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PXIe-8135

LabVIEW Communications LTE Application Framework 2.2

This document provides basic information about how to get started with LTE Application Framework 2.2.

Table of Contents

System Requirements

Software Requirements

- Windows 7 SP1 (64 bit) or Windows 8/8.1 (64 bit)
- LabVIEW Communications System Design Suite 2.0
- NI-USRP 17.2 or later
- LTE Application Framework 2.2

Hardware Requirements

To use the LTE Application Framework for a bidirectional data transmission, you need two of the following RF capable devices:

- USRP-2940/2942/2943/2944/2950/2952/2953/2954 Software Defined Radio Reconfigurable Device
- USRP-2974 Software Defined Radio Stand-Alone Device
- PXIe-7975/7976 FPGA Module for FlexRIO with an attached NI-5791 RF Adapter for FlexRIO

A special test mode using the loopback functionality provided by the framework can be executed with only one device.
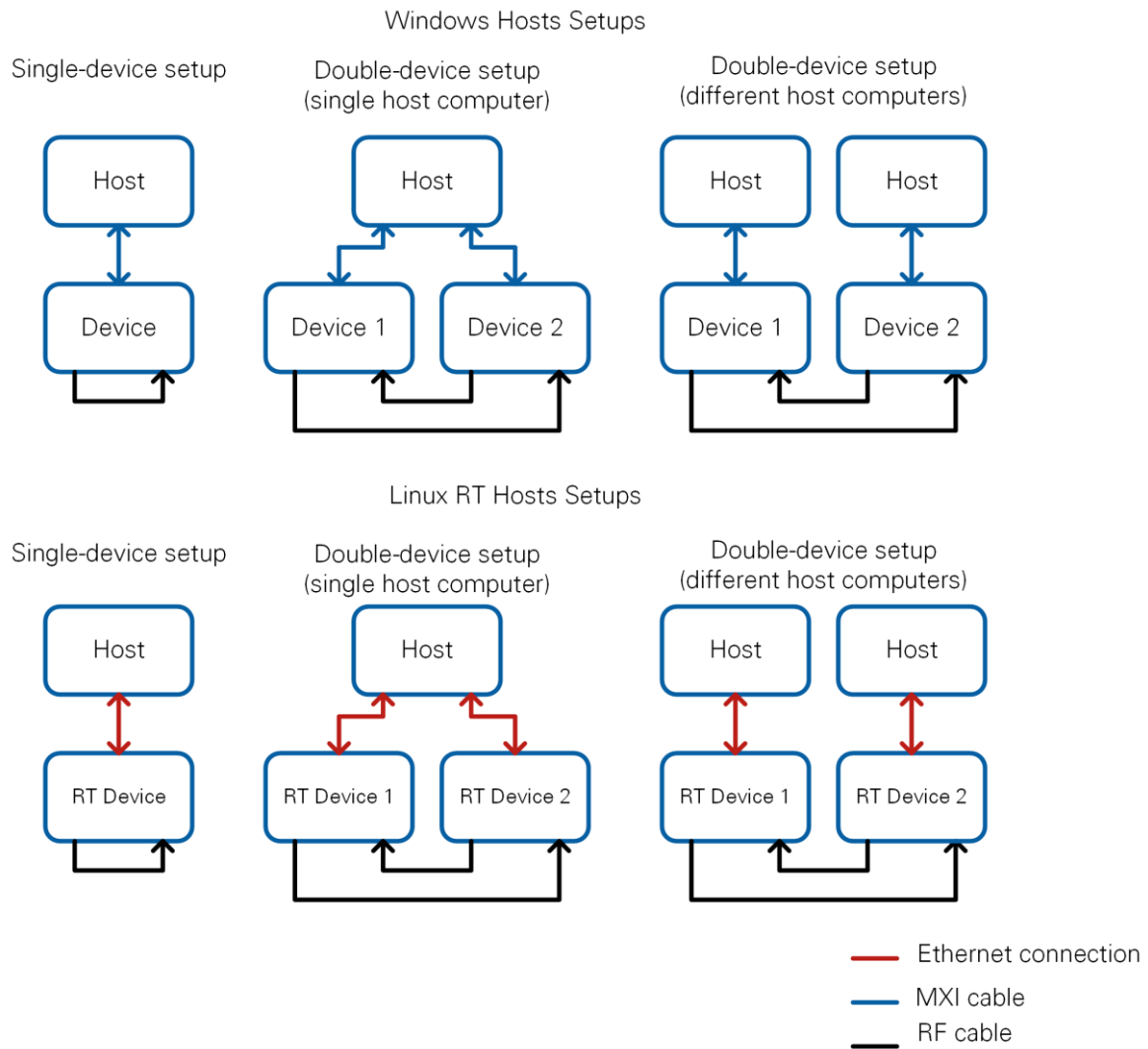
Figure 1 Hardware Configuration Options

The framework can run either on Windows hosts (without real time) or on Linux RT (with real time support). The RT controller must be installed on the controller attached to the RF hardware unless it comes preinstalled on the hardware. In both cases, you must use a PC to run the LabVIEW Communications executable. The PC needs an Ethernet connection to the RT system.

Table 1 Required Hardware

Configuration	All Setups		USRP-2974	USRP RIO				FlexRIO		
	SMA Cable	Antenna		Controller	USRP	Attenuator	MXI adapter	Controller	FlexRIO FPGA module	FlexRIO adapter module
Single device, cabled	1	-	1	1	1	1	1	1	1	1
Single device,	-	2	1	1	1	-	1	1	1	1

over-the-air										
Double device, cabled	2	-	2	1	2	2	2	1	2	2
Double device, over-the-air Error! Bookmark not defined.	-	4	2	1	2	-	2	1	2	2

- PXIe-1085 Chassis (recommended) or other chassis
  Note: A second chassis is needed when using different host computers.
- PXIe-8135 Controller or other controller
  Note: A second controller is needed when using different host computers.
- SMA (f)-to-SMA (f) cable, included with USRP RIO devices

Note: For information about using an antenna, refer to the "Over-the-Air Transmission (Single-Device)" or "Over-the-Air Transmission (Double Device)" section.

- Attenuator with 30 dB attenuation and SMA (m)-to-SMA (f) connectors, included with USRP RIO devices
- Hardware:
  - USRP-2940/2942/2943/2944/2950/2952/2953/2954/2974
  - PXIe-7975/7976
  - NI-5791

The preceding recommendations assume a PXI-based host system. Alternatively, you can use a PC with PCI-based or PCI Express-based MXI adapter or a laptop with an Express card-based MXI adapter.

Ensure your host meets the following specifications:
- 20 GB free disk space
- 8 GB RAM (16 GB RAM required to compile bitfiles for the device FPGA)
- Quad-Core CPU
- 2.3 GHz processor base frequency (minimum)

Notice: Before using your hardware, read all product documentation to ensure compliance with safety, EMC, and environmental regulations.

Components of the Sample Project

To create a new instance of the LTE Application Framework, navigate to one of the following projects in LabVIEW Communications:
- **Launch a Project>>Application Frameworks>>LTE Design USRP v2.2**

- **Launch a Project>>Application Frameworks>>LTE Design USRP 2974 v2.2**
- **Launch a Project>>Application Frameworks>>LTE Design FlexRIO v2.2**

The project is comprised of LabVIEW host code and LabVIEW FPGA code for the supported HW targets (USRP or FlexRIO). The related folder structure, operation modes, and components of the project are described in the following subsections.

Sample Project Folder Structure

Once you create a new instance, the following files and folders are created inside the specified folder:

o **LTE Design USRP v2.2.lvproject** or **LTE Design USRP 2974 v2.2.lvproject** or **LTE Design FlexRIO v2.2.lvproject**
  o The project file containing information about the linked subVIs, targets, and build specifications.
o **LTE Host DL.gvi**
  o The downlink (DL) only top-level host VI, implementing a downlink transmitter and a downlink receiver.
  o The host interfaces with the bitfile build from the top-level FPGA VI, named LTE FPGA USRP RIO 40 MHz BW DL.gvi, LTE FPGA USRP RIO 120 MHz BW DL.gvi or LTE FPGA USRP RIO 160 MHz BW DL.gvi, or LTE FPGA FlexRIO DL.gvi
o **LTE Host eNodeB.gvi**
  o The eNodeB (base station) top-level host VI, implementing a downlink transmitter and an uplink receiver.
  o The host interfaces with the bitfile build from the top-level FPGA VI, named LTE FPGA USRP RIO 40 MHz BW eNodeB.gvi, LTE FPGA USRP RIO 120 MHz BW eNodeB.gvi or LTE FPGA USRP RIO 160 MHz BW eNodeB.gvi or LTE FPGA FlexRIO eNodeB.gvi
o **LTE Host UE.gvi**
  o The user equipment (UE) top-level host VI, implementing a downlink receiver and an uplink transmitter
  o The host interfaces with the bitfile build from the top-level FPGA VI, named either LTE FPGA USRP RIO 40 MHz BW UE.gvi, LTE FPGA USRP RIO 120 MHz BW UE.gvi or LTE FPGA USRP RIO 160 MHz BW UE.gvi or LTE FPGA FlexRIO UE.gvi
o **Builds**
  o This folder containing the precompiled bitfiles for the three operation modes (DL, eNodeB, UE).
o **Common**
  o The common folder contains generic subVIs for host and FPGA that are used in but not limited to the LTE Application Framework, such as mathematical functions, type conversions, and so on.
o **FlexRIO** or **USRP RIO**
  o These folders contain target-specific implementations of host and FPGA subVIs, which handle setting gain and frequency. These subVIs are in most cases adapted from the target-specific streaming sample project.

- These folders also contain the target specific top-level FPGA VI for the three operation modes (DL, eNodeB, and UE).
  - **LTE v2.2**
    - This folder contains host and FPGA subVIs, which were specifically designed for the LTE Application Framework. The FPGA code is grouped into different folders that represent the part of the system where they are used, such as FPGA DL RX, FPGA DL TX, and so on.

Sample Project Operation Modes

The LTE Application Framework offers three operation modes, including host code and associated FPGA code, that are shown in Figure 2.

- **DL:**
  - Establishes a downlink link in either a single-device setup or a double-device setup.
  - Implements the DL transmitter (TX) of a base station and the DL receiver (RX) of a UE.
  - Top-level host VI: LTE Host DL.gvi
  - Top-level FPGA VI: LTE FPGA FlexRIO DL.gvi or LTE FPGA USRP RIO 40 MHz BW DL.gvi, LTE FPGA USRP RIO 120 MHz BW DL.gvi or LTE FPGA USRP RIO 160 MHz BW DL.gvi
- **eNodeB:**
  - Provides the base station side in a double-device setup.
  - Implements the DL TX and the UL RX of an eNodeB.
  - Top-level host VI: LTE Host eNodeB.gvi
  - Top-level FPGA VI: LTE FPGA FlexRIO eNodeB.gvi or LTE FPGA USRP RIO 40 MHz BW eNodeB.gvi, LTE FPGA USRP RIO 120 MHz BW eNodeB.gvi or LTE FPGA USRP RIO 160 MHz BW eNodeB.gvi
- **UE:**
  - Provides the UE side in a double-device setup
  - Implements the DL RX and the UL TX of a UE
  - Top-level host VI: LTE Host UE.gvi
  - Top-level LTE FPGA FlexRIO UE.gvi or LTE FPGA USRP RIO 40 MHz BW UE.gvi, LTE FPGA USRP RIO 120 MHz BW UE.gvi or LTE FPGA USRP RIO 160 MHz BW UE.gvi
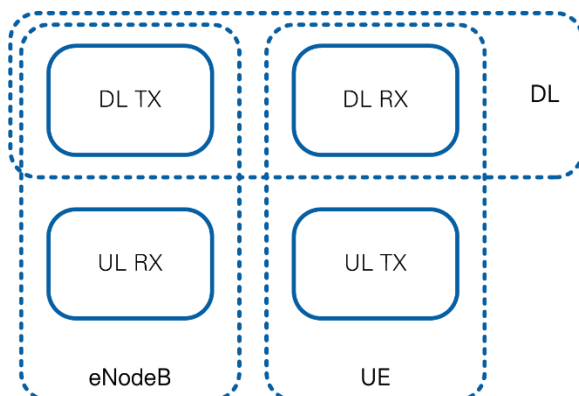
Figure 2 System Configurations (Host and Associated FPGA Code)

The DL operation mode can be used either in a single-device setup or in a double-device setup. The eNodeB/UE operation modes require a double-device setup.

All operation modes can be run either on Windows hosts or Linux RT targets.

