE FDD base station operating in the 2.6 – 2.7 GHz range. All these base stations have been installed at the same seventh floor of the building either on the ceiling of corridors or inside offices. The base stations are properly located to allow coexistence with WiFi access points.

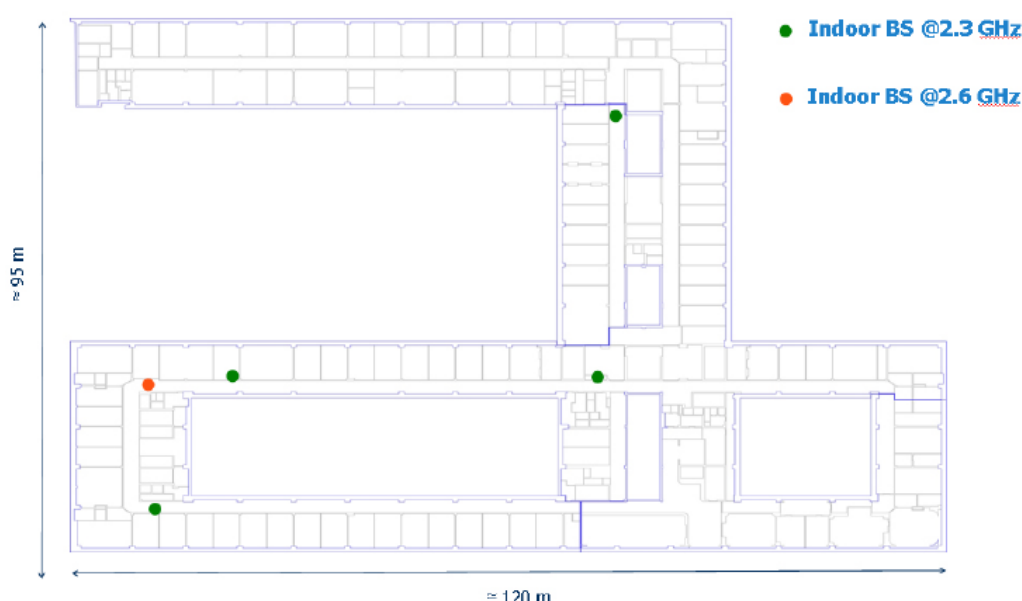


Figure 10: Indoor femtocell installation

### 3.8 Spectrum sharing in DTT band for IoT services provision, TD(16)01020, UPV Spain

This work considers 3 scenarios: a Smart city (urban) scenario with two cases of smart parking and traffic congestion, smart agriculture (rural) scenario again with two cases of smart farming monitoring and animal tracking, and an eHealth indoor scenario.

The work proposes the use of TV white spaces in the DTT band for spectrum sharing between DTT and IoT technologies. The scenarios consider a DVB-T2 network offering fixed rooftop reception as a primary service, and a NB-LTE network as a secondary service. Five representative scenarios to deploy IoT are evaluated, both uplink and downlink are considered. The aim of this study is to evaluate whether the coexistence of both technologies in co-channel or adjacency is possible by determining the margins of protection and Equivalent Isotropic Radiated Maximum Power (EIRP) that could transmit base stations and IoT devices. To achieve this objective, scenarios are emulated in laboratory conditions with professional equipment, by generating signals that meet the standards, hardware emulation of radio channels and use of commercial receivers to evaluate the quality of the decoded signal. The results want to satisfy the spectrum requirements for IoT technologies through the sharing of the DTT band. It also assesses an important candidate for IoT technology defining the power requirements to be met for coexistence with DTT. This solution, thanks to its narrowband nature of the IoT technology, offers efficient use of the radio spectrum that would allow better use of frequency with better adaptation to the portions of spectrum available.

A number of proposed scenarios:

#### Scenario 1 (Smart City - Urban)

This scenario under analysis considers urban or suburban environments characterized by buildings of 2 or 3 floors with wide and narrow streets. The cases proposed are:

Case A. Smart Parking; on the ground level, is considered a fixed sensor network that performs presence readings of the parked vehicles and notifies the report to a nearby IoT Small Cell. Case B. Traffic Congestion; at a height of 2 or 4 meters on poles or traffic lights, it is considered a network of sensors and fixed IoT devices that monitors the current traffic and sends regular reports to a central node.

#### Scenario 2 (Smart Agriculture - Rural)

A rural environment characterized by large tracts of land and line-of-sight (LoS) is assumed, in which there is a main structure belonging to a farm or farming center, where the receiving DTT antenna is located. Case C. Smart Farming Monitoring; at a height of 1-3 meters is considered a network of IoT sensors that monitors the status of crops or weather condition. The devices make regular reports to an IoT small cell. Case D. Animal Tracking; at a height of 1.5 meters is considered a network of mobile IoT sensors worn by the animals to locate them in real time. The devices send periodic reports to the node located in the central structure.

#### Scenario 3 (eHealth - Indoor)

It is considered an indoor environment of a hospital of different heights which is surrounded by buildings. To contemplate the worst case, it is considered that

the hospital is higher than the building where is located the receiving DTT antenna. In this situation both the devices and the IoT Small Cell will be at the same height as the receiving DTT antenna, with line-of-sight between the antennas and with only the separation of the glass of a window. Case E. Patients Surveillance; inside the hospital there is a network of IoT devices worn by the patients and medical staff to keep them continuously located. These devices make regular reports to various nodes spread across the centre.

