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Validation platform framework

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Abstract: The work packages Green Networks and Green Radios have provided input supporting the definition of the platform that will be set-up at the Test Plant of Telecom Italia for demonstration and validation of the added value of their solutions. Green Networks is focused on deployment strategies, network and radio resource management concepts and also on future energy efficient network architectures; in particular a network management solution named “ON/OFF scheme” conceived for assuring energy savings during low load traffic conditions is proposed for validation in this work package. Green Radios has provided input to the validation platform in order to consider measures on base station components for efficient handling of changing traffic loads and enhancements on interface techniques.

In order to set-up a validation platform framework, selected building blocks will be inserted into the Test Plant scenarios by means of a proper integration with the Test Plant resources. In particular, the above integration will comprise the set up of interfaces, the adoption of equipment and the use of instruments which, together with the selected building blocks, will define the final validation platform. The validation results coming out from the test campaigns will be assessed and visualized in a suited way, to clearly prove the advances obtained by the EARTH project.

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Acronyms and Abbreviations

3G	Third Generation
4G	Fourth Generation
ADC	Analogue to Digital Converter
BB	Base Band
BS	Base Station
CD	Component Deactivation
CMOS	Complementary Metal Oxide Semiconductor
CPCH	Common Packet Channel
CPRI	Common Public Radio Interface
CTCH	Common Transport Channels
DAC	Digital to Analogue Converter
DC	Direct Current
DL-SCH	Downlink Shared Channel
DSPC	Digital Signal Processing and Control
DTCH	Dedicated Transport Channel
DTX	Discontinuous Transmission
EARTH	Energy Aware Radio and neTwork tecHnologies
EE	Energy Efficiency
EM	Element Manager
EPC	Enhanced Packet Core
FB	Feedback
FPGA	Field Programmable Gate Array
FTP	File Transfer Protocol
HSPA	High-Speed Packet Access
HW	HardWare
ISD	Inter Site Distance
JTAG	Joint Test Action Group
LMT	Local Maintenance Terminal
LTE	Long Term Evolution
RF	Radio Frequency
RNC	Radio Network Controller
RX	Receive(r)
TRX	Transceiver
TX	Transmit(er)
OPA	Operating Point Adjustment
PA	Power Amplifier
PC	Personal Computer
P _{OUT}	Output Power
PLL	Phase Locked Loop
QoE	Quality of Experience
QoS	Quality of Service
REF	REference
RF	Radio Frequency
SISO	Single-Input Single-Output

EARTH PROJECT

SLA-TRX	Signal Load Adaptive Transceiver
SMA	SubMiniature version A connector
SMB	SubMiniature version B connector
SOTA	State Of The Art
SW	SoftWare
TOL	Test Object List
UE	User Equipment
UL-SCH	UpLink Shared Channel
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
VCO	Voltage Controlled Oscillator
VOIP	Voice Over IP
WCDMA	Wideband Code Division Multiple Access

1. INTRODUCTION

The aim of this document is to define the platform to validate the solutions of energy efficiency proposed in the EARTH project for experimental evaluation. These solutions, originally conceived and proposed in [EARTH-D5.1], have been further developed by all the partners of WP5 and are explained in detail in this document. These solutions are of two different types.

The first category relates to network features and implies new algorithms for radio resource management designed to spare energy during a specific phase of BS operation, in this case low traffic conditions. One example is a so-called “ON/OFF scheme”, already introduced in D5.1, where the surrounding neighbour cells are expected to assure their coverage to allow for an omni-cell under test to be turned off with preserved coverage for end users. The algorithm is controlled by the traffic-load level in the cell under test as well as in the supporting neighbour cells. The ultimate verification of this concept would entail the use of physically separated network sites and reserved test frequencies. As this is not available an alternative test scenario has been proposed and described in the following to allow for network performance evaluations. This concept will be evaluated for 3G and 4G networks based on experimental investigations for 4G case and by deriving from it the performance expected for the 3G case by theoretical analysis.

The second category relies on the development of new hardware modules already introduced by a conceptual point of view in [EARTH-D5.1]. These prototypes are designed to assure low energy consumptions during multiple phases of BS operation.

The prototype activities can be divided into two different groups one for *small*-cell applications and one for *macro*-cell applications. This is a practical and even necessary division considering the different hardware requirements and power consumption patterns for macro and small base stations. The developed components under test and the related features will be evaluated applying varying traffic load and output power based on the EARTH reference traffic scenarios [EARTH-D2.3]. For small base stations, the power scalability and efficiency of the complete downlink analogue transceiver system for different signal paths, traffic loads (and traffic load profiles) and eventually frame structures are proposed for evaluation. Techniques such as bandwidth adaptation, on-off switching and performance scaling of the components shall be implemented. The validation expected for transceiver systems in macro base stations will focus on the Signal-Load-Adaptive-Transceiver concept that follows the operating point adjustment and the deactivation of components dependent on the transceiver output power level. It enables different power saving concepts acting on node and system level and benefits from medium and low load situations.

The validation of the “EARTH Transceiver System” will comprise the execution of a campaign of tests properly designed in order to evaluate the energy efficiency performance of the EARTH Transceiver System proposed in the above described test scenarios.

For a certain application the average power efficiency of the transceiver system is to be captured. The applications of interest will be related to concepts proposed in the project, like:

- Bandwidth or capacity adaptation;
- DTX features.

These evaluations will be based on Operating Points Adjustment and on Component Deactivation, the main features proposed for the transceiver system for macro BS, which can be applied individually or in combination.

Doing these tests by applying the proposed features for energy efficiency improvement and even by not applying them, allows determining the benefit in terms of energy efficiency improvement due to different features considered for different application.

This document is structured in two main chapters: (1) the Green Networks and Green Radios concepts proposed for validation are presented and (2) the Proof of Concepts activities, in terms of devices under test, test setups, test procedures and test object lists are defined: all these information will deliver the performance of power reduction concepts by experimental evaluation leading to their validation.

2. CONCEPTS PROPOSED FOR VALIDATION

Different concepts to increase the energy efficiency of mobile-radio systems on component, node and system level have been proposed in the EARTH project. An important part of the project scope is to propose and verify methods for assessing and scientifically evaluate these concepts with regard to energy consumption and with a holistic view. The overall holistic evaluation of the EARTH concept is not possible to validate in reality, instead that will be carried out by advanced system level simulations, see e.g. [EARTH-D6.2a]. However, to support that activity selected solutions will be prototyped and verified in the “real world”.

Section 2.1 is related to the concept of power saving due to deactivation of base stations in mobile networks, considering the energy efficiency due to the “ON/OFF schemes”.

The algorithms of the “ON/OFF schemes” have been designed and developed to turn off or on a cell of a BS on the basis of the traffic requests inside the cell. The concept evaluation shall prove the proper execution of all the procedures and of the corresponding commands requested by the ON/OFF scheme and shall estimate the reaction time of the algorithms implementing the on-off switching. The benefit of the evaluated concept is to be determined by measuring the power consumed for a defined traffic scenario and by comparing the power required by applying the ON/OFF scheme with the power required by not applying this concept in both test scenarios for WCDMA/HSPA technology and for LTE technology

Section 2.2 is related to the energy efficiency performance evaluation on transceiver system, designed and developed for both macro and small base stations: specific hardware components have been realized allowing the validation of hardware solutions not available in current products.

The validation expected for small base stations shall illustrate, based on measurements, the power scalability and efficiency of the complete downlink analogue transceiver system for different signal paths, traffic loads (and traffic load profiles) and eventually frame structures. The validation platform uses techniques such as bandwidth adaptation, performance scaling and deactivation of components. The validation expected for transceiver systems in macro base stations enables the experimental EE performance evaluation of the Signal Load Adaptive Transceiver concepts. The benefit of different features can be assessed individually and even in combination, based on different test scenarios presented for transceiver system evaluation.

2.1. POWER SAVINGS DUE TO DEACTIVATION OF BASE STATIONS IN MOBILE NETWORKS

A careful observation shows that in current mobile networks exist certain periods when the load decreases and thus the deployed infrastructure is underutilized, which results in a considerable waste of energy.

Given a series of probable valid alternatives, the main goal would then be creating an intelligent network management mechanism to switch on and off base stations depending on the traffic load, reshaping the cell topology and maintaining QoS and QoE during the process. This way, a minor quantity of network nodes is in use, being also possible to define a proper setting of the power emitted by each BS adjusted to the requirements on the network.

Through various theoretical studies, it has been shown that the percentage of energy saved by applying these schemes is worthy of consideration, being necessary to validate such results in a real environment.

2.1.1. VALIDATION OF ENERGY EFFICIENCY DUE TO ON-OFF SCHEME

The validation criteria that will be adopted for the energy efficiency performance of the ON-OFF scheme will be the power savings measured in the laboratory environment by applying a time varying pattern of LTE data traffic on each of the three cells handled by one eNodeB.

2.2. ENERGY EFFICIENCY PERFORMANCE EVALUATION ON TRANSCEIVER SYSTEMS

Several energy efficiency concepts are considered for experimental validation based on EARTH transceiver systems. These hardware prototypes implement transceiver solutions proposed by the activities in Green Radios [EARTH-D4.2] for decreasing the power consumption of these components and for supporting energy efficient radio interface solutions. The transceiver solutions are presented in the following two sections, while the radio interface solutions are described in section 2.2.3.

2.2.1. VALIDATION OF TRANSCEIVER SOLUTIONS FOR MACRO-CELL BASE STATIONS

For macro-cell base stations a Signal Load Adaptive Transceiver (SLA-TRX) has been proposed for enabling the reduction of power consumed by the base stations by making use from characteristics of LTE signals. It implements the deactivation of components (CD) in time slots without signal transmission and operating point adjustment (OPA) at medium and low transceiver output power (section 4.2 in [EARTH-D4.1]). The SLA-TRX concept supports energy efficient radio interface solutions like bandwidth/capacity adaptation and cell DTX (section 2.2.3).

The performance expected due to theoretical evaluations from this component solution shall be validated by hardware characterization. Power characteristics shall be provided for CD and OPA to be included in the BS power models of EARTH. Tests with variable load signals (special LTE test signals described in section 3.4) shall provide the benefit due to these hardware solutions for real applications and shall support the evaluation of radio interface solutions.

The tests will be performed as described in section 3.2.

2.2.2. VALIDATION OF TRANSCEIVER SOLUTIONS FOR SMALL-CELL BASE STATIONS

In the frame for small-cell base stations, different solutions have been proposed in [EARTH-D4.1] to adapt and optimize the energy efficiency by exploiting the characteristics of LTE signals and the user dynamics within heterogeneous networks. Some of these solutions will be validated based on hardware implementation and validation. The validation covers the transceiver solutions and the antenna interface solutions.

2.2.2.1. TRANSCEIVER SOLUTION

Transceiver solution components considered for validation are the small-signal transceiver and the adaptive energy efficient power amplifier (AEEPA) solutions. These components support adaptive SINAD performance and operation bandwidth, component deactivation and operation point adjustment. This component adaptation will be exploited to increase the energy efficiency by applying radio interface solutions like bandwidth/capacity adaptation and cell DTX (section 2.2.3).

Tests with variable load signals (special test signals or real LTE signals) shall provide the benefit due to these hardware solutions for real applications and shall support the evaluation of radio interface solutions.

2.2.2.2. ANTENNA INTERFACE SOLUTION

The validation of the proposed antenna interface solution consists to compare a low loss RF front-end architecture without duplexer with a standard RF front-end architecture with duplexer. Two key criteria have to be validated. The first one is the energy efficiency improvement on the transmit path. The second one concerns isolation between transmission and reception paths which have to be equivalent to the standard architecture.

The tests will be performed as described in section 3.3.2.

2.2.3. VALIDATION OF RADIO INTERFACE CONCEPTS

Different concepts defined in the project for providing power savings in the base stations are acting on the radio interface and make use from hardware solutions defined in the EARTH transceiver systems. An experimental validation of these concepts is proposed on the basis of transceiver solutions presented in the sections above.

Energy savings by bandwidth adaptation

The validation of this radio interface concept defined in section 3.4 of [EARTH-D4.1] shall be performed by using a test setup based on the SLA-TRX. The concept considers special resource utilization based on an energy efficient scheduling and makes use from the OPA feature of the transceiver hardware which allows the adaptation of the power consumption to the output power. The required special resource utilization will be considered by using special test signals based on bandwidth adaptation as described in section 3.4.

Using these signals for measurements with the EARTH transceiver system and applying the OPA allow the evaluation of the energy efficiency improvement due to this concept delivering results restricted on the power consumed by the transceiver.

The tests will be performed as described in section 3.2.

Cell DTX

The validation of this radio interface concept defined in section 3.5 of [EARTH-D4.1] shall be done by using the test setup based on the SLA-TRX. The concept considers special resource utilization which provides a maximum of time slots without signals for transmission and makes use from the CD feature of the transceiver hardware which allows the deactivation of hardware components reducing the power consumption. The required special resource utilization will be considered by using special test signals based on Cell DTX as described in section 3.4.

Using these signals for measurements with the EARTH transceiver system and applying the CD allow the evaluation of the energy efficiency improvement due to this concept delivering results restricted on the power consumed by the transceiver.

The tests will be performed as described in section 3.2.