Sample Project Components

Figure 3 and Figure 4 show the block diagram of the system in the previously described operation modes.
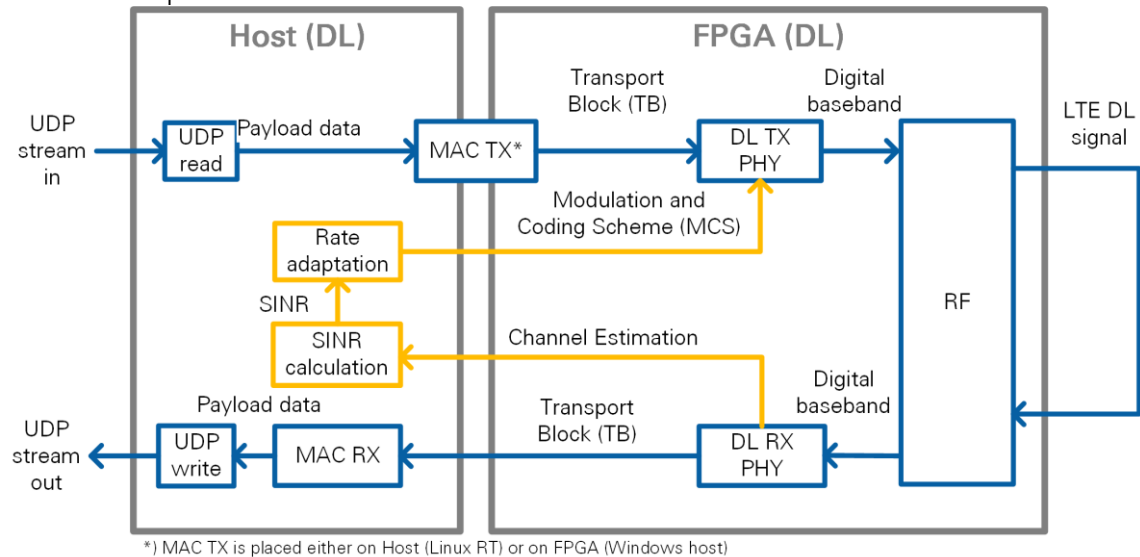
Figure 3 Block Diagram of the System in DL Operation Mode (Single-Device Setup)
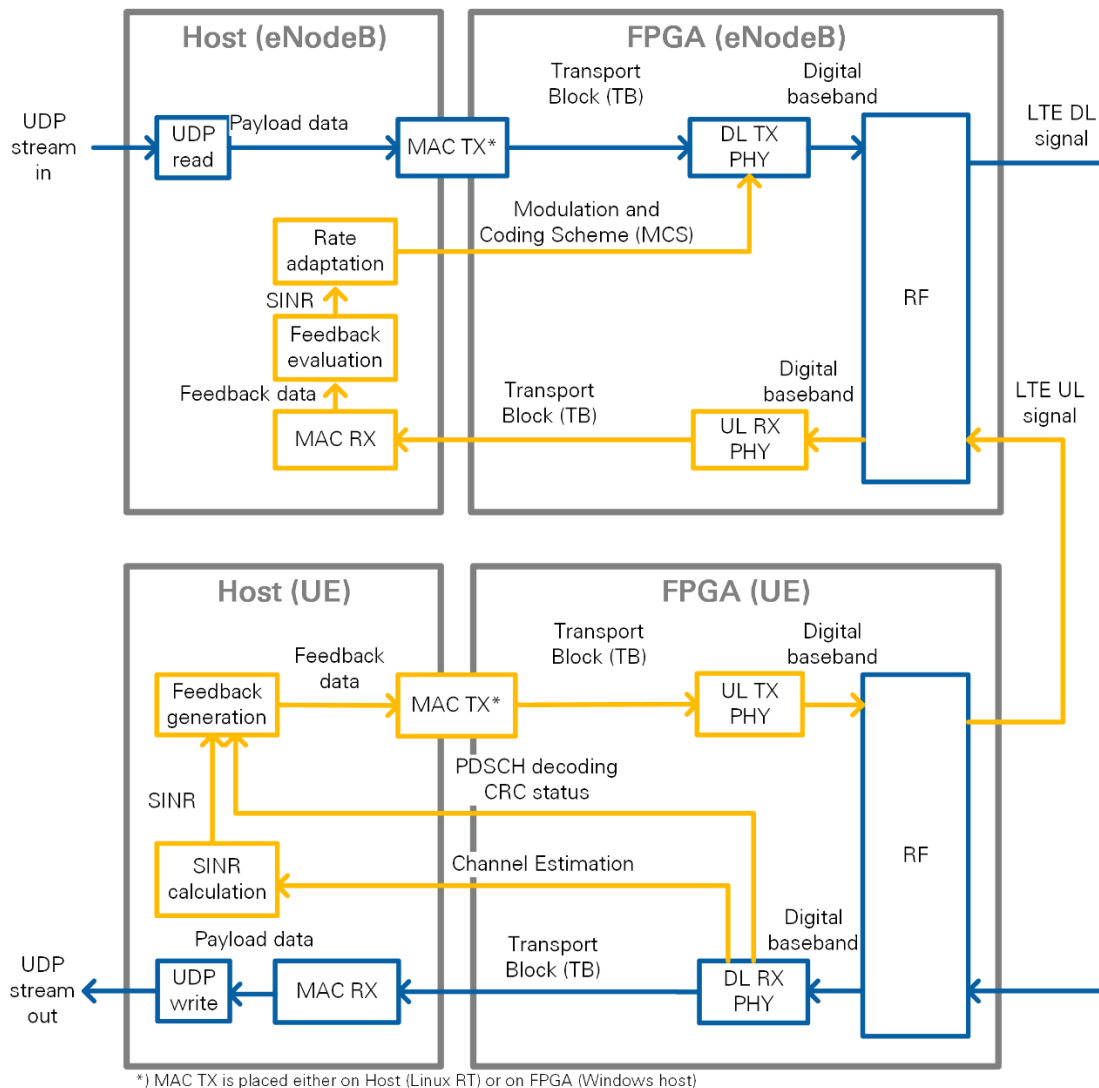
Figure 4 Block Diagram of the System in eNodeB/UE Operation Mode (Double-Device Setup)

The components shown in the figures above perform the following tasks:

- o **UDP read:** Reads data, provided by an external application, from a user datagram protocol (UDP) socket. The data is used as payload data in the transport block (TB). This data is then encoded and modulated as an LTE DL signal by the DL TX.
- o **UDP write:** Writes the payload data, which was received and decoded from the LTE DL signal by the DL RX, to an UDP socket. The data can then be read by an external application.
- o **MAC TX:** A simple medium access control layer (MAC) implementation that adds a header to the TB containing the number of payload bytes. The header is followed by the payload bytes and the remaining bits of the TB are filled with padding bits.
- o **MAC RX:** Disassembles the TB and extracts the payload bytes.
- o **DL TX PHY:** Physical layer (PHY) of the DL TX. Encodes the physical channels and creates the LTE DL signal as digital baseband in-phase/quadrature (I/Q) data. This code includes encoding of the physical DL control channel (PDCCH), encoding of the physical DL shared channel (PDSCH), resource mapping, and orthogonal frequency division multiplexing (OFDM) modulation.

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- **DL RX PHY:** PHY of the DL RX. Demodulates the LTE DL signal and decodes the physical channels. This code includes primary synchronization sequence (PSS)-based synchronization, OFDM demodulation, resource demapping, channel estimation and equalization, decoding of the PDCCH, and decoding of the PDSCH.
- **UL TX PHY:** PHY of the uplink UL TX. Encodes the physical channels and creates the LTE uplink signal as digital baseband I/Q data. This code includes encoding of the physical UL shared channel (PUSCH), resource mapping, and OFDM modulation.
- **DL RX PHY:** PHY of the UL RX. Demodulates the LTE DL signal and decodes the physical channels. This code includes OFDM demodulation, resource demapping, channel estimation and equalization, and decoding of the PUSCH.
- **SINR calculation:** Calculation of the signal-to-interference noise ratio (SINR) based on the channel estimation that was used for PDSCH decoding. Channel estimation is either based on cell-specific reference signals (CRS) or on UE-specific reference signals (UERS).
- **Rate adaptation:** Sets the modulation and coding scheme (MCS) depending on the measured/reported SINR. The aim is to ensure to keep the block error rate (BLER) of the PDSCH decoding low.
- **Feedback generation:** Creates a feedback message that contains the measured subband and wideband SINR as well as the acknowledgement (ACK)/negative acknowledgement (NACK) information (that is, the cyclic redundancy check (CRC) result of the PDSCH decoding) of the previously received radio frame.
- **Feedback evaluation:** Extracts the subband and wideband SINR as well as the ACK/NACK information from the feedback message.

Sample Project Statement of Compliance and Deviations

The LTE Application Framework implements parts of the 3rd Generation Partnership Projects (3GPP)-Long Term Evolution (LTE) release 10 DL and UL PHY TX and RX. To reduce the complexity of this application framework, the following settings are fixed and can only be changed by modifying the design:
- 20 MHz bandwidth
- For time division duplex (TDD) operation: UL/DL configuration 5, special subframe configuration 5
- Normal cyclic prefix
- Resource mapping for two TX antennas (only first antenna used)
- Downlink:
    - Primary synchronization signals (PSS) once per radio frame (10 ms periodicity instead of 5 ms periodicity)
    - Proprietary downlink control information (DCI) message format and length, PDCCH format 1 (CFI = 1)
    - No secondary synchronization signals (SSS), physical broadcast channel (PBCH), physical control format indicator channel (PCFICH), or physical hybrid automatic repeat request (ARQ) indicator channel (PHICH)
- Uplink:
    - OFDM access (OFDMA) is used as wideband modulation (instead of single-carrier frequency division multiplexing access (SC-FDMA))

- No physical random access channel (PRACH)
- No physical uplink control channel (PUCCH)

Visit `ni.com/info` and enter the Info Code LTEAppFWManual for more details.

Running the Sample Project (Single-Device)

This section describes how to run the LTE Application Framework using a RF loopback configuration with a single USRP or FlexRIO device. This corresponds to the single device use case shown in Figure 1.

Configuring the Hardware (Single-Device)

Complete the appropriate steps for your hardware configuration.

Configuring the USRP Device (Single-Device)

1. Ensure the USRP device is properly connected to the host system running LabVIEW.
2. Create the RF loopback configuration using one RF cable and attenuator:
    1. Connect the cable to RF0/TX1.
    2. Connect the 30 dB attenuator to the other end of the cable.
    3. Connect the attenuator to RF1/RX2.
3. Power on the USRP device.
4. Power on the host system.
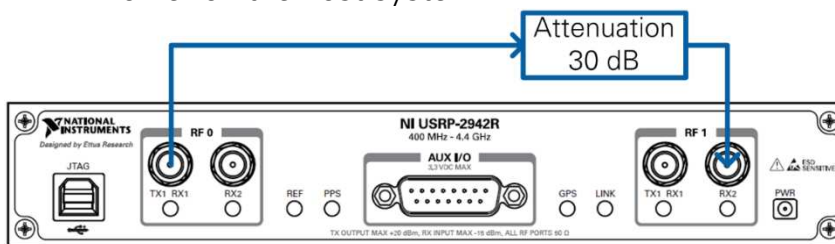
Figure 5 USRP Hardware Configuration

Configuring the FlexRIO Module (Single-Device)

1. Ensure the PXIe-7975/7976 with an attached NI-5791 is properly installed in the chassis containing the embedded controller used as the host system running LabVIEW.
2. Create an RF loopback configuration by connecting the TX of NI-5791 with the RX of NI-5791. For this loopback connection, no external attenuator is needed, since the NI-5791 RX IN port is designed to handle the output power provided by the NI-5791 TX OUT port.
3. Power on the PXI chassis.
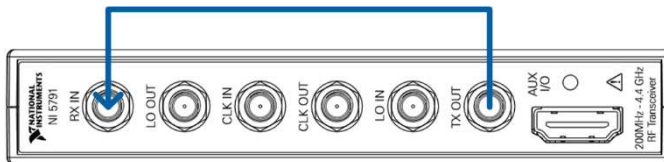
Figure 6 FlexRIO Hardware Configuration

Over-the-Air Transmission (Single-Device)

The configuration for over the air transmission is like that of the cabled setup. Cables and attenuators are replaced by antennas suitable for the selected channel center frequency and system bandwidth.

Notice: Before using your hardware, read all product documentation to ensure compliance with safety, EMC, and environmental regulations.

Running the LabVIEW Host Code (Single-Device)

The single-device hardware configuration uses the downlink-only host variant of the LTE Application Framework (LTE Host DL.gvi), which implements a downlink transmitter and a downlink receiver.

Initializing the System (Single-Device)

Ensure the LabVIEW Communications System Design Suite and the LTE Application Framework are installed on your system. Installation is started by running `setup.exe` from the provided installation media. Follow the installer prompts to complete the installation process.

1. Launch LabVIEW Communications System Design Suite, by selecting **LabVIEW Communications 2.0** from the Start menu.
2. From the Project Templates on the **Launch a Project** tab, select Project **Application Frameworks » LTE Design....** to launch the project.
   - Select **LTE Design USRP 2974 v2.2** if you are using the USRP-2974.
   - Select **LTE Design USRP RIO v2.2** if you are using any other USRP device.
   - Select **LTE Design FlexRIO v2.0** if you are using a FlexRIO device.
3. (LTE Design USRP 2974 v2.2 only) Ensure you are mapped to the RT target.
   a. Open System Diagram.
   b. Select the USRP device.
   c. On the Configuration pane, check that **mapped to** names the correct USRP.
   d. If **mapped to** is **do not map**, then map to the correct USRP by either selecting the right USRP from the dropdown list or by **map to another device by address**. When you map to another device, use the device IP address and root as user name. Leave **password** empty if you did not change it.
4. Within that project, open the LabVIEW top-level host VI in the downlink-only variant, **LTE Host DL.gvi**. The panel of this VI is shown in Figure 7.
5. (FlexRIO and USRP RIO devices only. Skip this step when using the USRP-2974.) Set the **RIO Device** to the alias of the device connected to your system. You can use NI Measurement & Automation Explorer (MAX) to get the RIO alias for your device.
6. Click the **Run** button, ▷, on the LabVIEW host VI. If successful, the **FPGA Ready** indicator lights. If you receive an error, check if your device is connected properly.
7. Set **eNB TX Frequency [Hz]** to a frequency supported by your device, as shown in Table 2.
8. Set **UE RX Frequency [Hz]** to the same value as in step 7.
9. Enable the eNB Transmitter, which implements a DL TX, by setting the switch control to **On.** If successful, the **eNB TX Active** indicator lights.
10. Enable the UE Receiver, implementing a DL RX, by setting the **Switch** control to On. If successful, the **UE RX Active** indicator lights.
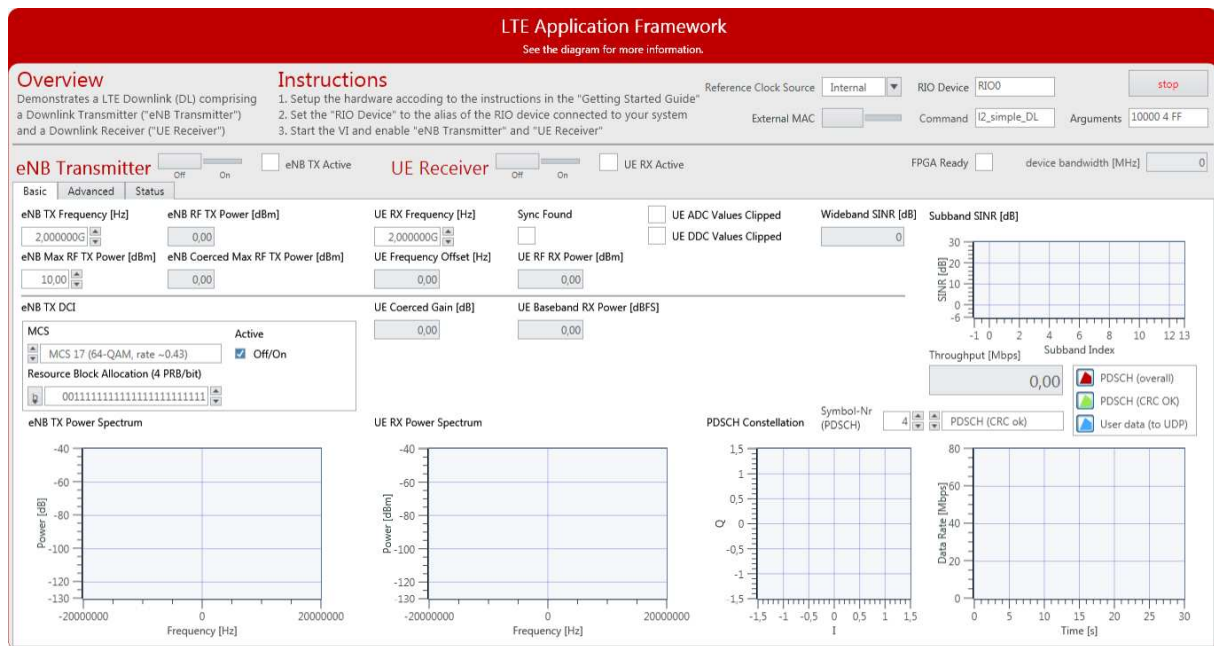
Figure 7 Front Panel of LTE Host DL.gvi (Downlink-Only Host Variant)

Table 2 Supported Frequency Ranges of USRP and FlexRIO Devices

Device	Supported Frequency Range
USRP-2940/2950	50 MHz to 2.2 GHz
USRP-2942/2952	400 MHz to 4.4 GHz
USRP-2943/2953	1.2 GHz to 6 GHz
USRP-2944/2954/2974	10 MHz to 6 GHz
PXIe-7975/7976 and NI-5791	200 MHz to 4.4 GHz

Verifying the System (Single-Device)

If the system is running as expected, the downlink signal generated by the transmitter is correctly received and decoded by the receiver. In this case, the host panel should appear as shown in Figure 8 and Figure 9.