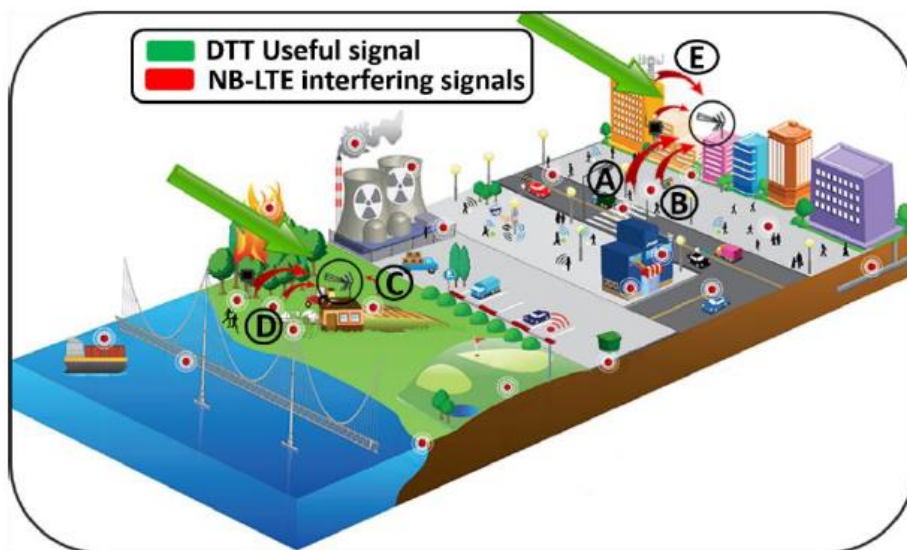


Figure 11: DTT and NB-LTE spectrum sharing scenarios.

Parameters used in all scenarios: As a function of DVB-T2 and NB-LTE carrier separation and duty cycle, the protection ratios are measured by varying the central frequency of the NB-LTE signal from co-channel to adjacent channel in steps of 200 KHz. For DVB-T2, a signal generator with channel emulator (R&S SMU 200) can be used. A Rice channel model for DVB-T2 can be considered, which will be equivalent to assume line-of-sight between the DTT transmitters to the rooftop receiver (DVB-T2 link). The NB-LTE signal can be generated using a physical layer simulator using Matlab.

## 4. Scenarios for Spectrum Sensing and moving to LPWAN and LR-WPAN

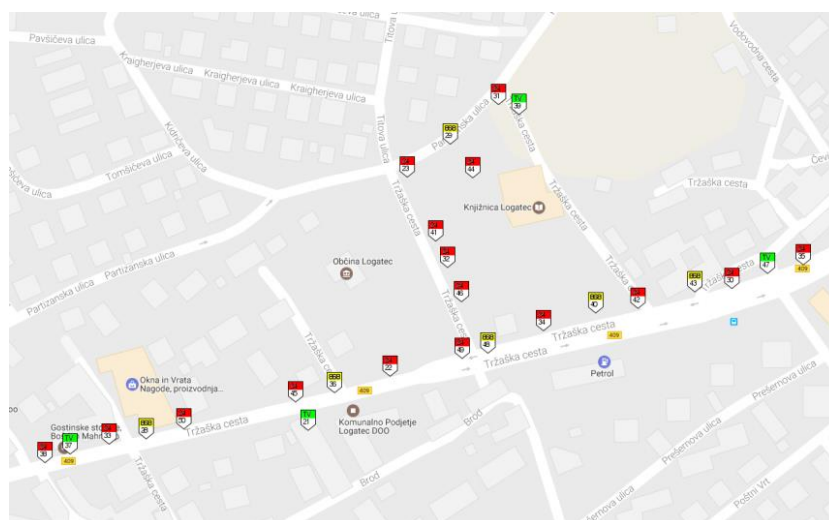
### 4.1 LOG-a-TEC testbed current state and future plans, TD(17)03040 Josef Stefan Institute, Slovenia

A set of testbeds initially defined to experiment in the area of cognitive radio and spectrum sensing can be provided. Authors have been evolved the scenarios to M2M/MTC/dense IoT experimentation using technologies for LPWAN and LR-WPAN such as LoRa and SigFox. The testbed is a member of the Fed4FIRE federation of testbeds, the European FP7 project oriented to federate experimentation facilities targeting future internet.

Several clusters of permanently mounted sensor nodes that are remotely accessible over the internet (access is protected by password), and named respectively:

- Logatec city centre, street level cluster (27 nodes)
- Logatec industrial zone, street level cluster (24 nodes)
- Logatec city centre, antenna tower sensor (1 node)

Each sensor node is equipped with multiple reconfigurable radio interfaces, allowing to experiment in TV whitespaces as well as frequency bands for unlicensed devices.





The web app (GUI) is split in two parts, one showing the map with nodes in different colours according to their role in the network (gateway, ISM band sensing node, TV band sensing node, etc.), while the other is used for the interaction between the user and the testbed. It uses an open-source radio planning tool named GRASS-RaPlaT. An experiment is configured via a web interface and the results of the experiment are also accessible via the web interface. Include a GUI (Graphical User Interface) as well as CLI (Command Line Interface) and a tutorial.



