LSA pilot

Sharing analysis in a live LTE network in the 2.3-2.4 GHz band

Test configuration and results

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JOINT RESEARCH CENTRE

FUB
Fondazione Ugo Bordoni
Research and Innovation

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EXECUTIVE SUMMARY

In 2015, the Italian Ministry of Economic Development and the Joint Research Centre of the European Commission (JRC) have started a pilot project on the sharing of radio spectrum at 2.3 GHz band, based on the Licensed Shared Access (LSA). The pilot was developed under the technical coordination of Fondazione Ugo Bordoni (FUB) (Italy) and involves industrial partners from numerous European countries: PosteMobile (Italy), Qualcomm Technologies, Inc. (Italy), Athonet (Italy), Nokia Networks (Italy/Finland), Cumucore (Finland) Fairspectrum (Finland) and Red Technologies (France).

The Italian Administration was the first in the world to promote and organise a Licenced Shared Access (LSA) pilot on a large scale to verify both the technical feasibility and the regulatory compliance of this technique applied to a real, live LTE network. The pilot was deployed in Rome, in a building hosting the Ministry of Economic Development.

This report constitutes a high-level account of the pilot architecture and configuration, and contains key measurement results. More detailed data may be provided subsequently, in specific documents.

Measurement results show the feasibility and compliance of LSA to provide mobile broadband services in the 2300 2400 MHz band without detriment to incumbent services (such as Fixed Service which is currently using this band in Italy).

Coexistence is particularly favoured when the LTE network is based on a (possibly dense) indoor femtocell deployment, while compatibility issues become more challenging for outdoor LTE deployments. In the latter case, the shared usage of the band based on LSA might be restricted, either in terms of effective radiated power or geographic location, in larger parts of the intended service area.

LIST OF ACRONYMS AND ABBREVIATIONS

In the present document we will use the following abbreviations and acronyms:

AP	Access Point
BS	Base Station
CEPT	European Conference of Postal and Telecommunications Administrations
CNCER	National Control Centre of Radio-electrical Emissions (in Italian: "*Centro Nazionale di Controllo Emissioni Radioelettriche*")
EIRP	Equivalent Isotropic Radiated Power
EMF	Electromagnetic Field
eNodeB	Evolved NodeB
EPC	Evolved Packet Core
EZ	Exclusion Zone
FS	Fixed Service
FUB	Fondazione Ugo Bordoni
I/N	Interference to Noise ratio
ICNIRP	International Commission on Non-Ionizing Radiation Protection
JRC	Joint Research Centre of the European Commission
LSA	Licenced Shared Access
LTE	Long Term Evolution
MFCN	Mobile/Fixed Communications Networks
MISE	Italian Ministry of Economic Development (in Italian: "*MInistero dello Sviluppo Economico*")
NF	Noise Figure
NRA	National Regulatory Authority
OAM	Operation Administration & Maintenance
OFDM	Orthogonal Frequency Division Multiplexing
PCI	Physical Cell Identifier
PMSE	Programme Making and Special Events
PZ	Protection Zone
RF	Radio Frequency
RSRP	Reference Signal Received Power
RZ	Restriction Zone
SIM	Subscriber Identity Module
SON	Self-Organising Network
TDD	Time Division Duplex
UE	User Equipment
WHO	World Health Organization
Wi-Fi	IEEE Standard 802.11x

1. INTRODUCTION

The world's first regulatory pilot on Licenced Shared Access (LSA) in the 2.3-2.4 GHz band [1] was established in Italy to delve deeper on the role that spectrum sharing has for efficient use of spectrum. This report describes the pilot testbed architecture, as well as the sharing framework and rules currently defined within the LSA pilot to protect the incumbent users in Italy. Sharing conditions are investigated through a massive measurement campaigns, corroborated by simulation, in femtocells and microcells environments, which are expected to represent the optimal use case for spectrum sharing towards high capacity mobile broadband. Subsequently, key results and technical indications are presented.

With the current and projected exponential rate of growth in data over wireless services ([2], [3]), recently rolled out 4G systems are expected to reach saturation before long. To meet future societal needs, the vision of 5G communications has been adopted by the industry and the R&D community alike [4]. A general consensus is emerging that 5G networks will integrate existing 3G and 4G networks operating below 6 GHz with new wireless broadband technologies operating at much higher frequency bands up to 100 GHz. Whereas the use of higher frequencies will release more resources, the fundamental challenge of spectrum crunch remains to be tackled: spectrum is a limited natural resource and therefore must be used efficiently. Due to the attractive propagation characteristics of radio waves below 6 GHz, efficient use of the spectrum remains a priority for the regulators in both the short term as well as the long term.

Recent regulatory initiatives in the EU and elsewhere are focusing on spectrum sharing as a new tool to achieve efficient use of the spectrum. The Radio Spectrum Policy Programme [5] in the EU and the PCAST report in the USA [6] represent high-level policy drivers in this context. However, spectrum sharing is a new regulatory concept, yet to be fully developed, tested and experienced before regulators and the industry will be able to adopt it as a standard model.

The European Commission in 2014 gave a mandate to the European Conference of Postal and Telecommunications Administrations (CEPT) to identify harmonised technical conditions for spectrum sharing in 2300 2400 MHz band [7]. In response, the CEPT has developed a set of technical recommendations on the methodology, known as Licensed Shared Access (LSA), [8] and the relevant sharing conditions ([9]-[11]). The LSA approach envisages exclusive shared use of the spectrum in time, location and frequency with the incumbent who uses its spectrum infrequently or less extensively. The associated technical and regulatory conditions allow spectrum sharing in such a band so that on the one hand the incumbent(s) are protected from unwanted interference from the new entrant licensed users and, on the other hand, the latter can have a guaranteed (though conditional) access to the spectrum to ensure predictable quality of service in the shared band.

Previous studies and trials [12] have already established technological feasibility of LSA. However, what has been lacking so far is a deeper investigation of spectrum sharing in real scenarios to achieve the necessary experience in order to take informed decisions on spectrum sharing as a regulatory tool. The LSA pilot, started in Italy in 2015, was the first such regulatory experiment.

2. PILOT DESCRIPTION

2.1 SCOPE AND OBJECTIVES

The scope of the LSA Pilot was to study the technical conditions and operational feasibility of licensed spectrum sharing in the 2.3-2.4 GHz band through a realistic indoor and outdoor deployment to allow the necessary evaluation of the LSA approach from a regulatory perspective.

Different objectives were achieved by the pilot. The main goals addressed in this report are:

(a) the definition and implementation of a testbed for LSA, developed in compliance with the national regulatory framework;

(b) test and measurement of RF coexistence of LTE systems operating under the LSA with other services on the same band;

(c) verification of the technical feasibility and limits of LSA with respect to incumbent uses, particularly the Fixed Service (FS).

2.2 PILOT NETWORK ARCHITECTURE

The LSA Pilot was set up at the premises of the Ministry of Economic Development (MiSE) in Rome (Fig. 1).

FIG. 1

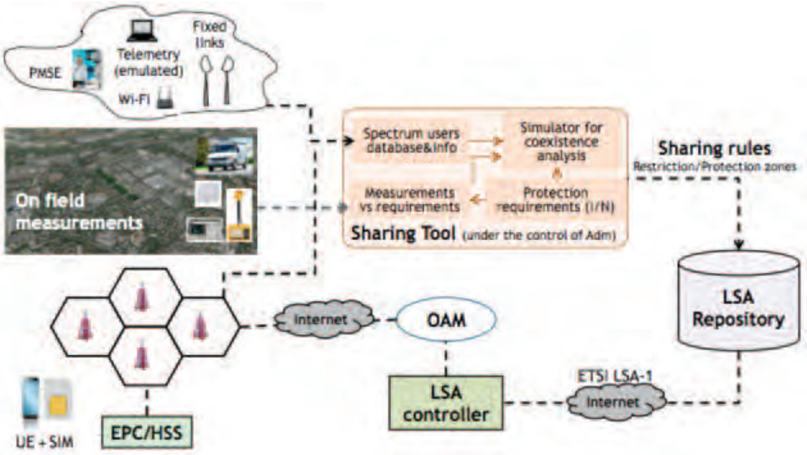
The MISE building that hosted the Italian LSA pilot (front and aerial view)

Radio coverage at 2.3-2.4 GHz was achieved through 5 indoor and 2 outdoor TDD LTE radio base stations (BSs). The outdoor BSs were located over the rooftop in the north-western wing, i.e. top left corner in the aerial photo. For the indoor scenario, the radio coverage of the top floor of the building was specifically targeted, while coverage on lower floors was also partially achieved.

The architecture of the LSA Pilot is shown in Fig. 2. The various elements of the pilot were provided by the different partners who cooperated to its realisation on a voluntary basis.

FIG. 2

The Italian LSA Pilot Architecture



The indoor and outdoor BSs employed for the LSA Pilot are connected to the Evolved Packet Core (EPC), which allows the communication toward user equipment (i.e. commercial smart phones equipped with authenticated test SIMs). A network management system (OAM) communicates with the LSA controller and is capable of managing the mobile network in order to cope with the requirements imposed by the sharing rules stored in the LSA repository.

The different elements of the pilot were provided by different entities and some of them were located outside Italy, namely OAM and LSA controller (Finland) and LSA repository (France). Connection to these elements was granted through the internet.

The LSA system within the pilot is implemented in compliance with the provisions of CEPT ([8] [10]) and ETSI ([13], [14]).

The LSA Controller is implemented as part of a Self-Organising Network (SON) solution with an enhanced power control concept algorithm, which maximises spectrum availability for the licensee and overall throughput to end users while respecting the incumbent's protection.

Incumbent protection is based on the regulatory sharing framework and sharing arrangement. Protected areas can be divided in three categories: Exclusion Zones (EZ) within which LSA Licensees are not allowed to have active radio transmitters, Protection Zones (PZ) where Incumbent receivers will not be subject to harmful interference caused by LSA Licensees' transmissions and Restriction Zones (RZ), where LSA Licensees are allowed to operate radio transmitters, under certain restrictive conditions, like maximum Effective Isotropic Radiated Power (EIRP) limits and constraints on antenna parameters.

3. REGULATORY FRAMEWORK AND TECHNICAL ISSUES

3.1 THE LSA REGULATORY PROCESS

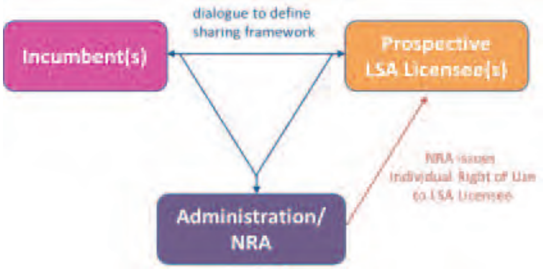
ECC Report 205 [8] as well as CEPT Report 56 [9] highlight that, before the introduction of wireless broadband under the LSA approach, the regulatory process requires:

- a dialogue involving Administration/NRA, Incumbent(s) and prospective LSA Licensees, in order to define the sharing framework;
- the Administration/NRA issuing an individual right of use to the LSA Licensee, following a procedure that is compliant with the Authorisation Directive [25].

The exact implementation of LSA is likely to differ from country to country, in order to adapt to national circumstances.

FIG. 3

Regulatory process required before the introduction of MFCN in a band under LSA



The most relevant use of the 2.3-2.4 GHz band in Italy is for the Fixed Service, operated by numerous licensees. This prevents the incumbent users to be directly involved in the regulatory process schematically depicted in Fig. 3.

Therefore, for the LSA pilot, the Italian Ministry of Economic Development (National Administration) acts as the focal point representing the incumbent users and is in charge of their protection. The incumbent users operating the licensed fixed links are not directly involved in the dialogue for the definition of the sharing framework, being represented and safeguarded by the administration instead.

3.2 THE LSA SHARING FRAMEWORK

The sharing framework is the main element for the implementation of LSA, as it defines, for a given frequency band, the spectrum that can be available for LSA with the corresponding technical and operational conditions.

As highlighted in the ECC Report 205 [8], National Administrations play a fundamental role in the definition of the sharing framework and have to consider a number of key issues in granting LSA rights of use and defining the associated sharing rules:

- Identification of the incumbent(s) to be protected;
- Terms and conditions under which the incumbent and LSA users may access the spectrum;
- Identification of frequencies, locations and periods that must be protected for the incumbent, together with the level of protection.

For the LSA pilot purposes, the definition of the sharing framework, including sharing rules, is governed by the Ministry, but it also involves trusted third parties for practical coexistence analysis between the incumbent users and the mobile service.

3.2.1 Incumbent users in the Italian scenario

The knowledge on how spectrum is actually used is essential for the definition of the sharing framework.

In particular, the 2.3-2.4 GHz band is mostly used in Italy for the Fixed Service. Programme Making and Special Events (PMSE) authorisations have also been granted, while the Governmental use affects only a very small portion of the band.

3.2.2 Principles to protect the incumbent users

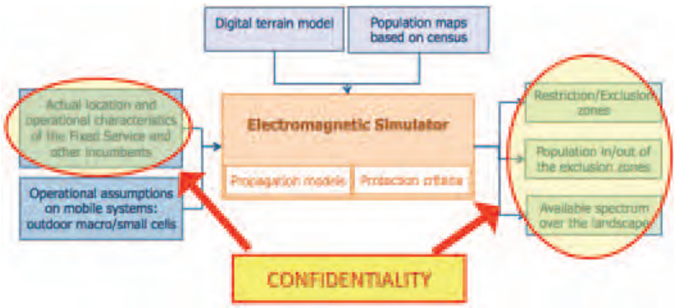
For the LSA pilot purposes, the protection zone ([8][10]) concept is applied both to the Governmental telemetry service and PMSE, while the restriction/exclusion zone concept is applied to the Fixed Service, as it is more suitable to cope with confidentiality requirements posed by the Italian administration with respect to the fixed link locations.

3.2.3 Sharing rules

The application of the LSA sharing framework requires the definition of the sharing rules. This process relies on the analysis of coexistence between the incumbent users and the mobile broadband service, performed through a Sharing Tool, developed and operated by a trusted third party on behalf of the administration maintaining the due level of protection for sensitive and confidential data.

The Sharing Tool is based on an electromagnetic simulator (see Fig. 4) for coexistence analysis. It embeds a radio propagation simulator, which is fed with information on network topologies, positions and technical characteristics of the systems operated both by the incumbent and LSA users. Protection requirements of the incumbent services are taken into account.

FIG. 4
Electromagnetic simulator, core of the Sharing Tool



3.2.4 Confidentiality issues

The coexistence analysis performed within the Sharing Tool requires information on how the incumbent actually uses the spectrum at their disposal, in terms of actual locations and the related operational characteristics.

This information is considered as sensitive and confidential and is not available in the public domain. As shown in Fig. 4, confidentiality issues involve both input data on the radio systems (e.g. FS links) and output data (e.g. restriction/exclusion areas and population). Therefore, the analysis to determine the sharing rules needs properly:

- to guarantee due level of confidentiality to the administration;
- to deliver due amount of information to LSA Repository.

3.3 PROTECTION CRITERIA AND REQUIREMENTS

3.3.1 Protection criteria

The Administration guarantees the protection of the incumbentsby specifying the maximum permitted interference levels at the victim receivers according to given protection criteria.