Basic Tab

- **TX Power spectrum**—Spectrum matches the resource block allocation configured by the control **Resource Block Allocation (4 PRB/bit)**
- **RX Power spectrum**—Spectrum matches the TX power spectrum
- **Sync Found**—Constantly on, indicating sync success
  Note: Sync success is a prerequisite for correct PDCCH (and PDSCH) reception and decoding.
- **PDSCH Constellation**—Clean and stable quadrature phase shift keying (QPSK) or quadrature amplitude modulation (QAM) constellation. The modulation depends on the MCS that are configured by the **MCS** control on the eNB TX side. This graph indicates whether the PDSCH subcarriers were received correctly.
- **Throughput**—Constant green curve; constant value for **PDSCH (CRC ok)**
  - No red portions in the curve
  - Value **PDSCH (CRC ok)** equals value **PDSCH (overall)**
  - Indicates correct PDSCH channel decoding without cyclic redundancy check (CRC) errors
- (USRP-2974 only) **SFN**—Number running between 0 and 1023

- (USRP-2974 only) **TTI**—Number running between 0 and 9
- (USRP-2974 only) **Received Confirmations**—Success counts up. Other counters stay 0.

Advanced Tab

- **PDCCH Constellation**—Clean and stable QPSK constellation (allocated PDCCH subcarriers) with an additional dot in the origin (unallocated PDCCH subcarriers). The graph indicates correct reception of the PDCCH subcarriers.
- **PDCCH Received DCI Message**—**Valid** flag is constantly on
  - **MCS** and **Resource Block Allocation (4 PRB/bit)** match the equally named controls on the **eNB Transmitter** side. This indicator shows whether PDCCH subcarrier data was received correctly.

Note: Correct PDCCH reception and decoding is a prerequisite for PDSCH reception and decoding.

- **UE Failure / Block Error Rate (BLER)**
  - **Sync** is constantly zero.
  - **PDCCH** is constantly zero.
  - **PDSCH** is constantly zero.

Note: Sync success is a prerequisite for correct PDCCH (and PDSCH) reception and decoding. Correct PDCCH reception and decoding is a prerequisite for PDSCH reception and decoding. Correct PDSCH reception and decoding is a prerequisite for error-free data exchange.

- **Channel Estimation**
  - Normalized Amplitude
    - Cabled setup: flat curve around 0 as shown in Figure 9
    - Over-the-air setup: any curve (highs and lows indicate a frequency-selective channel caused by multipath fading)
    - Phase, cabled setup: saw tooth curve (straight line, wrapping two times) as shown in Figure 9 (indicating that FFT cuts slightly into the cyclic prefix)
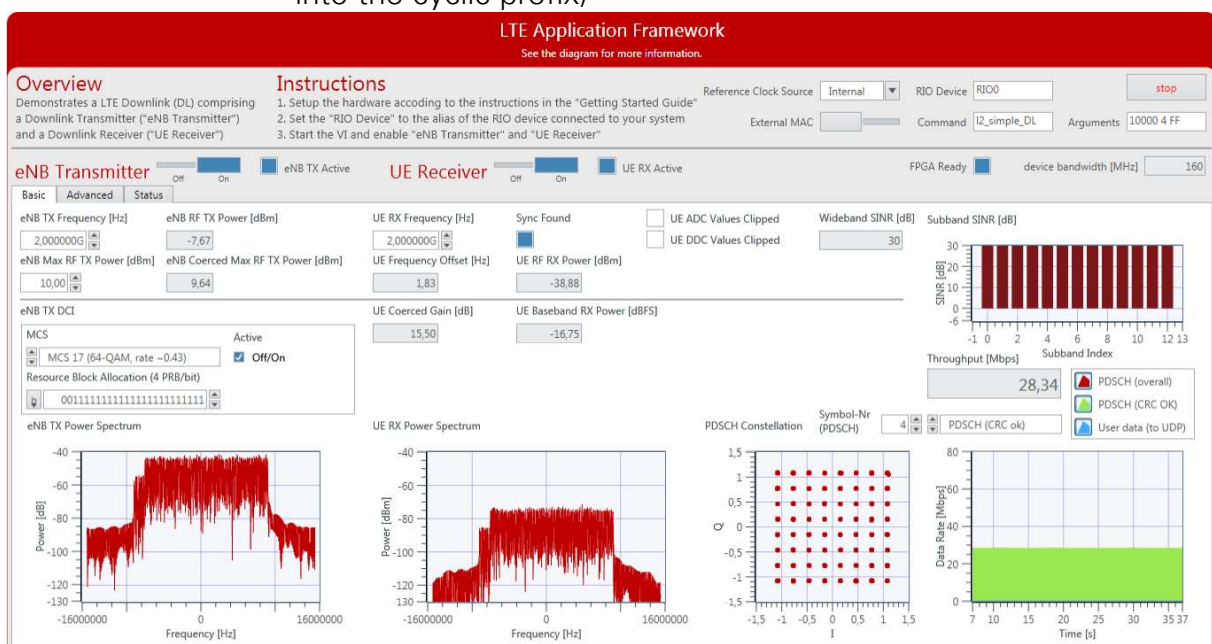
Figure 8 Front Panel of LTE Host DL.gvi / Basic Tab When Running Successfully
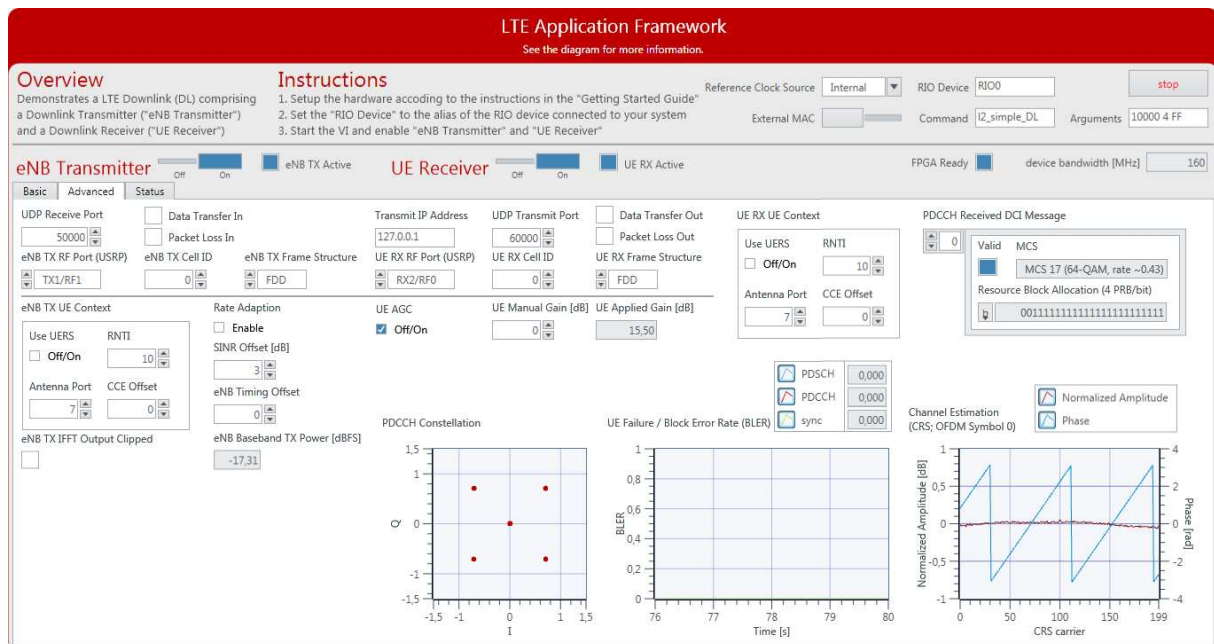
Figure 9 Front Panel of LTE Host DL.gvi / Advanced Tab When Running Successfully
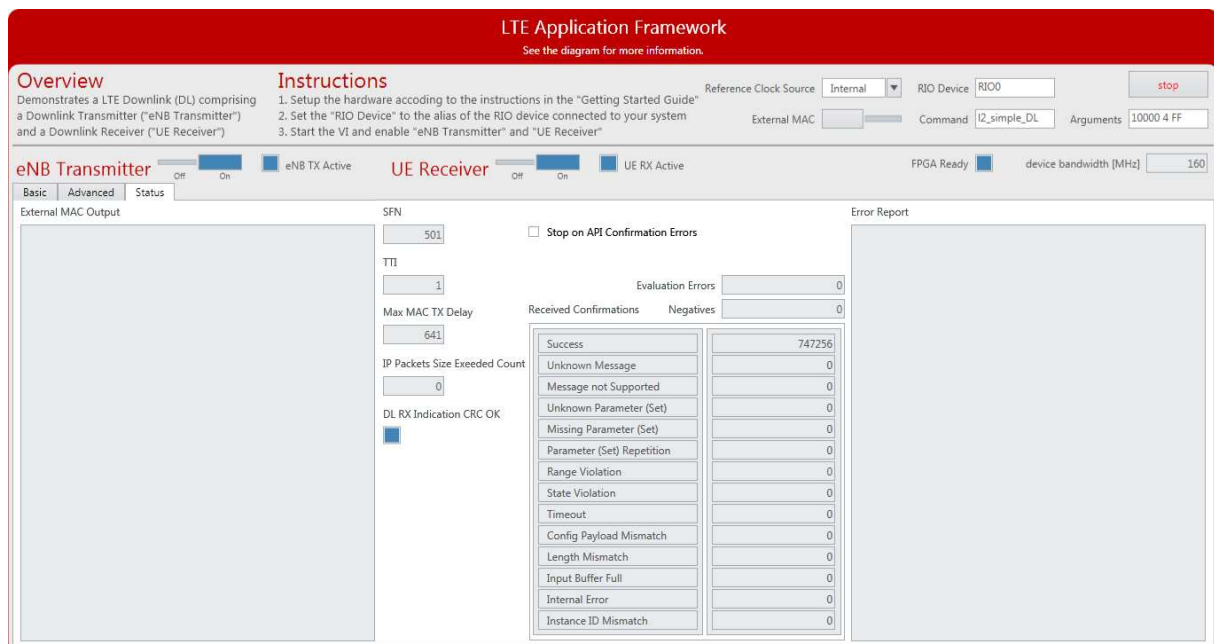
Figure 10 Front Panel of LTE Host DL.gvi / Status Tab When Running Successfully

Running Video Streaming (Single-Device)

The previous section described how to use the downlink host variant of the LTE Application Framework (LTE Host DL.gvi) to establish an LTE downlink link between the transmitter and the receiver. A basic MAC implementation allows for packet-based data exchange of user-defined payload data. The payload data can be provided to the host using UDP as shown in Figure 11. You can use any program capable of transmitting UDP data as data source. Similarly, you can use any program capable of receiving UDP data as data sink.

The LTE Application Framework allows you to transmit video streams if you use a video streaming application as data source and a video player as data sink. For example, you can use the VLC media player, which is available at www.videolan.org.

Figure 11 Data Streaming to/from the System Using UDP (Downlink-Only Operation Mode)

Initializing Video Stream Transmitter

1. Start `cmd.exe` and change the directory to the VLC installation directory.
2. Start the VLC application as a streaming client with the following command:
   `vlc.exe --repeat "<PATH_TO_VIDEO_FILE>"`
   `:sout=#std{access=udp{ttl=1},mux=ts,dst=IP:50000}`, where
   <PATH_TO_VIDEO_FILE> is replaced with the location of the video to be
   used. *IP* should be replaced with the IP address of the system that runs the
   host code. When running on Linux RT make sure to use the IP address of
   the Linux RT device.

Port 50.000 is the default UDP Receive Port. For ease of use, you can also save this
command line to a batch file, for example, `Stream Video LTE.bat`.
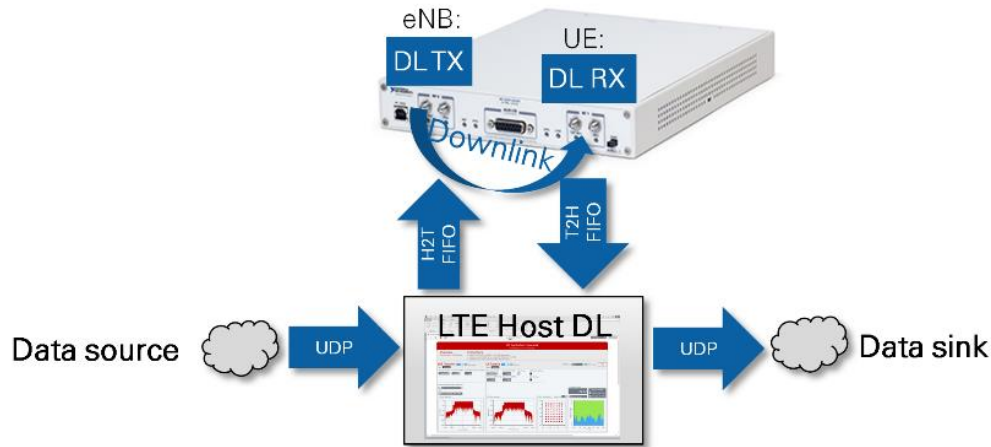
Initializing Video Stream Receiver

1. Change **Transmit IP Address** on the **Advanced** tab to the IP of the PC that
   you start the VLC application on.
2. Start `cmd.exe` and change the directory to the VLC installation directory.
3. Start the VLC application as a streaming client with the following command:
   `vlc.exe udp://@:60000`.

Port 60.000 is the default UDP Transmit Port. For ease of use, you can also save this
command line to a batch file, for example, `Play Video LTE.bat`.

Running External MAC Demo Application (Single-Device)

The basic MAC implementation of the LTE Application Framework can also be
replaced by a full featured external implementation. For this purpose, the LTE
Application Framework offers an API to interact with an external MAC. Attaching an
external MAC requires a Linux RT setup such as the USRP-2974.