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## Technical Documents (TD) with reference scenarios included in the deliverable

	TD number	Title	Authors
1	TD(17)03073	Implementation Analysis of Cloud Radio Access Network Architectures in Small Cells	T. Monteiro, L. M. Correia, R. Dinis
2	TD(17)03074	Design of C-RAN Fronthaul for existing LTE Networks	H. da Silva, L. M. Correia, P. Costa
3	TD(17)03037	A modified Proportional Fair RRM scheme in virtual RAN	B. Rouzbehani, L. M. Correia, L. Caeiro
4	TD(16)0216	On the use of serious game engineering for 5G system performance evaluation	C. Herranz, D. Martin-Sacristan, S. Inca, J. F. Montserrat, N. Cardona
5	TD(17)03075	Balancing the load in LTE urban networks via inter-frequency handovers	J. Guita, L. M. Correia
6	TD(17)03014	Performance Comparison of UL and DL Techniques under DUDE Strategies for Heterogeneous Networks	H. Wang, M. Garcia-Lozano, E. Mutaftanga, X. Yin, S. Ruiz
7	TD(17)04062	Generic system level simulation for advanced resource management solutions: holistic approach for complex network deployments	P. Rodriguez, P. Sarasua, L. Diez, R. Agüero
8	TD(17)05003	Load balance performance analysis with a quality of experience perspective in LTE networks	M. L. Mari-Altozano, S. Luna, M. Toril
9	TD(16)01024	Effects of Hyper-Dense Small-cell network deployment on a realistic urban environment	D. M. Rose, T. Kürner
10	TD(16)01027	EMF exposure assessment in a real femtocell environment under 5G paradigm	D. Guiducci, C. Carciofi, S. Valbonesi, M. Barbiroli, V. Petrini, E. Spina, P. Chawdhry
11	TD(16)01020	Spectrum sharing in DTT band for IoT services provision	K. Llamas, G. Martinez-Pinzón, N. Cardona
12	TD(17)03040	LOG-a-TEC testbed current state and future plans	Javornik, Igor Ozimek, A. Hrovat, T. Solc, A. Bekan, C. Fortuna, M. Vucnik, K. Bregar, M. Smolnikar, M. Mohocic, A. Bekan
13	TD(17)04001	A Fair Mechanism of Virtual RRM in Multi-RAT Wireless Het-Nets	B. Rouzbehani, L. M. Correia, L. Caeiro

14	TD(16)02001	Emergency Ad-Hoc networks by using drone mounted base stations for a disaster scenario	M. Deruyck, J. Wyckmans, L. Martens, W. Joseph
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## **COST Action CA15104**

# **Assessment of 5G radio access techniques through experimental platforms**

COST Action CA15104 (IRACON) aims to achieve scientific networking and cooperation in novel design and analysis methods for 5G, and beyond-5G, radio communication networks. In this framework, different experimental facilities are made available by institutions to IRACON participants in order to test new algorithms, techniques and protocols in real-world contexts, enabling a coordinated effort among experts of separate disciplines, as complex test beds need a variety of suitably joint and coordinated competences.

This deliverable describes the experimental facilities available in the consortium for assessing 5G and beyond radio access techniques. New waveforms, cognitive radio approaches, or massive MIMO, are possible examples.

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**Editors:** Mark Beach, Florian Kaltenberger

**Date:** January 2018

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## 1. Introduction

IRACON, aims to achieve scientific breakthroughs, by introducing novel design and analysis methods for 5G, and beyond-5G, radio communication networks. IRACON aims at proposing solutions for inclusive and multidimensional communication systems with a wide variety of devices, practical constraints and real-world scenarios, addressing systems ranging from very simple transceivers and sensors, to smartphones and highly flexible cognitive radios. One of the challenges of the project is to perform experimental research on Over-the-Air (OTA) testing, IoT, localisation, tracking and radio access. These topics are addressed within four Experimental WGs (EWGs), focused on specific topics through a transversal approach.

In this framework, different experimental facilities are made available by institutions to IRACON participants in order to test new algorithms, techniques and protocols in real-world contexts, enabling a coordinated effort among experts of separate disciplines, as complex test beds need a variety of suitably joint and coordinated competences.

This deliverable describes the experimental facilities available in the EWG Radio Access.

## 2. EWG-RA: Radio Access

The goal of this Experimental Working Group (EWG) is to experimentally validate the many techniques that will be implemented at the PHY and MAC layers of the radio access part of 5G, especially those developed within DWG2. New waveforms, cognitive radio approaches, or massive MIMO, are possible examples.

The experimental facilities made available by partners are described below.

### 2.1 OpenAirInterface

OpenAirInterface<sup>1</sup> is an open source initiative that today provides a 3GPP compliant reference implementation of eNodeB, User Equipment (UE), and evolved packet core (EPC) that runs on general purpose computing platforms together with off-the-shelf software defined radio (SDR) cards like the ETTUS USRP, Lime SDR, and ExpressMIMO2. It allows users to set up a compliant 4G LTE network and inter-operate with commercial equipment.

The objective of OpenAirInterface is to allow experimentation with state-of-the-art cellular radio technology (4G and 5G) while preserving full compatibility with commercial 3<sup>rd</sup> party equipment. The open-source nature of the code allows experimenters to insert their own code easily. OAI uses their own open-source license, the OAI public license 1.1, which is based on Apache 2.0, but includes a clause that makes it compatible with current 3GPP licensing schemes. The

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<sup>1</sup> <http://www.openairinterface.org>

OAI software alliance has been created to promote this license and to foster collaboration around OAI.

In this section we firstly describe the “classical” or “monolithic” version of OAI and the existing OAI massive MIMO testbed. Secondly we describe the recently introduced and currently being developed functional splits of OAI that will enable C-RAN deployments of OAI. Last but not least we describe the current state and vision of the C-RAN testbed at Eurecom and how we are planning to map our existing work on massive MIMO onto this new testbed.