Energy savings by bandwidth adaptation combined with cell DTX

Measurements based on the SLA-TRX hardware allow the evaluation of these two concepts in a combined way. Using test signals which are based on both concepts and applying the CD and OPA features of the EARTH transceiver system allow the validation of an optimized combination of the concepts.

The tests will be performed as described in section 3.2.

Adaptability to system dynamics in small cells

The validation of this small-cell radio interference concept partly indicated in 3.6 of [EARTH-D4.1] can be done by changing the modulation and coding scheme and the SINAD performance depending on the channel

conditions. A variable channel will be emulated with a variable amplifier at the small-cell transceiver output. Targeting a 'just good enough' performance at the terminal side, the SINAD performance of the transceiver and the modulation and coding scheme will be adapted for highest energy efficiency in the base station. This validation concept might be combined with bandwidth adaptation.

The tests will be performed as described in section 3.2.

3. TEST SETUPS, TEST PROCEDURES AND TEST OBJECT LISTS

Test setups and test object lists (TOL) have been defined for:

- Evaluation of power savings due to deactivation of BS in mobile networks:
- EE Performance evaluation on transceiver systems for small- and macro-cells:
 - TRX system
 - SLA-TRX (macro-cells)
 - SC-BTS with AEEPA (small-cells)
 - SC-BTS with load modulated PA with TMN (small-cells)
 - Low loss antenna interface

3.1. PERFORMANCE EVALUATION OF MOBILE NETWORK SOLUTIONS

The application of ON-OFF schemes to obtain reduction in power consumption in networks has been the selected track to test on a real infrastructure. To achieve the desired goals, it is necessary to have a test plant with the necessary equipment ready as well as to design a battery of tests that cover all aspects under review and verification. Below is proposed a test setup in order to carry out the performance evaluation of the ON-OFF schemes with LTE technology.

As far as WCDMA/HSPA technology is concerned, the evaluation of power consumption can be done without setting up a test scenario. Considering a traffic distribution and the results due to the performance evaluation based on the test scenario using LTE technology, allows evaluating the energy efficiency performance for the WCDMA/HSPA case by calculation. That is, considering the power consumption of the WCDMA/HSPA BS measured in a static way and in different traffic conditions, and applying the same pattern of traffic used with the test scenario based on LTE technology allows evaluating the ON/OFF scheme performance for a WCDMA/HSPA network.

3.1.1. DEACTIVATION OF BASE STATIONS IN MOBILE NETWORKS

The assumptions for the simulations regarding aspects such as cell layouts, number and activity of users, data traffic, are not easily transportable to the test plant, so the proposed algorithm has to experiment certain modifications to fit into the characteristics of the facilities and thus be really suitable.

LTE Test setup

In order to implement the proposed test scenario based on LTE technology, it's necessary that the equipment meets a series of requirements. First of all, a PC implementing the ON-OFF algorithm is needed, as well as one eNodeBs at least, to implement the proposed layouts. The test scenario depicted in Figure 1 shows one possible test setup entailing the adoption of one eNodeB equipped with three cells. Starting from the right part of Figure 1, this test scenario comprises the use of:

- One Ericsson eNodeB connected by means of the S1 interface to the Ericsson LTE Core Network and equipped with three cells, named cell1, cell2 and cell3.
- Ericsson Element Manager LMT (Local Maintenance Terminal) to be used for: monitoring S1 interface in order to get the number of active services per cell basis.
- PC equipped with the ON-OFF scheme.

Moreover it is necessary to assure the presence of a section fully dedicated to the generation of calls, in order to properly simulate the beginning and end of a certain call, and another section including several RF

attenuators making feasible to attenuate the signals coming from the three involved cells of the eNodeB. Therefore the left part of Figure 1 reports:

- Control of the RF attenuators.
- A set of LTE user equipments to be used to make the data calls.

The 4G Ericsson Element Manager that is the software based on SUN/UNIX equipment that can get on per cell basis, by monitoring each cell of the eNodeB, information concerning the number of active LTE data sessions calls. The above information is reported as printout and can be saved in a log file available for processing every tenth of seconds. The PC running the ON/OFF scheme can get the log file from the Element Manager after having opened a telnet session and by using a proper set of commands furnished by Ericsson.

The type of physical connection between the Element Manager and the PC equipped with the ON/OFF scheme will be fast Ethernet while the switching off or switching on of a single cell will be done by sending the proper command from the pc equipped with "ON/OFF scheme" to the Element Manager used to manage the three cells. To this purpose, additional software will be developed with the aim of:

- Managing the interfaces with the equipment.
- Focusing on the design of a valid traffic pattern.
- Scheduling the call generation for testing.

The suite envisaged for the automatic LTE data call generation and end will be mainly based on a SW tool developed by Telecom Italia.

Each LTE data card will be connected to a single computer in order to activate the PDP context and will receive the RF signal from each of the three involved cells, i.e. cell1, cell2 and cell3 with different receiving levels. It will be possible by varying properly the attenuations with which each cell will be felt by a data card. Just to make an example, data card 1 will receive from:

- Cell 1 a RF signal -65 dBm (best serving cell)
- Cell 2 a RF signal -70 dBm
- Cell 3 a RF signal -75 dBm

Data card 2 will receive from:

- Cell 2 a RF signal -65 dBm (best serving cell)
- Cell 3 a RF signal -70 dBm
- Cell 1 a RF signal -75 dBm

Data card 3 will receive from:

- Cell 3 a RF signal -65 dBm (best serving cell)
- Cell 1 a RF signal -70 dBm
- Cell 2 a RF signal -75 dBm

The same approach in terms of received RF signal will be adopted for the other six data cards that will be used in the test activity execution ...

On the basis of the example above depicted, every time the "ON/OFF scheme" will decide to lock cell 1, which is currently the best serving cell of data card 1, the continuity of the coverage will be granted by the other two cells, cell 2 (-70 dBm) and cell 3 (-75 dBm).

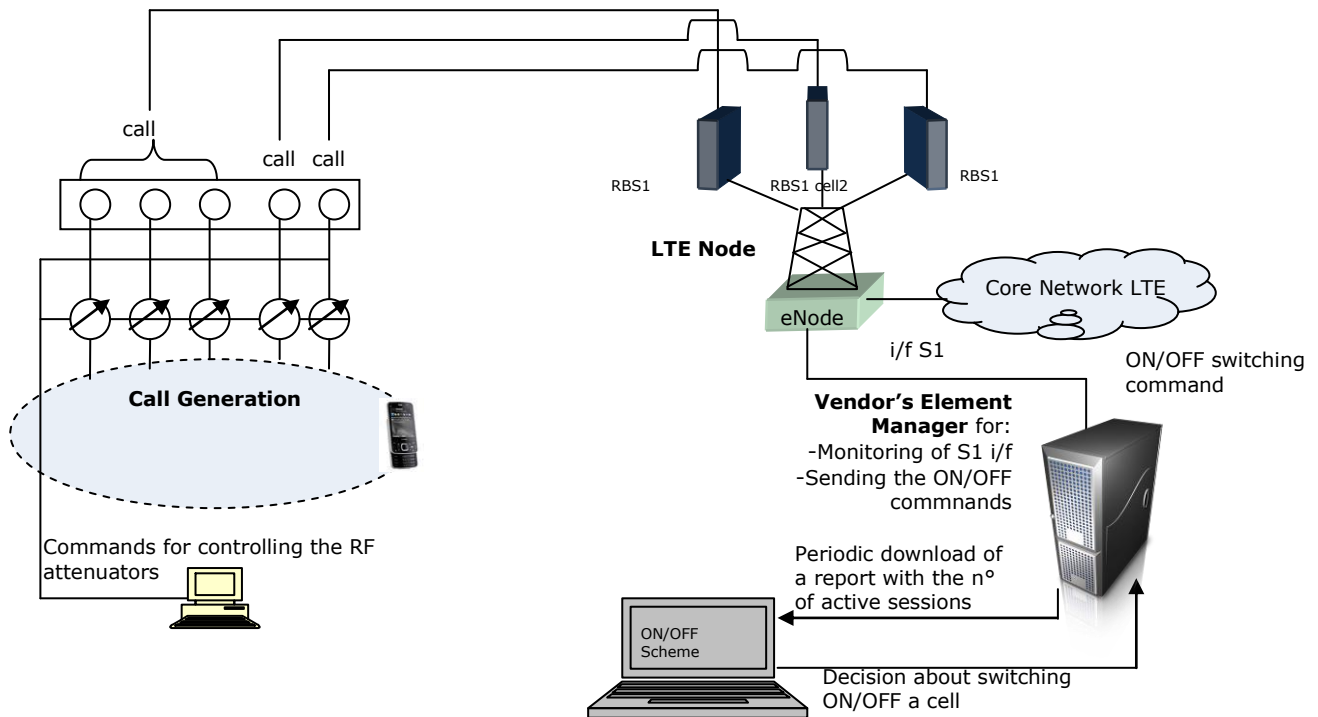


FIGURE 1. Test scenario for performance evaluation of ON/OFF scheme based on LTE technology

Test procedure

As far as the test scenario based on LTE technology is concerned, it will be based on the deployment of one eNodeB equipped with three cells. It is foreseen to set up to two or three data calls per cell.

As previously hinted, the computer running a basic version of the ON-OFF algorithm will communicate with 4G Ericsson Element Manager in charge of managing the three deployed cells belonging to the eNodeB, thus monitoring the network status and, in particular, sending the proper ON/OFF command in order to:

- Switch off at all a cell every time there will be no users engaged in traffic inside a single cell; the switching off of the cell in Ericsson technology will entail the absence of transmission of the RF signal with a consequent absence of transmission of all the common channels
- Switch on a cell when the traffic load inside each of the other two cells goes above a predefined threshold of traffic; the switching on of the cell in Ericsson technology will entail the presence of transmission of the RF signal with the consequent transmission of all the common channels.

In order to properly communicate the ON-OFF algorithm with the cell manager previously depicted, it is necessary, apart from a physical connection, to follow a certain protocol using a series of commands which make this interaction possible.

The software developed so as to perform the envisaged tests with real equipment, behaves as it is depicted on FIGURE 2. Once the program is initialized, it will flow between 3 main states, depending on how many sectors are unlocked.

Each sector is described into more detail in the following list. For each sector, the general behaviour is depicted not being this the case of the needed commands to be executed in order to get information from the eNodeB and to act over it:

- **INIT State:** It is the one in charge of establishing the connection and set the proper parameters in order to start interacting with the eNodeB.
- **3 Sectors State:** It will be executed when the load of the network is above 5 data calls. When the software is on this state and a new iteration comes, two situations can be envisaged:
 - **The new load is again over 5 data calls.** Then, it will remain another iteration in the same state.
 - **The new load is between 2 and 6 data calls:** One cell can be switched off.
- **2 Sectors State:** It happens when the load of the network is lower than 6 but greater than 2. When the system is on this state, three situations may occur once a new load reading comes:
 - **The new load is again between 2 and 6 data calls.** Then, it will remain another iteration in the same state.
 - **The new load is higher than 5 data calls:** The cell that was switched off should be switched on.
 - **The new load is below 3 data calls:** Another cell can be switched off
- **1 Sector State:** Applying when the load is below 3 data calls, and only one sector is enough in order to handle the traffic of the network. Again, two situation may occur when receiving the new reading of data calls:
 - **The new load is again lower than 3 data calls.** Then, it will remain another iteration in the same state.
 - **The new load is between 2 and 6 data calls:** One out of the two cells that were switched off should be switched on.

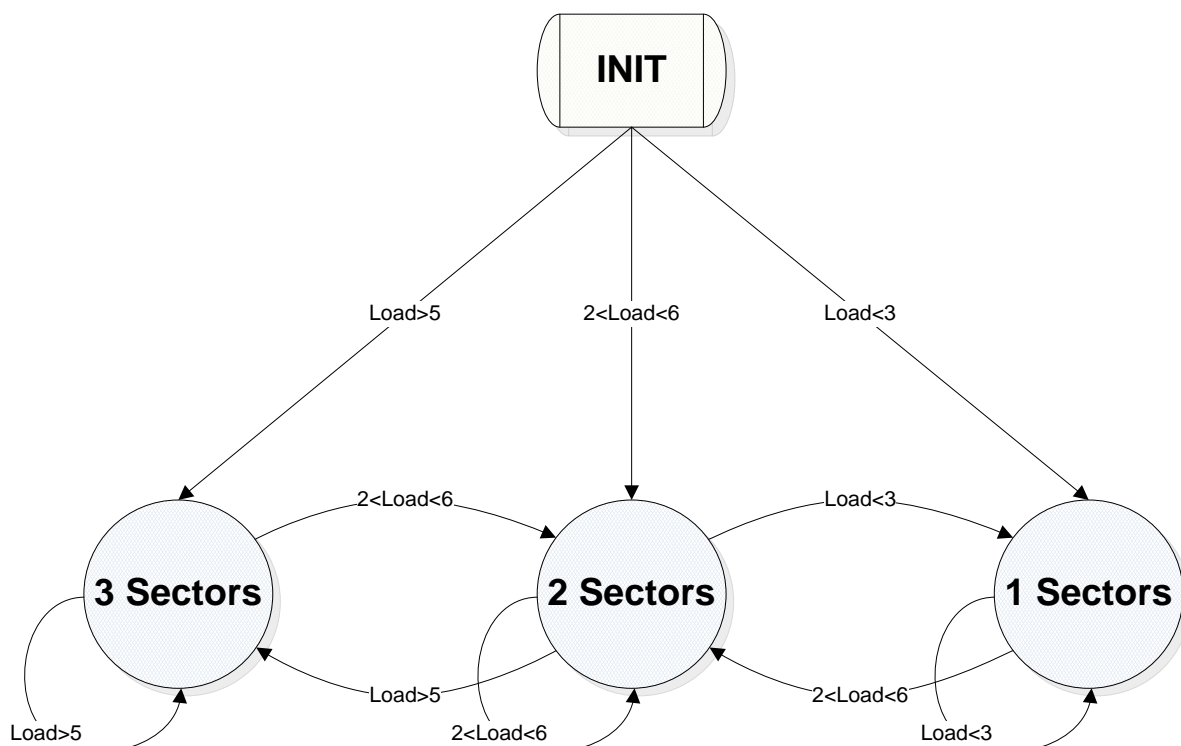


FIGURE 2. State diagram for ON/OFF Software

Test equipment list

For the LTE based test scenario, the following test equipment list should be defined:

- One eNB equipped with three cells
- A Mobile Core Network
- Equipment for managing the RF attenuations.
- Equipment for managing in manual and/or automatic way the data calls.
- Equipment for the measurement and the monitoring of the current absorption of the eNodeB.
- PC equipped with the “ON/OFF scheme”.
- Ericsson Element Manager for managing eNodeB (e.g. in terms of switching ON/OFF the cells).