Within the LSA pilot, the interference to noise ratio (I/N) criterion was adopted to guarantee the protection of the incumbent services in the 2.3-2.4 GHz frequency band; other choices such as the signal-to-noise-plus-interference (C/(I+N)) may also be adopted. The I/N criterion has already been considered in sharing and compatibility studies in ITU-R F.758-5 for FS [15] in CEPT Report 58 for PMSE [10] and in ECC Report 172 for telemetry [11], where the minimum requirement on I/N are defined for the incumbent users of interest in the 2.3-2.4 GHz band.

The maximum admitted received interference power at the victim receiver is directly derived from the maximum admitted I/N value; in dB:

$$I_{max} = N + (I/N)_{max} \qquad (1)$$

TABLE I
PROTECTION REQUIREMENTS FOR INCUMBENTS F=2340 MHZ

Parameters	Fixed Service	PMSE	Telemetry
Receiver noise, NF [dB]	3.5	4	4
Noise power, N [dBm]	-107.47	-100.95	-99.98
I/N [dB]	-10	-6	-6
I_{max} [dBm]	-117.47	-106.95	-105.98

3.3.2 Protection of PMSE video links and Telemetry systems

The PMSE equipment considered for the LSA pilot is represented by a portable video link. System characteristics and protection requirements for PMSE are derived from CEPT Report 58 [10] and ECC Report 219 [16]. The sharing rules are defined so that within a protection zone the maximum admitted interference is set to E = 37.65 dBμV/m in 8 MHz bandwidth for a receiver height of 3 m. The protection zone is a circle with a 200 m radius, centred where the PMSE equipment is located, as shown in Fig. 5 (a).

For the telemetry service, sharing conditions in line with those already available from studies performed in other countries have been adopted: within a protection zone, the maximum admitted interference is set to E = 38.62 dBµV/m in a 10 MHz bandwidth for a receiver height of 15 m. The protection zone is a circle with a 2 km radius, centred in the assumed position of telemetry site, as shown in Fig. 5 (b).

FIG. 5
Protection zone concepts for (a) PMSE video links and (b) telemetry systems

(a) (b)

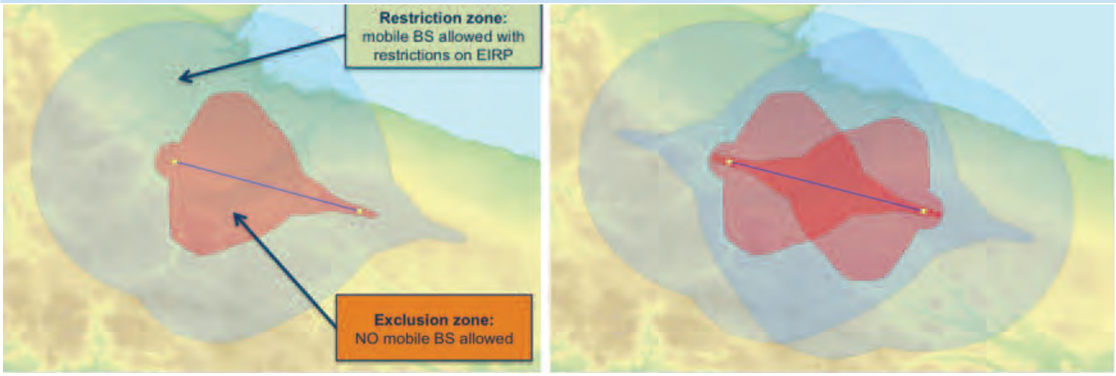
3.3.3 Protection of the Fixed Service

As already mentioned, the protection of the incumbent fixed links is achieved through the application of the restriction/exclusion zone concept as depicted in Fig. 5. The definition of the restriction and exclusion zones is based on coexistence analysis between the incumbent fixed links and the mobile service operated under the LSA approach.

The interference level, I, is calculated by assessing the amount of interference generated by the mobile service, which falls within the fixed link victim receiver operational bandwidth.

By imposing a maximum admitted value of (I/N), one can compute the maximum allowed EIRP that the mobile system can transmit in a given location (i.e. a pixel) by means of the sharing tool in the considered area. As the outcome of the computation, areas where no mobile BS transmission is admitted (i.e. exclusion zones) are identified.

FIG. 6
Restriction/Exclusion zone concepts



Restriction/exclusion zones were investigated considering all the FS links potentially affected from the area where the BSs for the pilot are located. The maximum admitted EIRP that a mobile BS can transmit in a given pixel is computed so that the protection of any possible incumbent fixed link deployed over the landscape is guaranteed; computations are referred to square pixels 100mx100m in size. The mobile base station parameters considered in the computation of exclusion and restriction zones are recalled in TABLE II, whereas for the FS victim receivers their actual radioelectric parameters (e.g. channel bandwidth, gain, antenna height, etc.) have been taken into account.

For the Path Loss computation the effect of the terrain is taken into account, applying the diffraction model of Recommendation ITU-R P.526 [17]:

$$PL=PL_{FreeSpace} + PL_{526} \qquad (2)$$

where $PL_{FreeSpace}$ is the free space path loss and PL_{526} is the diffraction loss.

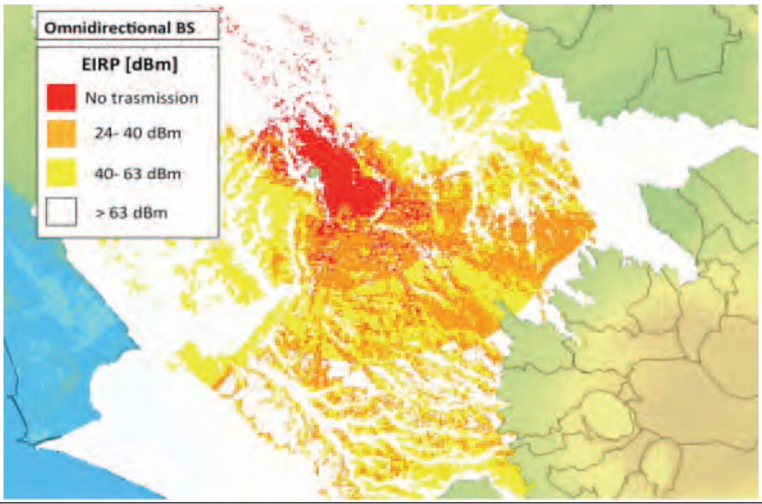
The cumulative effect of multiple base stations in terms of interference at the victim receivers was not taken into account in the activities performed so far, as it was not relevant in this case where only one outdoor site was active. However, an additional margin to take into account the aggregate interference originated by multiple BSs can be included when necessary.

TABLE II
LTE BASE STATION PARAMETERS

Parameters	Macro	Micro	Femto
Bandwidth	20 MHz	20 MHz	20 MHz
Height	≤ 30 m	≤ 10 m	≤ 6 m
Pattern	Omni	Omni	Omni
Environment	Outdoor	Outdoor	Outdoor

Fig. 7 shows an example of restriction zones computed for the macro cell scenario in the province of Rome; different colours correspond to different values of maximum allowed EIRP for the mobile system. EIRP restrictions become more stringent as colours from yellow turn to red.

FIG. 7
Example of EIRP restrictions on the mobile service developed under the restriction/exclusion zone concept



3.4 INCREASING SHARING OPPORTUNITIES UNDER THE RESTRICTION/EXCLUSION ZONE CONCEPT

In a general case, to save computation effort and reduce the burden for the administration, the restrictions on the maximum permitted EIRP in each given pixel might be computed referring to omnidirectional antennas at the LTE BS and considering macro-cellular layout. In the following, some examples are shown to highlight how these conservative assumptions might be refined in calculations to increase sharing opportunities. Since computational efforts increase as well, the administration has to identify a proper trade-off.

3.4.1 Restriction Zones with multi-sector base stations

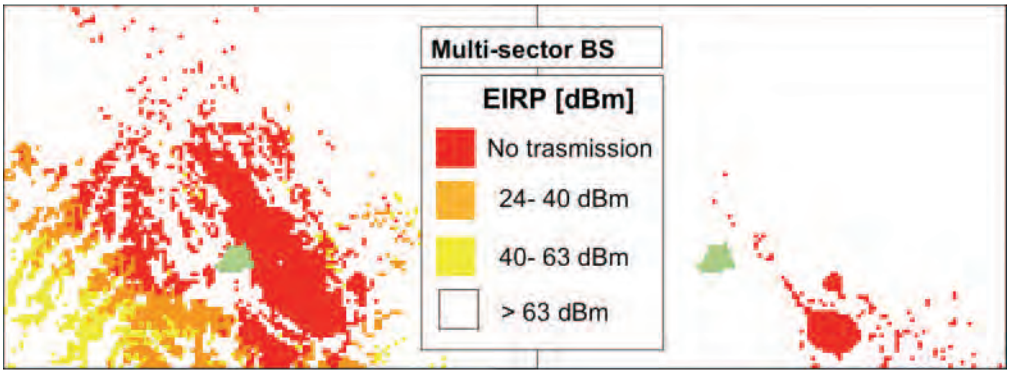
The restrictions in terms of the maximum EIRP allowed in each pixel might be refined and specifically computed for any particular base station sector. This would lead to more flexibility in the deployment of the mobile system, as well as to a likely relaxation of the restrictions for sectors with a limited impact on the victim receivers, due to the antenna angular discrimination. This would increase sharing opportunities.

Fig. 8 shows an example of the restriction/exclusion zones computed in the same area considering two different values of antenna orientation. The figure on the left shows the maximum EIRP permitted in each pixel for a BS-sector with an antenna orientation of 300 degrees, while the figure on the right refers to a BS-sector with an orientation of 120 degrees. In the first case the EIRP restrictions are more stringent than in the second one. This is due to the different antenna discrimination between the mobile BS and the victim receiver, which is more affected by interference generated by the sector with a 300-degree orientation. It is evident that base stations with a larger angular separation with respect to a FS victim receiver are subject to less stringent EIRP restrictions as their contribution to the overall interference is less significant.

Restrictions computed for various orientation of the BS/BS sector antenna are stored in the LSA Repository. In case a BS/BS sector is deployed with sector orientations different from those assumed in the calculations, proper EIRP restrictions may be derived, for instance, by interpolation.

FIG. 8

EIRP restrictions on the deployment of the mobile service, developed under the restriction/exclusion zone concept considering two different antenna orientation of 300 and 120 degrees[1]



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[1] Pixels in light green indicate territories outside Italy.

3.4.2 Restriction Zones for different mobile network layouts

Under the restriction/exclusion zone concept, an additional way to increase sharing opportunities is achievable by computing restrictions for different network layouts (e.g. macro-, micro-, femto-cells). The impact of a mobile network on FS victim receivers significantly depends on several BS characteristics, such as the antenna pattern, height and tilt, or the indoor/outdoor location.

The computation of restrictions for different mobile network layouts makes the possibility to deploy a BS in a given pixel not binary: in the case of calculations of restrictions for various network layouts, if a macro deployment caused an interference level at the victim receiver greater than the maximum tolerable, then a micro or femto deployment could be adopted instead, using relevant restrictions. Therefore, this approach increases flexibility for the mobile network deployment.

In this case, three different layouts have been considered for the computation of EIRP restrictions to address typical macro, micro and indoor femto scenario (TABLE II)

Antenna pattern at the interferer (i.e. sector orientation and tilt) has been disregarded. In the femto scenario, BSs are assumed to operate in indoor conditions and a penetration loss margin of 10 dB is taken into account in the calculations.

TABLE III shows the percentage of locations where a BS with specific characteristics of antenna height and EIRP can be used. The cells in pale blue have been computed for sake of completeness but refer to unusual configurations in terms of height and EIRP combinations for a BS. From the table it can be seen that if the indoor femto scenario is considered the LTE network deployment is prohibited only in the 0.54% of the pixels (exclusion zone), whereas this values is as high as 2.7% for higher values of the BS antenna height. It can be noted that there is also 11.01% of pixels where for a macro installation the maximum admitted EIRP cannot exceed 40dBm..

TABLE III

PERCENTAGE OF LOCATIONS WHERE A BS AT DIFFERENT HEIGHTS AND WITHIN SPECIFIC RANGE OF EIRP CAN BE USED

	No restriction	63-40 dBm	40-24 dBm	Exclusion
h ≤ 30 m	64.13%	21.44%	11.01%	2.7%
h ≤ 10 m	89.89%	5.15%	3.17%	1.78%
h ≤ 6 m (indoor)	96.14%	2.8%	0.51%	0.54%

4. MEASUREMENT CAMPAIGN DESCRIPTION AND PRESENTATION OF KEY RESULTS

The tests performed during the pilot were grouped into two main areas: functional tests, aimed at verifying the viability of LSA approach in a real, live LTE network, and regulatory compliance tests, aimed at verifying the compliance with the current regulatory framework in various respects. In this section we give account of the various tests performed during the pilot.
Details on setup used in performing the various sets of tests are given in Annex 1.

4.1 FUNCTIONAL TESTS

4.1.1 Coverage

In order to assess the functionalities of the LSA Pilot network and verify the compliance with the sharing framework, measurements of the LTE signal level were performed in both indoor and outdoor areas. Additionally, handover and speed tests were run to assess respectively mobility of user equipment (UE) between BS/Cells and UE channel bit rate.

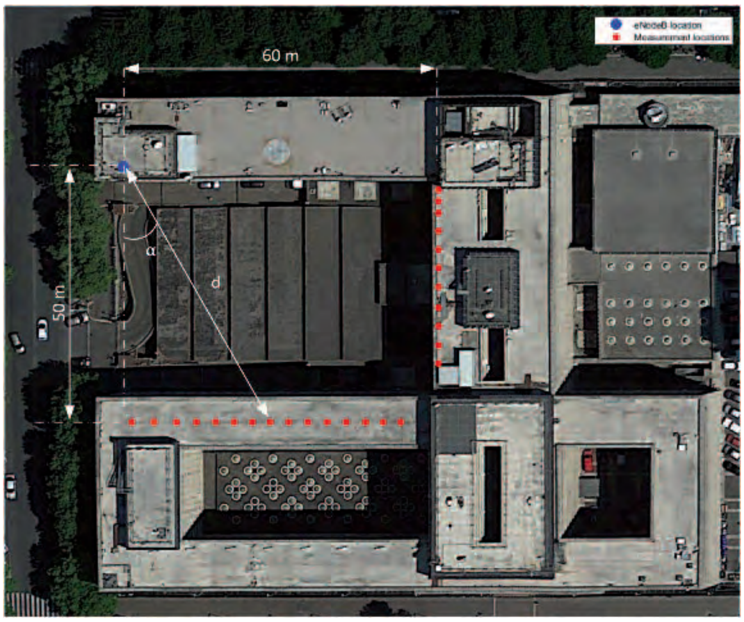
The LSA pilot network was composed of two outdoor BSs placed on the building rooftop and five indoor BSs. Field strength measurements were performed in different outdoor (drive tests) and indoor locations (walk tests).