### 2.1.1 Massive MIMO and LTE

Massive MIMO can also be smartly and perfectly fit into the current LTE standard. In fact, 3GPP has defined the notion of “Transmission Modes” (TMs) for different usage of MIMO in LTE such as single antenna transmission (TM1) transmit diversity (TM2), open-loop spatial multiplexing (TM3), closed-loop spatial multiplexing (TM4), etc. Different TMs use different antenna ports, which can then be mapped onto one or more physical antennas. TM 7 is defined in Release 8 and uses antenna port 5 to transmit both data and UE-specific pilots to a single user. The beamforming is thus transparent to the user and can be arbitrary. Release 9 extends TM 7 to TM 8, giving the possibility of transmitting two streams to a single user or two users, whereas in release 10, this is further extended to TM 9 where up to 8 layers for a single user transmission and up to 4 layers for multiuser transmission is supported. Release 11 adds TM 10, similar to TM 9 with up to 8 layers transmission but the transmit antennas can be physically located on different base stations. In Release 13, no new transmission mode is defined, but CSI Reference Signal (RS) has been extended to 16 ports. Moreover, the ongoing work item in release 14 on the enhancement of Full-Dimension MIMO (special case of massive MIMO in 3GPP) for LTE has defined the objective of extending the CSI-RS to 32 ports with enhancement on CSI reports and support for providing higher robustness against CSI impairments [7].

OAI currently supports TMs 1,2, and 7, and has experimental versions of TMs 3 and 4. TM 8 and 9 are currently in development. OAI does not (yet) support any CSI reference signals, but it does support sounding reference signal (SRS), which can be used in TDD together with a proper reciprocity calibration mechanism to estimate the CSIT.

The Eurecom massive MIMO testbed is based on TDD and TM 7 driving up to 64 co-located antenna elements. It uses uplink channel estimates based on the SRS and transforms them with the help of the calibration matrix (see next section) to a downlink channel estimate, which is then used to compute the beamforming weights. During our experiments we were able to establish communication with a commercial UE and achieve the maximum possible throughput for the given configuration [7].

## 2.1.2 Functional splits in OAI

In the massive MIMO testbed described above, all the eNB functionality was running in the same machine\footnote{using heavy parallelization to meet the real-time constraints}. In order to support a distributed antenna array built from remote radio heads, the monolithic architecture of OAI is split into several parts.

We have adopted the definitions of [1] for the software architecture of OAI. The eNB protocol stack is split in 3 different parts: the remote radio unit (RRU), which is an evolution of the classical remote radio head (RRH), the radio aggregation unit (RAU), which controls multiple RRUs potentially operating on different bands and with different coverages. As the name suggests this unit is responsible also for carrier aggregation and in the future also different radio access technologies. Last but not least the Radio Cloud Center (RCC) controls multiple RAUs. In the 3GPP 5G specifications the RCC is also called the central unit (CU) and RAU the distributed unit (DU).

The split between RRU and RAU is flexible and there are three possible options in OAI. The first two interfaces are similar to the ongoing standardization in [2]. IF5 is similar to the classical BBU-RRH interface and transports baseband time domain IQ samples. IF4.5 corresponds to the split-point at the input (TX) and output (RX) of the OFDM symbol generator (i.e. frequency-domain signals) and transports resource elements in the usable channel band. Both interfaces also support optional A-law compression. Additionally to these two interfaces, OAI today also supports the small cells FAPI interface specifications P5 and P7 between the PHY and the MAC layer [4] that allows to offload the lower PHY functionality to the RRU.

The interface between RAU and RCC is currently under development and we are retro-fitting the current 5G-NR specifications [5] for the F1 interface between CU and DU to 4G.

Figure 1 summarizes the functional splits in OAI.

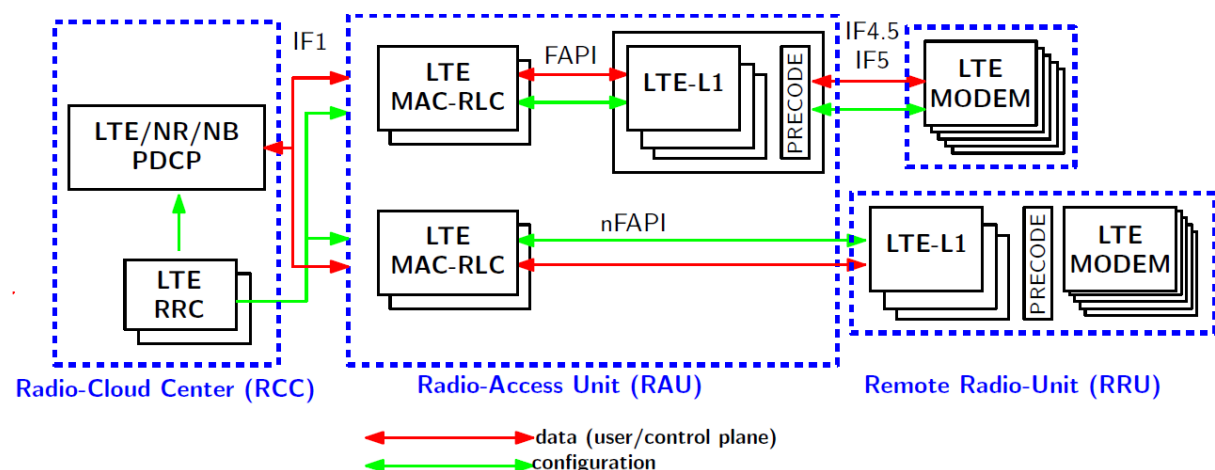


Figure 1: OAI functional splits

## 2.1.3 C-RAN testbed

Eurecom is currently building and deploying a C-RAN network on its premises

in Sophia-Antipolis. The platform will consist of a set of RRUs deployed on the ceilings of the corridors on levels -3 and -4 of the EURECOM building. The RRUs on each floor are connected by Gbit Ethernet to a switch which are in turn connected to a central server over optical 20Gbit Ethernet. An additional high power commercial remote radio head is connected to the C-RAN server through a CPRI gateway (see Figure 2).