Moreover, in order to assure a complete testing activity, the following actions will be carried on:

- Test the decision mechanism.
- Validate the real savings obtained when switching off power amplifier of the eNodeB transmitting inside a cell.
- Check the service availability when one single cell is switched off.
- Verify the network reconfiguration is correctly done.

3.2. PERFORMANCE EVALUATION ON TRANSCEIVER SYSTEM FOR MACRO BASE STATIONS

Different concepts and solutions listed in section 2.2 will be evaluated with a test setup based on the SLA-TRX system. As the component solutions proposed in the project for decreasing the power consumed by macro base stations are restricted to transceiver components, the validation of component features will focus only on the SLA-TRX and the validation of radio interface concepts will be restricted to energy efficiency evaluation on the transceiver system by applying the different concepts.

3.2.1. SIGNAL LOAD ADAPTIVE TRANSCEIVER SYSTEM

The component solutions proposed for energy efficiency improvement in macro base stations are integrated in the Signal Load Adaptive Transceiver defined in [EARTH-D4.1]. Hardware prototypes have been realized for the EARTH transceiver system “SLA-TRX” for enabling the validation of energy efficiency concepts presented in section 2.2.

3.2.1.1. DEVICES UNDER TEST

The EARTH transceiver system “SLA-TRX” is composed by 7 different circuit boards or modules as listed below:

- 1) DSPC – Digital signal processing and control
- 2) Interface board – to connect several boards with the DSPC board
- 3) SS-RFTRX (TX+FB) – Small signal RF transceiver for transmit and feedback
- 4) SS-RFTRX (RX) – Small signal RF transceiver for receive
- 5) AEEPA – Adaptive energy efficient power amplifier
- 6) APSU – Adaptive power supply unit
- 7) PSU – Power supply unit

These components are shown in FIGURE 3 to FIGURE 6:

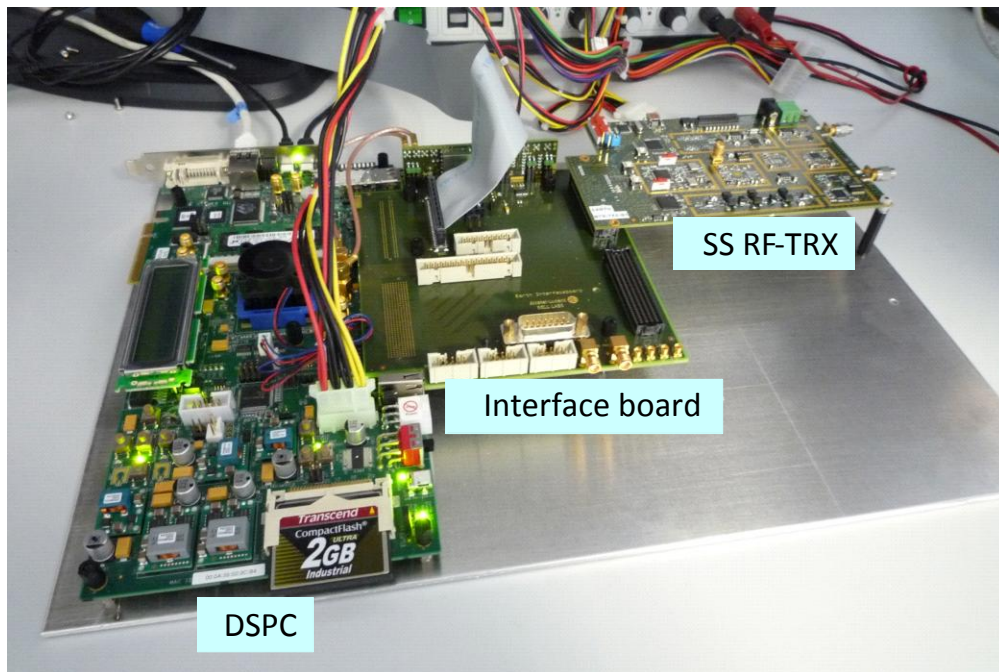


FIGURE 3. Pictograph of DSPC, interface board, and SS RF-TRX (TX+FB)

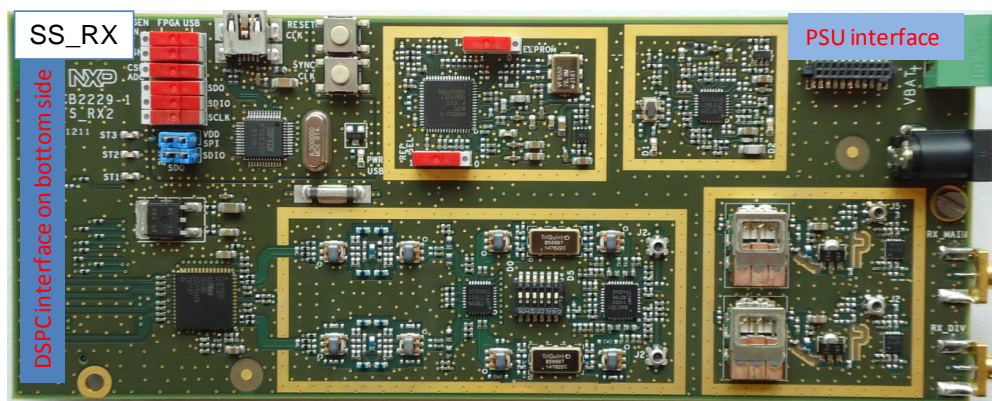


FIGURE 4. Pictograph of SS RF-TRX (RX)

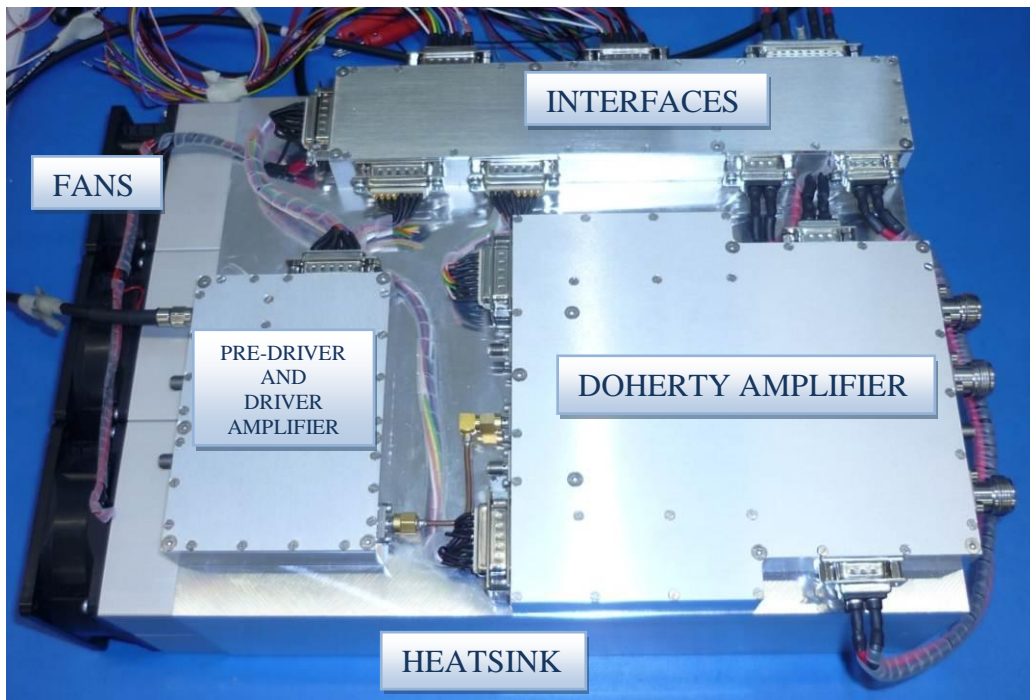


FIGURE 5. Pictograph of AEEPA

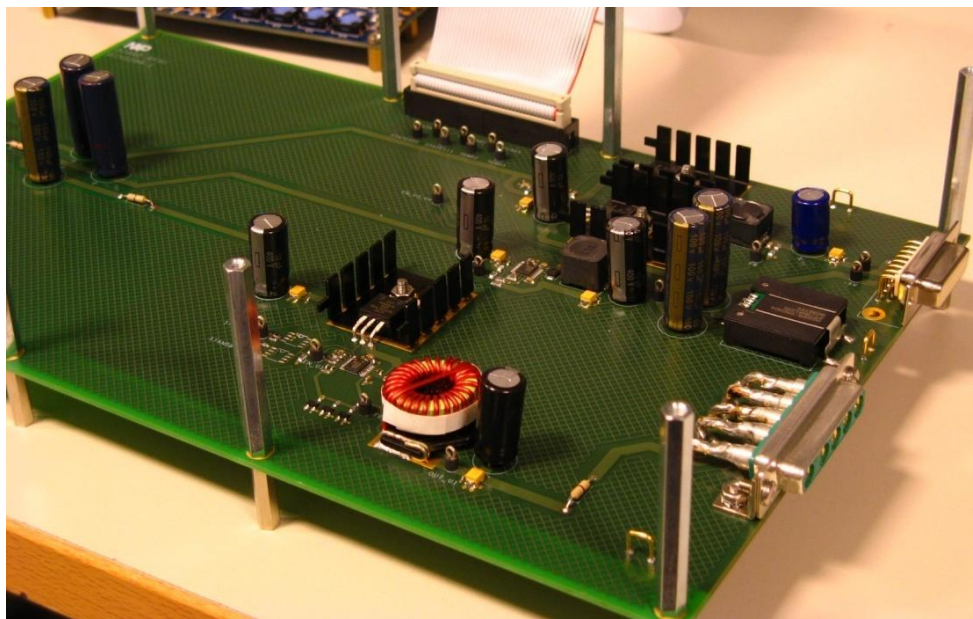


FIGURE 6. Pictograph of PSU and APSU

The individual boards and modules have to be integrated into the SLA-TRX system following the diagram presented in FIGURE 7:

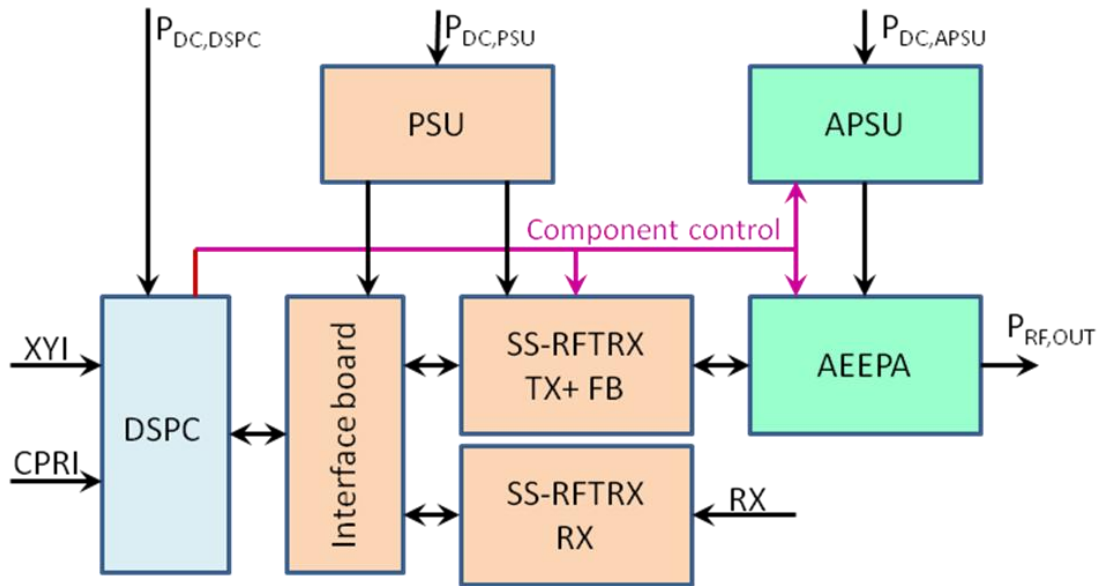


FIGURE 7. Block diagram of the EARTH transceiver system “SLA-TRX”

The SLA-TRX hardware shows a functional unity with following interfaces to the outside:

- 1) CPRI – Data and signalling interface to BS base band boards (optical fibre)
- 2) XYI – Supplemental interface for providing a user interface (RJ45 Ethernet; USB/JTAG)
- 3) $P_{RF,OUT}$ – PA output (coaxial connector)
- 4) RX – Receiver input (coaxial connector)
- 5) $P_{DC,DSPC}$ – DC power supply for the DSPC board
- 6) $P_{DC,PSU}$ – DC power supply for PSU, Interface board, SS-RFTRX TX+FB, and SS-RFTRX RX
- 7) $P_{DC,APSU}$ – DC power supply for APSU and AEEPA

The supply power is to be provided separately for three different blocks of the EARTH transceiver system. As the DSPC is realized on an evaluation board procured from an external provider, it shows power consumption not typical to the implemented features. Its dedicated power supply ($P_{DC,DSPC}$) allows for separating the power consumed by the DSPC from the power consumed by the other boards. The SS-RFTRX boards together with the interface board and the PSU have a common power supply ($P_{DC,PSU}$) allowing to evaluate the power performance of these circuits together. APSU and AEEPA are supplied together via $P_{DC,APSU}$, enabling the energy efficiency evaluation of the power amplifier combined with its dedicated power supply unit.