Preparing External MAC Executable (Single-Device)

1. Get ssh access to the Linux RT system, for example using Putty. Visit
   `ni.com/info` and enter the Info Code exmmx6 for additional details,
   including the default user name and password.
2. Transfer example application to the Linux RT system:
   `pscp -r \MAC root@RT_LINUX_IP:`
   replace *PATH_TO_AFW_PROJECT* with the path to the LTE Application
   Framework project and *RT_LINUX_IP* with the IP of the Linux RT Setup.

3. Log into the Linux RT system through ssh as root and run the following commands:
```
opkg update
opkg install g++ libstdc++-staticdev
cd ~/MAC
make install
```
4. Prepare LTE Host DL.gvi as described the "Initializing the System (Single-Device)" section. In addition, enable the **External MAC switch** control.

When everything is configured correctly, the system will behave as described in the "Verifying the System (Single-Device)" section. Because the sample application only sends packets for a fixed amount of time, LTE Host DL.gvi will stop execution after 10 seconds and report that the connection to the external MAC is broken. Observe that the number of PHY TX indications and PHY TX requests is exactly the number of packets given in the command line arguments. The number of PHY CNF received is the sum of the PHY TX requests. Because the external MAC might hit exit conditions before the last two PHY CNF are received, there are 30-50 fewer PHY DL RX indications received than the number of PHY TX requests. This is because the synchronization in DL RX needs a few radio frames to settle and there is still data in the loop between DL TX and DL RX when the external MAC hits the exit condition.

Host Panel Controls and Indicators (Single-Device)

This section gives information about how to use the controls and how to interpret the graphs and indicators that are available on the host panel.

Application Settings (Single-Device)

Set these parameters prior to running the GVI. Changes are only applied after stopping and restarting the GVI.

Table 3 Application Settings (Single-Device)

Parameter	Details
RIO Device	The RIO address of the RF hardware device.
Reference Clock Source	Configures the Reference Clock source used for the transceiver chain • **Internal**: Device internal clock • **REF IN / ClkIn**: Clock input at the RF device (rear connector pane for USRP devices, front connector pane for the NI-5791) • **PXI_CLK**: Backplane clock from the PXI Chassis (NI-5791 only) • **GPS**: GPS module (USRP-2950/2952/2953/2954/2974)
External MAC	When enabled a program is executed on the RT described by command line and arguments. This switch applies for RT only. When disabled an internal basic MAC will be executed.
Command	Command to execute for external MAC.
Arguments	Arguments to pass to the external MAC.

Basic Runtime Static Settings (Single-Device)

These settings, located on the **Basic** tab, can be changed without restarting the GVI. Value changes are applied when the corresponding transmitter or receiver chain is

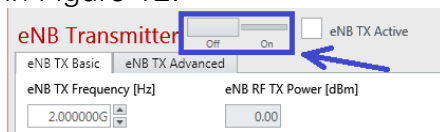restated using the associated Boolean control, that is, **eNB Transmitter** as shown in Figure 12.

Figure 12 Boolean Control to Enable the eNB Transmitter

Table 4 Basic Runtime S

Parameter	Details
eNB Transmitter	Enables or disables the transmitter using the current configuration.
eNB TX Frequency [Hz]	DL TX center frequency, allowed range depends on used RF device.
eNB Maximum RF TX Power [dBm]	Maximum RF transmit power (upper bound - achievable for a full scale complex sine wave (CW) signal) **Note:** The actual time-domain RF transmit power depends on the configured resource allocation and is typically at least 15 dB lower to allow for the OFDM peak-to-average power ratio (PAPR) backoff.
UE Receiver	Enables or disables the receiver using the current configuration.
UE RX Frequency [Hz]	DL RX center frequency, allowed range depends on used RF device.

Advanced Runtime Static Settings (Single-Device)

These settings, located on the advanced tab, can be changed without restarting the GVI. Value changes are applied when the corresponding transmitter or receiver chain is restarted using the associated Boolean control, for example, **eNB Transmitter** as shown in Figure 12.

Table 5 Advanced Runtime Static Settings (Single-Device)

Parameter	Details
UDP Receive Port	The UDP port the host monitors for incoming packets to be transferred to the FPGA PDSCH chain.
eNB TX RF Port (USRP)	Selects the HW RF port the DL TX is transmitted on (USRP only).
eNB TX Frame Structure	Select between frequency division duplex (FDD) and TDD using subframe configuration 5 and special subframe configuration 5 (3GPP TS 36.211 §4).
eNB TX Cell ID	Physical cell ID used for PSS, CRS, UERS sequence generation and PDCCH/PDSCH scrambling. [0…511]
Transmit IP Address	The IP address the UDP packets received from PDSCH shall be sent to.
UDP Transmit Port	The UDP port the UDP packets received from PDSCH shall be sent to.
UE RX RF Port (USRP)	Selects the HW RF port the DL RX will be received from (USRP only).

Parameter	Details
UE RX Frame Structure	Select between FDD (frequency division duplex) and TDD (time division duplex) using subframe configuration 5 and special subframe configuration 5 (3GPP TS 36.211 §4).
UE RX Cell ID	Physical cell ID used for PSS, CRS, UERS sequence generation and PDCCH/PDSCH scrambling. [0…511]

Runtime Dynamic Settings (Single-Device)

These settings can be changed while the corresponding transmitter or receiver chain is running. Value changes are applied immediately.

Table 6 Runtime Dynamic Settings (Single-Device)

Parameter	Details
eNB TX DCI	Downlink control information for the PDCCH content and the PDSCH transmission.
Active	Enables or disables the transmission of PDCCH and PDSCH.
Resource Block Allocation	Resource allocation given as bitmap with each bit representing four physical resource blocks (DL resource allocation type 0, 3GPP TS 36.213 §7.1.6.1). The left-most bit represents lowest resource block index.
MCS	MCS used for PDSCH transmission according to 3GPP TS 36.213 §7.1.7.
eNB TX UE Context	UE specific parameters for DL transmission.
Use UERS	If enabled, the DL transmitter feeds UE-specific reference signals into the PDSCH data stream. The usage of UERS is closely related to Transmission Mode 9 defined in the LTE standard 3GPP TS 36.213 §7.1.
Antenna Port	The antenna port used for generating UERS, Range: 7…14 according to 3GPP TS 36.213 §7.1.
RNTI	The radio network temporary identifier used for PDSCH scrambling and PDCCH CRC mask generation.
CCE Offset	First control channel element to be used for PDCCH transmission. According to 3GPP TS 36.211 §6.8.1/.2.
eNB Timing Offset	Changes the eNodeB timing (start of radio frame). Given in 30.72 MS/s.
Rate Adaptation	If enabled, **eNB TX MCS** is automatically adapted to reported/measured **Wideband SINR [dB]** to handle with channel quality fluctuations. The adaptation is calibrated so that the applied MCS produces approximately 5% to 10% BLER under current MCS conditions. If that is not desired, modify **SINR Offset [dB]**.
SINR Offset [dB]	This value is effectively subtracted from the reported SINR before looking up the MCS in the adaptation table (that is, if a positive offset is configured, a higher reported SINR is required to adapt to a certain MCS to avoid block errors).
UE RX UE Context	UE specific parameters for DL reception.

Parameter	Details
Use UERS	If enabled the DL receiver will use UE specific reference signals for equalizing PDSCH assigned I/Q samples. The usage of UERS is closely related to Transmission Mode 9 defined in the LTE standard 3GPP TS 36.213 §7.1.
Antenna Port	The antenna port used for generating UERS for channel estimation, Range: 7…14 according to 3GPP TS 36.213 §7.1.
RNTI	The radio network temporary identifier used for PDSCH scrambling and PDCCH CRC mask check.
CCE Offset	First control channel element to be used for PDCCH reception. According to 3GPP TS 36.211 §6.8.1/.2.
Symbol-Nr (PDSCH)	The OFDM symbol number (counting from 0 with symbol 0 being occupied by the PDCCH) used for displaying constellation data for PDSCH I/Q samples.
Throughput [Mbps] select	Selects the used values for throughput calculation: • **PDSCH (overall)**: The total throughput scheduled by the eNodeB TX regardless of CRC result. • **PDSCH (CRC ok)**: The actual achieved physical layer throughput, which could be decoded successfully. • **User data (to UDP)**: The higher layer throughput (from/to UDP stream) after removing the padding.
UE AGC	Enables or disables the automated gain control on the receiver side. If enabled the analog RX gain of the RF device will be automatically configured within its valid range to meet a target range for the baseband input signal power.
UE Manual Gain Value [dB]	Controls the analog RX gain in case **UE AGC** is switched off.

Graphs and Indicators (Single-Device)

The indicators on the front panel represent the state of the target device and show information about ongoing transfers.

Table 7 Graphs and Indicators (Single-Device)

Parameter	Details
FPGA ready	Indicates that the FPGA bitfile has been downloaded and that the device has been initialized and is ready for configuration. Initialization can take up to 20 seconds.
eNB TX Active	Indicates that all eNB TX control configurations have been applied and the transmitter is running.
eNB RF TX Power [dBm]	Actual eNB RF transmit power in dBm.
eNB Coerced Max RF TX Power [dBm]	Indicates the coerced value actually used as maximum RF transmit output power after applying the device capabilities (range and resolution limitations) to the configured **eNB Maximum RF TX Power [dBm]**.

Parameter	Details
eNB TX Power Spectrum	Shows the power spectrum of the DL TX baseband signal transferred to the RF.
Data Transfer In	Indicates that the configured UDP stream is receiving data on the configured **Receive Port**.
Packet Loss In	Indicates that the system loses UDP data because of overload, which can occur when data inflow from UDP port is higher than configured PDSCH throughput.
eNB TX IFFT Output Clipped	Indicates a numeric overflow after the inverse FFT (IFFT).
eNB Baseband TX Power [dBFS]	Actual eNB baseband transmit power level [baseband output power level] in dB full scale.
UE RX Active	Signals that all UE RX control configurations have been applied and the receiver is running.
Sync Found	Indicates that the synchronization module has successfully detected and synchronized to a DL RX signal.
UE Frequency Offset [Hz]	The estimated and compensated frequency offset detected in the RX signal.
UE RF RX Power [dBm]	The measured time domain input power at the RX RF port.
UE ADC Values Clipped	Indicates a numeric overflow at the ADC output. An overflow can occur when the analog RX RF gain is too high, or the receiver power level is too high.
UE DDC Values Clipped	Indicates a numeric overflow at the output of the digital downconversion block (that is, analog RX RF gain too high or receive power level too high).
UE Coerced Gain [dB]	The actual used analog RX RF gain either set by AGC, if enabled, or by **UE Manual Gain Value [dB]**.
UE Baseband RX Power [dBFS]	The measured baseband input power level in dB full scale.
UE RX Power Spectrum	Shows the power spectrum of the DL RX baseband signal received from RF. If synchronization is successful, frequency offset compensation is applied.
PDSCH Constellation	Constellation of RX I/Q samples allocated for PDSCH transmission after equalization. Only samples for the configured OFDM **Symbol-Nr (PDSCH)** are displayed.
Wideband SINR [dB]	The estimated SINR over the full 20 MHz band using cell-specific reference signals.
Subband SINR [dB]	The estimated SINR for each subband occupying 8 PRBs. Comparable to Reporting Mode 3-0 in 3GPP TS 36.213 §7.2.1. Usage of CRS or UERS for estimation depends on setting of **Use UERS** switch in **UE RX System Parameters**.
Throughput [Mbps]	Numerical and graphical indication of scheduled, successfully decodable and actually used channel capacity. • **PDSCH (overall)**: The total throughput scheduled by the eNodeB TX regardless of CRC result. • **PDSCH (CRC ok)**: The actual achieved physical layer throughput, which could be decoded successfully.

Parameter	Details
	• **User data (to UDP)**: The higher layer throughput (from/to UDP stream) after removing the padding.
Data Transfer Out	Indicates that the configured UDP stream is sending data to the configured **Transmit IP Address** using **Transmit Port**.
Packet Loss Out	Indicates that the system loses UDP data caused by overload, which can occur when data inflow from the PDSCH is higher than UDP throughput.
PDCCH Constellation	Constellation of RX I/Q samples allocated for PDCCH transmission after equalization.
UE Failure / Block Error Rate (BLER)	Numerical and graphical display of error rates for synchronization detection and PDCCH and PDSCH decoding.
Channel Estimation	Graphical representation of the normalized channel amplitude and phase estimated on the cell specific reference signals.
PDCCH Received DCI Message	Array of decoded and interpreted downlink control information messages received on PDCCH and applied to PDSCH decoding. Each element corresponds to a DL subframe.

Running the Sample Project (Double Device)

This section describes how to run the LTE Application Framework using an RF loopback configuration with either two USRP devices or two FlexRIO devices. This configuration corresponds to the double-device setups shown in Figure 1. The devices can be either connected to the same host computer or to different host computers.

Configuring the Hardware (Double Device)

Depending on the available hardware, configure your device using the appropriate instructions.

Configuring the USRP Devices (Double Device)

1. Ensure both USRP devices are properly connected to the host system running LabVIEW Communications.
2. Create a RF connection as shown in Figure 13:
    o On the device acting as eNodeB, connect the cable to RF0/TX1.
    o Connect the other end of that cable to the 30 dB attenuator.
    o Connect the attenuator to RF1/RX2 on the device acting as UE.
    o On the device acting as UE, connect the cable to RF0/TX1.
    o Connect the other end of that cable to the 30 dB attenuator.
    o Connect the attenuator to RF1/RX2 on the device acting as eNodeB.
3. Power on the USRP devices.
4. Power on the host system(s).
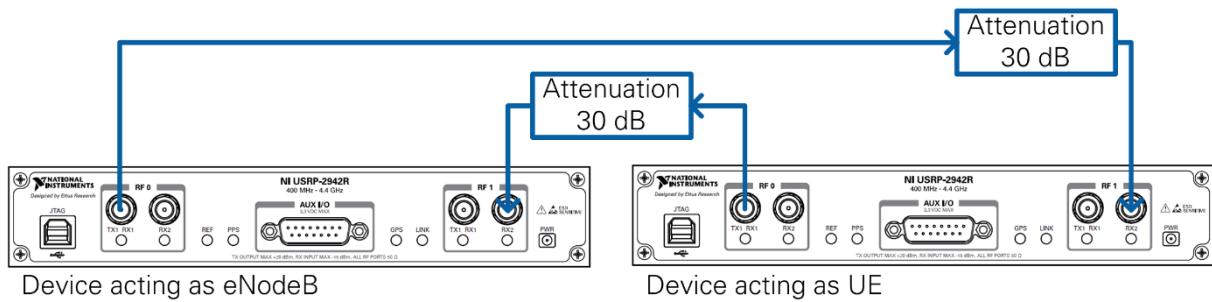
Device acting as eNodeB · Device acting as UE

Figure 13 Cabled Connection of Two USRP Devices

Configuring the FlexRIO Modules (Double Device)

1. Ensure both FlexRIO devices are properly installed in PXI Express chassis containing the embedded controller that is used as the host system running LabVIEW.
2. Create a RF connection as shown in Figure 14:
   a. On the device acting as eNodeB, connect the cable to TX.
   b. Connect the cable to the RX port on the device acting as UE.
   c. On the device acting as UE, connect another cable to the TX port.
   d. Connect the cable to the RX port on the device acting as eNodeB.
3. Power on the PXI chassis.