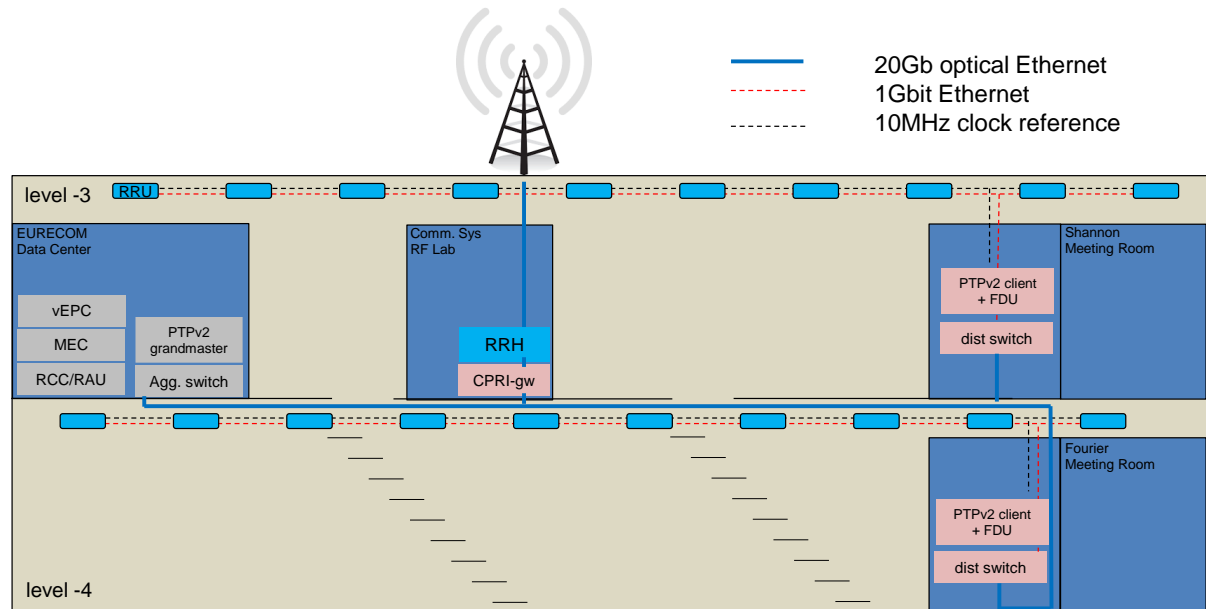


Figure 2: Floor plan of the Eurecom C-RAN deployment

Frequency synchronization is provided by a clock distribution unit which provides a 10MHz reference signal on each floor. Timing synchronization is achieved by a special protocol in the RRUs that first listens to other RRUs within its range to derive the frame number and the start of the frame. In the future, the FDU on each floor can further be synchronized using the PTPv2 (IEEE 1588) protocol over optical fiber. For this a PTPv2 grandmaster clock will be placed in the server room and a PTPv2 client in the local server rooms.

The RRUs consist of an up-board from Intel, a B200 mini from Ettus research, a RF frontend designed by Eurecom and PoE module (see Figure 3). The RRUs will use Band 38 (2.5 GHz) time-division duplex (TDD) for which EURECOM has been granted a license from the French regulatory body (ARCEP) for both indoor and short-range outdoor experiments (1km radio around our building).