3.2.1.2. HARDWARE VALIDATION PLATFORM

The experimental evaluations to be done with the SLA-TRX will be based on the test setup “Basic evaluations” defined in [EARTH-D5.1]. Based on this principle, the setup is proposed to be realized as shown in FIGURE 8.

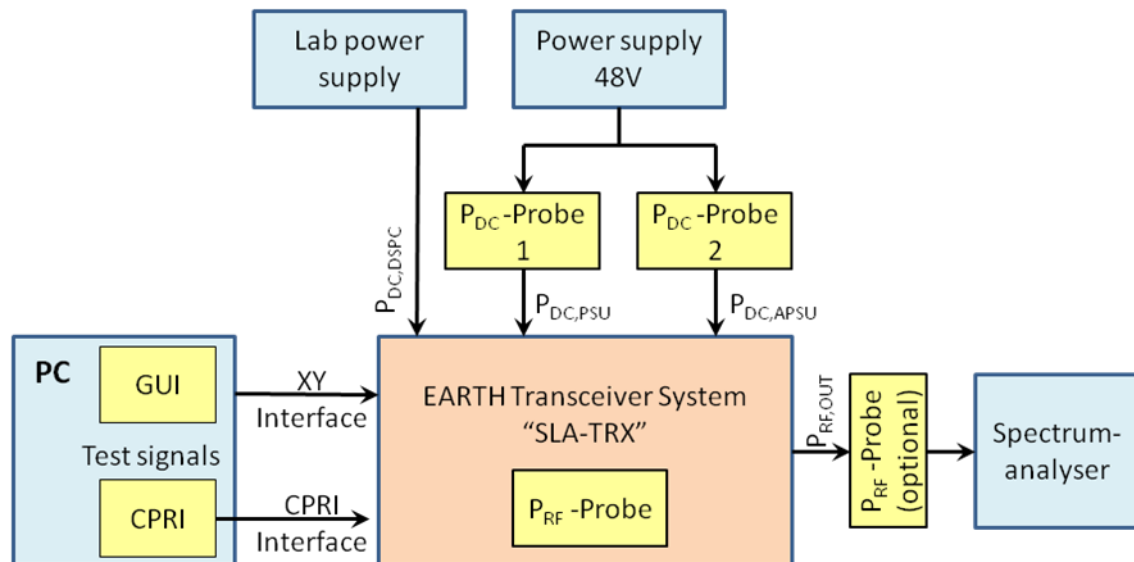
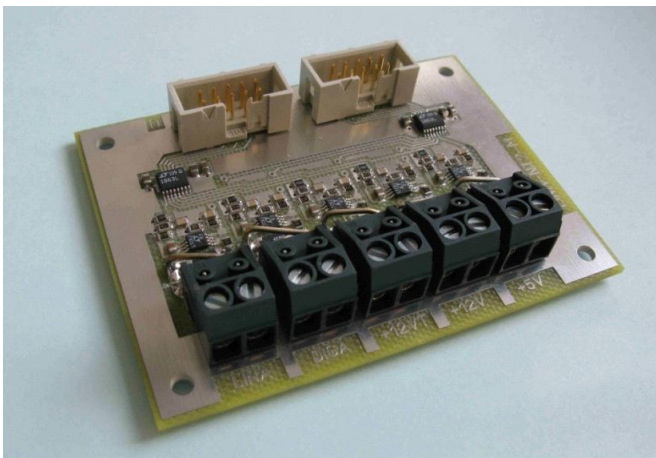
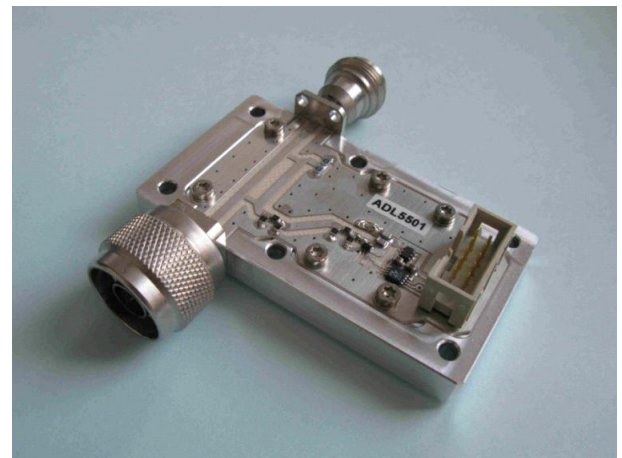


FIGURE 8. Block diagram of test setup "Signal Load Adaptive Transceiver"

The measurements are controlled by the PC which also provides the test signals via a CPRI interface to the EARTH Transceiver System. This SLA-TRX is supplied with DC power at three points as discussed above. The transceiver output signal is provided to a spectrum analyzer for monitoring the spectral quality of the signal assuring the proper operation of the test setup. DC-probes and RF-probes allow measuring the supplied DC power and the transmitted RF output power enabling the power efficiency evaluation of the transceiver components. The power probes are shown in FIGURE 9.



DC-probes



RF-probes (optional)

FIGURE 9. Pictograph of DC- and RF-Probes

3.2.1.3. ENERGY EFFICIENCY EVALUATION OF THE SLA-TRX

For measuring the energy efficiency performance of the SLA-TRX, test signals are provided from the PC via a CPRI interface to the EARTH transceiver system. Additional information on signal parameters can be provided via this interface to the DSPC if necessary. The XY interface allows setting predefined operation procedures of the SLA-TRX via the user interface (GUI). For assuring the correct operation of the transceiver from signal quality point of view, the PA output signal $P_{RF, OUT}$ is analysed and monitored with a spectrum analyser to assure, that the standard requirements are fulfilled.

The power consumed by the SLA-TRX is measured with P_{DC} -Probes which allow the accurate measurement of variable DC power by capturing the voltage and current values. The power consumed by the PA block and the small signal RF block can be determined separately as described in the section “Devices under test”. The RF power at the PA output will be determined by using the power information available from the transmitter feed-back path. A data processing in the digital transceiver part determines the transmit power. This procedure is pointed out as “ P_{RF} -Probe” in FIGURE 8. As an alternative, the RF output power can be measured by using an external probe “ P_{RF} -Probe (optional)”. The power efficiency of the transceiver blocks is calculated as P_{RF}/P_{DC} .

The performance evaluation of the SLA-TRX hardware is to be done by measuring and comparing the power consumed when the power saving solutions are applied and when they are not applied.

3.2.1.4. PERFORMANCE EVALUATION OF RADIO INTERFACE SOLUTIONS

The performance evaluation of radio interface solutions like bandwidth adaptation and cell DTX is based on appropriate LTE test signals which consider a typical daily traffic load and the characteristics of the respective concept as described in section 3.4. By comparing the power consumed by the SLA-TRX when using these concept-typical test signals with the power consumed for state-of-the-art operation, the benefit due to the respective concept will be determined.

3.2.1.5. TEST EQUIPMENT LIST

The test setup "Signal Load Adaptive Transceiver" will be composed by following components:

- 1) EARTH transceiver system “SLA-TRX”
- 2) PC with GUI and CPRI board
- 3) Spectrum analyser
- 4) P_{DC} -Probe (2x)
- 5) Optional: P_{RF} -Probe (optional)
- 6) Lab power supply (multiple voltages?)
- 7) 48V power supply
- 8) Optical fibre and RF cables

3.3. PERFORMANCE EVALUATION ON TRANSCEIVER SYSTEM FOR SMALL-CELL BASE STATIONS:

In the frame for small-cell base stations, different solutions have been proposed in [EARTH-D4.1] to adapt and optimize the energy efficiency by exploiting the characteristics of LTE signals and the user dynamics within heterogeneous networks. These solutions cover both interface concepts and hardware components. The validation platform comprises some of these hardware components. This platform enables to validate these components and some of the radio interface concepts described in section 2.2.3 .

3.3.1. SMALL-CELL BASE STATION WITH ADAPTIVE ENERGY EFFICIENT PA

The small-cell transceiver validation platform is a stand-alone collection of hardware and software that enables to verify some of the energy adaptive solutions proposed in [EARTH-D4.1]. This platform has been constructed to be easily transportable and connects with a computer via a USB™ and GPIB™ interface. The signal processing software and control is performed in Matlab™. The transceiver is a SISO transmitter solution

that targets output powers lower than 35dBm. A realistic antenna, antenna interface or wireless link is not part of the validation platform. The channel can be emulated by means of a variable attenuator.

The small-cell transceiver validation platform consists of (1) a hardware validation platform and (2) a validation software to interface, control and validate the energy adaptive solutions.

3.3.1.1. HARDWARE VALIDATION PLATFORM

The small-cell hardware validation platform comprises two component solutions from [EARTH-D4.1]: the small-cell flexible RF transceiver and the low-power energy adaptive power amplifier. Additional hardware modules are added to obtain a working measurement platform with only few test and measurement equipment. The hardware platform is illustrated in following figures. The different modules interconnect via piggy-bag, mezzanine, flat-cable and conventional coaxial connections.

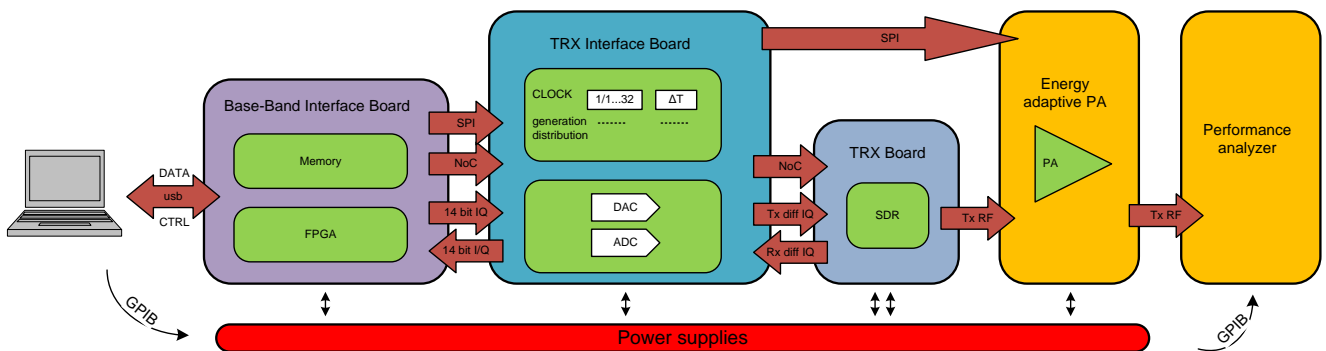


FIGURE 10. Small-cell hardware validation platform

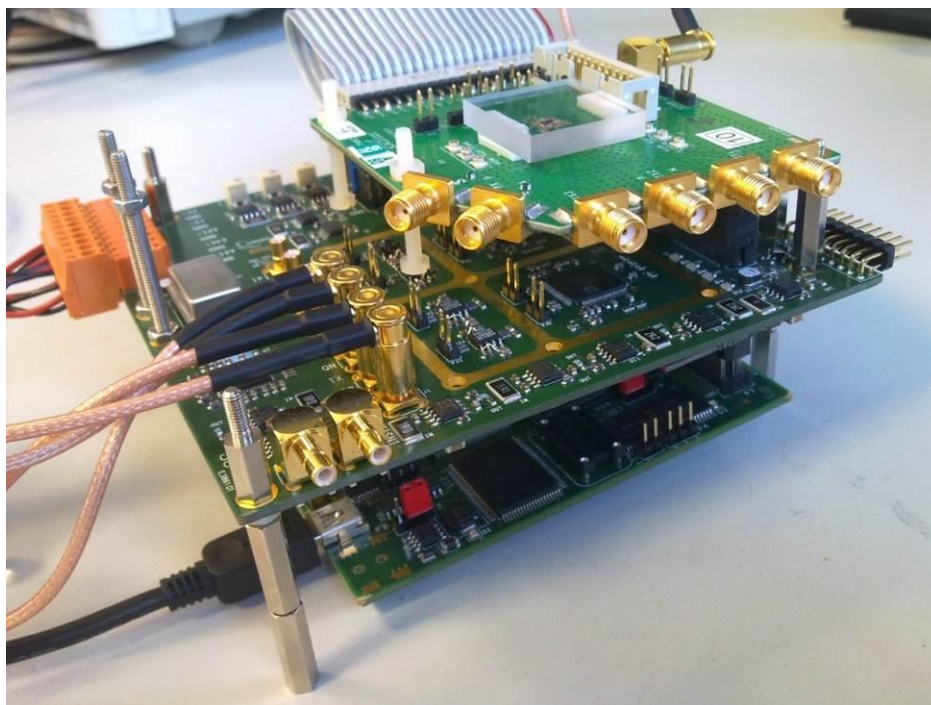


FIGURE 11. Pictograph of the small-cell hardware validation platform

The different hardware modules depicted in previous figures are discussed next.