4.1.1.1 Rooftop power measurements

Power measurements were performed on the roof of MISE Viale America building to measure the equivalent isotropically radiated power (EIRP) of the outdoor eNodeB and estimate its beamwidth. These parameters are required for the interpretation of any measurement performed at some distance from the eNodeB.

The blue dot in Fig. 9 shows the outdoor eNodeB and serves as the origin of a rectangular coordinates system whose axes are parallel to the building. Measurements points represented by red dots were situated along two perpendicular wings of the building. Their coordinates are deduced from the estimation of the first and the last measurement points coordinates (M1 {1,-50} and M26 {60,4}), the distance between measurement points being recorded by counting the number of the 25 cm tiles separating them. Rectangular coordinates were then converted in polar coordinates (α,d) and finally the azimuth angle ϕ was calculated taking into account the building orientation: ϕ = 201° - α.

FIG. 9
Rooftop measurement points



Two series of measurements were made with the antenna in vertical and horizontal polarisation at a height of 1.90 m. For each measurement point the antenna was oriented towards the outdoor base station and the channel power averaged over a 50 ms period was recorded. The eNodeB was operated in test mode at full power. A correction factor CF = 2.65 dB was applied to obtain the actual power during transmission.

The EIRP (in dBm) versus azimuth angle is calculated as follows:

$$\mathrm{EIRP}(\Phi)=\mathrm{Pr}\ (\Phi,d)+\ \mathrm{Lc}-\mathrm{Gr}+\mathrm{CF}-20\ \mathrm{Log}(\lambda/4\pi d) \qquad (3)$$

with Pr: Averaged channel power (dBm)

Lc: Cable and filter losses (dB)

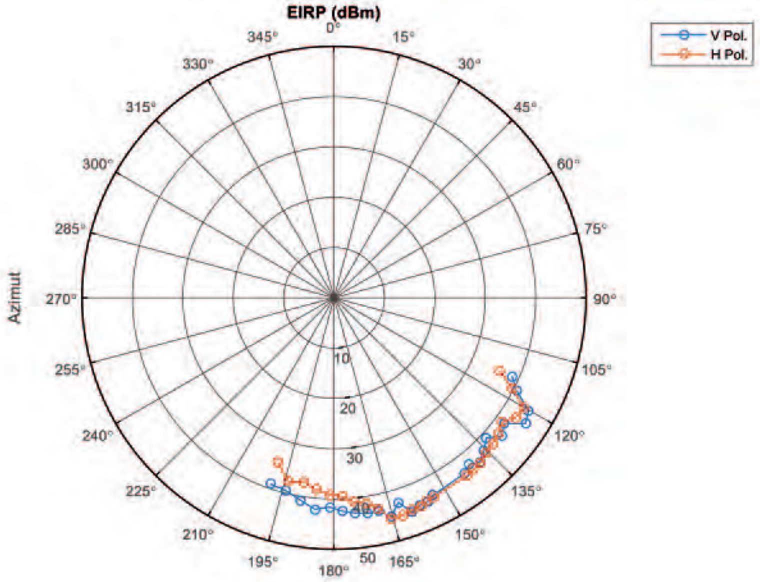
Gr: Measurement antenna gain (dBi)

CF: Duty cycle correction factor (dB)

d: distance from eNodeB

Measurement results are shown in Fig. 10. The maximum EIRP is found be +45.5 dBm in the vertical polarization and +45.4 dBm in the horizontal polarization. These results are very consistent with the nominal EIRP of +45 dBm of the outdoor eNodeB (Pmax=5W, and antenna gain 8 dBi). The 3-dB beamwidth is estimated to be 60° and 50° respectively in vertical and horizontal polarisation. The main direction of the radiation is difficult to estimate accurately for such a wide beam but it can be observed that the radiation is relatively uniform in the azimuth range of 130° to 165°.

FIG. 10
EIRP estimation



4.1.1.2 Outdoor drive tests

MISE provided the measurement set-up and equipment for the drive tests, composed of an omnidirectional antenna (vertical polarisation, gain 6.2 dBi @2340 MHz, 1.8 m at the top of the vehicle), a Rohde & Schwarz TSMW network analyser, a test receiver Rohde & Schwarz ESMD and Spectrum Analyser Anritsu MS2720T.

The outdoor signal has been measured in two different configurations: with all the outdoor and indoor BSs ON and with only the indoor BSs ON respectively. Fig. 11 shows the received power in different outdoor routes when all BSs are ON, while in Fig. 12 the signal received from a single BS either at the ground (a) or at the seventh floor (b) has been isolated.

FIG. 11
Outdoor drive test results (all BSs ON)

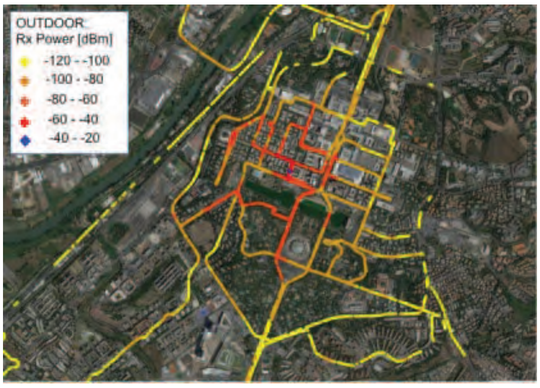
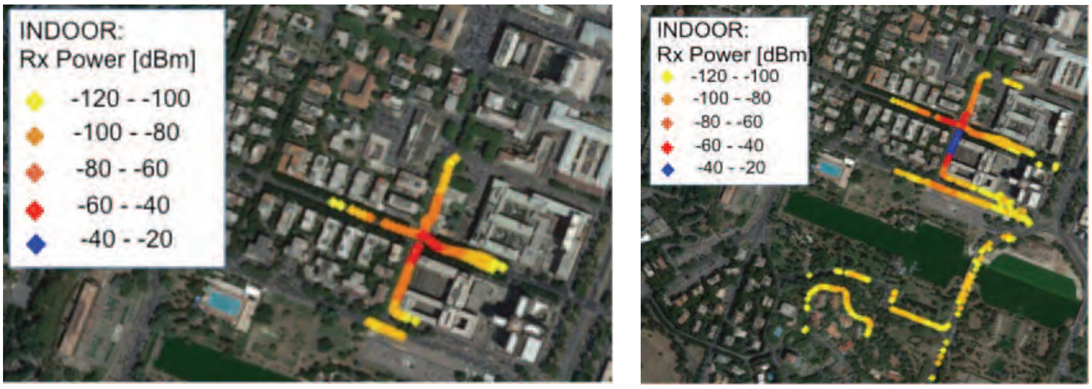


FIG. 12
Outdoor drive test with only one indoor BS at the first floor (a) and at the seventh floor (b)



(a) (b)

It can be noted that the signal from the indoor BSs reaches a restricted area around the MISE building and, in particular, the BS at the 7th floor can be detected in a larger area (e.g. in the garden in front of the MISE building as well as across the small lake). Based on these results a preliminary consideration on sharing can be promptly derived in the surrounding of the building: the protection requirement for a PMSE receiver (maximum interference lower than -106.95 dBm, see TABLE I) are fulfilled in a much larger area if the indoor deployment is considered rather than with outdoor BSs. In fact, field strength levels originated from the outdoor BS are still above the protection requirement as far as 1.5 km from the building. Drive tests results concur with simulations (see TABLE III), as sharing opportunities based on LSA are higher with femtocells. In case of small- and macrocell deployments, coexistence with incumbents would require either a proper geographical separation (exclusion zone) or restrictions on the BS parameters (such as power and antenna pattern).

4.1.1.3 Indoor walk tests

Indoor field strength measurements (walk tests) were performed in different locations at the 7th floor of the MISE building using two UEs.

The measurements points and the handover locations are highlighted in Fig. 13, while the corresponding received power levels are shown in Fig. 14. A remarkable signal variability in the range -50 dBm to -75 dBm is observed, mainly due to the characteristics of the considered indoor environment, which has many corridors, corners and several metal structures (e.g. doors and lifts).

FIG. 13
Indoor BS deployment at MISE - 7th floor

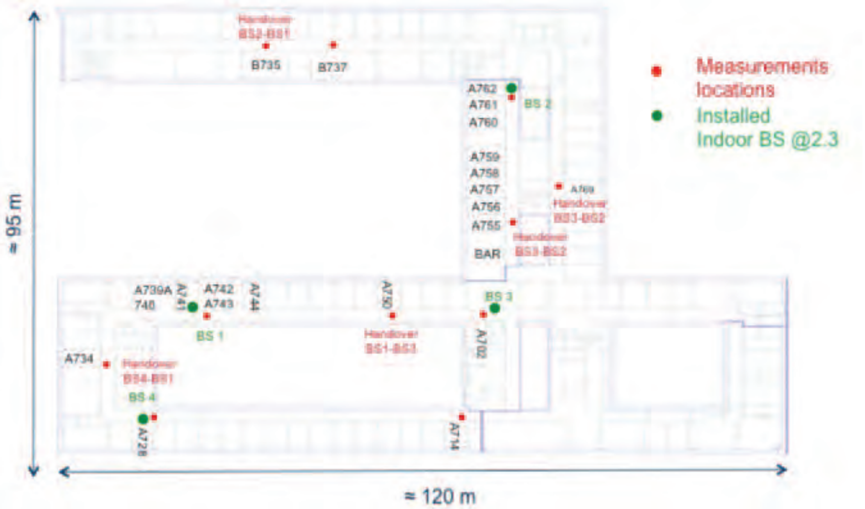
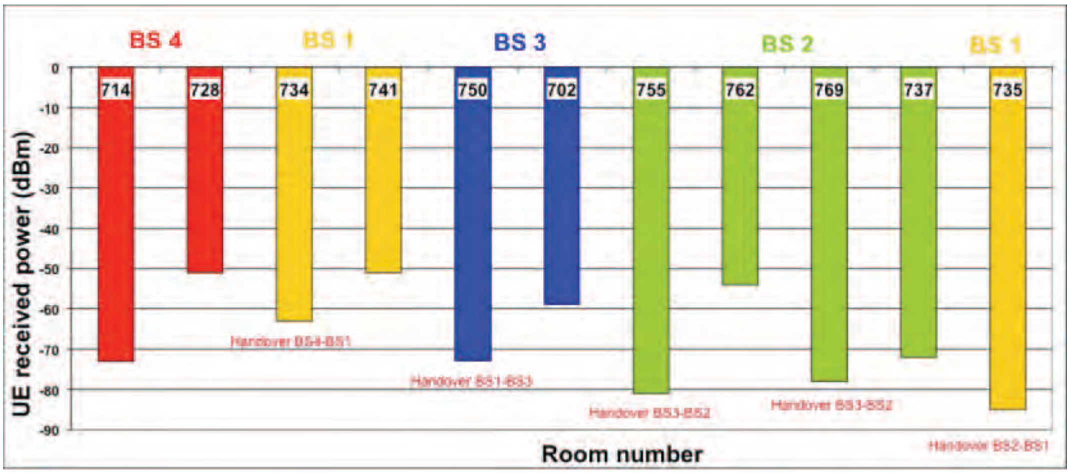


FIG. 14
Indoor received power and handover locations within various rooms

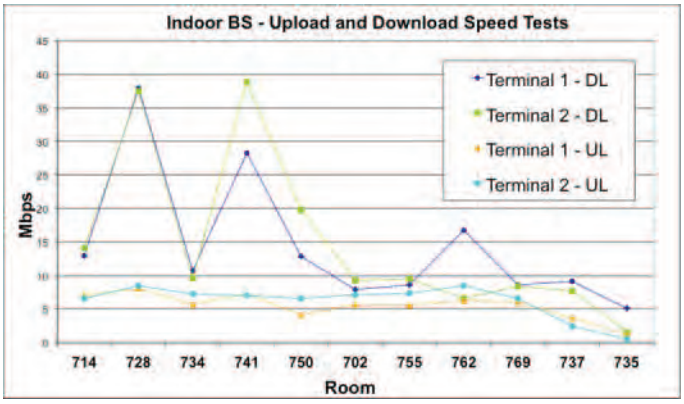


4.1.2 Hand-over and speed tests

Handover and speed tests were also performed, in order to assess the performance of a dense LTE network (based on a deployment of indoor femtocells).

Despite signal variability, handover tests have been successfully completed and a hysteresis margin of about 10-15 dB can be inferred from Fig. 14, while Fig. 15 shows results of upload and download speed tests or the two considered UEs. A strong fluctuation of the measured download bit rate (Mbit/s) was observed among different locations, while the upload speed was more stable.

FIG. 15
Upload and download bit rate (Mbps)



The achieved speed test and handover results show that a well performing indoor LTE network has been realised in compliance with requirements to protect FS incumbent users (in this case expressed through exclusion/restriction zones). In other words, the application of LSA allowed using a portion of the 2.3-2.4 GHz band for indoor mobile, without prejudice for the current operation of incumbent fixed links.

4.1.3 Channel preemption

Tests on channel preemption (also known as evacuation) were realised considering a possible incumbent PMSE user, requesting frequency resources in a given location.

The consequent response of the LSA system has been assessed by measuring the so-called evacuation time, that is the time needed to reconfigure the LTE network so to make the channel available for PMSE.

The channel preemption request issued by the PMSE user is transmitted to the LSA Repository (located in Paris in the specific case of the LSA Pilot), where a circular protection zone of 200-metre radius (see par. 3.3.2) is activated, and then communicated to the LSA Controller (in Helsinki). The proper configuration of the LTE network is finally determined and applied to fulfil the preemption request from the incumbent PMSE.

The LTE network configuration strongly depends on the mutual distance and orientation between the incumbent PMSE and the LTE interferer. In particular the LTE nodes (or part of them) may be either switched off or their carrier power may be properly reduced to limit interference at the PMSE victim receiver below the set threshold (e.g. I/N<-6 dB, see TABLE I).

It should be noted that the carrier power reduction is an additional features that provides more flexibility to the LTE network to achieve compliance with the protection requirements for the incumbents. As far as channel preemption is concerned, test results show that evacuation time is independent of the action taken by the network (either LTE cells locking or carrier power reduction), as it is highlighted in the following.

The test locations selected for channel preemption tests are shown in Fig. 16. Two different positions (PMSE_1 and PMSE_2) have been considered, where a potential PMSE user requests a channel for its operations. The corresponding circular protection zones have also been highlighted in the figure.

FIG. 16
PMSE locations for the channel pre-emption tests (protection zones are highlighted in shaded red)

On spot measurements have been conducted in support to the channel preemption tests. In particular the MISE van has been located in a position where any variation on the outdoor LTE BSs emitted power could be detected (occasionally, variations on the power emitted by indoor LTE BSs could also be detected, as clarified in the following).

A first set of tests has been realised without carrier power reduction features in the LTE network.

4.1.3.1 Test case 1

The mutual distance and orientation between the PMSE victim receiver, assumed in location PMSE_1, and the LTE BSs requires both all the outdoor and indoor LTE nodes being switched off, as a consequence of the channel preemption request from the PMSE user.

The evacuation time has been measured from the moment when the LSA Repository receives the channel preemption requests to the moment when the LTE cells status is changed, meaning that the LSA Controller receives notification that cell operational status has changed.

Results of various samples collected for the estimation of the evacuation time are reported in TABLE 1, together with the mean and the median values.

