Protocol-stack testing for LTE technology

Christina Gessner - May 29, 2008

Producers of mobile phones and mobile infrastructure are working on the next big step in the development of the UMTS (universal mobile-telecommunications system): UMTS LTE (long-term evolution). The new standard will ensure that UMTS remains competitive and give users enhanced mobile-Internet access. The first commercial LTE networks could be in place by 2010, and LTE standardization is progressing as part of Release 8 from the 3GPP (Third Generation Partnership Project). Manufacturers, therefore, will soon need suitable test capability to verify their LTE products.

LTE networks must provide downlink data rates higher than 100 Mbps and uplink rates higher than 50 Mbps. They must also significantly reduce the latency times for packet transmissions so users won’t experience unacceptable delays. To achieve these goals, the 3GPP is defining new air-interface-transmission methods and is revamping the protocol and network architecture of UMTS.

Whereas UMTS used WCDMA (wide-band-code-division multiple access) for transmitting signals, the LTE downlink uses OFDMA (orthogonal-frequency-division multiple access), which is particularly robust when handling the varying propagation conditions in mobile radios. The LTE uplink will employ SC-FDMA (single-carrier frequency-division multiple access), which is a precoded OFDMA.

Another significant feature of LTE is bandwidth as high as 20 MHz. Because the usable bandwidth is scalable, LTE can also operate in the 5-MHz UMTS-frequency bands or in even smaller bands. Developers of LTE base stations and wireless devices must also account for a transmission-time interval of only 1 msec between data packets.

LTE systems can also employ MIMO (multiple-input/multiple-output) antenna systems. In one MIMO technique, multiple antennas can transmit the same data stream to improve data-transmission reliability, resulting in diversity gain. In another, the antennas use spatial multiplexing—simultaneously transmitting different data streams to increase throughput; this method results in multiplexing gain. Spatial multiplexing is necessary to achieve the greater-than-100-Mbps data rates in the downlink direction.
An LTE base station can have as many as four transmitting antennas, and an LTE wireless device will have as many as four receiving antennas. Initial implementations will probably consist of $2 \times 2$-antenna systems—that is, two on the transmitting end and two on the receiving end.

**Protocol architecture LTE**

The 3GPP is completely reworking the network and protocol architecture of UMTS so LTE can support high data rates and short latencies. LTE is a purely packet-oriented technology whose developers designed it in accordance with the 3GPP’s SAE (system-architecture-evolution) effort. LTE uses a minimal network architecture to reduce latency time (Figure 1). The LTE base station, or eNB (eNodeB), initiates connections on the air interface. It also assigns air-interface resources and performs scheduling.

Each LTE base station connects to the core network through the 3GPP-defined S1 interface. The base stations themselves interconnect through the X2 interface so they can initiate and complete actions, such as handovers. As a result, the RNC (radio-network controller) that UMTS used is now unnecessary, which significantly reduces the number of internal interfaces in the network. The eNB basically assumes the functions that the RNC previously handled.

Figure 2 shows the protocol architecture for the user and control planes. The Layer 1 and Layer 2 protocols of the air interface terminate in the wireless device and in the eNB. The Layer 2 protocols include the MAC (medium-access-control) protocol, the RLC (radio-link-control) protocol, and the PDCP (packet-data-convergence protocol). The Layer 3 RRC (radio-resource-control) protocol also terminates in both the wireless device and the base station. The protocols of the NAS (nonaccess stratum) in the control plane terminate in the wireless device and in the mobility-management entity of the core network.

LTE simplifies many of the procedures of UMTS. For example, LTE employs the shared-channel principle, which provides multiple users with dynamic access to the air interface. In contrast to the conventional circuit-switched operation, the packet-oriented LTE network does not assign resources to a user for the entire duration of a connection. Instead, the base station gives the user a resource on the shared channel only when a data packet is ready for transmission. During transmission pauses, LTE can assign the resource to other subscribers. The dedicated channels used in GSM (global-system-for-mobile communication) and UMTS are thus no longer necessary, greatly simplifying the LTE-protocol architecture and ensuring efficient use of the resources on the air interface.

The addition of procedures for link adaptation further improves the performance of the shared channels. With link adaptation, the base station selects the optimum modulation and coding scheme based on the connection quality. The base station also makes frequency-dependent scheduling decisions, such as whether a user would have better connection quality in a specific range of bandwidths. The scheduling mechanism is therefore complex and, if improperly implanted, can significantly degrade the performance of the LTE system. The stringent timing requirements are important because the base station makes a scheduling decision every millisecond.