- The baseband interface board

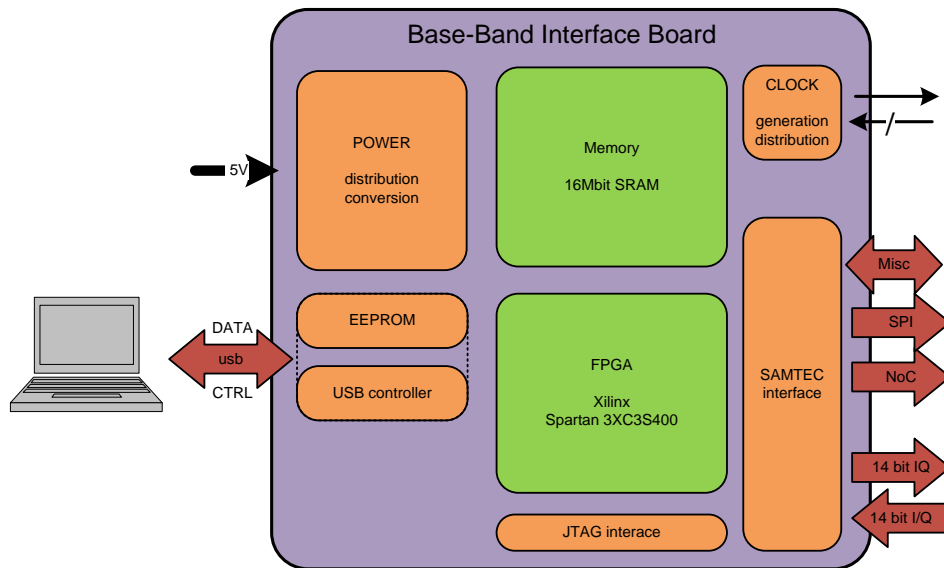


FIGURE 12. Small-cell baseband interface board

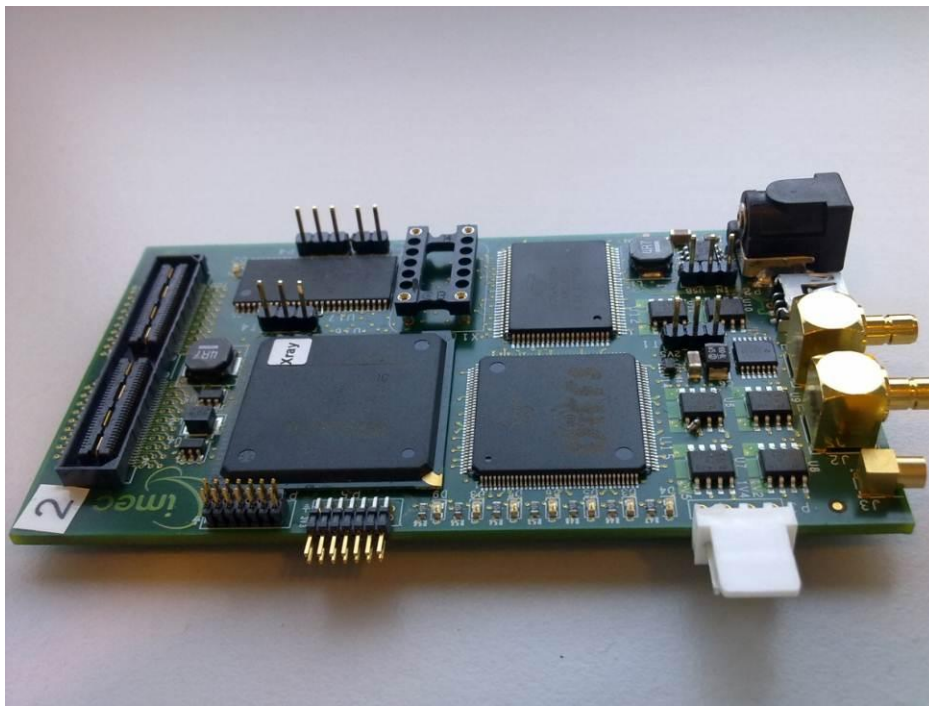


FIGURE 13. Pictograph of the small-cell baseband interface board

The main function of the baseband interface board is to act as a digital interface between the computer and the analogue/digital interface module. It comprises an USBTM controller to interface directly with the computer. The validation platform does not aim for real-time signal processing. Sequences of test signals will be stored in memory and will be read via an indexed loop. The memory to store these sequences is available in the 16Mbit SRAM. Two serial protocols are implemented on the XilinxTM FPGA to configure the system and its components. The SPITM [SPI] interface controls the TRx interface board and the energy adaptive power amplifier solution. The NoC [NoC] interface controls the small-cell flexible transceiver. Additionally, several FPGA pins are directly provided to the miscellaneous output. These signals can be used as fast direct control lines for e.g. the energy adaptive power amplifier. The JTAG interface allows customizing the FPGA when the system is not operational. The FPGA operates on 3.3V and is clocked on the signals coming from the

transceiver interface board. The baseband interface board is supplied with 5V. This board is not optimized for energy efficiency and will not be a measure for the power validation.

- Transceiver interface board

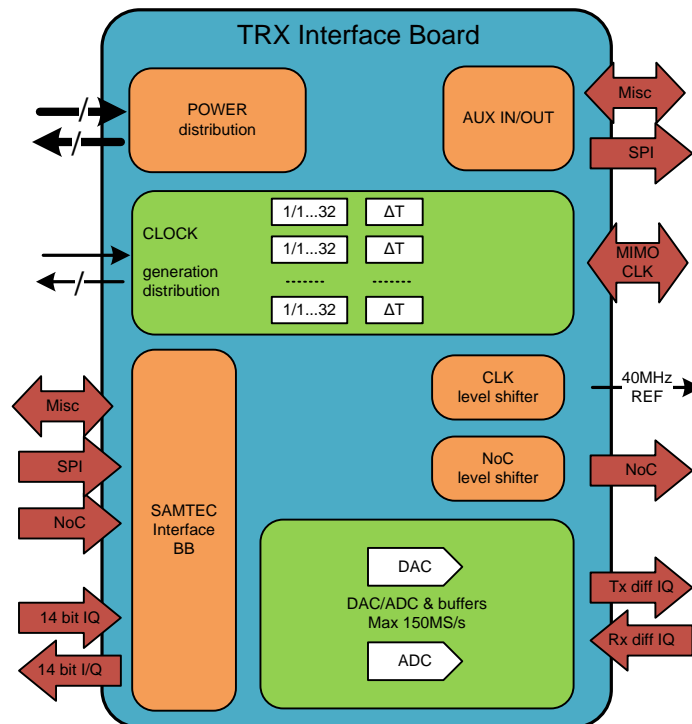


FIGURE 14. Small-cell transceiver interface board

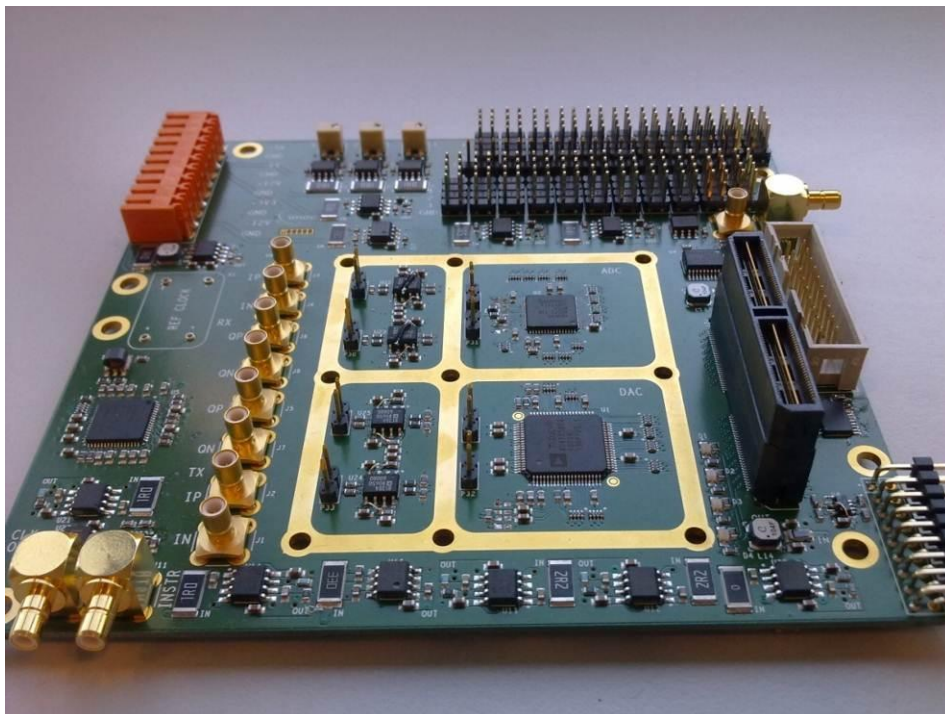


FIGURE 15. Pictograph of the small-cell transceiver interface board

The transceiver interface board performs the conversion between the digital and the analogue signals and provides and distributes the system clock. The Analogue to Digital Converter (ADC) and Digital to Analogue Converter (DAC) provide two 14bit digital streams up to 150MS/s. The dynamic range of the analogue streams is maximally 1Vrms and they are accessed via SMA connectors. The DAC and ADC are controlled via an SPI™ protocol implemented in the FPGA. The clock is generated from an on-board crystal oscillator and can be divided and delayed to provide the appropriate clock signals for the DAC/ADC, the FPGA, the NoC, the small-signal transceiver and the measurement equipment (10MHz REF). Given that the small-signal transceiver IO ring operates on 2.4V, this board will shift the levels from the FPGA voltages. The remaining digital lines coming from the FPGA via the SAMTEC™ connector are available for additional control. These lines will be used for an additional SPI interface with the power amplifier. This board is not optimized for energy efficiency and will not be a measure for the power validation.

- Small-signal transceiver

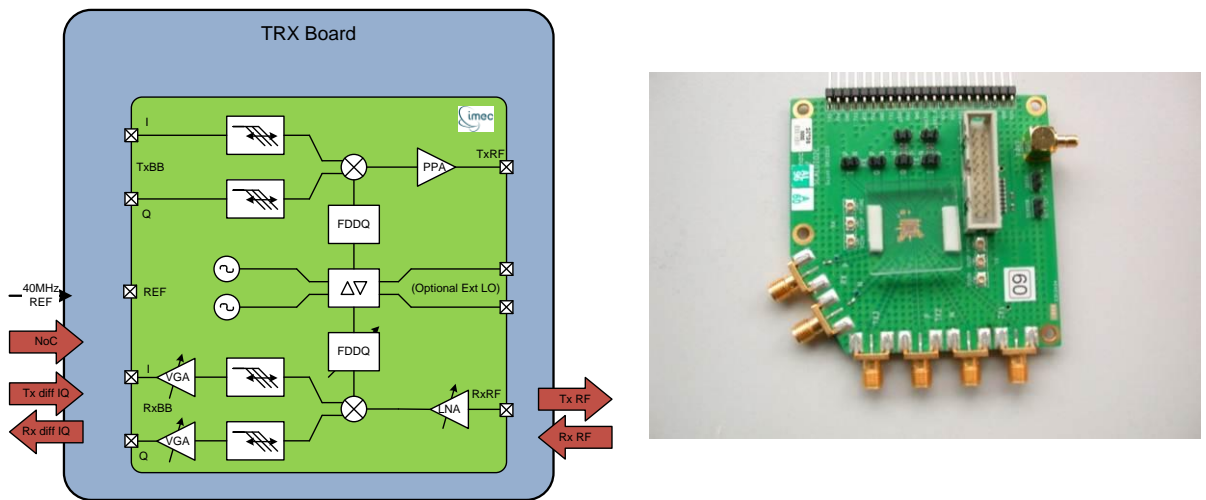


FIGURE 16. Small-cell transceiver board

The small-signal transceiver comprises (1) a transmitter section to up-convert the analogue baseband signal to a RF frequency, (2) a receiver section to down-convert the RF signal back to baseband frequencies and (3) a Local Oscillator (LO) generation section consisting of VCO integrated in a PLL which locks on an external reference. To support the energy adaptation solutions described in [EARTH-D4.1], the transceiver of choice is highly flexible in terms of bandwidth, SiNAD performance and gain distribution. This multiband transceiver is described in detail in [GilS11] and is fabricated in 40nm low power CMOS. This transceiver has direct-conversion architecture. The huge flexibility over the different building blocks is controlled via a high speed Network on Chip (NoC) interface [NoC]. This NoC is a serial protocol which can run up to 200MHz with digital levels of 0/2.4V. The maximal average output power of the transmitter is 3dBm and the dynamic range of the transmitter baseband input should not exceed 1Vrms. The clock reference signal (locking the PLL) frequency is 40MHz with digital levels of 0/2.4V. Optionally, the PLL can be bypassed and an external LO signal can be provided. The supply power for the transmitter section is 1.2V except for the last amplification stage which is supplied with 2.4V. The IO ring operates on 2.4V.