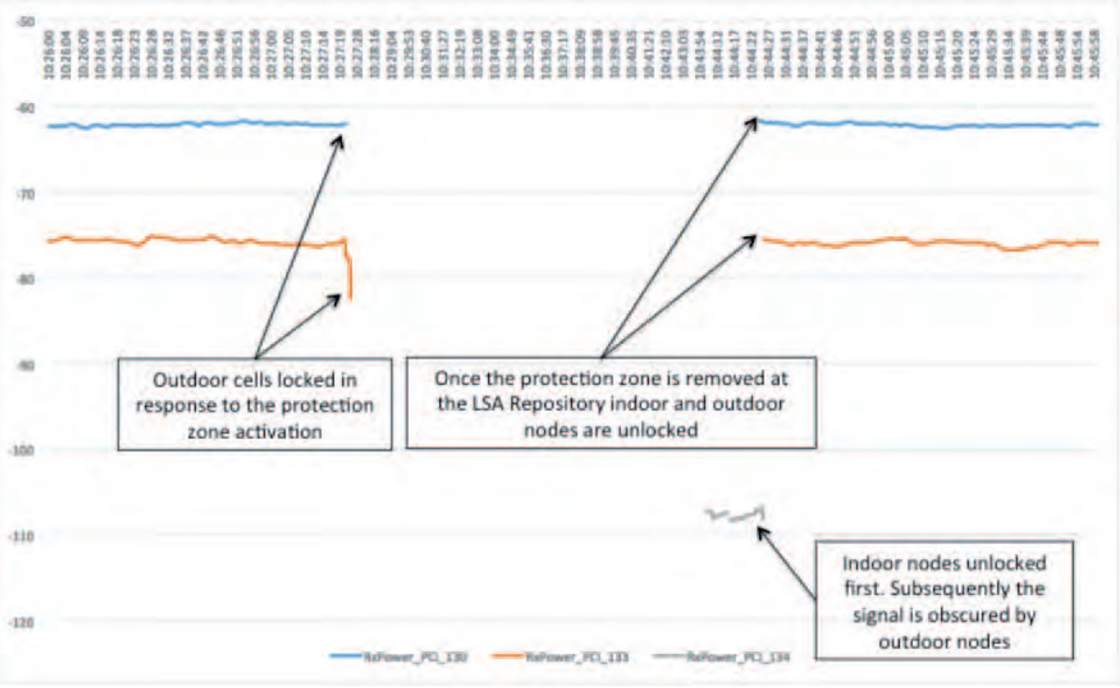
The evacuation time is always below 40 seconds; a delay of 400 ms between the LSA Repository and the LSA Controller, located in different European cities, is included in the measurements.

TABLE IV
EVACUATION TIME – CASE 1

Samples [s]	34.067486
	38.994463
	35.431072
	39.672110
	32.946012
	39.945379
	34.887924
	35.890664
	37.877315
	37.451986
Mean value [s]	**36.716441**
Median value [s]	**36.671325**

Measurements in Fig. 17 confirm that actions on the LTE network have been properly taken. In particular the curves clearly show that outdoor nodes (PCI 130 and 133) are switched off (locked), once the PMSE user issues its request. LTE nodes are then switched on (unlocked) once the PMSE user does not require the channel resource and the related protection zone is released at the LSA Repository. It has to be noted that an indoor node (PCI 134) can sporadically be detected, as highlighted in the figure. This could happen only if the outdoor signals were locked. The absence of indoor signals when the outdoor cells are locked confirmed that also indoor nodes were switched off in response to the channel pre-emption request from the PMSE user. All LTE nodes were then unlocked (first indoor and then outdoor as shown in Fig. 17), as soon as the PMSE user releases its operational channel (i.e. the relevant protection zone is deactivated at the LSA Repository).

FIG. 17
On-field measurements results for Test Case 1



4.1.3.2 Test Case 2

This second test case is very similar to the previous Case 1, except that the mutual distance and orientation of the victim PMSE and the LTE interferer is such that only one of the outdoor LTE sectors affects the PMSE receiver. This means that, in response to a channel pre-emption request, only one cell (PCI 133) will be locked, while the other one (PCI 130) continues its operation. Indoor nodes are also kept in operation.

Results on the measured evacuation time are shown in TABLE V. Values in line with those for the previous case 1 have been collected.

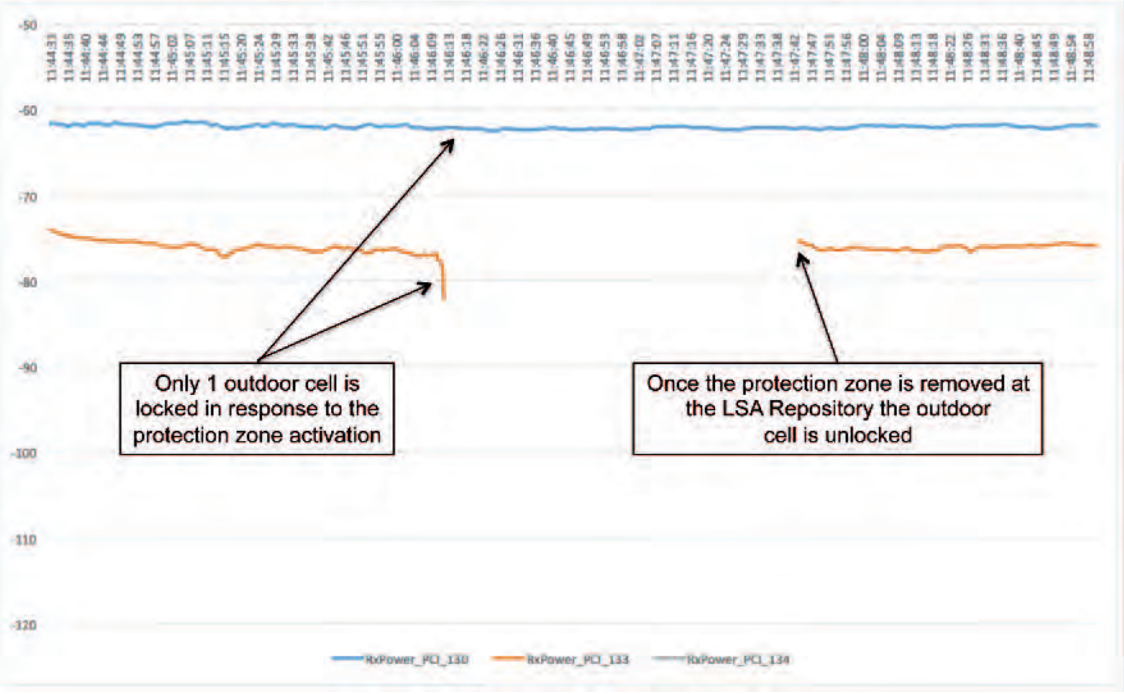
TABLE V
EVACUATION TIME – CASE 2

Samples [s]	37.784439
	34.619608
	35.730612
	34.482797
	36.944632
	37.136974
	33.265537
	31.217865
	38.095514
	38.510492
Mean value [s]	**35.778847**
Median value [s]	**36.337622**

Measurements in Fig. 18 confirm that actions to protect the incumbent PMSE user are properly taken by the system. Although indoor cells are kept in operation, the indoor signal cannot be detected as it is obscured by the outdoor cell signal.

FIG. 18

On-field measurements results for Test Case 2



Only 1 outdoor cell is locked in response to the protection zone activation

Once the protection zone is removed at the LSA Repository the outdoor cell is unlocked

4.1.3.3 Test Case 3: Location PMSE_2 with carrier power reduction

Carrier power reduction features have been activated in the LSA system for this test case, assuming a PMSE receiver in the same location as for Case 2. While granting the proper level of protection to the incumbent, carrier power reduction features allow more flexibility to the system, as the LSA Controller may request the LTE cells (or part of them) to decrease their emitted power, instead of locking the transmission.

In this specific test configuration, a channel preemption request originated by a PMSE user in location PMSE_2 requires one outdoor cell (PCI 133) to be locked, while the carrier power of the other outdoor cell (PCI 130) is reduced by 11 dB, from the 37 dBm to 26 dBm.

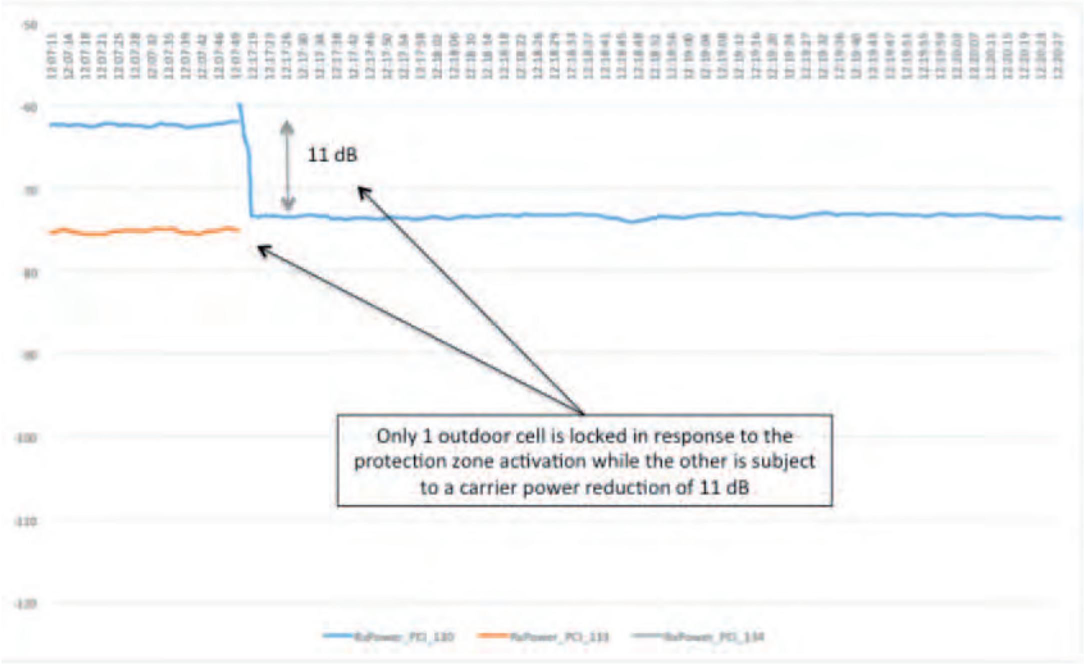
It should be noted that in case 3, the outdoor cell which remains unlocked (i.e. PCI 130) is subject to a decrease of its carrier power, while in previous case 2 it could continue operating unchanged. This is due to a more cautious approach in the prediction algorithm to protect the incumbent with respect to the case where carrier aggregation features are not active.

The mean value of the evacuation time in this test case is equal to 35.646237 seconds, i.e. in line with those of previous test cases.

Measurements in Fig. 19 confirm the carrier power reduction of one outdoor node (PCI 130) to protect the incumbent PMSE user, while the other outdoor cell is locked.

It has to be noted that the reduction of the carrier power of a given cell implies an initial delay of about 4 minutes to reconfigure the LTE network. However, this operation is required only once, as consequently the carrier power is maintained at the reduced level although the protection zone is removed at the LSA Repository.

FIG. 19
Carrier power reduction for Test Case 3



4.2 REGULATORY COMPLIANCE

4.2.1 Compliance with the sharing rules

In order to verify the compliance of the eNodeB with FS and PMSE protection requirements different measurements have been performed by MISE-CNCER (Centro Nazionale di Controllo Emissioni Radioelettriche) in collaboration with FUB and JRC.

Two crucial aspects emerged during the implementation of this test procedure: first, a very sensitive equipment such as that provided by MISE-CNCER is required to assess very low interference power levels due to the need of verify a stringent I/N requirement (i.e., to measure an interference level 6 or 10 dB below the noise floor, see TABLE I).

Secondly, the analysis of emission characteristics of LTE BSs (antenna pattern, power level, pointing direction) and of the propagation environment is essential for a proper choice of measurement locations to test compliance with the requirements for the protection of the incumbents.

4.2.1.1 Compliance with the sharing rules for the Fixed Service use case

As already clarified, the protection of the incumbent fixed links is based on the restriction/exclusion zone approach. To verify the compliance of the interference level generated by the LTE network at the MISE premises, the measurement van was located next to a FS receiver in the area of Rome, whose exact location is not reported due to confidentiality constraints.

However, the measurement equipment could not detect any interfering LTE signal, although theoretic prediction would suggest that a signal slightly below the target value (e.g. slightly less than 6 dB below the noise level) should be received in the chosen measurement locations. This is due to the unavoidable inaccuracies of prediction models (e.g. due to unexpected severe obstruction of the propagation path which generally occurs in dense urban environments), which play a significant role, against the need of detecting such low signals.

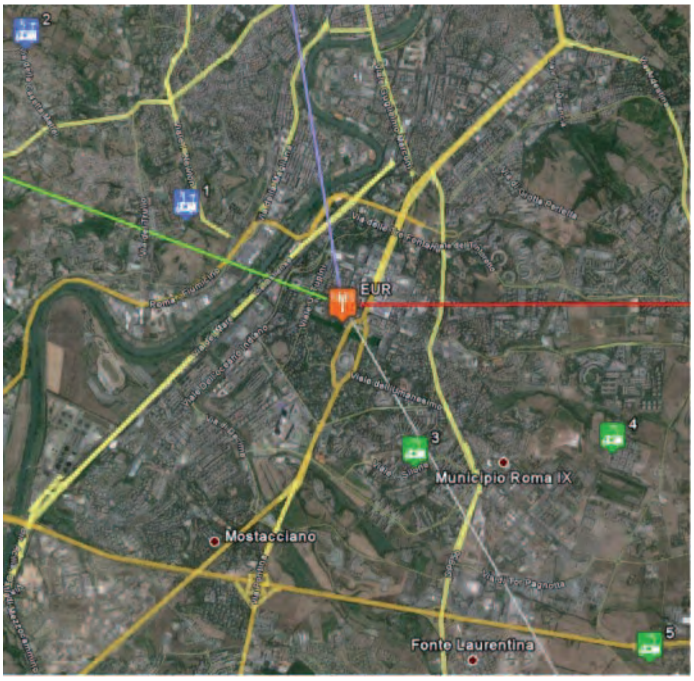
It has to be noted that the measurement setup has an adequate sensitivity to detect interfering LTE signals well below the noise floor of the victim receiver.

Therefore, it was decided to choose a different set of measurement locations where compliance with the I/N requirements for the FS could be tested indirectly.