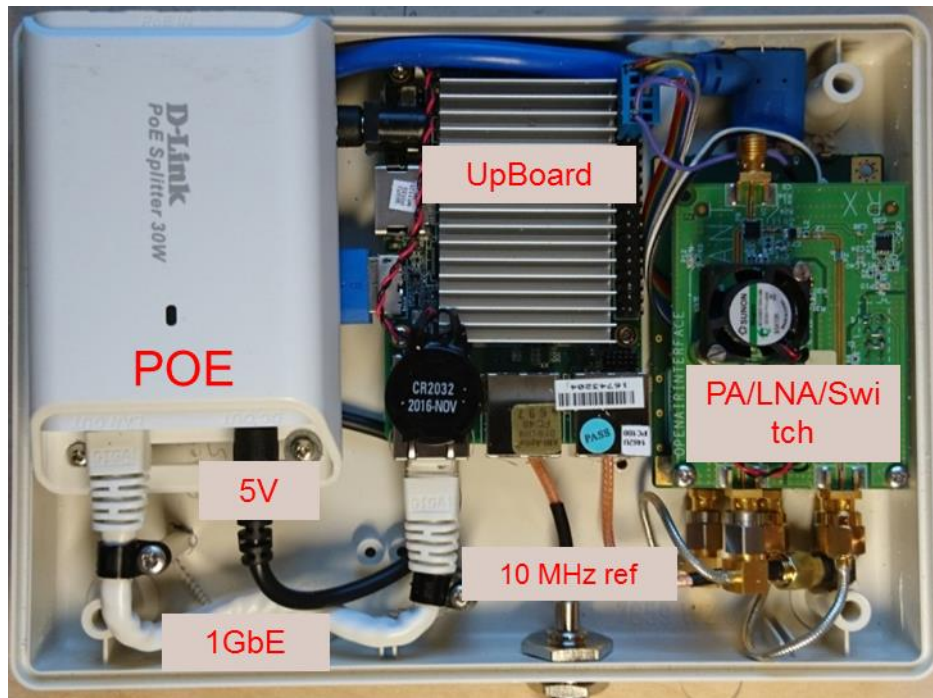


Figure 3: Remote Radio Unit (RRU) built from commodity hardware

#### 2.1.4 Accessibility

The OAI C-RAN testbed at Eurecom is accessible for all members of IRACON. At the moment remote access is under development, but interested people are invited to Eurecom to carry out their experiments in collaboration with the Eurecom team.

The following TDs have more information on the testbed.

- TD(16)02044
- TD(17)03065
- TD(17)04002

Also see the website [www.openairinterface.org](http://www.openairinterface.org) for more details.

## 2.2 The Lund massive MIMO (LuMaMi) testbed

The Lund University Massive MIMO, LuMaMi, testbed is the world's first real time testbed for massive MIMO communication [8]. The testbed is based on Software Defined Radios (SDR) interconnected with a synchronous high capacity network and provide a flexible platform for experimental work with massive MIMO under real life conditions. A few other testbeds based on the same design principles have been assembled, e.g. the massive MIMO testbeds at the University of Bristol, Norwegian University of Science and Technology and KULeuven in Belgium. Below is a summary of the design and features of the LuMaMi testbed based on the thorough and detailed description in [9], please see this document for further details on the setup and on massive MIMO testbed requirements and designs in general.



The LuMaMi testbed can use up to 100 coherent base station antenna elements and can serve up to 12 single antenna users. OFDM is used and the transmission scheme has been made as similar to LTE as possible. The bandwidth is 20 MHz using an IFFT size of 2048, meaning 1200 active sub channels with a subcarrier spacing of 15 kHz. Basic parameters are summarized in Table 0.

Table 1. Basic parameters

Nr. of coherent RF channels	100
Nr. of users	12 single antenna users/6 dual antenna users
RF bandwidth	20 MHz
Center frequency	3.7 GHz
Output power	16 dBm per channel
Pre-coding	MRC/MRT, ZF, regularized ZF
Modulation	OFDM: 4, 16, 64, 256 QAM
Nr. of sub-carriers	1200
Sub-carrier spacing	15 kHz

The system is controlled by the host on the base station. There, operational parameters are set and operation is monitored in real time. It has an integrated Windows controller running LabView.

### 2.2.1 Frame Structure

The frame structure used for transmission is defined by frames of 10 ms, each divided into 10 subframes with 1 ms duration, which in turn is divided into 2 slots. Each slot of 0.5 ms, comprises 7 OFDM symbols. The first one is an uplink pilot symbol, where the 12 users simultaneously transmit on each 12<sup>th</sup>

subcarrier in an interleaved fashion to support uplink channel estimation. The system is using time division duplex, TDD. The uplink pilot symbols are used also for downlink pre-coding, based on a reciprocity calibration scheme [11]. There are also downlink embedded pilots to support channel estimation and equalization at the UE side.

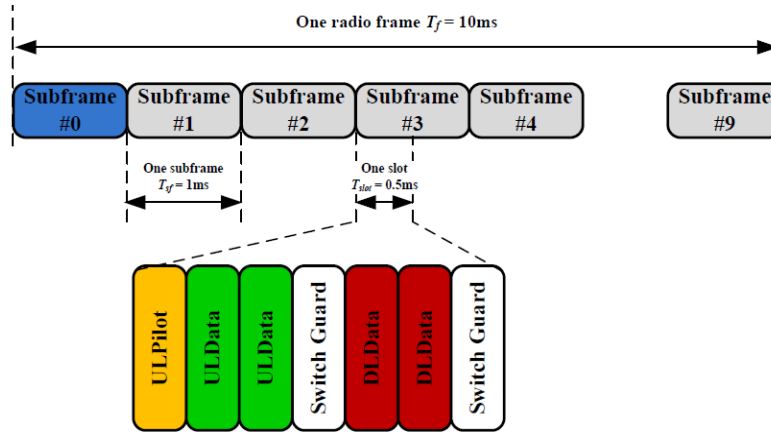


Figure 4. Frame structure

### 2.2.2 Mobility

As the establishment of the communication links are based on downlink pre-coding, the maximum velocity supported is determined by the time between the uplink pilots and the last downlink data symbol in the slot. With the frame structure above, a maximum Doppler frequency of 240 Hz can be supported in a straightforward manner. Given the carrier frequency typically used, 3.7 GHz, this thus corresponds to a maximum velocity of 70 km/h. A mobility test has been performed [10], showing successful operation at 50 km/h without any additional optimization.

### 2.2.3 Antenna Array

The base station array has 160 dual polarized patch elements spaced half a wavelength apart. It provides 320 possible antenna ports that manually can be reconfigured. Typically, for outdoor operation, a dual polarized configuration with the upper part of the T shaped antenna is used, resulting in a dual polarized  $4 \times 25$  antenna configuration. For indoor operation, where the elevation spread is larger, it is possible to use a more compact array structure and then the central  $5 \times 10$  dual polarized part can be used. In any case, any antenna configuration is possible and there is no restriction on maximum antenna spacing for successful massive MIMO operation.