The low power transceiver of less than 2x2mm² is directly mounted and bonded on a PCB. This PCB interfaces via SMA connectors for the RF in- and output, an SMB connector for the clock input and U-FL connectors for the optional LO input and output (LO verification). The baseband signals are connected via DIL studs and the NoC can be connected via a dedicated flat-cable or via the SAMTEC™ connector.

- Adaptive energy efficient power amplifier (AEEPA)

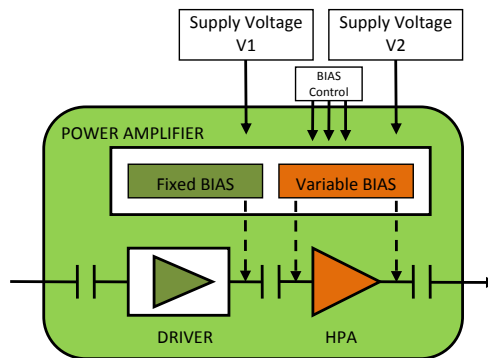


FIGURE 17. Adaptive Energy Efficiency Power amplifier for small-cell board

The adaptive energy efficient power amplifier comprises two stages. The first stage acts as a driver using an amplifier supplied by a fixed voltage, +5V. And the second stage presents an amplifier with variable supply voltage to provide an adaptive energy efficient performance. Its average output power is 24dBm with 12dB PAPR, so its peak output power is 36dBm.

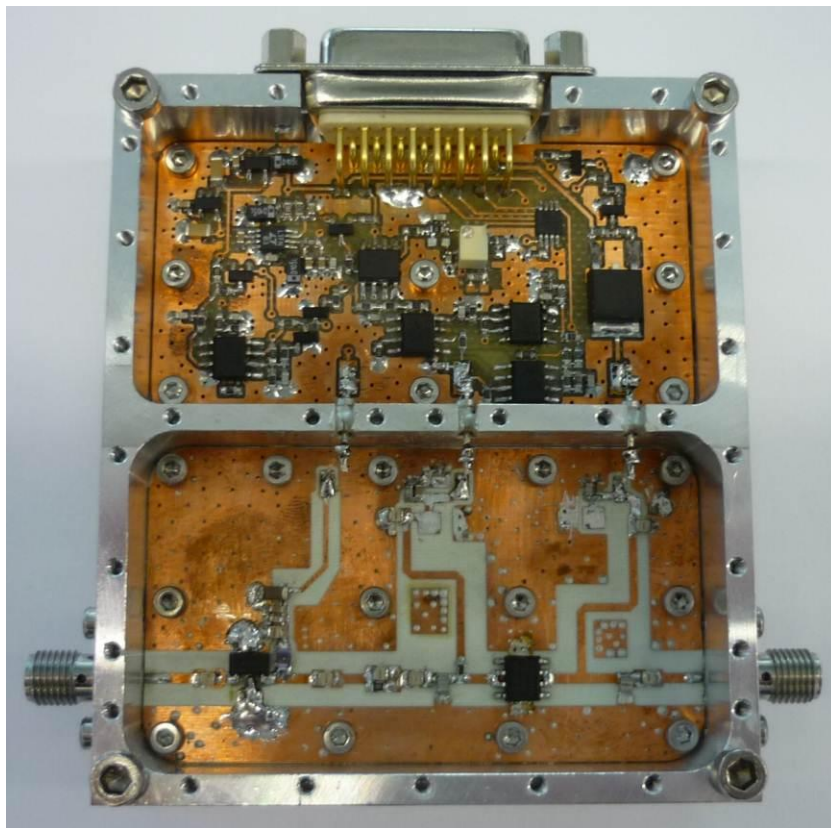


FIGURE 18. Pictograph of Adaptive Energy Efficiency Power Amplifier for small-cell

The hardware development differs between two boards: a RF board with two SMA connectors providing RF input and RF output, and a biasing and control board with a DB15 connector. This DB15 connector provides the supply voltages, +28V and +5V, and the control signals to implement two techniques: the operating point adjustment and the component deactivation.

The amplifier is supplied externally and controlled by GPIB. The operating point adjustment feature is implemented by a SPI interface because different supply voltages are required to provide different output power levels in AEEPA, while the component deactivation is implemented by a fast switching line.

- Performance analyzer

The downlink performance will be analyzed with T&M equipment connected to the computer via GPIB. This equipment should measure the spectrum and offer down-conversion and baseband IQ capturing at user-defined carrier and sampling frequency. The performance analyzer will operate on the 10MHz REF provided by the transceiver system.

- Power supply

At least five power supply outputs should be available, covering 1.2V, 2.4V, 5V and 28V, all with a maximal current of less than 1A. During validation, the power supplies remain constant and the current will be measured and provided to the computer via the GPIB interface.

- Computer

From the hardware side, a standard computer with multiple USB ports is sufficient to control the system. From the software side, all control and signal processing will be performed in Matlab™. The required toolboxes are: Instrument Control Toolbox, Signal Processing Toolbox, Statistical Toolbox and the Communication toolbox. Additional drivers are also required, such as GPIB™ driver software.

3.3.1.2. VALIDATION SOFTWARE

The validation software covers basically 4 modules:

- test signal generation and analysis software
- energy adaptive algorithms
- interface/control software (drivers, protocols)
- graphical user interface

The validation is performed based on predefined test signals. These test signals are loaded in the platform's memory and are looped based on an indexed sequence. The test signals are thus generated off-line. The performance at the system output will be analyzed with test signal analysis software.

At run-time, the validation hardware is configured based on the instantaneous test signal and the validation interface concepts presented in section 2.2.3. The energy adaptive algorithm performs the translation into a control strategy for the validation hardware.

The interface/control software enables to transfer data, implement the serial protocols and to control the complete system. Towards the user, all these diverse software is controlled via Matlab™.

The graphical user interface allows to easily configure the energy optimisation strategy and to show the respective measured power consumption.

3.3.1.3. TEST EQUIPMENT LIST

The following hard- and software is required to perform the test and validation (<opt>: optional or sporadic usage):

Hardware: Computer, minimal 5 GPIB controlled power supplies with current measurement capability (2x AGT N6705A 3x20V, 1x 50V), USB-GPIB controller from National Instruments™, Vector signal Analyzer Rohde&Schwarz FSQ26, multimeter, <opt> clock generator, <opt> CW generator, <opt> oscilloscope with REF in, <opt> Jtag interface.

Cables: RF cables SMA, RF cables SMB, flat cables, U-FL cables, coax cables, GPIB cables, power supply cables

Software: Matlab™ (minimal R2011a) including toolboxes (Instrument Control Toolbox, Signal Processing Toolbox, Statistical Toolbox and the Communication toolbox), GPIB™ driver software, <opt> FPGA programming software etc.

3.3.2. LOW LOSS ANTENNA INTERFACE

The validation of the proposed low loss antenna interface (LLAI) solution consists in comparing a low loss RF front-end architecture without duplexer with a standard RF front-end architecture with duplexer. The standard RF front-end architecture is composed of a single access antenna, a duplexer filter and a linear PA with fixed matching network (FMN).

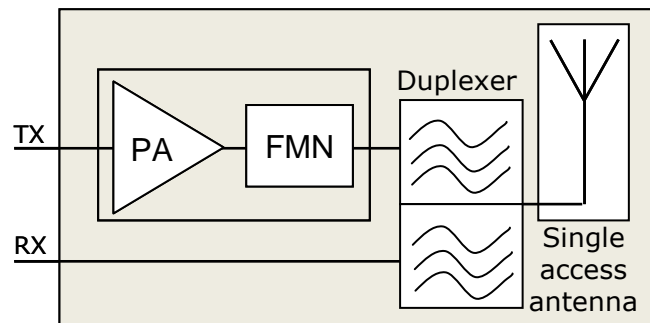


FIGURE 19. Standard RF front-end architecture (EARTH “OFF”)

The low loss RF front-end architecture is composed of a duplexing antenna (dual access antenna with separate RX/TX access), separate TX and RX filters, and a load adaptive PA based on a tuneable matching network (TMN).

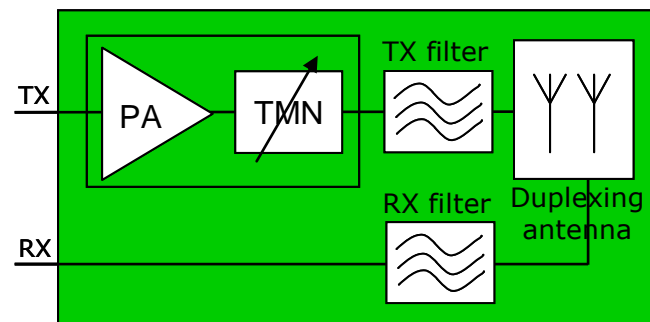


FIGURE 20. Low loss RF front-end architecture (EARTH “ON”)

3.3.2.1. DEVICES UNDER TEST

For validation, different hardware demonstrators are considered:

- A standard RF front-end architecture based demonstrator with a single access patch antenna, a Band I duplexer from ANATECH (AM1950-2140SD345) and a linear PA from SKYWORKS (SKY65120)

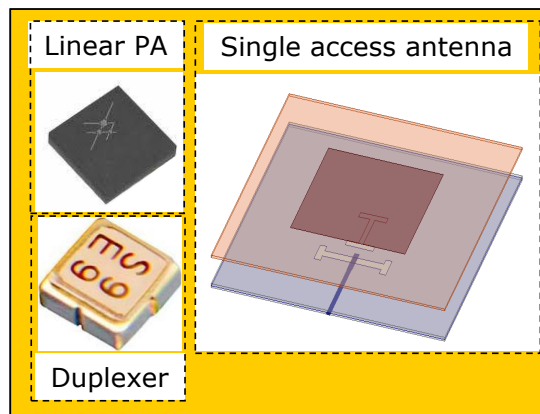


FIGURE 21. Standard RF front-end demonstrator

- A low loss RF front-end demonstrator, composed of a TX filter with relaxed rejection specifications and low insertion loss (LLTXF), a standard RX filter (RXF) and two component solutions from [EARTH-D4.1]: the duplexing antenna and the load adaptive power amplifier.

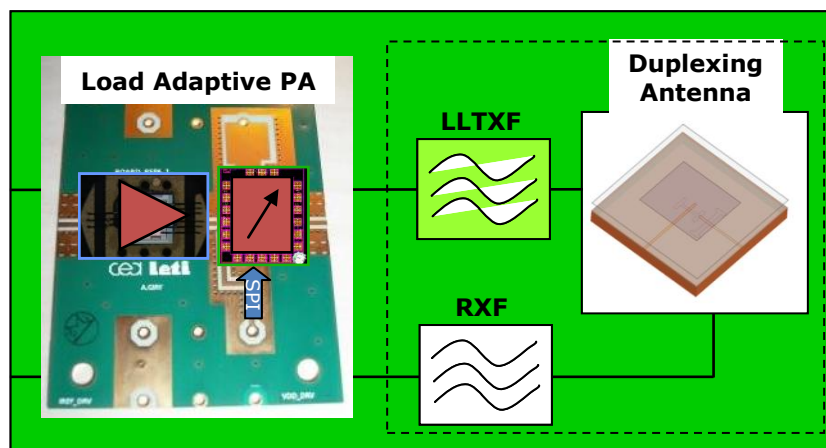


FIGURE 22. Low loss RF front-end demonstrator

- The duplexing antenna

The key idea consists in eliminating the duplexer by using a dual orthogonal polarization antenna which ensures at least 30dB isolation between Tx and Rx accesses. The Tx access of the *Dedicated UP/DL* duplexing antenna covers only the DL frequency band (2110 – 2170 MHz) and the Rx access covers only the UL frequency band (1920 – 1980 MHz). The antenna design and the use of very few dielectric substrates allow optimizing the radiation efficiency of the patch antenna. A plastic radome used to protect the antenna will cover it during the experimental characterization in order to quantify its impact on the isolation level. Prototyping a more than 40 dB isolation antenna would lead to too much stringent mechanical accuracy. Thus an additional Tx filter (LLTXF) with relaxed constraint is used to ensure the 50 dB level of isolation between Tx and Rx accesses. The LLTXF has very low insertion loss (0.5 dB) in the Tx frequency band.

- The load adaptive PA with tuneable matching network (TMN)

In the proposed load adaptive PA implementation, the load impedance of the PA is varied dynamically according to the RF signal amplitude through the use of a tuneable matching network. The power

amplifier device and the tuneable matching network (TMN) are integrated in a Silicon-on-Insulator (SOI) CMOS 0.13 μ m process and are designed as two separate chips which will be mounted on the same board using chip-on-board (COB) assembly.