Five different positions were properly identified, as shown in Fig. 20. Measurement locations are between 2 and 5 km from the LTE BSs, in the main lobe of one of the two outdoor cells: PCI 130 (azimuth 160°) and PCI 133 (azimuth 340°):

1) RM Zanzucchi (41°50’31.9”N 012°26’35.3”E): 2.3 km distance from BTS EUR
2) RM Mattei (41°51’38.5”N 012°25’10.9”E): 5 km distance from BTS EUR
3) RM Campanile (41°48’55.6”N 012°28’36.2”E): 2 km distance from BTS EUR
4) RM Vassalle (41°49’01.3”N 012°30’20.0”E): 3.6 km distance from BTS EUR
5) RM GRA (41°47’39.6”N 012°30’39.9”E): 5.6 km distance from BTS EUR

FIG. 20
Measurement Locations for the FS use case

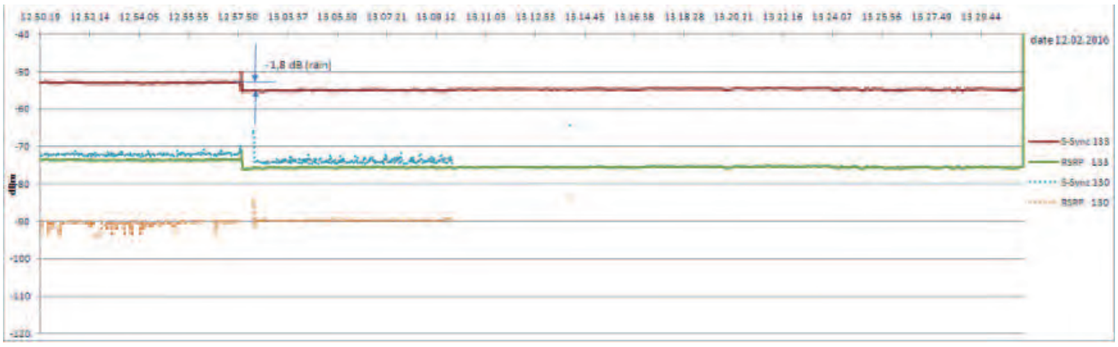


For sake of brevity, results are only shown for location 2, RM Mattei.

From the chosen location the LTE signal generated by outdoor cell was clearly received. Therefore, starting from a configuration where the outdoor cells EIRP is set to 37 dBm, the EIRP restrictions were activated at the LSA Repository and transmitted to the LSA controller. In particular, for the specific pixel where the LTE BSs are placed, the EIRP restriction requires that the LTE signal is decreased to 35 dBm, so that a carrier power reduction of 2 dB needs to be applied at the outdoor cells. This restriction is needed to protect the fixed links potentially affected by LTE in the 2.3-2.4 GHz band.

As shown in Fig. 21, measurements confirm that the carrier power of the outdoor cells was reduced once the restriction zone was activated. This would guarantee the protection of the incumbent FS.

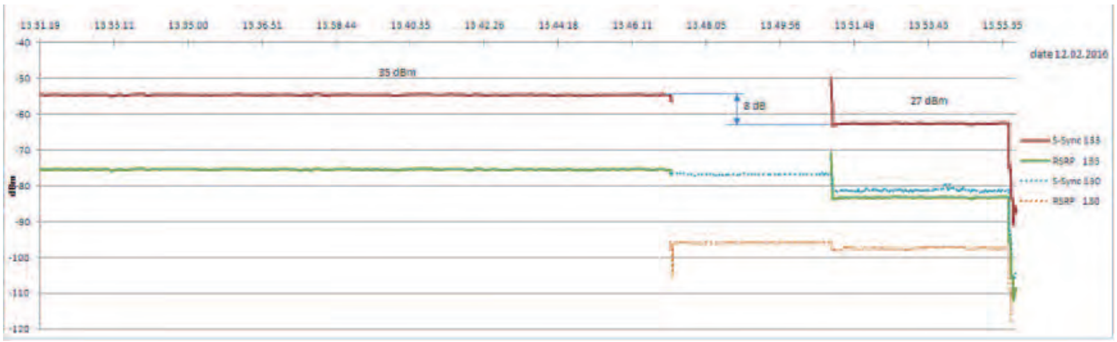
FIG. 21
Carrier power reduction for the outdoor cells upon activation of the restriction zones



A second test was run in the same location, imposing additional restrictions to the maximum admitted EIRP level at the LTE BSs locations. These restrictions have been derived, considering a test FS as an additional potential victim receiver in a given location. In this case, restrictions are applied only for cells whose antenna orientation is along a specific direction, that is outdoor cell PCI 133, which transmits in the direction of the considered measurement point.

Again, the activation of the restriction zone at the LSA Repository and the consequent communication to the LSA Controller determine the reduction of the carrier power of the outdoor signal (8 dB carrier power reduction in Fig. 22).

FIG. 22
Carrier power reduction for the outdoor cells upon activation of the restriction zones



4.2.1.2 Compliance with the sharing rules for the PMSE use case

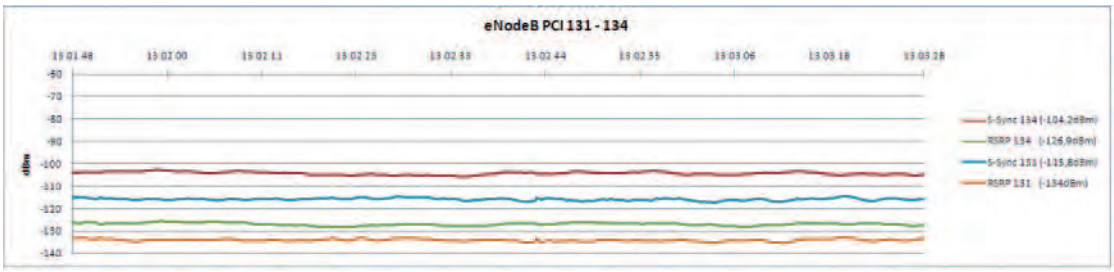
For the PMSE use case analysis only indoor LTE BSs were active, while outdoor nodes were switched off.

The choice to focus on indoor signals is due to the need to address measurements comparable to the noise floor of the potential victim receivers. This is more easily achievable focusing on indoor nodes. The selected measurement location, about 340 m from the MISE premises, is shown in Fig. 23.

FIG. 23
Measurement Locations for the PMSE use case

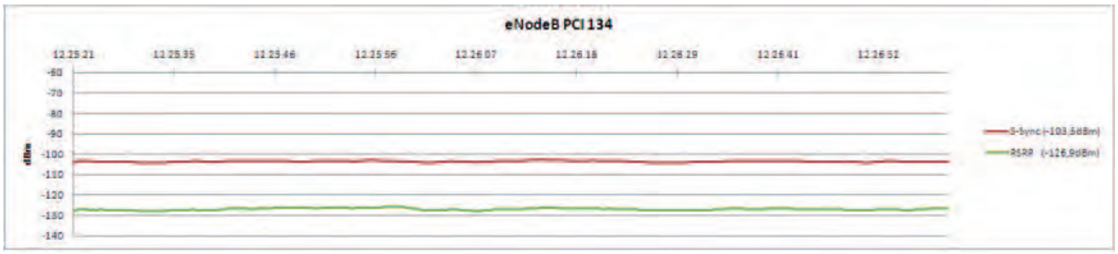
Fig. 24 shows the S-Sync and RSRP signal levels. Although the chosen location is quite close to the LTE indoor BSs, on 2 indoor cells could be detected (PCI 134 and PCI 131).

FIG. 24
S-Sync and RSRP signal levels



Subsequently all the indoor cells were switched off except cell with PCI 134. In this case, measurements shown in Fig. 25 were performed both with a network analyser and a spectrum analyser, obtaining the same results.

FIG. 25
Measurements for eNodeB with PCI 134



The measured interfering LTE signal was compared with the noise floor which could be measured when LTE BSs were off, to estimate how the measured noise floor differs from the noise floor levels computed for the various victim receivers (see TABLE I).

This kind of measurements can only rely on test setup equipped with a spectrum analyser, which provides poorer sensitivity with respect to the case of interference measurements when LTE signals are on-air (these latter measurements are performed by means of a network analyser).

At the observed location the measured noise floor was as high as -93.2 dBm @20 MHz, which means that the sensitivity of the measurement equipment was reached.

4.2.2 EMF exposure

4.2.2.1 Italian normative framework on EMF exposure

Most of international regulations are essentially based on the guidelines formulated by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [18] a non-governmental organisation formally recognised by the World Health Organization (WHO).

However, the Italian administration adopted a conservative approach to ensure an even higher degree of protection to the citizens.

Without entering into details, we may recall here that the current regulation is based on a multi-level protection.

The protection against acute health effects is defined through exposure limits that are "values of electric, magnetic, and electromagnetic fields that shall never be exceeded in any exposure condition". Exposure limits for the 0.1 MHz - 300 GHz frequency range is listed in TABLE VI.

The protection against possible long-term effects is sought by defining the attention thresholds, i.e., "values of electric, magnetic, and electromagnetic field, that shall not be exceeded in residential areas, schools, and other environments where people may have a prolonged stay", namely, a continuous presence for more than four hours. The attention threshold value is 6 V/m for the whole frequency range as can be seen in TABLE VII.

TABLE VI
ITALIAN EXPOSURE LIMITS

Frequency range	E (V/m)	H(A/m)	Power Density (W/m^2)
0.1 – 3 MHz	60	0.2	-
3 – 3000 MHz	20	0.05	1
3 – 300 GHz	40	0.01	4

TABLE VII
ATTENTION THRESHOLDS

Frequency range	E (V/m)	H(A/m)	Power Density (W/m^2)
0.1 MHz – 300 GHz	6	0.016	0.1 (3 MHz – 300 GHz)

4.2.2.2 Measurement methodology and test plan

Both wideband and narrowband measurements were performed at the seventh floor of the MISE building to assess exposure levels in the femtocell indoor environment. Main sources are expected to be two LTE indoor base stations operating at 2.3-2.4 GHz and 2.6-2.7 GHz and Wi-Fi APs at 2.4 GHz (TABLE VIII).

TABLE VIII

FREQUENCY RANGES FOR NARROWBAND MEASUREMENTS

Source	Fmin (MHz)	Fmax (MHz)
LTE @2.3 GHz	2300	2400
W-iFi	2400	2482
LTE @2.6 GHz	2570	2690

One should remind that the 2.3-2.4 GHz band, where basically all the pilot operates (except the LTE node at 2.6 GHz) is not employed for commercial mobile services in Italy.

In order to fully characterise EMF exposure, electric field levels were measured inside offices and along the corridors in different points with a step of about 5 m.

Wideband measurements were performed by a PMM 8053B field meter equipped with the EP333 probe which is more suitable for digital OFDM signals. The operating frequency range is 100 kHz-3.5 GHz with a sensitivity of 0.15 V/m.

Narrowband measurements used a portable spectrum analyser Narda SRM 3000 operating in the 100 KHz-3 GHz frequency range and a sensitivity of 0.25 mV/m, equipped with an isotropic tri-axial probe operating in the 75 MHz-3 GHz band.

4.2.2.3 Measurement results

Tests were performed in three different configurations of the dedicated LTE BSs (see TABLE IX).

TABLE IX

LTE BSS CONFIGURATIONS

Configuration	Indoor @2.3 GHz	Indoor @2.6 GHz	Outdoor @2.3 GHZ
1	OFF	OFF	OFF
2	ON	ON	OFF
3	ON	ON	ON

Configuration 1 allowed the characterisation of the residual field strength when all the LTE nodes were OFF. Since the indoor exposure level can be affected also by outdoor contributions, narrowband measurements were carried out on the building rooftop to identify outdoor sources and their spectrum occupation. From the results, that are not reported here for sake of brevity, it was could be noted that in the 2.3-2.4 GHz band there was no significant external contribution while in the 2500-2690 MHz band outdoor LTE signals operated by commercial services originated a measurable field. However, its peak value in this band being 0.45 V/m (well below the attention threshold) this would not prevent adding new sources at these frequencies.

Subsequently, wideband measurements were carried out for the three configurations (see a graphical representation of exposure levels in Fig. 26, Fig. 27 and Fig. 28, respectively).

FIG. 26
Wideband exposure levels (BSs OFF- configuration 1)

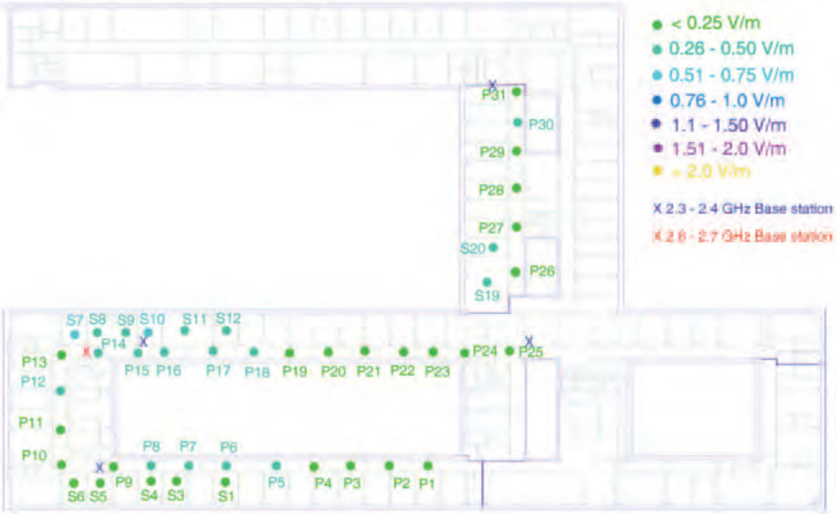


FIG. 27
Wideband exposure levels (Indoor BSs ON – configuration 2)

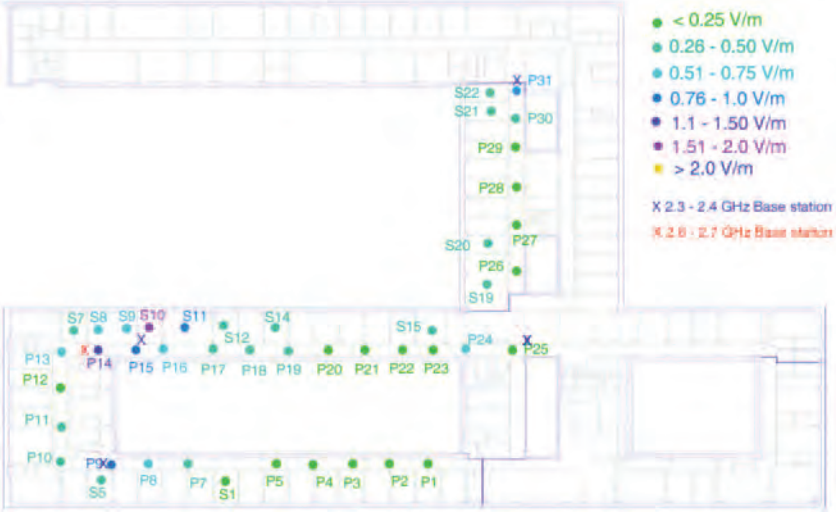
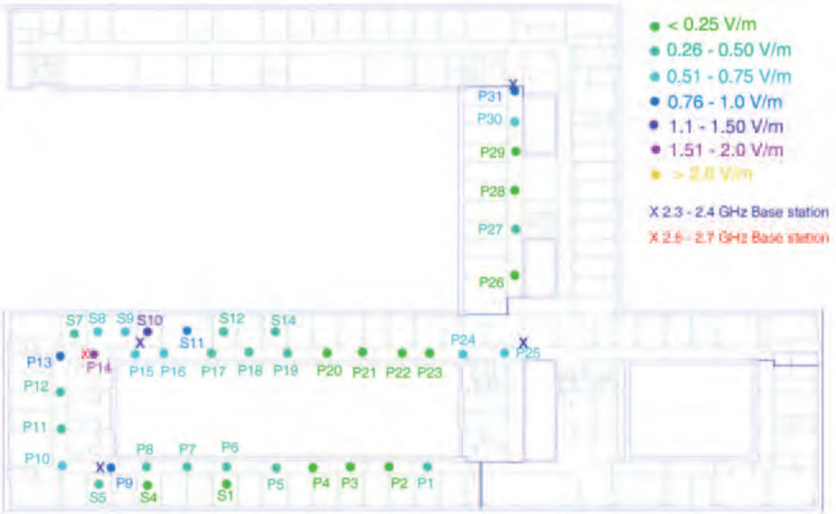


FIG. 28

Wideband exposure levels (Indoor BSs and one outdoor BS ON – configuration 3)



Indoor stations operated in test mode (configuration 2) result in a slight increase of EMF levels with respect to configuration 1; this increase is appreciable limited to points located nearby the LTE nodes.