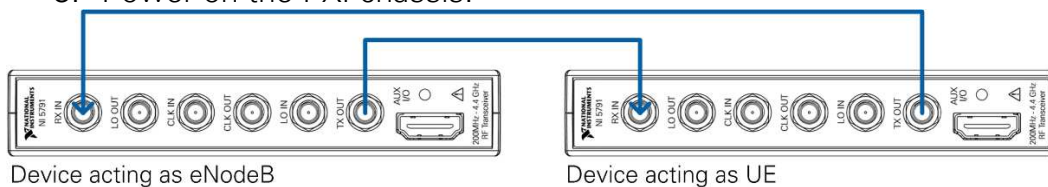Device acting as eNodeB · Device acting as UE

Figure 14 Cabled Connection of Two FlexRIO Devices

Over-the-Air Transmission (Double Device)

The configuration for over the air transmission is like that of the cabled setup. Cables and attenuators are replaced by antennas suitable for the selected channel center frequency and system bandwidth.

Notice: Before using your hardware, read all product documentation to ensure compliance with safety, EMC, and environmental regulations.

Running the LabVIEW Host Code (Double Device)

Depending on the selected host applications, the following different operation modes are possible:
- One device acts as eNodeB by running `Host eNodeB.gvi` (downlink transmitter and uplink receiver) and the other device acts as UE by running `Host UE.gvi` (downlink receiver and uplink transmitter).
- Alternatively, both devices can act as downlink transmitters and receivers by running the downlink-only host variant (`LTE Host DL.gvi`) on both host computers.

This section describes how to run the system in the eNodeB/UE operation mode. The downlink-only operation mode using a double-device setup is not further described here because it is similar to the downlink-only operation mode using a single-device setup that is described in the previous chapter.

Note: When using a double device setup with the USRP-2974, a single host computer that runs LabVIEW Communications is sufficient. Ensure the RT targets are mapped to the correct device.

Initializing the System (Double Device)

1. Initialize the system on the eNodeB host computer.
    a. Launch LabVIEW Communications System Design Suite by selecting **LabVIEW Communications 2.0** from the Start menu.
    b. From the Project Templates on the **Launch a Project** tab, select Project **Application Frameworks » LTE Design....** to launch the project.
        1. Select **LTE Design USRP 2974 v2.2** if you are using the USRP-2974.
        2. Select **LTE Design USRP RIO v2.2** if you are using any other USRP device.
        3. Select **LTE Design FlexRIO v2.2** if you are using FlexRIO device.
    c. (LTE Design USRP 2974 v2.2 only) Ensure you are mapped to the RT target.
        1. Open System Diagram.
        2. Select the USRP device.
        3. On the Configuration pane, check that **mapped to** names the correct USRP.
    d. If **mapped to** is **do not map**, then map to the correct USRP by either selecting the right USRP from the dropdown list or by **map to another device by address**. When you map to another device, use the device IP address and root as user name. Leave **password** empty if you did not change it.
    e. Within that project, open the LabVIEW top-level host VI for the eNodeB operation mode, **LTE Host eNodeB.gvi**. The front panel of this VI is shown in Figure 15.
    f. (FlexRIO and USRP RIO devices only. Skip this step when using the USRP-2974.) Set the **RIO Device** to the alias of the RIO device connected to your system. You can use NI MAX to get the RIO alias for your device.
    g. Click the **Run** button, ▶, on the LabVIEW host VI. If successful, the **FPGA Ready** indicator lights. If you receive an error, check whether your RIO device is connected properly.
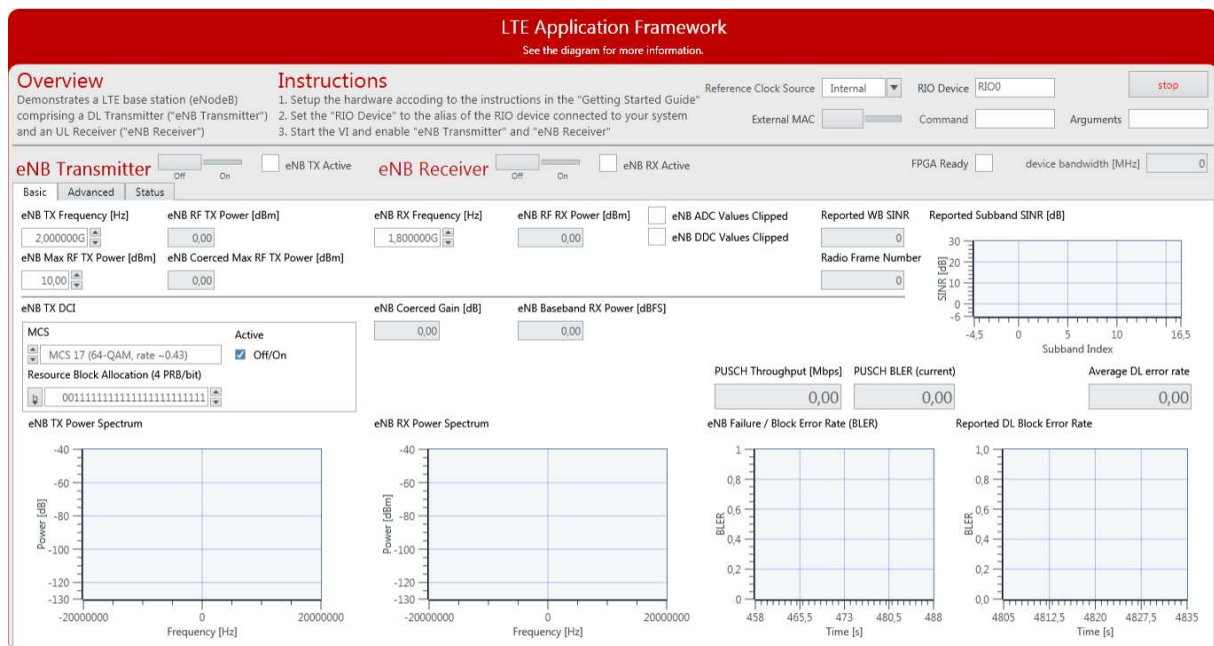
Figure 15 Front Panel of LTE Host eNodeB.gvi

2. Initialize the system on the UE host computer.
   a. Launch LabVIEW Communications System Design Suite by selecting **LabVIEW Communications 2.0** from the Start menu.
   b. From the Project Templates on the **Launch a Project** tab, select Project **Application Frameworks » LTE Design....** to launch the project.
      1. Select **LTE Design USRP 2974 v2.2** if you are using the USRP-2974.
      2. Select **LTE Design USRP RIO v2.2** if you are using any other USRP device.
      3. Select **LTE Design FlexRIO v2.2** if you are using a FlexRIO device.
   c. (LTE Design USRP 2974 v2.2 only) Ensure you are mapped to the RT target.
      1. Open System Diagram.
      2. Select the USRP device.
      3. On the Configuration pane, check that **mapped to** names the correct USRP.
   d. If **mapped to** is **do not map**, then map to the correct USRP by either selecting the right USRP from the dropdown list or by **map to another device by address**. When you map to another device, use the device IP address and root as user name. Leave **password** empty if you did not change it.
   e.
   f. Within that project, open the LabVIEW top-level host VI for the UE operation mode, `LTE Host UE.gvi`.
   g. The front panel of this VI is shown in Figure 16.
   h. Set the **RIO Device** to the alias of the RIO device connected to your system. You can use NI MAX to get the RIO alias for your device.

i. Click the **Run** button, ▷, on the LabVIEW host VI. If successful, the **FPGA Ready** indicator lights. If you receive an error, check if your RIO device is connected properly.
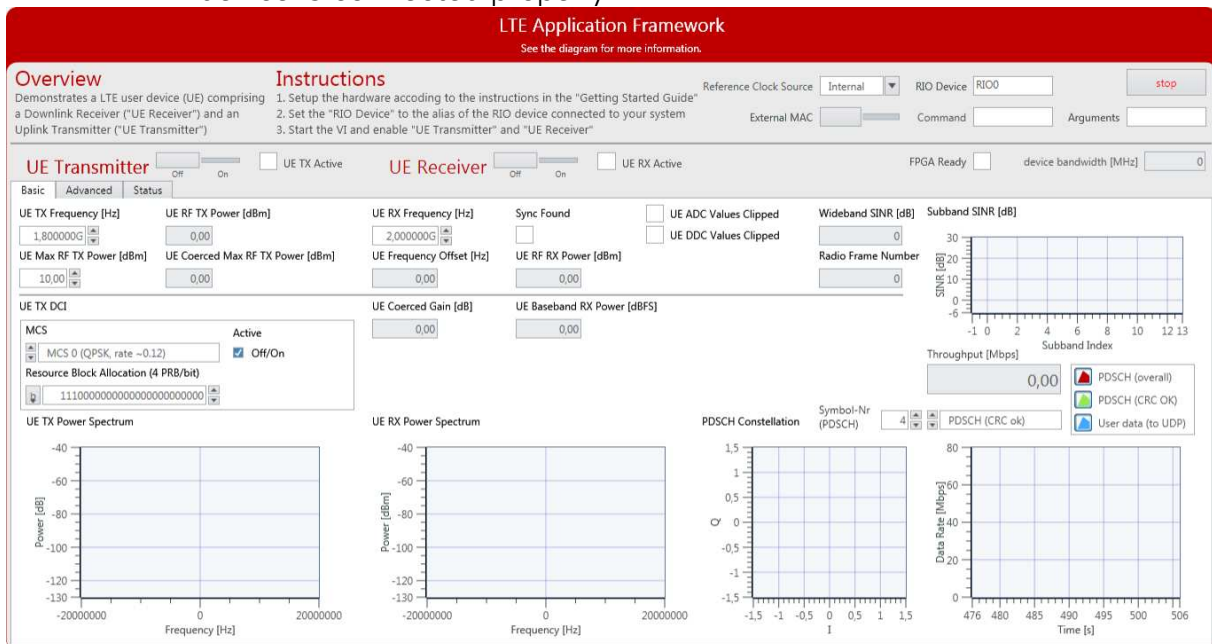

Figure 16 Front Panel of LTE Host UE.gvi

3. Continue initializing the system on the eNodeB host computer.
    a. Set the control **eNB TX Frequency [Hz]** to a frequency supported by your USRP or FlexRIO device, refer to Table 2.
    b. Enable the **eNB Transmitter** (implementing a DL TX) by setting the switch control to **On**. If successful, the **eNB TX Active** indicator lights.
4. Continue initializing the system on the UE host computer.
    a. Set the control **UE RX Frequency [Hz]** to the same value as you have chosen for **eNB TX Frequency [Hz]**.
    b. Enable **UE Receiver** (implementing a DL RX) by setting the switch control to **On**. If successful, the **UE RX Active** indicator lights.
    c. Set the control **UE TX Frequency [Hz]** to a frequency supported by your USRP or FlexRIO device, see Table 2.
    d. Enable the **UE Transmitter** (implementing a UL TX) by setting the switch control to **On**. If successful, the **UE TX Active** indicator lights.
    e. Continue initializing the system on the eNodeB host computer.
    f. Set the control **eNB RX Frequency [Hz]** to the same value as you have chosen for **UE TX Frequency [Hz].**
    g. Enable **eNB Receiver**, which implements a UL RX, by setting the switch control to **On**. If successful, the **eNB RX Active** indicator lights.

Verifying the System (Double Device)

If the system is running as expected, all necessary steps as illustrated in Figure 17 were completed successfully. As a result, the indicators and graphs on the host panel should look like the host panels shown in Figure 18, Figure 19, and Figure 21.
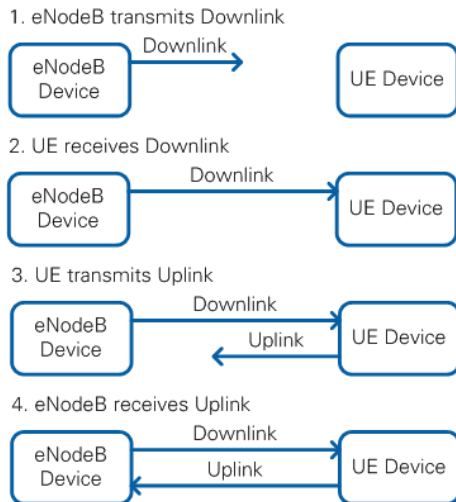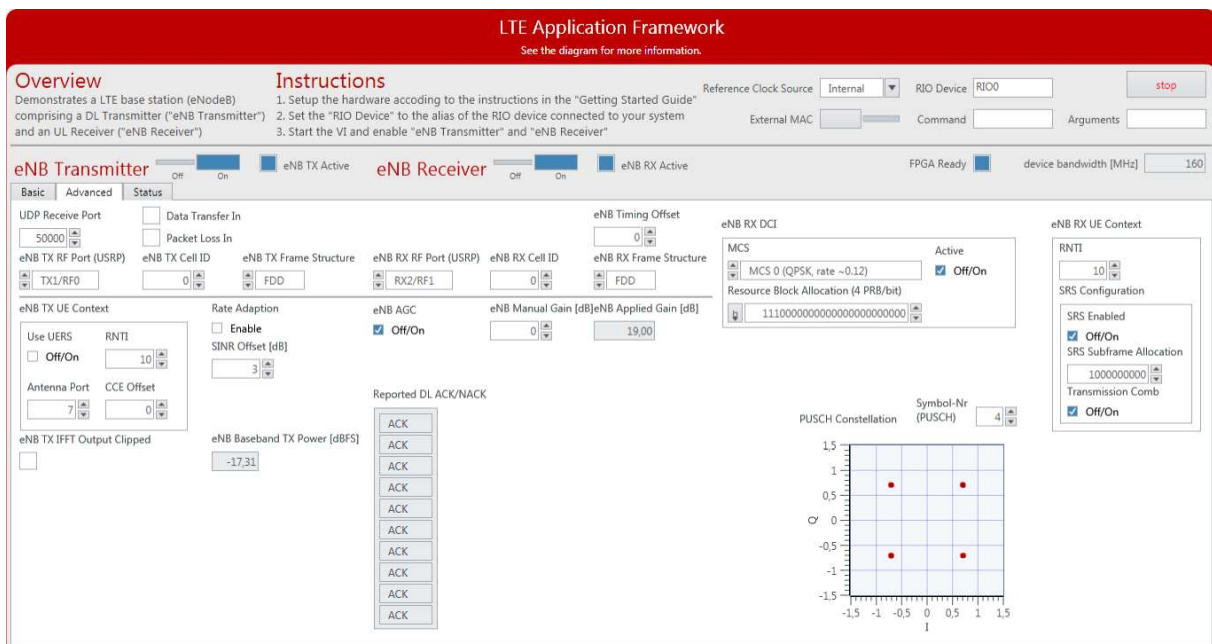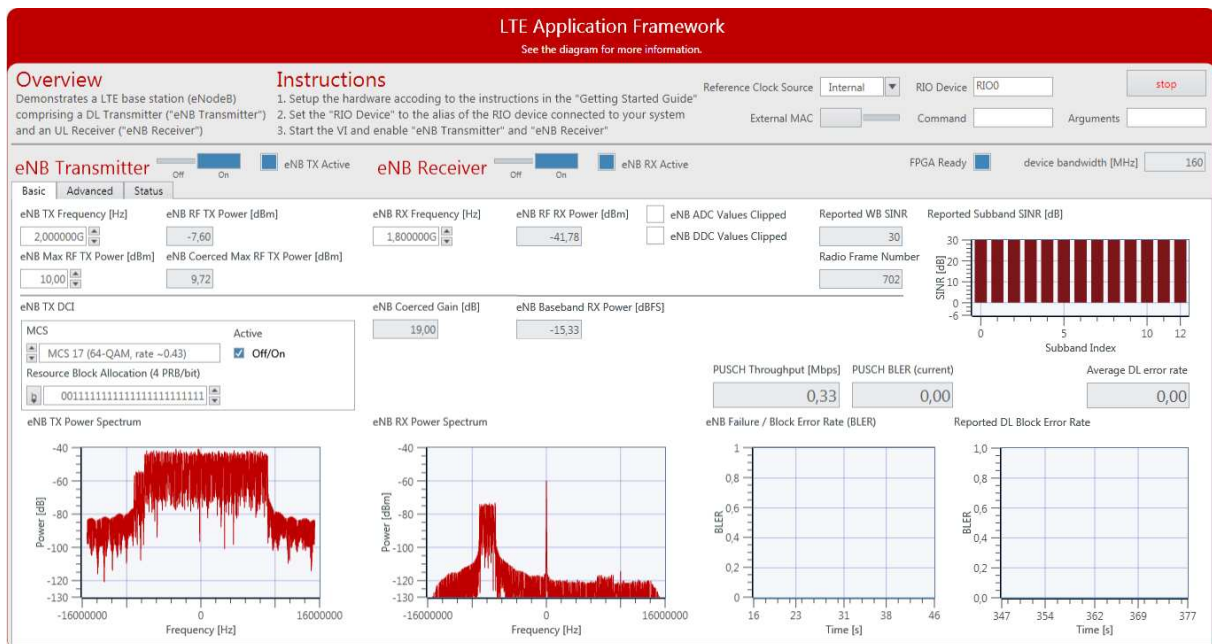
Figure 17 Establishing a DL and UL Connection between eNodeB and UE