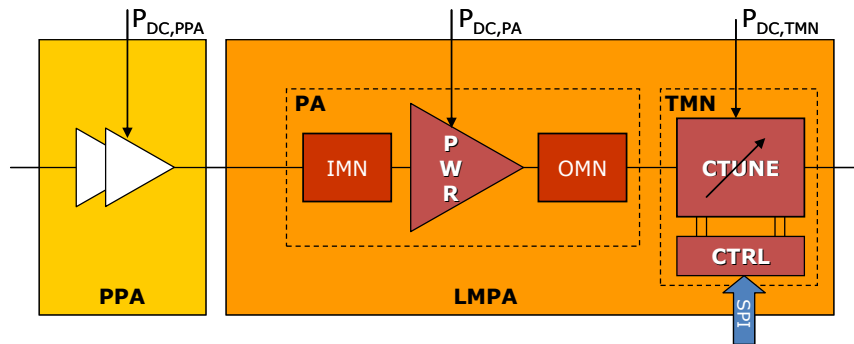


FIGURE 23. Block diagram of the load adaptive PA

The TMN comprises fixed inductances/transmission lines for inductive sections of the matching network and tuneable high Q capacitors ($Q > 50$) for capacitive sections. Tuneable capacitors consist of arrays of binary weighted switched capacitors using floating body SOI NMOS transistors as switch. Control logic is integrated on chip and allows selection of appropriate capacitance values through an integrated SPI interface. The TMN circuit occupies an area of less than 1mm² and operates under 2.5V voltage supply.

The PA consists of a SOI LDMOS power stage (PWR) and on board fixed input matching network (IMN) and output matching network (OMN). It can operate up to 5.0V voltage supply and provides around 35dBm saturated power at 2.14GHz under 4.0V voltage supply.

A pre-amplifier on a separate PCB is used at the input of the LMPA to provide proper RF drive to the LDMOS power stage. The two different PCBs interfaces via SMA connectors for the RF input and output.

Output of the load adaptive PA is connected to a 50Ohm load (eg Spectrum Analyzer, Digital oscilloscope,...) via an optional external coupler for down conversion of the output RF signal and possible digital signal processing (time alignment, predistortion,...).

3.3.2.2. TEST SETUPS

Classical linear quadripole characterization will be used for the guided components (filter, duplexer...) and classical antenna measurements techniques will be carried out for the radiating part of the demonstrators. For the PA devices (SKY65120 and load adaptive PA), large signal measurements with continuous wave (CW) and modulated signals (WCDMA, LTE) will be performed.

Before being combined with the PA devices, the antennas and filters will be put together on the same board (Antenna/Filter modules) to be tested independently of the PA.

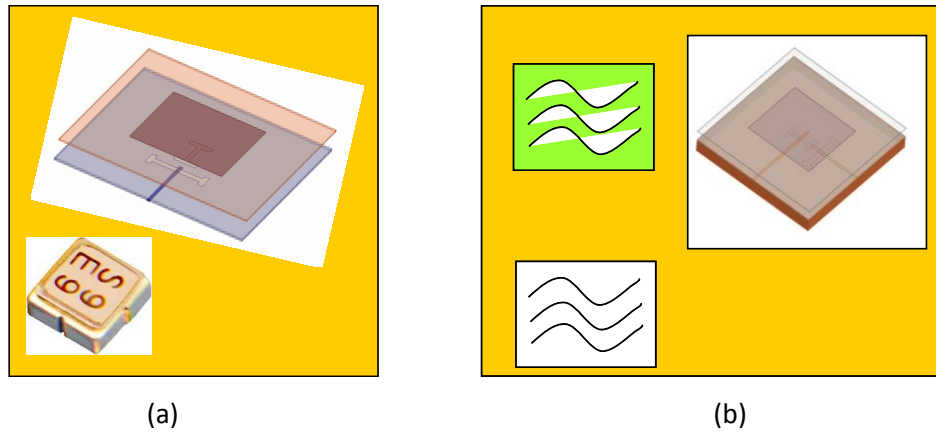


FIGURE 24. Antenna/filter modules: Single access antenna and duplexer module (a) and duplexing antenna and TX/RX filters module (b)

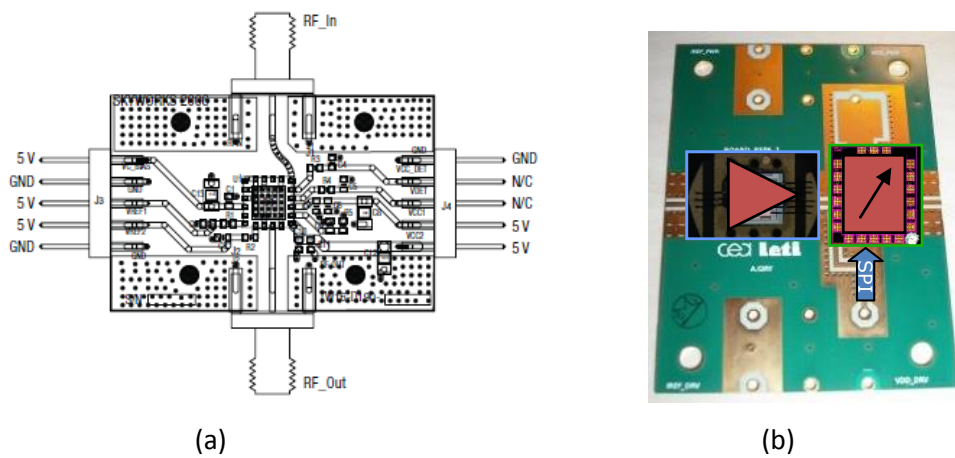


FIGURE 25. PA modules: SKY65120 module (a) and load adaptive PA module (b)

- Antenna/filter modules test setup

Performances comparison between both antenna/filter modules will be carried out with a vector network analyser in the frequency domain. First the transmission path is characterized (FIGURE 26 (a)) and the radiation efficiency is processed by integrating the measured gain in the whole angular direction. Impedance matching and gain in the main direction will be also characterized. Then a second test setup is used to measure the isolation between Tx and Rx accesses (FIGURE 25 (b)).

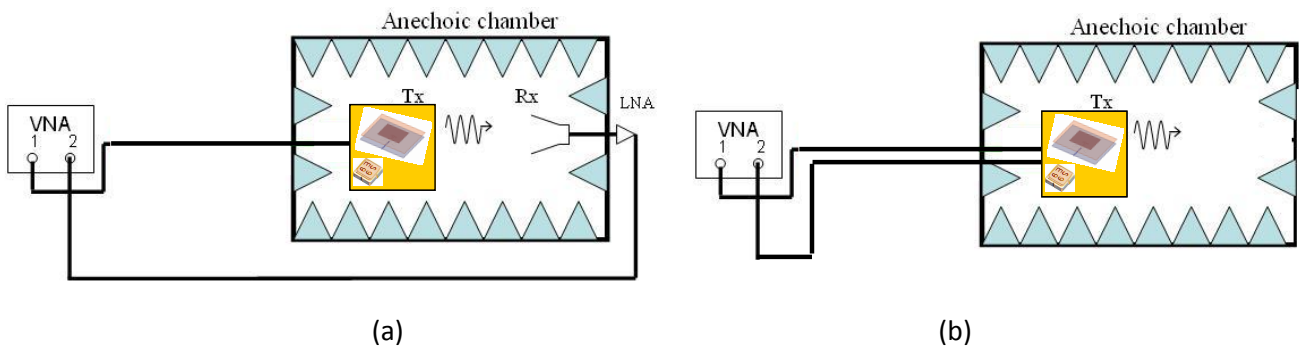


FIGURE 26. Test Setup for antenna/filter modules characterization: gain characterization (a) and Tx/Rx isolation characterization (b)

The classical comparative method will be used to measure the antenna gain in the different angular directions. Radiation efficiency will be derived from the integration of the previous measurements. A second radiation efficiency measurement method could be carried out thanks to a Wheeler Cap cavity, depending on the size of the device under test.

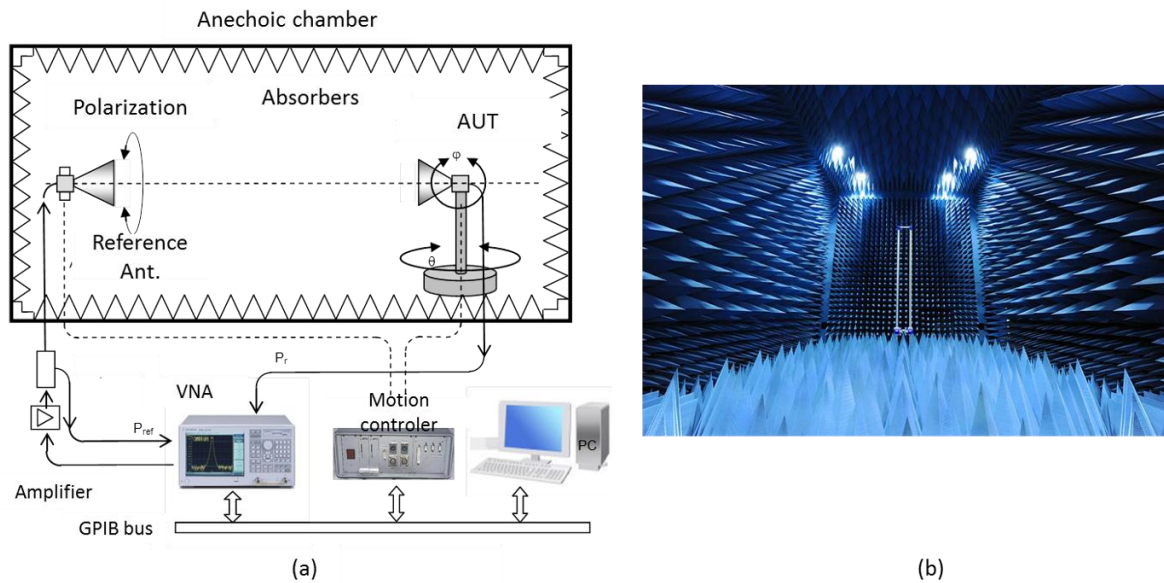


FIGURE 27. Test bench for 3D antenna gain measurements (a) and picture of the 24 m long anechoic chamber (b)

- PA modules test setup

Performances comparison (efficiency, output power and TX spectrum) between both PA modules will be carried out with a Vector Signal Generator (VSG), two DC supplies, a PA driver (for the load adaptive PA module only), and a Vector Signal Analyzer (VSA). For the load adaptive PA module, digital control of the TMN will be done through a SPI bus, at first statically (FIGURE27) and then dynamically (FIGURE 28).

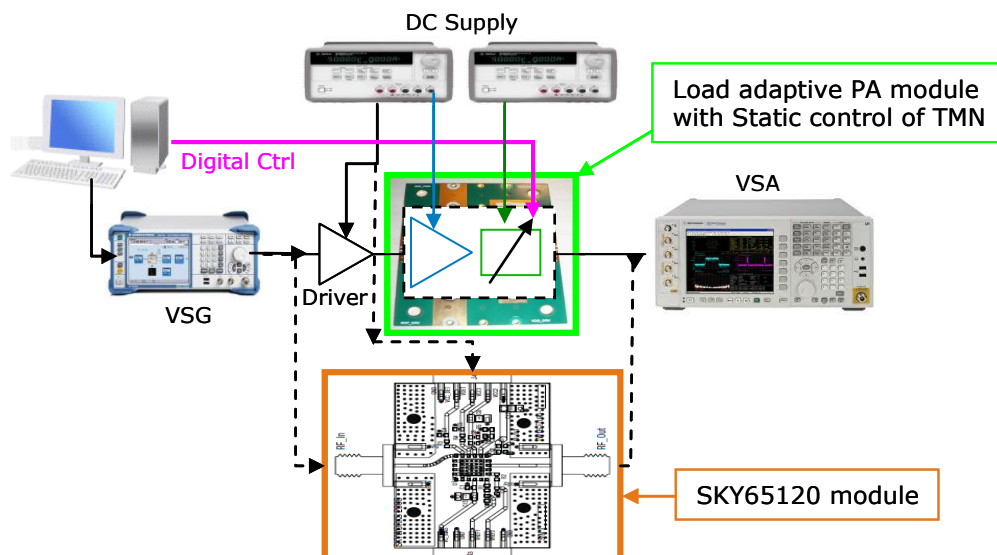


FIGURE 28. PA module test setup for SKY65120 module and load adaptive PA module with static control of the TMN

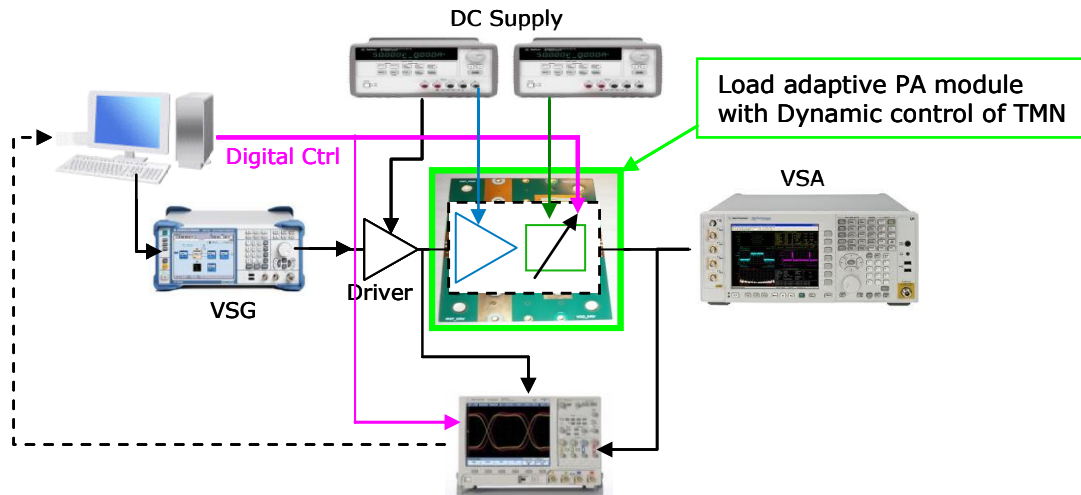


FIGURE 29. PA module test setup for load adaptive PA with dynamic control of the TMN

In the context of LTE, dynamic tuning of the TMN is necessary and requires properly calculated PA input and TMN control signals to avoid distortion of the output signal. Especially, time alignment between both input signals has to be precisely controlled because of its critical impact on linearity. Digital predistortion (DPD) can help to relax the time-alignment sensitivity and may be necessary regarding strong linearity requirements from LTE standard.