The comparison between values obtained with all outdoor and indoor base stations in test mode (configuration 3) and those obtained in configuration 2 shows that the contribution of the 2.3-2.4 GHz LTE outdoor signal are generally negligible in the indoor environment.

Finally, it is worth noting that in all the configurations the indoor electromagnetic field levels are always well below the limit of 6 V/m imposed for population.

4.2.3 Propagation model

Measured results were compared with simulations performed by a proprietary tool, which implements several models, including ITU-R P. 452 [23], ITU-R P. 526 [17] (for diffraction effects), ITU-R P. 1546 [24] and the COST 231- Hata model ([20], Chapter 4, pp. 134-135), which is an extension of the formula proposed by Hata [21] and based on the measurements performed by Okumura *et al.* [22]. Even though the model in its original formulation was restricted to frequencies between 1500 and 2000 MHz, several subsequent studies have demonstrated that it can also be applied to frequencies up to 3 GHz without introducing excessive errors.

Path loss is computed as:

$$L_b = 46.2 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - a(h_m) + \left[44.9 - 6.55\log_{10}(h_b)\right]\log_{10}(d) + C_m \qquad (3)$$

where:

L_b is the path loss (dB)

f is the carrier frequency (MHz)

h_b is the base station antenna effective height (m)

h_m is the mobile terminal antenna effective height (m)

d is the propagation distance (km)

$a(h_m)$ is a correction factor for the mobile antenna height expressed by equation (4) below:

$$a(h_m) = (1.1\log_{10}(f) - 0.7)\,h_m - (1.56\log_{10}(f) - 0.8) \qquad (4)$$

and C_m is a correction factor which takes on the following values:

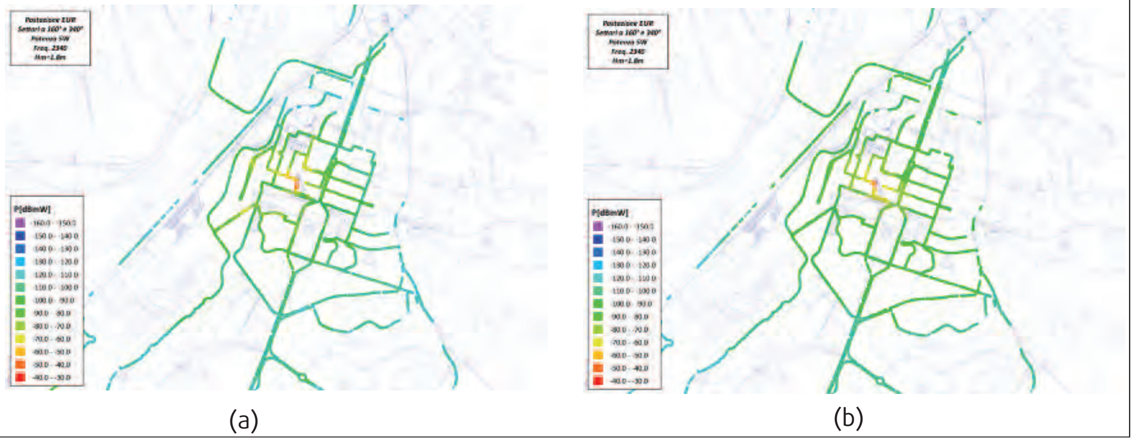
C_m = 0 dB for medium sized city and suburban centres with medium tree density

C_m = 3 dB for metropolitan centres

4.2.3.1 Comparison between simulations and measurements

Outdoor drive test results were compared with simulations performed with the simple model described above. Measurements were taken in as many as 113,467 locations and their values compared with the predictions. The outdoor cells (two sectors oriented towards 160° and 340° with respect to North) were ON. Fig. 29 gives a graphical representation of measurements (a) and simulations (b). The agreement between the two sets of values is clear even at a first glance.

FIG. 29
Outdoor drive test measurements (a) and simulations (b)



(a) (b)

This is corroborated also by a statistical analysis of the error, defined as the difference between the predicted and the measured received power. The mean error was as low as 2.35 dB, while its standard deviation was equal to 9.37 dB, in line with the shadowing standard deviation values generally used in urban areas.

5. CONCLUSIONS AND FUTURE ACTIVITIES

Recent regulatory initiatives in the EU and worldwide are focusing on spectrum sharing as a new regulatory tool to achieve efficient use of the spectrum for current 4G and future 5G systems. The importance of spectrum sharing in modern spectrum management should be highlighted further and combined technical and regulatory initiatives fostered to gain the necessary experience in order to make informed decisions on spectrum sharing as a regulatory instrument. The Italian LSA pilot is the first experiment on a large scale to study the technical conditions and operational feasibility of licensed spectrum sharing in 2.3-2.4 GHz band through a realistic indoor and outdoor deployment to allow the necessary evaluation of the LSA approach from a regulatory perspective.

Different objectives have been achieved by the pilot. The testbed for LSA has been defined and developed in compliance with the European and national regulatory framework. The implementation and correct operation of the LSA architecture which includes some remote elements is the result of a fruitful collaboration among different European partners who voluntarily participated to the success of the Italian LSA pilot experience.

Coexistence of LTE systems operating under LSA with has been demonstrated as feasible, applying the sharing rules properly identified based on the incumbent services characteristics and tested in a real scenario through experimental measurements. The main incumbent use in the 2.3-2.4 GHz band in Italy is the fixed service, which is protected based on the restriction/exclusion zones defined by the Administration, also to cope with confidentiality issues. To improve sharing opportunities under this approach, refined computations of restrictions for LTE BSs are also considered, with reference to multi sector BS and various LTE layouts. In particular it has been pointed out how the adoption of microcells and femtocells layouts might significantly increase sharing opportunities.

The technical feasibility and possible limits of LSA with incumbent uses has been deeply investigated. To this end, this report presents results on the on-field measurements performed to assess the LTE network functionalities and verify compliance with the incumbent protection requirements. Tests on channel evacuation were realised considering a possible incumbent PMSE user, requesting a channel for its operations in a given location. Results of various samples collected for the estimation of the evacuation time show that it is always below 40 seconds.

The compliance of the eNodeB with FS and PMSE protection requirements has been tested through different measurements. As for the assessment of compliance with the protection requirements through on-filed measurements, it emerged that very sensitive equipment is required to measure an interference level well below the noise floor. The performed measurements confirm that proper actions are taken by the whole system (LSA elements and LTE network) so to comply with the requirements for the protection of the incumbents, both under the restriction/exclusion and protection zone approach

The pilot allowed to verify the possibility of a shared use of the 2.3-2.4 GHz band to cater for the ever-increasing request of broadband wireless connectivity. The adoption of LSA would allow mobile operators to use new, valuable portions of spectrum while protecting services provided by incumbent operators from harmful interference.

This concepts tested within the pilot can be extended to other portions of spectrum. The first obvious candidate for this is the 3.4-3.8 GHz band (possibly up to 4.2 GHz in perspective) which may already respond to some specific 5G needs, as it provides opportunities for systems requiring large bandwidth. In this light, additional trials could be promoted in line with the 5G Action Plan for Europe [26].

In the medium term, tests of 5G-like signals can be performed also at mm-waves, imposing the relevant restrictions (e.g. frequency availability, EIRP limitations) to protect incumbent uses and allow coexistence for non-exclusive uses.

6. REFERENCES

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ANNEX 1. MEASUREMENT SETUP

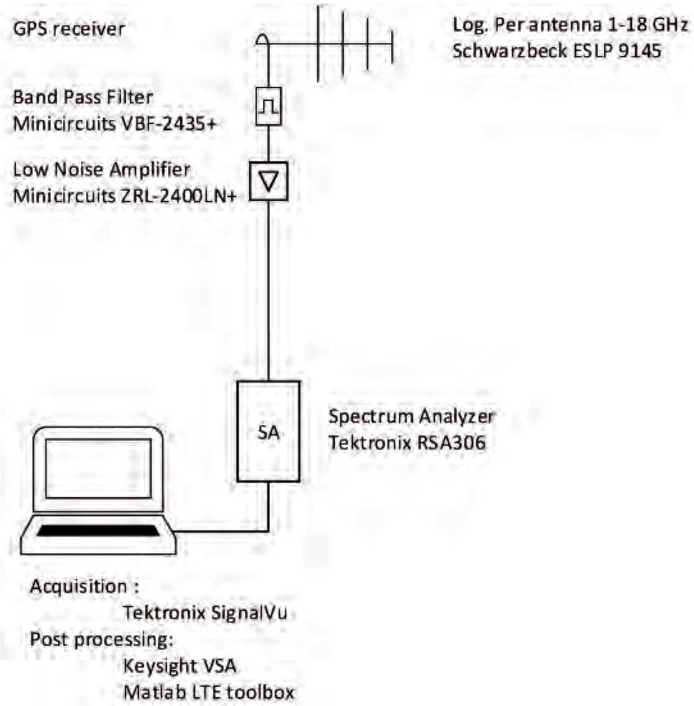
The LSA pilot was supported by an intense activity of measurements - on the field –, which was mainly carried out by technicians of MISE- CNCER (the national center for the control of radio emissions), also in collaboration with JRC and FUB. Measurements have posed several challenges fort their complexity, but they are of unquestionable value for validating coverage, propagation models and compliance with the sharing rules and framework in general.

JRC MEASUREMENT SETUP

The measurement setup is shown in Fig. 30. The RF chain consists of a Log Periodic antenna whose gain is 7.2 dBi at 2340 MHz, a 2340 2530MHz bandpass filter and a low noise amplifier connected to a real time spectrum analyser via a 5 m long cable. The bandpass filter acts as a pre-selector; it suppresses strong signals from broadcast transmitters and nearby base stations. The low noise amplifier was chosen for its low noise figure (typically NF = 1.2 dB), its third-order intercept point (IP3 > 40 dB) and its gain of 30 dB sufficient to compensate for the cable loss and the spectrum analyser's noise figure.

The system sensitivity is 35 dBµV/m in 8 MHz when measured in a quiet environment.

FIG. 30
JRC Measurement setup



]

The spectrum analyser is controlled with the Tektronix software SignalVu-PC which was configured to display LTE TDD channel power in a band of 19 MHz, power versus time and a spectrogram (Fig. 31).

Base band signal segments of 50 ms acquired in a 40 MHz bandwidth were recorded every 10 s together with GPS time and position. Data were then processed with Matlab to compute the channel power in different bandwidths. More advanced processing can be performed with either Keysight VSA software or Matlab LTE toolbox.

FIG. 31
Screenshot of Tektronix SignalVu software

-20.00 dBm
dB/div: 10.0 dB
MR: -55.00 dBm 2.340016902 GHz
-23.71 dBm
-120.00 dBm
Pos: 2.34000 GHz
Scale: 19.08 MHz
Avg Channel Power (Main): -23.71 dBm
Ch Offset Lower Upper

Spectrums/line: 1
Time/div: 2.97 ms
RBW: 15.0 kHz
Pos: 0.0 div
MR: -91.82 dBm
2.34 GHz
1.751 ms
17/12/2016 10:55:04.915362
CF: 2.34000 GHz
Span: 40.00 MHz

Time: Analysis
Offset: 0.000 s
Length:
MR: -91.82 dBm
1.770 ms
Position: 0.000 s
Scale: 50.000 ms

Trigger
○ Free Run
● Triggered
Source: External
Slope
● Rise
○ Fall
Triggers at TTL threshold
External Impedance: 10 kΩ

ChPwr and ACPR
Frequency 2.34000 GHz
Ref Lev -20.00 dBm
Res BW 15.000 kHz
Transfer
Acq Sampling params: manual control
Ref: Int
Connected:

SYSTEM CALIBRATION FOR PMSE

This section shows the methodology used to calibrate the measurement system.

Location: Via Groenlandia

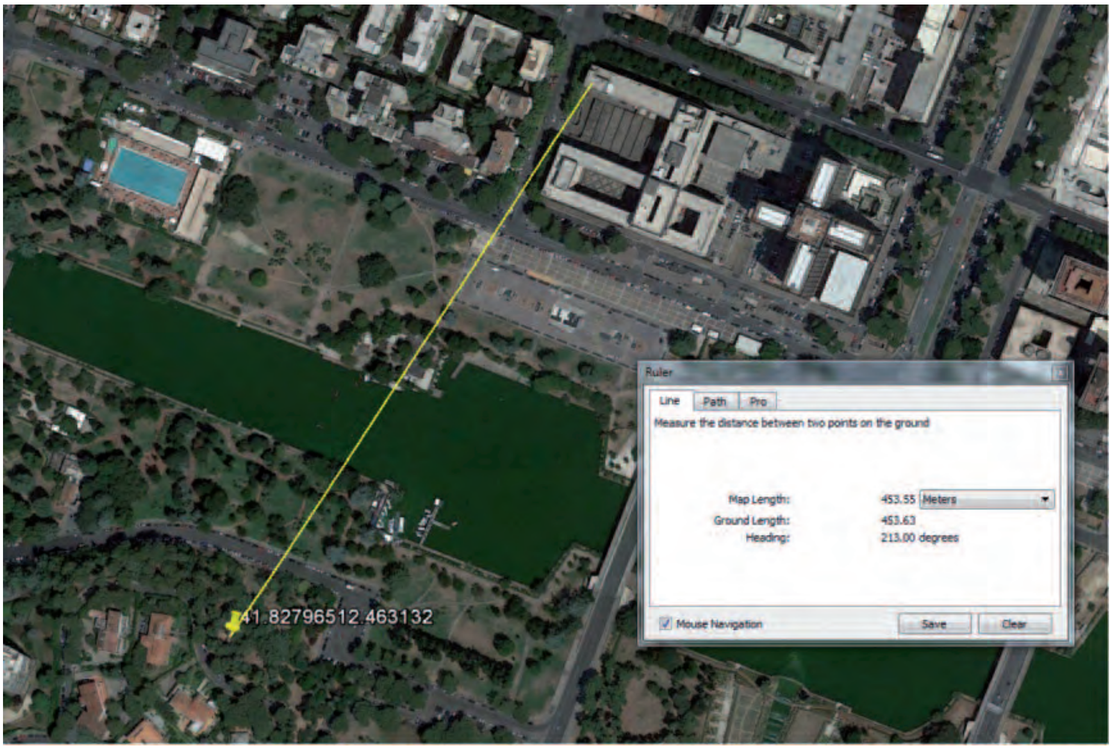
Coordinates: 41.827965N, 12.463132E

Ground distance from the base station: 453.63 m

Heading: 213 deg.