The following table provides details on how to confirm that your results look as expected.

Table 8 Verifying the System (Double Device)

Tab	What to Check	Confirm
eNB Basic	eNB TX Power Spectrum graph	Spectrum matches the resource block allocation configured by the **Resource Block Allocation [4 PRB/bit]** control. This confirms that the eNodeB is successfully transmitting the downlink.
	eNB RX Power Spectrum graph	Matches the UE TX Power Spectrum graph.
	eNB Failure / Block Error Rate (BLER) graph	Constantly zero, which indicates correct PUSCH reception without CRC errors.
	Reported DL Block Error Rate graph	Constantly zero, which indicates correct PDSCH reception without CRC errors on the UE RX side. The displayed value should match the PDSCH value of the UE Failure / Block Error Rate (BLER) graph on the **UE RX Advanced** tab.
	PUSCH Throughput [Mbps] indicator	Non-zero value. The actual value matches the theoretical data rate for the combination of MCS and resource block allocation set for the UE TX.
	Radio Frame Number indicator	Value is rapidly increasing.
eNB Advanced	PUSCH Constellation graph	Shows a clean QPSK or QAM constellation. The modulation depends on the MCS, which is configured on the **UE TX Basic** tab using the **MCS** control.
	Reported DL ACK/NACK indicator	With an FDD frame structure, the values are ACK, ACK,…, ACK; with a TDD frame structure, the values are ACK, DTX, DTX, ACK,…, ACK. This

Tab	What to Check	Confirm
		indicates the correct PDSCH reception without CRC errors on the UE RX side.
UE Basic	UE RX Power Spectrum graph	Spectrum matches the eNB TX Power Spectrum.
	Sync Found indicator	Indicator is constantly on, showing that the synchronization is successful. Synchronization success is required for correct PDCCH (and PDSCH) reception and decoding.
	PDSCH Constellation graph	Shows a clean QPSK or QAM constellation. The modulation depends on the MCS, which is configured on the **enB TX Basic** tab using the **MCS** control.
	Throughput graph	Shows a constant green curve, indicating a constant value for PDSCH (CRC ok). Shows no red portions in the curve, which means that the PDSCH (CRC ok) value equals the PDSCH(overall) value. Shows the correct PDSCH channel decoding without CRC errors.
	UE TX Power Spectrum graph	Matches the resource block allocation configured by the **Resource Block Allocation (4 PRB/bit)** control.
UE Advanced	PDCCH Constellation graph	Shows a clean and stable QPSK constellation (indicates allocated PDCCH subcarriers) with an additional dot in the origin (indicates unallocated PDCCH subcarriers). This confirms a correct reception of the PDCCH subcarrier data.
	PDCCH Received DCI Message indicator	**Valid** indicator is constantly on, and the **MCS** and **Resource GBlock Allocation [4 PRB/bit]** controls match the controls of the same name on the **eNB TX Basic** tab. This confirms that the PDCCH reception and decoding is successful, which is required for PDSCH reception and decoding.
	UE Failure / Block Error Rate (BLER) graph	The sync value, PDCCH value, and PDSCH value are all constantly zero. This indicates synchronization success, which is required for correct PDCCH reception and decoding, which is required for PDSCH reception and decoding, which is required for error-free data exchange.
	Channel Estimation graph	For a cabled setup, the Normalized Amplitude graph shows a flat curve around 0 as shown in Figure 19; for an over-the-air setup, any curve is acceptable, since the highs and lows indicate a frequency-selective channel caused by multipath fading. The Phase graph should show a saw tooth curve as shown in Figure 18, which indicates that the FFT cuts slightly into the cyclic prefix.

Figure 18 Front Panel of LTE Host eNodeB.gvi / Basic Tabs When Running Successfully

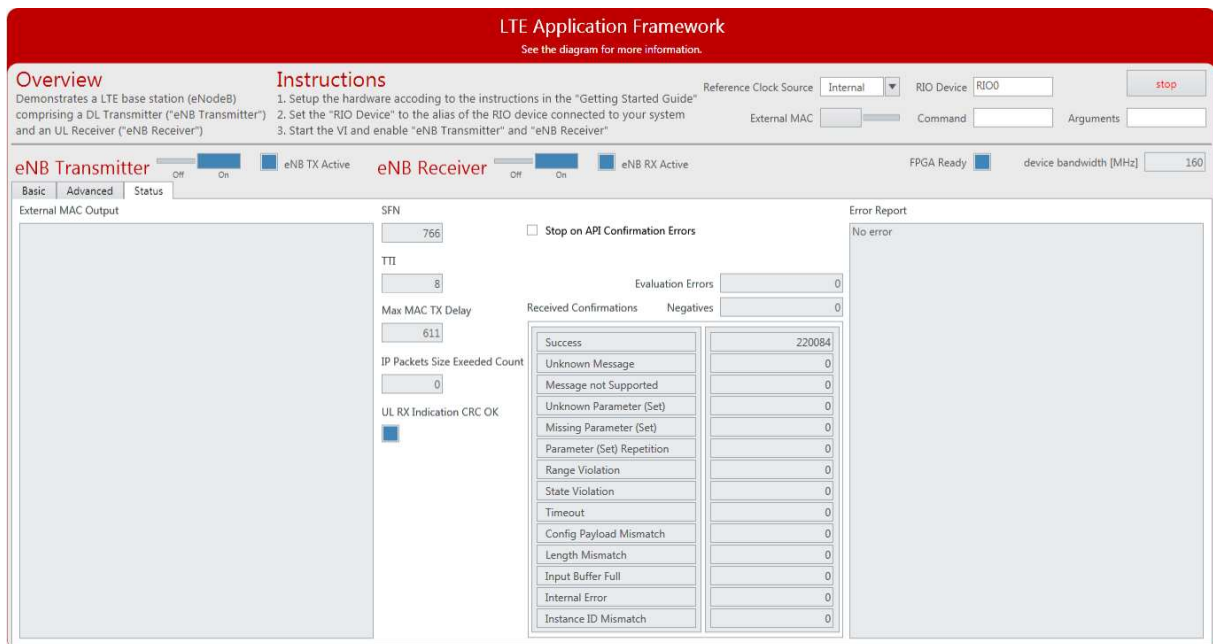*Figure 19 Front Panel of LTE Host eNodeB.gvi / Advanced Tabs When Running Successfully*

Figure 20 Front Panel of LTE Host eNodeB.gvi / Status Tabs When Running Successfully
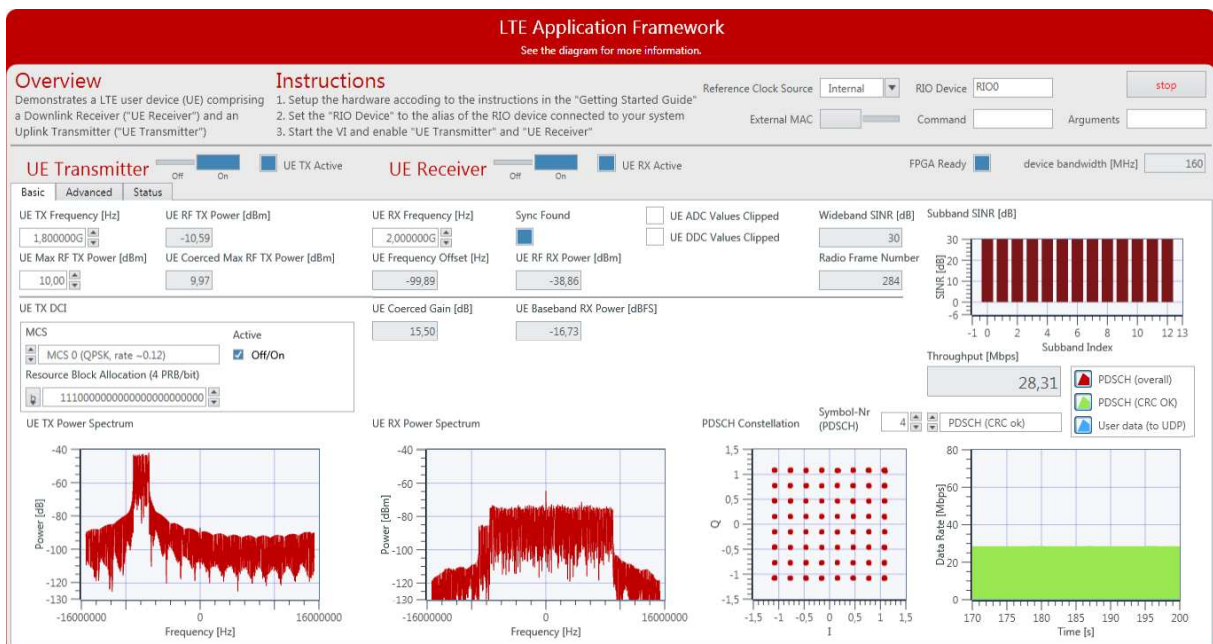
Figure 21 Front Panel of LTE Host UE.gvi / Basic Tabs When Running Successfully
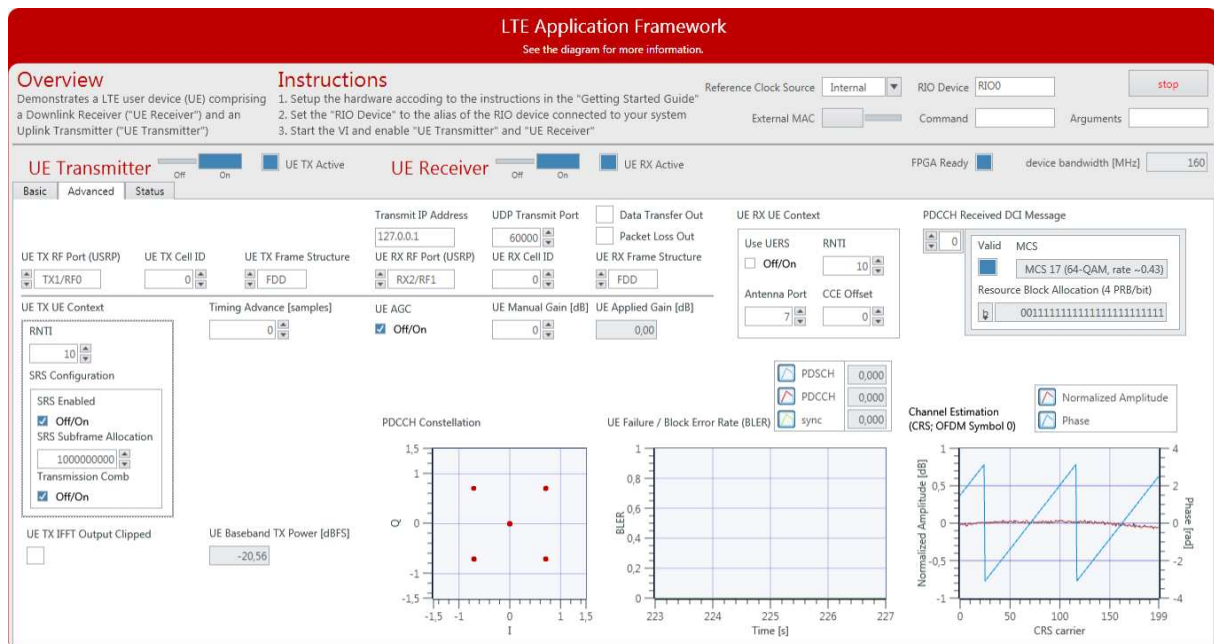
Figure 22 Front Panel of LTE Host UE.gvi / Advanced Tabs When Running Successfully
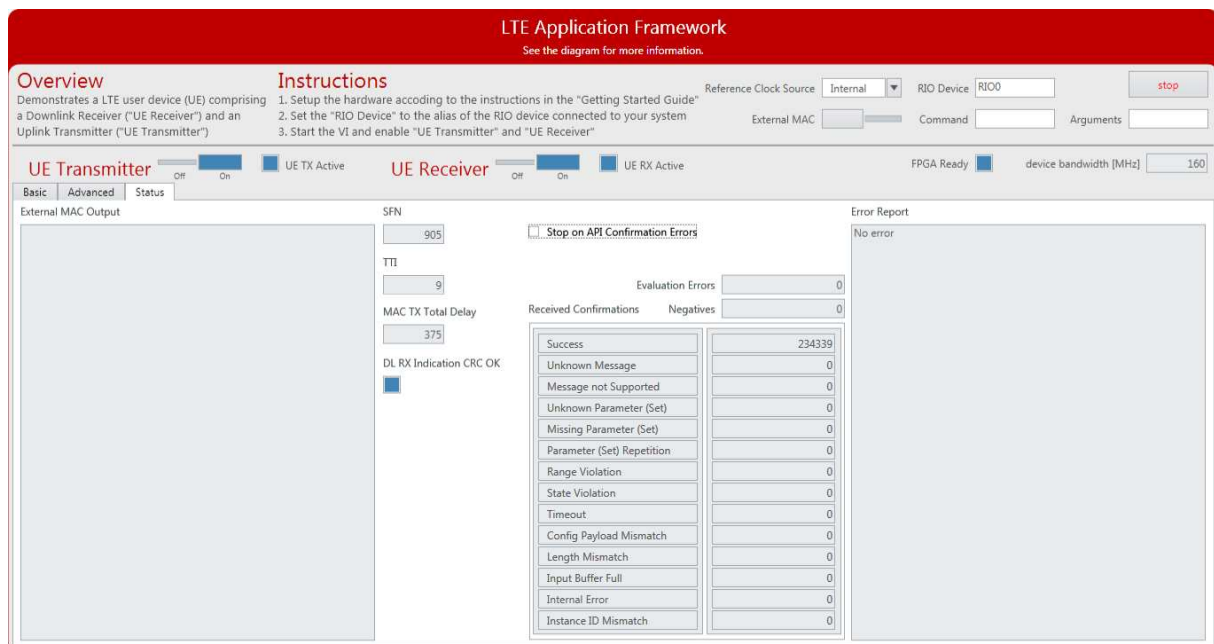
Figure 23 Front Panel of LTE Host UE.gvi / Status Tabs When Running Successfully