3.3.2.3. TEST EQUIPMENT LIST

The following hardware, cables and software are required to perform the validation:

- Hardware:
 - Computer, minimal 2 GPIB controlled power supplies (up to 20V/2A) with current measurement capability, USB-GPIB controller from National Instruments, Vector Signal Analyzer (VSA) minimally up to 6GHz, Vector Signal Generator (VSG) with 3GPP WCDMA/LTE modulations and internal baseband generator with real-time coder, digital high speed oscilloscope, Vector Network Analyzer (VNA), anechoic chamber and its test bench, Wheeler Cap (antenna efficiency characterization cavity)
- Cables:
 - RF cables (SMA), coax cables, GPIB cables, power supply cables
- Software:
 - Matlab with toolboxes, GPIB software

3.4. TEST SIGNALS

For evaluating the energy efficiency performance of transceiver systems, special LTE test signals will be used allowing for experiments in different load situations and providing different conditions for dynamic reconfiguration of transceiver hardware. These base band time domain test signals are generated by considering conditions due to resource utilisation scenarios defined as reference in the project [EARTH-D2.3], due to concepts proposed for validation, and due to used test setups and procedures.

The resource utilization scenarios allow for defining a collection with “snapshots” of typical LTE traffic scenarios to be considered for evaluation. They are characterized by a certain average traffic load and a certain short term signal variation defined by scheduling algorithms. Combining such snapshots in a well defined way allows the generation of the required test signal. In particular, test signals will be defined which show a similar traffic load profile as the considered 24 hours reference, but compressed into a short time slot of about 1 second duration.

FIGURE 30 shows the reference traffic load profile “EARTH” and two modified profiles “Micro DTX” and “CAP Adaptation”, which are adapted to the respective radio interface concepts presented in section 2.2.3. These modified profiles show low numbers of discrete average traffic levels, but lead to the same average traffic load for 24 hours. By using short signal streams of some tenths of milliseconds as “snapshots” adapted to the discrete traffic levels and defined in short term variation by scheduling algorithms typical for Micro DTX or Capacity Adaptation, short test signals can be synthesized following the load variation of a dense urban traffic with the same average load as the 24 hour reference. In the same way test signals for other traffic loads like the rural scenario can be defined, as shown in FIGURE 31.

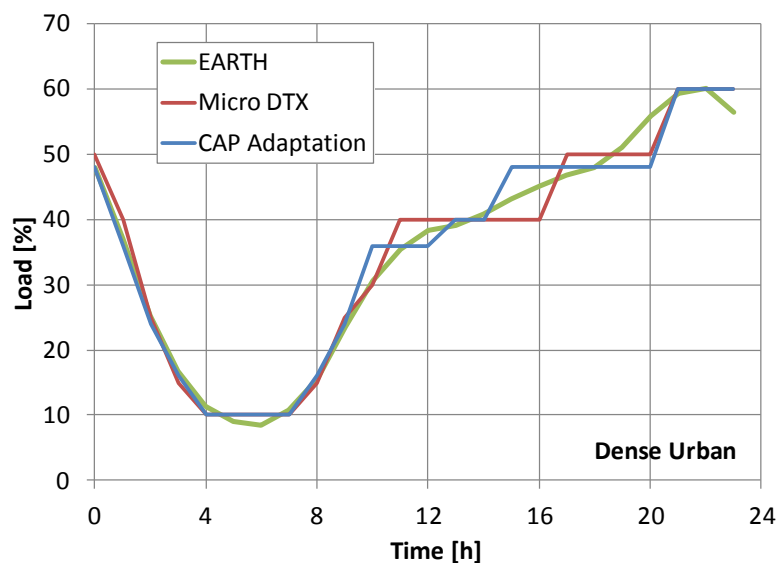


FIGURE 30. Discrete levels for 24 hours traffic load profile in dense urban scenario

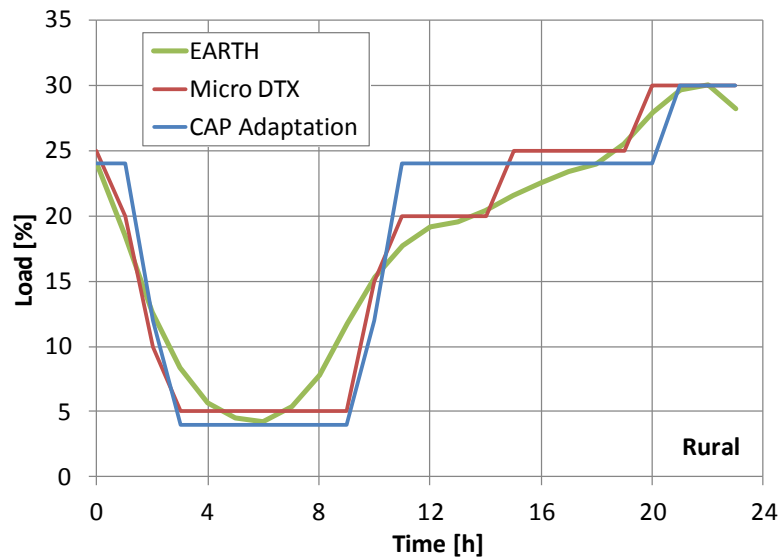


FIGURE 31. Discrete levels for 24 hours traffic load profile in rural scenario

FIGURE 32 and FIGURE 33 show examples of short signal streams as elements (snapshots) of a test signal defined for a certain traffic load level. The first one represents a LTE signal for 0% traffic load carrying only signalling information, but no user data. The second shows a LTE signal with 60% traffic load showing time periods of user data transmission but also time periods when only signalling symbols are transmitted with empty symbols in between.

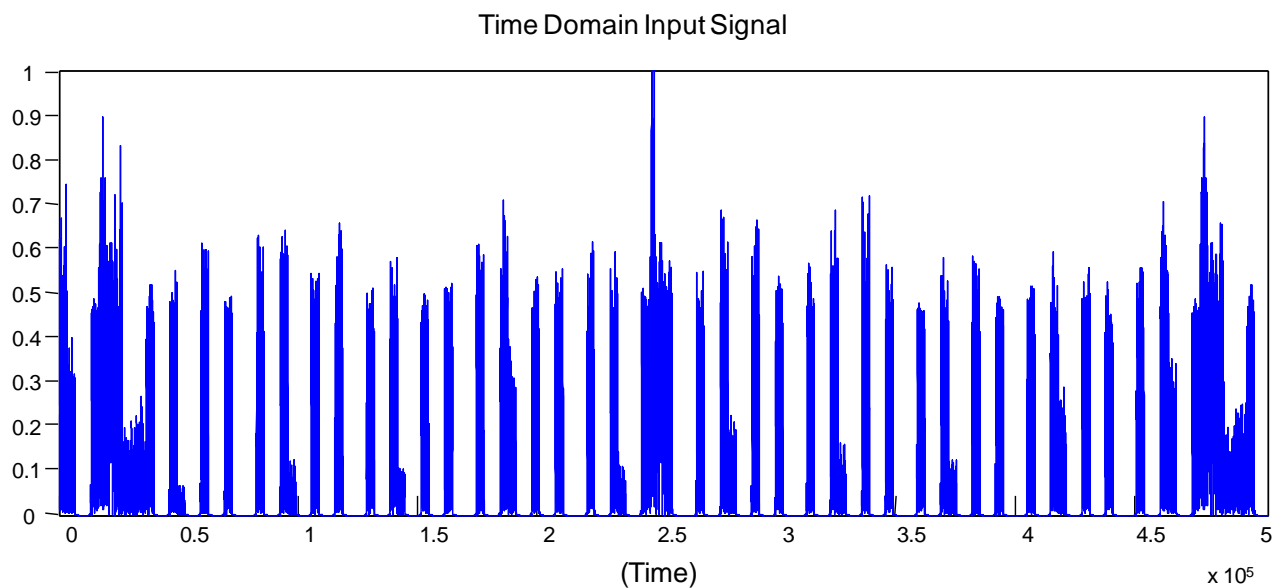


FIGURE 32. LTE signal (20ms, 0% traffic load)

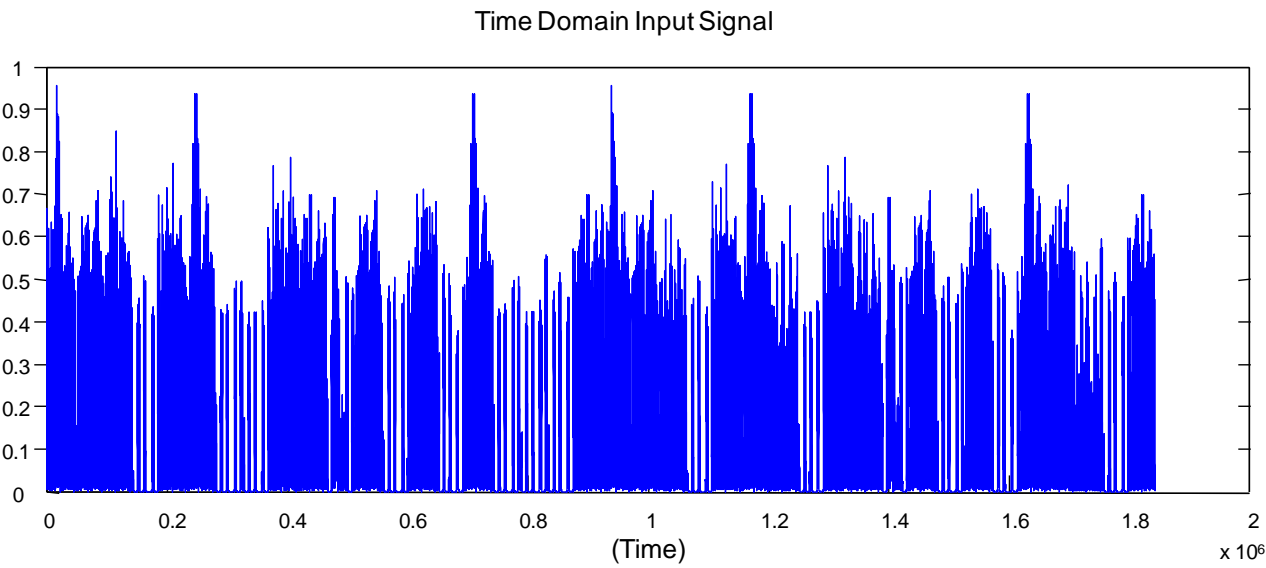


FIGURE 33. LTE signal (40ms, 60% traffic load)

4. CONCLUSIONS

In this document the Validation Platform Framework is defined that will be set-up at the Test Plant of Telecom Italia and that will be comprised of two main test scenarios to test the benefit, in terms of energy efficiency improvement, due to different features considered for two different categories of application.

The first category relates to network features and entails new algorithms (the ON/OFF scheme) for network management designed to spare energy during a specific phase of BS operation, in this case low traffic conditions. The scenario based on LTE technology is considered with higher priority for implementation in the Test Plant due to the emerging interest worldwide recognized for LTE technology. At the same time the evaluation of the ON/OFF scheme on WCDMA/HSPA could be carried out without setting up a test scenario, but by evaluating the energy efficiency performance for the WCDMA/HSPA case by calculation based on the power consumption of the WCDMA/HSPA BS measured in a static way and in different traffic conditions, and applying the same pattern of traffic used with the test scenario based on LTE technology.

The second category relies on the development of new hardware modules, designed to assure low energy consumptions during multiple phases of BS operation. The component activities can be divided into two different groups one for *small-cell* applications and one for *macro-cell* applications. This is a necessary division considering the different hardware requirements and power consumption patterns for macro and small base stations. The developed components under test and the related features will be evaluated applying varying traffic load and output power based on the EARTH reference traffic scenarios.

The validation of the selected concepts for energy efficiency improvement is to be done by comparing the power required applying the proposed features with the power required when not applying them.

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