Condition: not fully line of sight; receiver is, in principle, outside the shadow of the front of MISE building; however there were shadows of foliage in the direct path; nearby houses behind the measurement point (see Fig. 32).

FIG. 32
Location of measurements for PMSE Test 'Po Calibration'



Measure the distance between two points on the ground

Map Length: 453.55 Meters
Ground Length: 453.63
Heading: 213.00 degrees

Objective

The objective of the test was to do reference measurements in order to validate proper functioning of the LSA system in terms of its response to evacuation requests from the incumbent. In addition, the intention was to evaluate the measurement set up in terms of its ability to sense the signals below the noise floor, as required by the specified PMSE protection criteria (TABLE X, third column).

The test was carried out in the protection zone for the PMSE use case. It followed the procedure for the 'Test P0 - Calibration' of test specifications defined in advance. Base stations were controlled manually rather than through the LSA software.

Method

For this test, no PMSE camera was deployed.

The JRC measurement setup is shown in Fig. 30. In addition, Swisscol Qualipoc was used to read instantaneous values of RSRP and RSRQ. TABLE X below shows the series of actions and observations on Qualipoc as well as making reference to the live signal strength measurement graph in Fig. 33, from the JRC set up of Fig. 30.

Fig. 34 shows the behaviour of Secondary Synchronization Signal S-Sync and Reference Signals RS power in the same time interval.

Additional tests were performed subsequently (see TABLE XI).

Finally, Fig. 35, Fig. 36 and Fig. 37 report some screenshots of the measurement system, which displays LTE TDD channel power in a band of 19 MHz, power versus time and a spectrogram (as already seen in Fig. 31).

TABLE X
SERIES OF ACTIONS FOR PMSE USE CASE 'TEST P0 CALIBRATION'

Local Time: (UTC+1)	UTC Time (Fig. 33)	Condition / Action	Observations on Swissqual Qualipoc	Corresponding annotation point on the field strength graph in Fig. 33. FS value in dBµV/m/8 MHz
16:11	15:11	Start of tests. All eNodeBs operating at nominal power (switched on but no data traffic)	RSRP: -100 dBm	A: 67
16:11	15:11	Request to turn off all eNodeBs (indoor and outdoor) (= evacuation request), The nodes continue to operate over the next 5 mins.	RSRP: -100 dBm	A to B: 67
16:15	15:15	All BSs are now off	RSRP: -144.1 dBm	B to C: 41 to 49
16:26	15:26	Request to turn on the indoor BS 132 only	RSRP: -144.1 dBm	C: 42
16:29	15:29	BS 132 is now on (confirmed by the operator)	RSRP: -144.1 dBm RSRQ: -29.3	D
16:36	15:36	Both indoor BSs 131 &132 are now on (confirmed by the operator)	RSRP: -144.1 dBm RSRQ: -29.3 (no perceptible change)	E
16:41	15:41	Outdoor BS 130 is now on at nominal power	RSRP= -110 dBm RSRQ= -6.8	F
16:45	15:45	Outdoor BS 130 in Test Mode	RSRP: -144.1 dBm RSRQ: -29.3 (no perceptible changes)	G
16:50	15:50	Outdoor BS 130 switched off		H
		End of Test P0.		

TABLE XI
ADDITIONAL TESTS UNDER (A) TEST MODE, (B) UL TRAFFIC CONDITIONS, AND (C) DL TRAFFIC CONDITIONS

Local Time: (UTC+1))	UTC Time (Fig. 33)	Condition / Action	Observations on Swissqual Qualipoc	Corresponding annotation point on the field strength graph in Fig. 33. FS value in dBµV/m/8 MHz
		Start measurements		
16:50	15:50	Outdoor BS 130 is now switched off		H
16:58	15:58	Outdoor BS 130 in now turned on, in Test Mode		I
17:01	16:01	Outdoor BS 130 is on at nominal power; no traffic UL/DL		J
17:06	16:06	Outdoor BS 130 is on at nominal power with DL traffic generated via iperf		K
17:09	16:09	BS 130 back to nominal mode; no traffic UL/DL		L
17:12	16:12	Outdoor BS 130 is on at nominal power with UL traffic generated via iperf; UE located between the BS and measurement station antenna		M
17:??	16:??	???		N
17:16	16:16	???		O
17:18	16:18	Outdoor BS 130 is switched off. End of test.		P

FIG. 33
Average field strength versus time for three different channel bandwidth

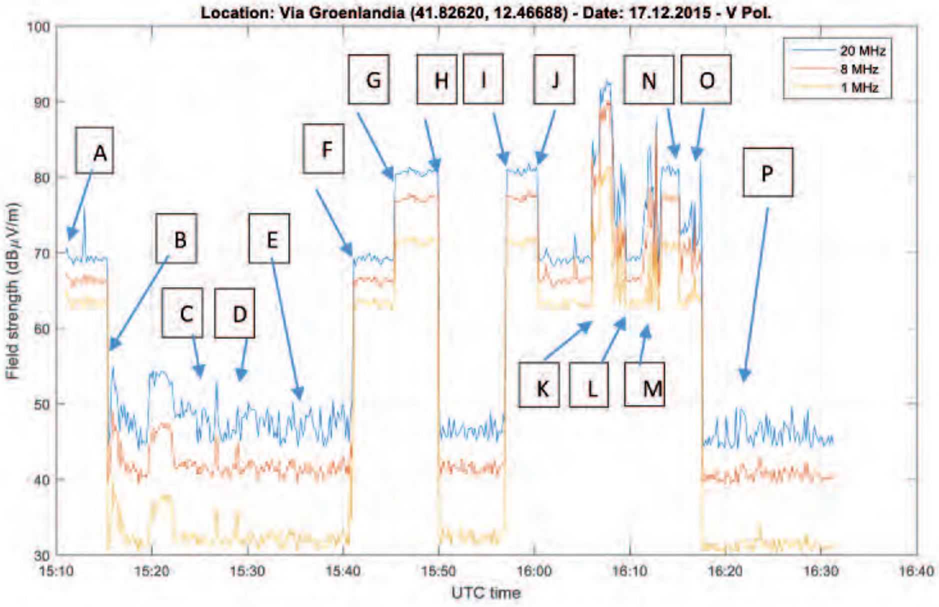


FIG. 34
Secondary Synchronization Signal S-Sync and Reference Signal RS power versus time

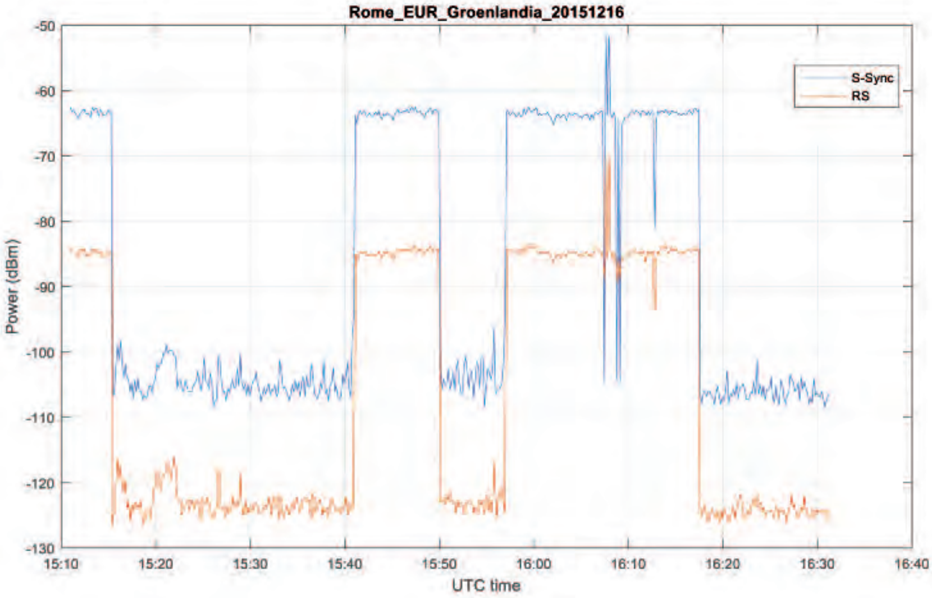
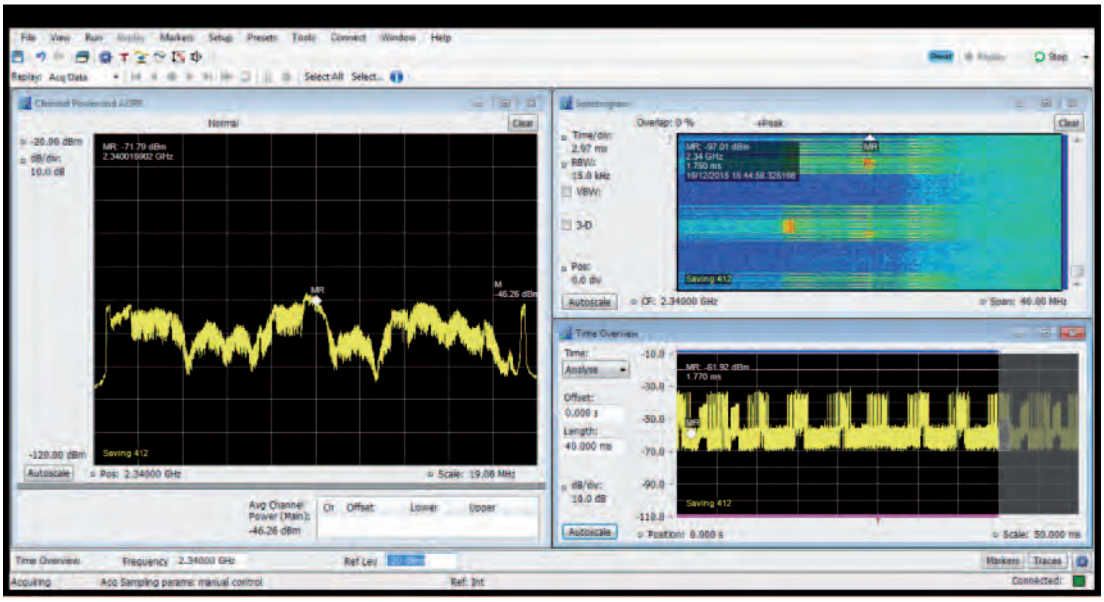


FIG. 35
Screenshot of Tektronix SignalVu software



-20.00 dBm
dB/div: 10.0 dB
MR: -71.79 dBm
2.340016902 GHz
-46.26 dBm
-120.00 dBm
Saving 412
Pos: 2.34000 GHz
Scale: 19.08 MHz
Avg Channel Power (Main): -46.26 dBm
Ch Offset Lower Upper

Overlap: 0 %
+Peak
Time/div: 2.97 ms
RBW: 15.0 kHz
☐ VBW:
☐ 3-D
Pos: 0.0 div
MR: -97.01 dBm
2.34 GHz
1.750 ms
16/12/2015 15:44:58.326166
Saving 412
CF: 2.34000 GHz
Span: 40.00 MHz

Time: Analyse
Offset: 0.000 s
Length: 40.000 ms
dB/div: 10.0 dB
MR: -61.92 dBm
1.770 ms
Saving 412
Position: 0.000 s
Scale: 50.000 ms

Time Overview
Frequency 2.34000 GHz
Ref Lev
Acquiring
Acq Sampling params: manual control
Ref: Int
Connected:

FIG. 36
Screenshot of Tektronix SignalVu software

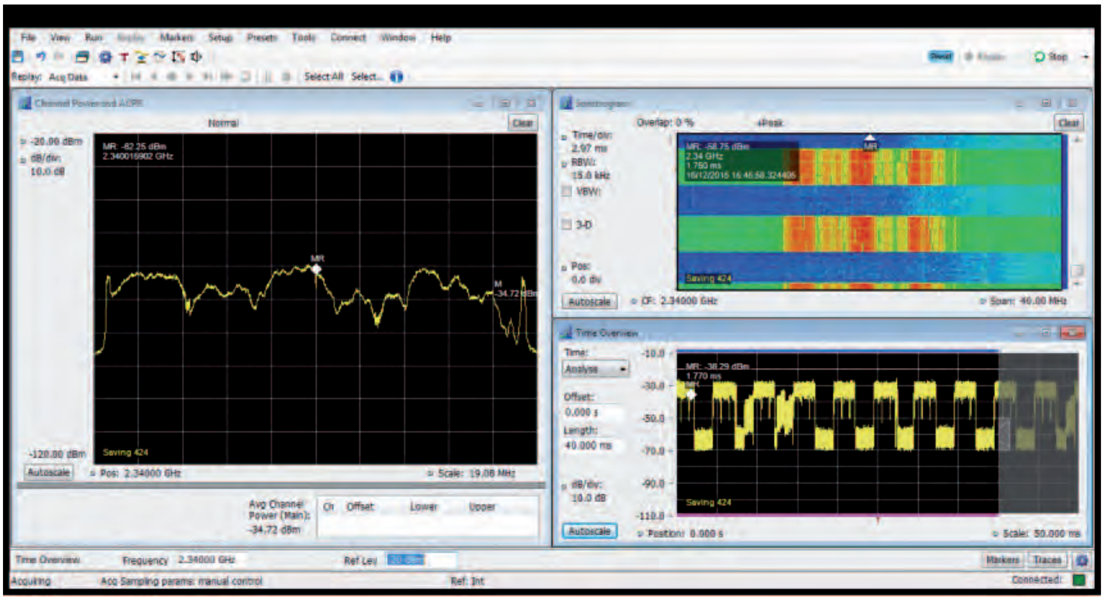
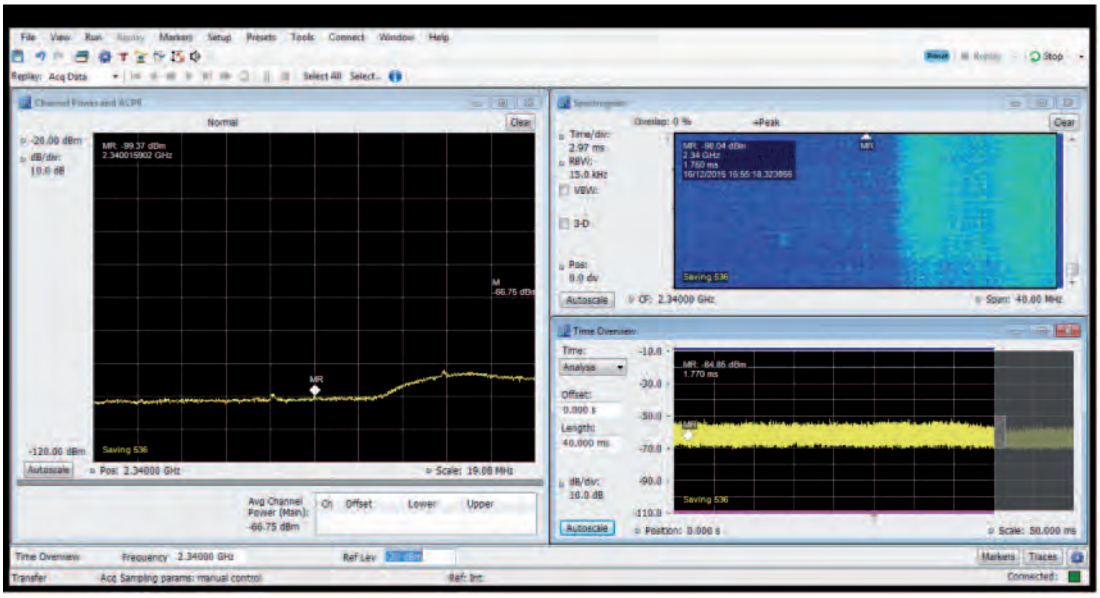