Running Video Streaming (Double Device)

The previous section described how to use the LTE Application Framework with the double-device setup in eNodeB/UE configuration for establishing an LTE downlink between the eNodeB device and the UE device. A basic MAC implementation allows for packet-based data exchange of user data between eNodeB and UE. The user data can be provided to the host using UDP as shown in Figure 11. Any program capable of transmitting UDP data can be used as data source. Similarly, any program capable of receiving UDP data can be used as data sink.

Figure 24 Data Streaming to/from the System Using UDP (eNodeB/UE Operation Mode)

As described in the "Running the Sample Project (Double Device)" section, the VLC media player can be used for streaming video data. The commands described in the "Initializing Video Stream Transmitter" section need to run on the host computer running LTE Host eNodeB.gvi. The commands described in the "Initializing Video Stream Transmitter" section need to run on the host computer running LTE Host UE.gvi.

Running External MAC Demo Application (Double Device)

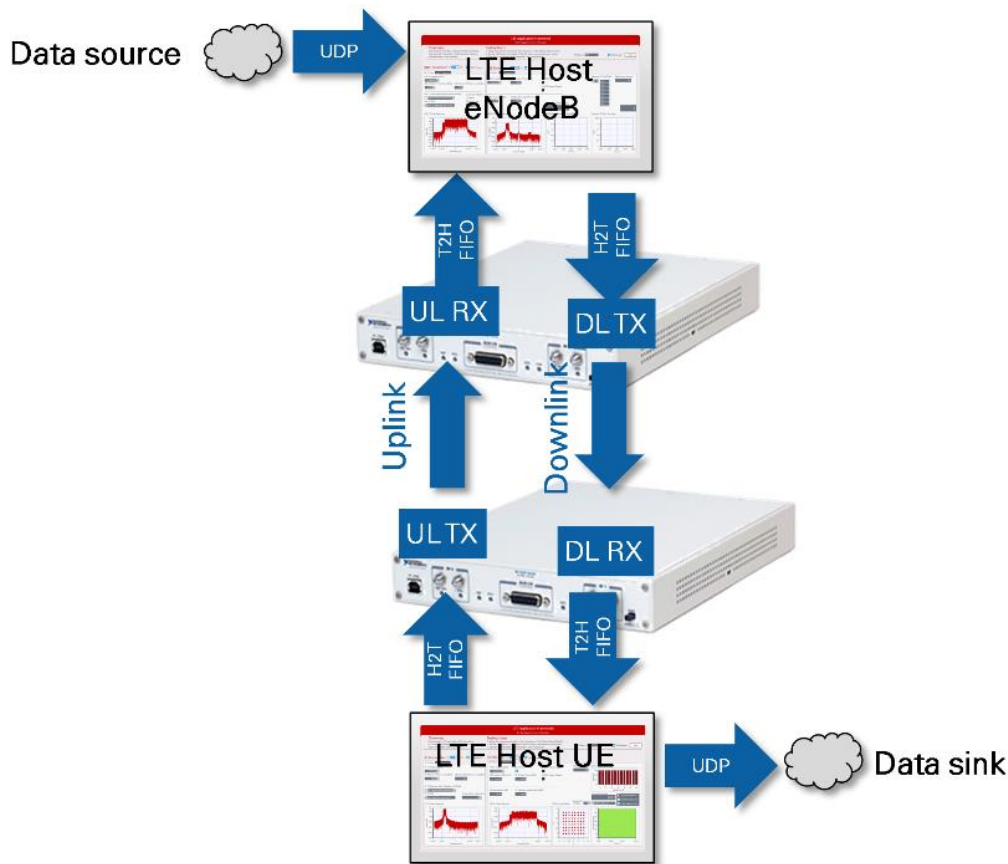The basic MAC implementation of the LTE Application Framework can also be replaced by a full featured external implementation. For this purpose, the LTE Application Framework offers an API to interact with an external MAC. Attaching an external MAC requires a Linux RT setup such as the USRP-2974.

Preparing External MAC Executable (Double-Device)

1. For both devices do the following steps
   a. Get ssh access to the Linux RT system, for example using Putty. Visit `ni.com/info` and enter the Info Code [exmmx6](#) for additional details, including the default user name and password.
   b. Transfer example application to the Linux RT system:
      `pscp -r \MAC root@RT_LINUX_IP:`
      replace `PATH_TO_AFW_PROJECT` with the path to the LTE Application Framework project and `RT_LINUX_IP` with the IP of the Linux RT Setup.
   c. Log into the Linux RT system through ssh as root and run the following commands:

```
opkg update
opkg install g++ libstdc++-staticdev
cd ~/MAC
make install
```

2. Prepare the system as described in Initializing the System (Double Device). In addition, enable the **External MAC switch** control before starting the any of the VIs.

When everything is configured correctly, the system will behave as described in the "Verifying the System (Single-Device)" section. Because the sample application only sends packets for a fixed amount of time, both hosts will stop execution after 10 seconds and report that the connection to the external MAC is broken. Observe that as much the number of PHY TX Indications and PHY TX Requests is exactly the number of packets given in the command line arguments. The number of PHY CNF received is the sum of the PHY TX requests. Because the external MAC might hit exit conditions before the last two PHY CNF are received. The number of PHY DL RX Indications received is around 30-50 smaller than the number of PHY TX requests. The reason for that is that the synchronization in DL RX needs a few radio frames to settle and there is still data in the loop between DL TX and DL RX when the external MAC hits the exit condition.

Host Panel Controls and Indicators (Double Device)

This section gives information about how to use the controls and how to interpret the graphs and indicators available on the host panel.

eNodeB Controls and Indicators (Double Device)

eNodeB Application Settings (Double Device)

These settings need to be set prior to running the GVI. Changes will only be applied after stopping and restarting the GVI.

Table 9 eNodeB Application Settings (Double Device)

Parameter	Details
RIO Device	The RIO address of the RF hardware device
Reference Clock Source	Configures the reference clock source used for the transceiver chain. • **Internal**: device internal clock • **REF IN / ClkIn**: Clock input at the RF device (that is, the rear connector portal for USRP devices and the front connector portal for NI-5791 modules) • **PXI_CLK**: Clock of the PXI Chassis (NI-5791 only) • **GPS**: GPS module (USRP-2950/2952/2953/2954/2974)
External MAC	When enabled a program is executed on the RT described by command line and arguments. This switch applies for RT only. When disabled an internal basic MAC will be executed.
Command	Command to execute for external MAC.
Arguments	Arguments to pass to the external MAC.

eNodeB Basic Runtime Static Settings (Double Device)

These settings on the basic tabs can be changed without restarting the GVI. Value changes are applied when the corresponding transmitter or receiver chain is restarted using the associated switch control (**Off** to **On**).

Table 10 eNodeB Basic Runtime Static Settings (Double Device)

Parameter	Details
eNB Transmitter	Enables or disables the transmitter using the current configuration.
eNB TX Frequency [Hz]	DL TX center frequency, allowed range depends on device used.
eNB Maximum RF TX Power [dBm]	Maximum RF transmit output power (upper bound - achievable for a full scale complex sine wave (CW) signal) **Note:** The actual time-domain RF transmit power depends on the configured resource allocation and is typically at least 15 dB lower to allow for the OFDM PAPR backoff.
eNB Receiver	Enables or disables the receiver using the current configuration.
eNB RX Frequency [Hz]	UL RX center frequency, allowed range depends on used RF device.

eNodeB Advanced Runtime Static Settings (Double Device)

These settings on the advanced tabs can be changed without restarting the GVI. Value changes are applied when the corresponding transmitter or receiver chain is restarted using the associated switch control (**Off** to **On**).

Table 11 eNodeB Advanced Runtime Static Settings (Double Device)

Parameter	Details
UDP Receive Port	The UDP port the host monitors for incoming packets to be transferred to the FPGA PDSCH chain.
eNB TX RF Port (USRP)	Selects the HW RF port where the DL TX is transmitted (USRP only).
eNB TX Frame Structure	Select between FDD and TDD using subframe configuration 5 and special subframe configuration 5 (3GPP TS 36.211 §4).
eNB TX Cell ID	Physical cell ID used for PSS, CRS, UERS sequence generation and PDCCH/PDSCH scrambling. [0…511].
eNB RX RF Port	Selects the HW RF port the UL RX will be received from (USRP only).
eNB RX Frame Structure	Select between FDD and TDD using subframe configuration 5 and special subframe configuration 5 (3GPP TS 36.211 §4).
eNB RX Cell ID	The physical cell ID used for PUSCH scrambling.

eNodeB Runtime Dynamic Settings (Double Device)

These setting can be changed while the corresponding transmitter or receiver chain is running. Value changes are applied immediately.

Table 12 eNodeB Runtime Dynamic Settings (Double Device)

Parameter	Details
eNB TX DCI	Downlink control information for the PDCCH content and the PDSCH transmission.
Active	Enables or disables the transmission of PDCCH and PDSCH.
Resource Block Allocation	Resource allocation given as bitmap with each bit representing four physical resource blocks (DL resource allocation type 0, 3GPP TS 36.213 §7.1.6.1). The left-most bit represents lowest resource block index.
MCS	MCS used for PDSCH transmission according to 3GPP TS 36.213 §7.1.7
eNB TX UE Context	UE specific parameters for DL transmission.
Use UERS	If enabled, the DL transmitter feeds UE-specific reference signals into the PDSCH data stream. The usage of UERS is closely related to Transmission Mode 9 defined in the LTE standard 3GPP TS 36.213 §7.1.
Antenna Port	The antenna port used for generating UERS, Range: 7…14 according to 3GPP TS 36.213 §7.1.
RNTI	The radio network temporary identifier used for PDSCH scrambling and PDCCH CRC mask generation.
CCE Offset	First control channel element to be used for PDCCH transmission. According to 3GPP TS 36.211 §6.8.1/.2.
eNB Timing Offset	Changes the eNodeB timing (start of radio frame). Given in 30.72MS/s.
Rate Adaptation	If enabled, **eNB TX MCS** is automatically adapted to reported/measured **Wideband SINR [dB]** to handle with channel quality fluctuations. The adaptation is calibrated so that the applied MCS produces about 5% to 10% BLER under current MCS conditions. If that is not desired, **SINR Offset [dB]** needs to be modified.
SINR Offset [dB]	This value is effectively subtracted from the reported SINR before looking up the MCS in the adaptation table. That is, if a positive offset is configured, a higher reported SINR is required to adapt to a certain MCS to avoid block errors.
eNB RX DCI	Parameters for reception of PUSCH.
Active	Enables or disabled the reception of the PUSCH.
MCS	Modulation and coding scheme used for PUSCH reception according to 3GPP TS 36.213 §7.1.7.
Resource Block Allocation	Resource allocation for PUSCH given as bitmap with each bit representing 4 physical resource blocks (DL resource allocation type 0, 3GPP TS 36.312

Parameter	Details
	§7.1.6.1). Leftmost bit represents lowest resource block index.
eNB RX UE Context	UE-specific parameters for UL reception.
RNTI	The radio network temporary identifier used for PUSCH scrambling.
SRS Configuration	The configuration used for receiving sounding reference signals.
SRS Enabled	If TRUE, sounding reference signal (SRS) location is reserved as last symbol in each UL subframe (FDD, TDD) and last 2 symbols in each special subframe (TDD) according to 3GPP TS 36.211 §5.5.3.3: FDD: srs-SubframeConfig = 0, TDD: srs-SubframeConfig = 7.
SRS Subframe Allocation	Bitmap determining the subframes actually used for SRS transmission. Periodicity of 10, leftmost bit represents subframe 0.
Transmission Comb	Parameter transmissionComb k_TC determining if even (0) or odd (1) subcarriers are used for SRS transmission/reception. See also 3GPP TS 36.211 §5.5.3.2
Symbol-Nr (PUSCH)	The OFDM symbol number used for displaying constellation data for PUSCH I/Q samples.
eNB AGC	Enables or disables the automated gain control on the receiver side. If enabled the analog RX gain of the RF device will be automatically configured within its valid range to meet a target range for the baseband receive power.
eNB Manual Gain Value [dB]	Controls the analog RX gain in case **eNB AGC** is switched off.

eNodeB Graphs and Indicators (Double Device)

The indicators on the front panel represent the state of the target device and show information about ongoing transfers.