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**Technical Features**

LTE differs from UMTS in dispensing with the compressed mode of WCDMA, which allows a wireless device to take measurements on other frequencies or radio technologies to optimize call quality and
to facilitate handovers. For this purpose, data transmission is compressed so that the wireless device can find gaps for performing measurements. This method is relatively complex to implement. Because LTE doesn’t use compressed WCDMA, the base station is responsible for providing subscribers with the necessary pauses for these measurements.

An important aspect, particularly from the point of view of network operators, is the integration of LTE into established mobile-radio networks. In addition to GSM/GPRS (general packet-radio service) and the UMTS networks, these include networks employing WiMax (worldwide interoperability for microwave access) and CDMA 2000. To ensure the successful handover of calls from LTE networks to those based on other technologies, the 3GPP specifies suitable handover mechanisms.

Protocol tests

During the early stages of development of LTE-capable chip sets and wireless devices, engineers should perform a protocol test and a functional test to ensure that the functioning of the protocols on the air interface complies with the 3GPP LTE specifications. Engineers should also test performance aspects, such as whether the product can handle the high-data-rate requirements of LTE.

Depending on the degree of integration, you can use various approaches for performing protocol tests. Several test-equipment manufacturers offer test instruments that include software-based LTE protocol testers. If a Layer 1 implementation is not yet available or integration has not yet taken place, you can use this software to perform a virtual test of the protocol software. In the Rohde & Schwarz CMW500 for LTE, for example, the test software emulates the behavior of the protocols on the network end. Developers can connect the protocol stack to be tested to a virtual tester using an IP (Internet Protocol) connection. LTE-test scenarios then verify the behavior of the protocol stack on the wireless device end. These scenarios can include a simple connection setup or more complex reconstructions. You can verify all important functions of the Layer 2 and Layer 3 protocols in the virtual-test environment of the CMW500, for example.

After Layer 1 integration, you can connect the wireless device or chip set to a bench-protocol tester for further testing. The connection can take place using RF or in the baseband—for example, over a digital in-phase/quadrature interface. You can then subject the device under test to the LTE-test cases to study the behavior of the device and detect possible errors.

When moving to the hardware version of a protocol tester, developers can reuse the scenarios from the virtual-test environment. The CMW500 for LTE also provides test cases that include Layer 1 functions. Of interest are the test cases that require an interaction between the downlink and uplink, such as MIMO or the hybrid ARQ (automatic-repeat-request) protocol. For throughput measurements, connection to the user plane—for example, to a video streaming server—is important because it allows the processing of user data in the protocol-test scenario. LTE devices must be able to work with other technologies, because service providers will not simultaneously roll out LTE services everywhere.

Test scenarios

When testing LTE devices, engineers should use a flexible programming language, such as C++, so that they can develop numerous complex test scenarios. You must make a distinction between the low-level API (application-programming interface) and the medium-level API, depending on whether the interface accesses on top of Layer 2 or Layer 3. The low-level API offers users flexibility for programming Layer 2 of the network simulator. Plus, the low-level API is available early because it
requires no Layer 3 implementation. (The 3GPP is still working on the specification of LTE Layer 3.)

On the other hand, the medium-level API is an efficient method because the user need not configure layers 1 and 2 on the tester end; Layer 3 automatically handles that task. The user needs to specify only the desired sequence of the protocol-test scenario and the contents of the Layer 3 messages for setting up the connection, for example. Figure 3 illustrates the use of the CMW500 for LTE for editing messages. State machines allow you to modularly set up the scenarios, so that you can easily reuse components. Figure 4, which the CMW500 message-analyzer function generates, shows every message that a tester and a device under test exchange.

Interoperability

Manufacturers will soon test the first LTE-capable wireless devices in networks. To comprehensively prepare for these field trials, producers of chip sets and wireless devices will need to perform interoperability tests to test a wireless device in the lab and prepare for all test cases in the field. As a result, they can detect implementation errors early and avoid surprises. If problems do still occur during the field trial, the testers can reproduce scenarios in the lab by using the protocol tester, and they can then eliminate the implementation error from the chip set or wireless device.

The 3GPP is working on test specifications for LTE. In addition to test cases for RF and radio-resource management, the 3GPP will develop numerous signaling-test cases. These cases will include those for layers 2 and 3, as well as NAS-test cases. The 3GPP will describe these test cases in TTCN-3 (testing and test-control notation, Version 3). The conformance test cases that 3GPP specifies will form the foundation for the certification of wireless devices, ensuring that all wireless devices worldwide comply with the same standards.

LTE involves many technical changes for UMTS. Developers of LTE-capable chip sets and wireless devices must early on perform numerous protocol tests to detect errors in the implementation, thus saving time and money. The interworking between LTE and other radio technologies will be an important task in protocol testing.