FIG. 37
Screenshot of Tektronix SignalVu software



CNCER MEASUREMENT SETUP

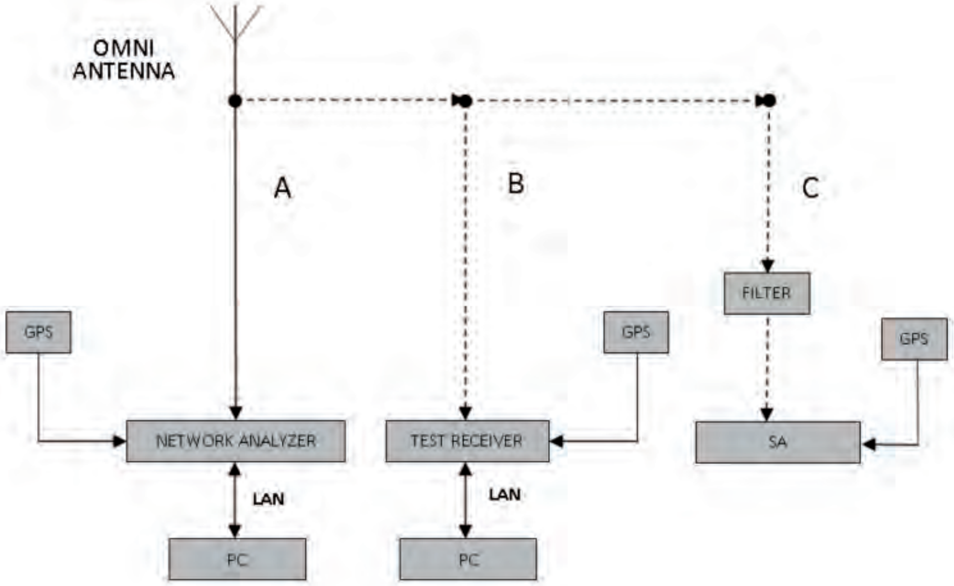
Drive tests

Fig. 38 shows the vehicle used for drive tests. An omni antenna (Huber + Suhner AG model SWA 0825/360/5/30/V, vertical polarisation, gain 6.2 dBi @2340 MHz) is mounted on its roof at 1.8 m above ground. The connecting cable is Suhner sucoflex 100, total loss 1.5 dB @2340 MHz.

FIG. 38
Antenna mounted on the vehicle rooftop

The measurement set-up used by CNCER for coverage and noise floor measurements is shown in Fig. 39.

FIG. 39
Measurement setup for drive tests



More technical details are shown in TABLE XII below.

TABLE XII
TECHNICAL DATA

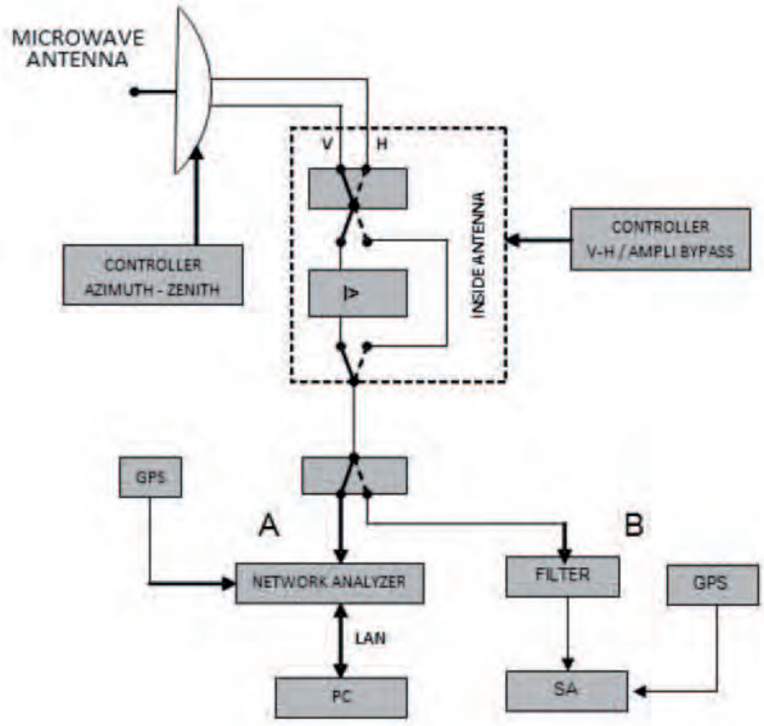
K TOTAL (*)	• 20.3 dB/m @ 2340 MHz (without Preamplifier) • -4.7 dB/m @ 2340 MHz (with Preamplifier)
NETWORK ANALYZER	• Rohde & Schwarz TSMW • Software Rohde & Schwarz ROMES4
SA	• Spectrum Analyzer Anritsu MS2720T
TEST RECEIVER	• Rohde & Schwarz ESMD • Software Rohde & Schwarz ARGUS
FILTER	• Trilithic high pass filter 6HC 1500/18000-3-K • Insertion loss 0.2 dB @ 2340 MHz • Attenuation > 72 dB @ 1 GHz
FILTER CONFIGURATIONS	• A coverage measurements • B or C noise floor measurements

(*) K = - 29.77 - Gi antenna (dBi) + 20 log Freq (MHz) + cable loss (dB) (CEPT/ERC 74-02)

On-spot measurements

The measurement set-up used by CNCER for on-spot measurements is shown in Fig. 40, while subsequent TABLE XI gives technical data for the adopted setup. Finally, Fig. 41 shows some photos of the mobile measurement lab.

FIG. 40
Setup for on-spot measurements

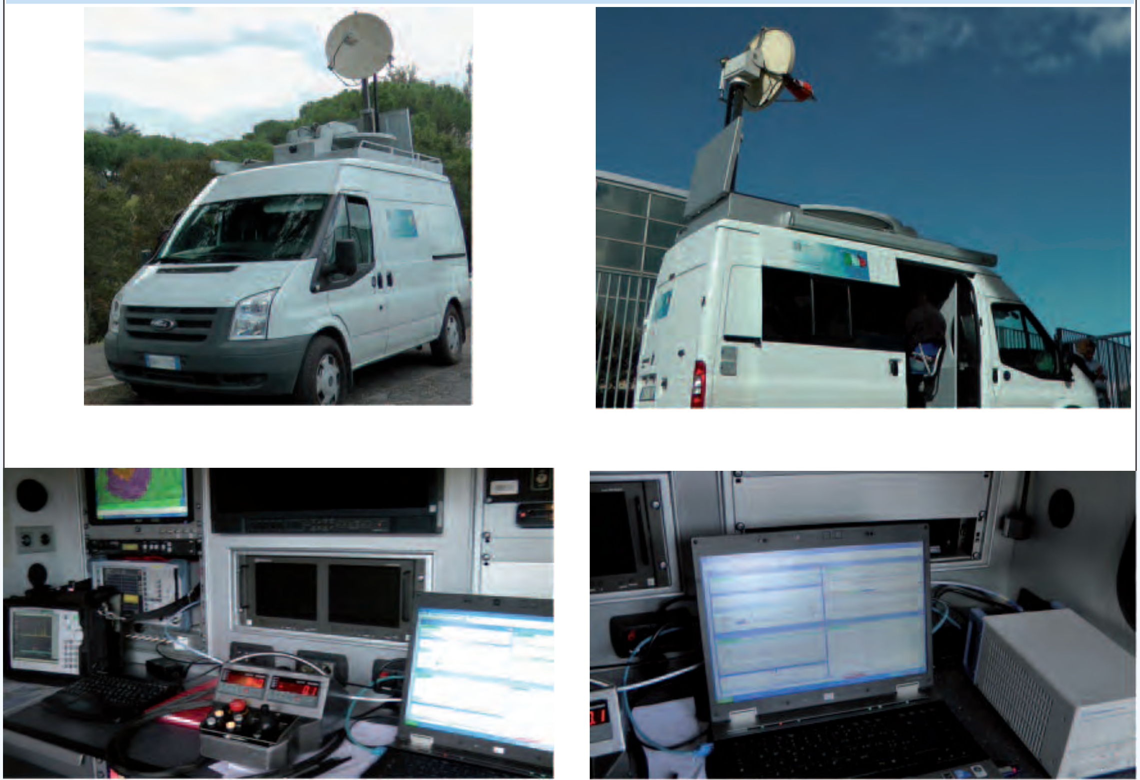


(*) K = - 29.77 - Gi antenna (dBi) + 20 log Freq (MHz) + cable loss (dB) (CEPT/ERC 74-02)

TABLE XIII
TECHNICAL DATA

MICROWAVE ANTENNA	• Rohde & Schwarz AC008 + Rohde & Schwarz HL050 (feed) • Polarisation: linear (V – H) • Gain 24 dBi @ 2340 MHz • Half-power beamwidth 11.5° @ 2340 MHz • Preamplifier Gain 25 dB @ 2340 MHz (Rohde & Schwarz inside antenna) • Height above ground level 4.5 metres
CONNECTING CABLE	• Suhner sucoflex 100 • Total loss 6.7 dB @ 2340 MHz
K TOTAL (*)	• 20.3 dB/m @ 2340 MHz (without Preamplifier) • -4.7 dB/m @ 2340 MHz (with Preamplifier)
NETWORK ANALYZER	• Rohde & Schwarz TSMW • Software Rohde & Schwarz ROMES4
SA	• Spectrum Analyzer Anritsu MS2720T • Spectrum Analyzer Tektronix RSA 3408B
FILTER	• Trilithic high pass filter 6HC 1500/18000-3-K • Insertion loss 0.2 dB @ 2340 MHz • Attenuation > 72 dB @ 1 GHz
FILTER CONFIGURATIONS	• A in-field measurements • B noise floor measurements

FIG. 41
Mobile measurement lab



LTE SIGNAL MEASUREMENT METHODOLOGY

LTE signal measurements have been performed considering the average power of secondary Synchronization Signal power S-Sync and Reference Signals RS.

The S-Sync aggregates the contribution of all synchronized base stations while RS is cell specific and allows to discriminate different LTE sources. RS power is calculated over the central 6 resource blocks (72 subcarriers) but can also be averaged over the full bandwidth to get the equivalent Wide Band RS or to any over band of interest (e.g. the incumbent band).

It can be seen that, contrary to the channel power, the levels of both S-Sync and RS signals do not vary with traffic conditions. Consequently, it is not necessary any more to force the traffic when using these demodulated signals.

Both S-Sync and RS signals can in principle be used to estimate the LTE power in the band of interest. In the case where all subcarriers have the same level (i.e. there are no boosted or de-boosted resource blocks), it is sufficient to apply a coefficient equal to the ratio of the number of subcarriers in channel of interest over the one of the measured signal. For example, to estimate the full power of a 20 MHz LTE channel, a coefficient equal to 10*log10(1200/62)=12.9 dB has to be added to S-Sync power (dBm) or 10*log10(1200/1)=30.8 dB to RS power (dBm).

S-Sync: 10*log10 (1200/62) = 12.9 dB

RS : 10*log10 (1200/1) = 30.8 dB

with 1200 subcarriers, B=20 MHz.

An example can be seen in Fig. 42, while TABLE XIV shows both the narrowband and wideband parameters that can be estimated with the used methodology.

FIG. 42
Example of LTE 3 MHz bandwidth

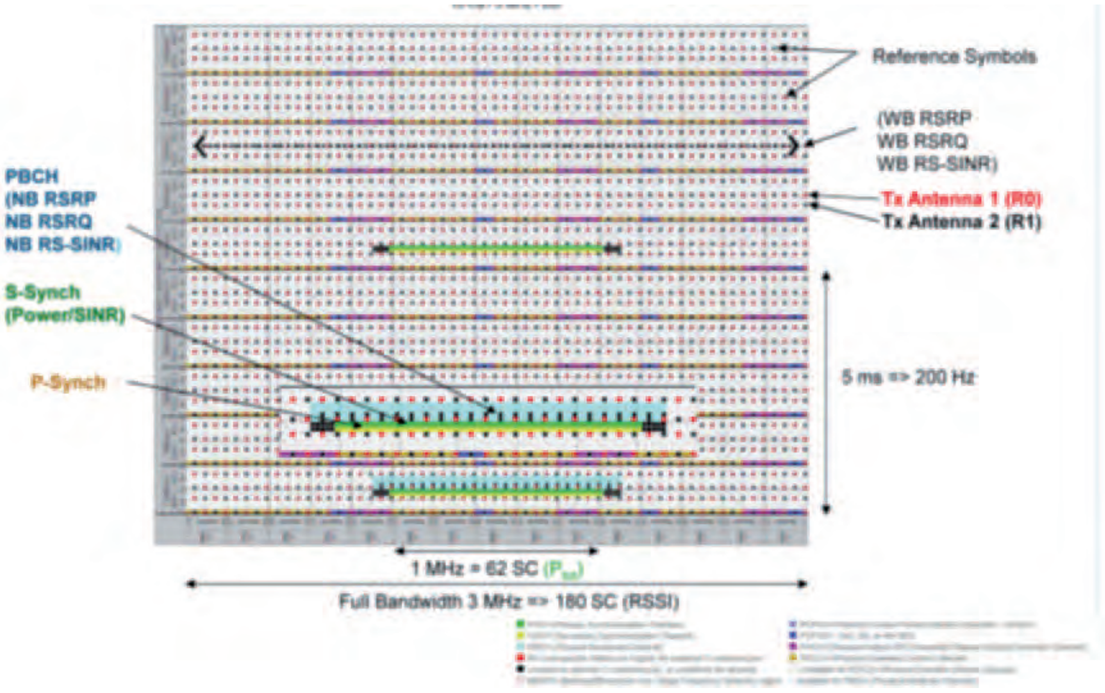


TABLE XIV
NARROWBAND AND WIDEBAND ESTIMATED PARAMETERS

	Narrowband (NB)	**Wideband (WB)**
Received power	Power Based on S-Sync (62 SC)	
	RSRP Based on RS in PBCH (72 SC)	WB-RSRP Based on RS (full bandwidth)
Quality	RSRQ Based on PBCH (72 SC)	WB-RSRQ Based on all received SC (full bandwidth)
SNR	SINR Based on S-Sync (62 SC)	
	RS-SINR Based on RS (72 SC)	WB-RS-SINR Based on RS (full bandwidth)
Total power		RSSI Based on all received SC (full bandwidth)

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