### 2.2.4 User Equipment

The UEs are implemented using software defined radios (SDRs), with one or two antennas each. The SDRs are connected to laptops for user interface and logging, whereas the antennas of the UEs are connected with SMA-cables.

### 2.2.5 Synchronization

Synchronization is maintained internally at the base station through a star synchronization network transmitting a 10 MHz reference and 1 PPS signal to all units. The UEs are synchronizing to the base station through an over the air

procedure to find the proper timing. If needed the UEs can also be disciplined by GPS reference signals to minimize frequency offsets.

#### 2.2.6 Accessibility

The testbed is stationed in Lund, Sweden. In general, we are open to research collaboration and joint projects. Contact Fredrik Tufvesson, [fredrik.tufvesson@eit.lth.se](mailto:fredrik.tufvesson@eit.lth.se), if you have ideas to discuss. The testbed has previously been used in the EU project MAMMOET, Massive MIMO for efficient transmission (<https://mammoet-project.eu>), as an experimental platform for massive MIMO research.

The following TDs have used the testbed.

- TD(17)03043, Paul Harris, Steffen Malkowsky, Joao Vieira, Fredrik Tufvesson, Wael Boukley Hasan, Liang Liu, Mark Beach, Simon Armour and Ove Edfors: Temporal Analysis of Measured LOS Massive MIMO Channels with Mobility, 3<sup>rd</sup> MCM Lisbon, Portugal 2017.
- TD(17)04049, Erik L. Bengtsson, Peter C. Karlsson, Fredrik Tufvesson, Fredrik Rusek, Steffen Malkowsky, Ove Edfors: A Simulation Framework for Multiple Terminal Antennas in Massive MIMO Systems Evaluated Against Measurements, 4<sup>th</sup> MCM Lund, Sweden, 2017

### 2.3 Self-interference cancellation testbed for In-band Full-duplex transceiver prototyping

The Bristol self-interference cancellation (SIC) testbed is a reconfigurable hardware/software platform implementing several combinations of multi-stage SIC. The purpose of the testbed is to allow development and prototyping of adaptive RF circuit control algorithms and digital domain cancellation algorithms, and characterise cancellation performance when subject to hardware imperfections and in dynamic environments.

The cancellation performance achieved by a particular system is heavily dependent not only on the particular design, but also on implementation specific details. In the case of active RF cancellation, circuit imperfections such as phase noise and non-linearity in the Tx chain are the primary limiting factor in determining cancellation performance. Similarly, the type and placement of antennas can have a large impact on achievable isolation. Furthermore, the isolation achieved by a particular technique, and the resulting self-interference channel transfer function, have a substantial impact on the requirements and performance of further stages of cancellation.

Due to the dependence of the performance of digital cancellation techniques on the design and performance of the prior stages of cancellation, prototyping and characterisation of digital baseband cancellation algorithms can only be properly performed using a testbed which implements the preceding RF domain suppression techniques. Similarly, the performance of adaptive control algorithms for RF and digital domain cancellation loops depends heavily on the dynamics of the self-interference channel, and therefore adaptive cancellation

algorithms and only be properly characterised when subject to realistic environmental conditions.

This section summarises the following reference, which documents this testbed in detail.

- C. Zhang, L. Laughlin, M. A. Beach, K. A. Morris, J. L. Haine, A Self-Interference Cancellation Testbed for Full-Duplex Transceiver Prototyping, *Personal, Indoor, and Mobile Radio Communications (PIMRC), 2016 IEEE 27th Annual International Symposium on*, Valencia, 2016.

### 2.3.1 SIC techniques and testbed architecture

The testbed is based on National Instruments Vector Signal Transceivers and implements the following SIC techniques:

- Antenna separation
- Electrical balance duplexing (EBD)
- Active RF cancellation
- Linear baseband cancellation
- Non-linear digital baseband cancellation

Figure 5 : Dual antenna and electrical balance duplexer configurations of the SIC testbed. depicts the testbed architectures. The testbed implements two hardware configurations, utilizing either separate Tx and Rx antennas, or an EBD as the first stage of SI suppression. The following stage of suppression uses a reconfigurable active RF canceller, and finally the digital baseband cancellation processing is implemented in MATLAB. The system uses National Instruments VSTs as the Tx and Rx radios. Transceiver hardware control and active cancellation signal generation is implemented in LabView, along with hardware control of the EBD hardware in the EBD configuration (using a MIPI interface to control MEMS tunable capacitors in the balancing network). Baseband Tx and RX signals are exchanged between LabView and MATLAB, allowing the digital baseband cancellation process to be performed offline in MATLAB.

This testbed architecture has been chosen to provide a highly flexible platform to characterise cancellation performance across a range of system configurations. The physical layer implementation is highly reconfigurable, and allows many parameters to be easily adjusted, for example, modulation scheme, bandwidth, Tx power, subcarrier spacing and carrier frequency can all be easily changed. The use of MATLAB for the digital baseband cancellation facilitates ease of implementation and experimentation in the development of digital cancellation algorithms, leveraging the fast development cycle of MATLAB to provide rapid prototyping of digital cancellation algorithms using real self-interference signals from a fully operational reconfigurable self-interference cancelling transceiver front end. The reconfigurable nature of the testbed physical layer also allows the impact of various different hardware configurations and physical layer parameters on the performance of prototype digital cancellation algorithms to be investigated. Additional hardware can be

included in this testbed, for example, an external Power Amplifier (PA) can be included in the Tx chain to increase the Tx power and degrade Tx Error Vector Magnitude (EVM), and an external Low Noise Amplifier (LNA) and/or attenuator can be included in the Rx chain in order to adjust the Rx noise figure.