Table 13 eNodeB Graphs and Indicators (Double Device)

Parameter	Details
FPGA ready	Signals that the FPGA bitfile has been downloaded and that the device has been initialized and is ready for configuration. Initialization can take up to 20 seconds.
eNB TX Active	Signals that all eNB TX control configurations have been applied and the transmitter is running.
eNB RF TX Power [dBm]	Actual eNB RF transmit power in dBm.
eNB Coerced Max RF TX Power [dBm]	Indicates the coerced value actually used as maximum RF transmit output power level after applying the

Parameter	Details
	device's capabilities (range and resolution limitations) to the configured **eNB Maximum RF TX Power [dBm]**.
eNB TX Power Spectrum	Shows the power spectrum of the DL TX baseband signal transferred to the RF.
Data Transfer In	Indicates that the configured UDP stream is receiving data on the configured **Receive Port**.
Packet Loss In	Indicates that the system loses UDP data due to overload. Data inflow from UDP port is higher than configured PDSCH throughput.
eNB TX IFFT Output Clipped	Indicates a numeric overflow after the IFFT.
eNB Baseband TX Power [dBFS]	Actual eNB baseband transmit power level [baseband output power level] in dB full scale.
eNB RX Active	Indicates that all eNB RX control configurations have been applied and the receiver is running.
eNB RF RX Power [dBm]	Measured time domain receive power at the RX RF port.
eNB ADC Values Clipped	Indicates a numeric overflow at the ADC output. Overflows can be caused when the analog RX RF gain too high or the receive power level too high.
eNB DDC Values Clipped	Indicates a numeric overflow at the output of the digital downconversion block. Overflows can be caused when the analog RX RF gain too high or the receive power level too high.
eNB Coerced Gain [dB]	The actual used analog RX RF gain either set by automatic gain control (AGC), if enabled, or by **UE Manual Gain Value [dB]**.
eNB Baseband RX Power [dBFS]	The measured baseband RX power level in dB full scale.
eNB RX Power Spectrum	Shows the power spectrum of the UL RX baseband signal received from RF.
PUSCH Throughput [Mbps]	Achieved throughput on the PUSCH channel.
eNB Failure / Block Error Rate (BLER)	Graphical display of PUSCH reception block error rate.
Reported DL ACK/NACK	Array showing the latest received DL ACK/NACK report from UE side.
Radio Frame Number	The number of the latest successfully received report ranging from 0…1023.
Reported DL Block Error Rate	Graphical and numerical representation of the DL receiver block error rate on the UE side reported back to the eNodeB.
Reported Subband SINR [dB]	The reported SINR for each subband occupying 8 PRBs. Comparable to Reporting Mode 3-0 in 3GPP TS 36.213 §7.2.1. Usage of CRS or UERS for estimation depends

Parameter	Details
	on setting of **Use UERS** switch in **UE RX System Parameters** on the UE side.
Reported Wideband SINR [dB]	The reported SINR over the full 20 MHz band using cell specific reference signals.
PUSCH Constellation	Constellation of RX I/Q samples allocated for PUSCH transmission after equalization. Only samples for the configured OFDM **Symbol-Nr (PUSCH)** are displayed.

Host Panel UE (Double Device)

UE Application Settings (Double Device)

These settings need to be set prior to running the GVI. Changes will only be applied after stopping and restarting the GVI.

Table 14 UE Application Settings (Double Device)

Parameter	Details
RIO Device	The RIO address of the RF hardware device.
Reference Clock Source	Configures the reference clock source used for the transceiver chain • **Internal**: device internal clock • **REF IN / ClkIn**: Clock input at the RF device (that is, rear connector port of the USRP device, front connector port for the NI-5791 module) • **PXI_CLK**: Clock of the PXI Chassis (NI-5791 only) • **GPS**: GPS module (USRP-2950/2952/2953/2954/2974)
External MAC	When enabled a program is executed on the RT described by command line and arguments. This switch applies for RT only. When disabled an internal basic MAC will be executed.
Command	Command to execute for external MAC.
Arguments	Arguments to pass to the external MAC.

UE Basic Runtime Static Settings (Double Device)

These settings on the basic tabs can be changed without restarting the GVI. Value changes are applied when the corresponding transmitter or receiver chain is restarted using the associated switch control (**Off** to **On**).

Table 15 UE Basic Runtime Static Settings (Double Device)

Parameter	Details
UE Transmitter	Enables or disables the transmitter using the current configuration.
UE TX Frequency [Hz]	UL TX center frequency, allowed range depends on used RF device.
UE Maximum RF TX Power [dBm]	Maximum RF transmit output power; the upper bound is achievable for a full scale CW signal. The actual time-domain RF transmit power depends on the configured resource allocation and is typically at least 15 dB lower to allow for the OFDM PAPR backoff.

Parameter	Details
Timing Advance [samples]	The applied UL timing advance, that is, the number of samples the UL TX is started earlier than the DL RX. Given in 30.72 MS/s domain.
UE Receiver	Enables or disables the receiver using the current configuration.
UE RX Frequency [Hz]	DL RX center frequency, allowed range depends on used RF device.

UE Advanced Runtime Static Settings (Double Device)

These settings, placed on the advanced tabs, can be changed without restarting the GVI. Value changes are applied when the corresponding transmitter or receiver chain is restarted using the associated switch control (**Off** to **On**).

Table 16 UE Advanced Runtime Static Settings (Double Device)

Parameter	Details
UE TX RF Port (USRP)	Selects the HW RF port the UL TX will be transmitted on (USRP only).
UE TX Frame Structure	Select between FDD and TDD using subframe configuration 5 and special subframe configuration 5 (3GPP TS 36.211 §4).
UE TX Cell ID	Physical cell ID used for PUSCH scrambling.
Transmit IP Address	The IP address the UDP packets received from PDSCH shall be sent to.
UDP Transmit Port	The UDP port the UDP packets received from PDSCH shall be sent to.
UE RX RF Port	Selects the HW RF port the DL RX will be received from (USRP only).
UE RX Frame Structure	Select between FDD (frequency division duplex) and TDD (time division duplex) using subframe configuration 5 and special subframe configuration 5 (3GPP TS 36.211 §4).
UE RX Cell ID	Physical cell ID used for PSS, CRS, UERS sequence generation and PDCCH/PDSCH scrambling. [0…511].

UE Runtime Dynamic Settings (Double Device)

These settings can be changed while the corresponding transmitter or receiver chain is running. Value changes are applied immediately.

Table 17 UE Runtime Dynamic Settings (Double Device)

Parameter	Details
UE TX DCI	Parameters for transmission of PUSCH.
Active	Enables or disabled the transmission of the PUSCH.
MCS	MCS used for PUSCH transmission according to 3GPP TS 36.213 §7.1.7.
Resource Block Allocation	Resource allocation for PUSCH given as bitmap with each bit representing four physical resource blocks (DL resource allocation type 0, 3GPP TS 36.312 §7.1.6.1). Leftmost bit represents lowest resource block index.

Parameter	Details
UE TX UE Context	UE-specific parameters for UL transmission.
RNTI	The radio network temporary identifier used for PUSCH scrambling.
SRS Configuration	The configuration used for transmitting sounding reference signal.
SRS Enabled	If TRUE, SRS location is reserved as last symbol in each UL subframe (FDD, TDD) and last 2 symbols in each special subframe (TDD) according to 3GPP TS 36.211 §5.5.3.3: FDD: srs-SubframeConfig = 0, TDD: srs-SubframeConfig = 7.
SRS Subframe Allocation	Bitmap determining the subframes actually used for SRS transmission. Periodicity of 10, leftmost bit represents subframe 0.
Transmission Comb	Parameter transmissionComb k_TC determining if even (0) or odd (1) subcarriers are used for SRS transmission/reception. See also 3GPP TS 36.211 §5.5.3.2.
UE RX UE Context	UE specific parameters for DL reception.
Use UERS	If enabled the DL receiver will use UE specific reference signals for equalizing PDSCH assigned I/Q samples. The usage of UERS is closely related to Transmission Mode 9 defined in the LTE standard 3GPP TS 36.213 §7.1.
Antenna Port	The antenna port used for generating UERS for channel estimation, Range: 7…14 according to 3GPP TS 36.213 §7.1.
RNTI	The radio network temporary identifier used for PDSCH scrambling and PDCCH CRC mask check.
CCE Offset	First control channel element to be used for PDCCH reception. According to 3GPP TS 36.211 §6.8.1/.2.
Symbol-Nr (PDSCH)	The OFDM symbol number (counting from 0 with symbol 0 being occupied by the PDCCH) used for displaying constellation data for PDSCH I/Q samples.
Throughput [Mbps] select	Selects the used values for throughput calculation. **PDSCH (overall)**: the total throughput scheduled by the eNodeB TX regardless of CRC result. **PDSCH (CRC ok)**: the actual achieved physical layer throughput that could be decoded successfully. **User data (to UDP)**: the higher layer throughput (from/to UDP stream) after removing the padding.
UE AGC	Enables or disables the automated gain control on the receiver side. If enabled the analog RX gain of the RF device will be automatically configured within

Parameter	Details
	its valid range to meet a target range for the baseband receive power.
UE Manual Gain Value [dB]	Controls the analog RX gain in case **UE AGC** is switched off.

UE Graphs and Indicators (Double Device)

The indicators on the front panel represent the state of the target device and show information about ongoing transfers.

Table 18 UE Graphs and Indicators (Double Device)

Parameter	Details
FPGA ready	Signals that the FPGA bitfile has been downloaded and that the device has been initialized and is ready for configuration. Initialization can take up to 20 seconds.
UE TX Active	Signals that all UE TX control configurations have been applied and the transmitter is running.
UE RF TX Power [dBm]	Actual UE RF transmit power in dBm.
UE Coerced Max RF TX Power [dBm]	Indicates the coerced value actually used as maximum RF transmit output power after applying the device's capabilities (range and resolution limitations) to the configured **UE Maximum RF TX Power [dBm]**.
UE TX Power Spectrum	Shows the power spectrum of the UL TX baseband signal transferred to the RF.
UE TX IFFT Output Clipped	Indicates a numeric overflow after the IFFT.
UE Baseband TX Power [dBFS]	Actual UE baseband transmit power level [baseband output power level] in dB full scale.
UE RX Active	Signals that all UE RX control configurations have been applied and the receiver is running.
Sync Found	Indicates that the synchronization module has successfully detected and synchronized to a DL RX signal.
UE Frequency Offset [Hz]	The estimated and compensated frequency offset detected in the RX signal.
UE RF RX Power [dBm]	The measured time domain receive power at the RX RF port.
UE ADC Values Clipped	Indicates a numeric overflow at the analog-to-digital converter (ADC) output, that is, the analog RX RF gain is too high or the receive power level is too high.
UE DDC Values Clipped	Indicates a numeric overflow at the output of the digital downconversion block, that is, the analog RX RF gain is too high, or the input power level is too high.
UE Coerced Gain [dB]	The actual used analog RX RF gain either set by AGC, if enabled, or by **UE Manual Gain Value [dB]**.
UE Baseband RX Power [dBFS]	The measured baseband receive power level in dB full scale.

Parameter	Details
UE RX Power Spectrum	Shows the power spectrum of the DL RX baseband signal received from RF. If synchronization is successful frequency offset compensation is applied.
PDSCH Constellation	Constellation of RX I/Q samples allocated for PDSCH transmission after equalization. Only samples for the configured OFDM **Symbol-Nr (PDSCH)** are displayed.
Wideband SINR [dB]	The estimated SINR over the full 20 MHz band using cell specific reference signals.
Subband SINR [dB]	The estimated SINR for each subband occupying 8 PRBs. Comparable to Reporting Mode 3-0 in 3GPP TS 36.213 §7.2.1. Usage of CRS or UERS for estimation depends on setting of **Use UERS** switch in **UE RX System Parameters**.
Throughput [Mbps]	Numerical and graphical indication of scheduled, successfully decodable and actually used channel capacity. • **PDSCH (overall)**: the total throughput scheduled by the eNodeB TX regardless of CRC result. • **PDSCH (CRC ok)**: the really achieved physical layer throughput, which could be decoded successfully. • **User data (to UDP)**: the higher layer throughput (from/to UDP stream) after removing the padding.
Data Transfer Out	Indicates that the configured UDP stream is sending data to the configured **Transmit IP Address** using **Transmit Port**.
Packet Loss Out	Indicates that the system loses UDP data due to overload, that is, the data inflow from PDSCH is higher than the UDP throughput.
PDCCH Constellation	Constellation of RX I/Q samples allocated for PDCCH transmission after equalization.
UE Failure / Block Error Rate (BLER)	Numerical and graphical display of error rates for synchronization detection, PDCCH and PDSCH decoding.
Channel Estimation	Graphical representation of the normalized channel amplitude and phase estimated on the cell specific reference signals.
PDCCH Received DCI Message	Array of decoded and interpreted downlink control information messages received on PDCCH and applied to PDSCH decoding. Each element corresponds to a DL subframe.

Known Issues

Visit `ni.com/info` and enter the Info Code ex876e to access the known issues for LTE Application Framework 2.2.

Related Information

- Refer to ni.com/manuals to access the getting started guide for your hardware.
- Visit `ni.com/info` and enter the Info Code LTEAppFWManual to access the *LabVIEW Communications LTE Application Framework Manual* for more information about the LTE Application Framework design.

- Visit `ni.com/info` and enter the Info Code [commsmanual](#) to access the *LabVIEW Communications System Design Suite Manual* for information about LabVIEW concepts or objects used in this sample project.
- You also can use the **Context Help** window to learn basic information about LabVIEW objects as you move the cursor over each object. To display the **Context Help** window in LabVIEW, select **Item»Documentation»Context Help** or press Ctrl+H
- [3GPP TS 36.211 (Physical channels and modulation) Release 10](#)
- [3GPP TS 36.212 (Multiplexing and channel coding) Release 10](#)
- [3GPP TS 36.213 (Physical layer procedure) Release 10](#)

Abbreviations

Abbreviation	Meaning
3GPP	3rd Generation Partnership Projects
ACK	Acknowledgement
ADC	Analog-to-digital converter
AGC	Automatic gain control
ARQ	Automatic repeat request
BLER	Block error rate
BW	Bandwidth
CCE	Control channel element
CDI	Downlink control information
CFI	Control format Indicator
CRC	Cyclic redundancy check
CRS	Cell specific reference symbols
CW	Complex sine wave
DCI	Downlink control information
DL	Downlink
eNB/eNodeB	Evolved NodeB (base station in LTE network)
FDD	Frequency division duplex
FFT	Fast Fourier transform
IFFT	Inverse FFT
I/Q	In-phase/quadrature
LTE	Long Term Evolution
NACK	Negative acknowledgement
MAC	Medium access control layer
MCS	Modulation and coding scheme
OFDM	Orthogonal frequency-division multiplexing
OFDMA	OFDM access
PAPR	Peak-to-average power ratio
PBCH	Physical broadcast channel
PCFICH	Physical control format indicator channel
PDCCH	Physical downlink control channel
PDSCH	Physical downlink shared channel
PHICH	Physical hybrid-ARQ indicator channel
PHY	Physical layer
PRACH	Physical random access channel
PSS	Primary synchronization sequence
PUCCH	Physical uplink control channel

Abbreviation	Meaning
PUSCH	Physical uplink shared channel
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
RX	Receive
SC-FDMA	Single-carrier frequency division multiplexing access
SINR	Signal to interference noise ratio
SRS	Sounding reference symbols
SSS	Secondary synchronization sequence
TB	Transport block
TDD	Time division duplex
TX	Transmit
UDP	User datagram protocol
UE	User equipment (user device in LTE network)
UERS	UE specific reference symbols
UL	Uplink