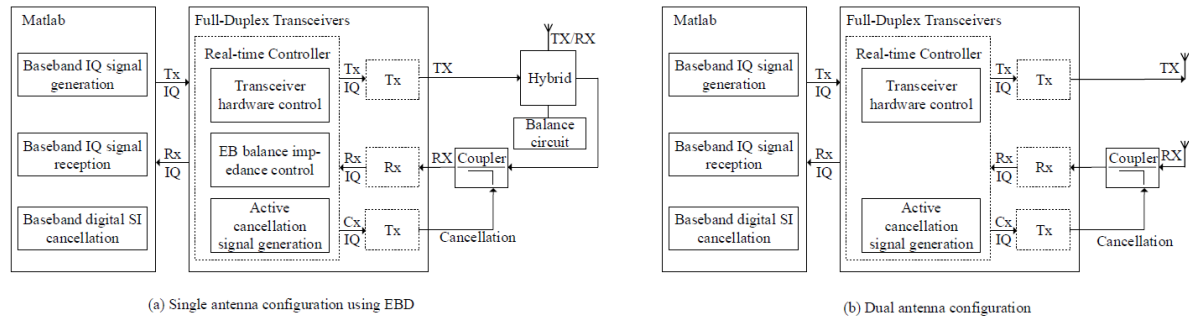


Figure 5 : Dual antenna and electrical balance duplexer configurations of the SIC testbed.

### 2.3.2 Physical layer

The testbed implements and LTE-like OFDM physical with subcarrier spacing of 15 KHz and bandwidth up to 120 MHz, as provided by the NI PXIe-5644R VST. However it should be noted that, for non-linear cancellation, an excess bandwidth ratio of the order of the non-linear processing is required (for example, the system can support 3rd order non-linear processing up to a 40 MHz modulation bandwidth). All baseband digital signal processing, including Quadrature Amplitude Modulation (QAM) and demodulation, OFDM sub-carrier mapping and de-mapping, the Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT), and cyclic prefix processing is implemented in LabView and runs on the controller. A state machine architecture is utilised to perform EBD balancing, SI channel estimation, and active self-interference cancellation sequentially.

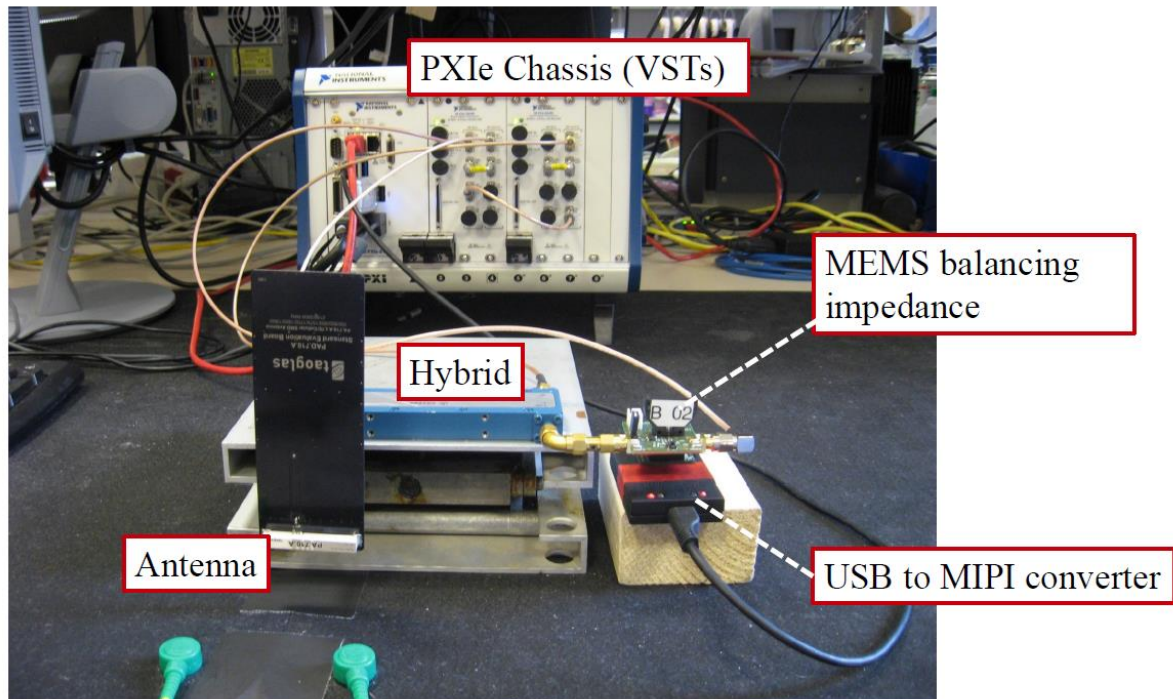


Figure 6 : Photograph of IBFD testbed in the electrical balance duplexer configuration.

### 2.3.3 Availability

Remote access is unavailable for this testbed, however is available for use at the University of Bristol to members of IRACON.

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