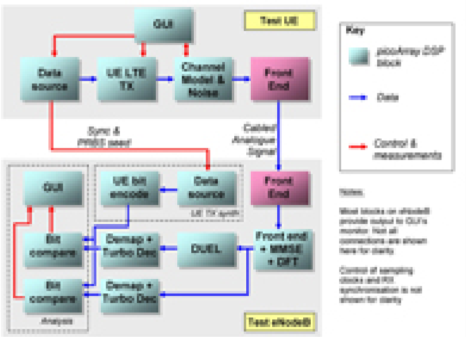
Challenges in Designing a New Modulation Scheme for LTE

Developing the LTE uplink, especially the receiver for the base station, requires complex design approaches and a significant capability in test systems.

By Tim Fowler, Cambridge Consultants Ltd.



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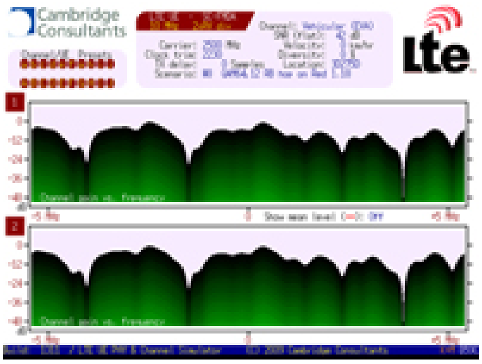
click to enlarge
Figure 1. Functional test equipment.

LTE, or Long Term Evolution, is the latest mobile broadband standard and represents the start of the fourth generation of cellular communication systems. The downlink for LTE uses OFDMA modulation, which is a well understood technology from development of existing systems like WiMAX. But the LTE uplink is a new modulation scheme called SC-FDMA (Single Carrier - Frequency Division Multiple Access). This has been chosen to provide high uplink data speeds while using less power from the terminal battery. It is based on OFDM, but has sufficient differences that mean there are new challenges in its implementation. Cambridge Consultants has invented a new uplink receiver equalizer for LTE called DUEL™; the process of its development is described here.

Broadband wireless technologies occupy a large bandwidth of radio spectrum. On modern standards this is anything up to 20 MHz. Radio spectrum is a scarce commodity and so systems are forced to operate at carrier frequencies of anything from many hundreds of megahertz up to several gigahertz. A radio receiver operating at these carrier frequencies has a number of problems to overcome, including noise and interference from other radios in the band of operation, and the ever-changing multipath channel environment. It is specifically the multipath in the radio environment that complicates the design of the LTE uplink. To design a better uplink receiver, we needed to design a repeatable and controllable radio-path that met accepted standards for multipath simulation.



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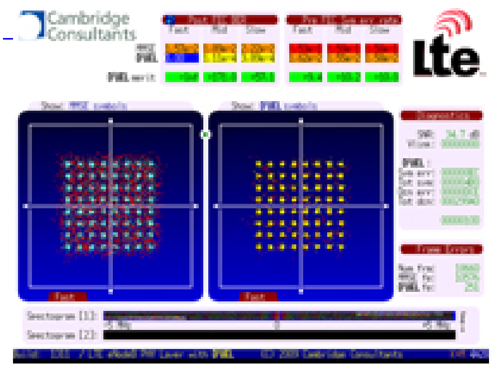
We initially chose to make use of our SDRFramework™ (a toolbox and modelling process we have developed for use on PHY developments) to build a model of the LTE uplink, including the terminal transmitter, the multipath radio channel and, of course, our new DUEL receiver. This model allowed us to simulate (at very small fraction of real time) what would happen on the uplink under pre-defined scenarios. This allowed us to examine the fundamental mathematics to see if they performed, which showed that DUEL delivered considerable benefits compared to Minimum Mean Squared Equaliser (MMSE, a text-book design for OFDM systems).

While using this approach showed good performance for DUEL, we could not easily explore whether the benefits the simulations promised would really exist in a real-world implementation, especially with real-world constraints such as finite processing time, fixed-point arithmetic and finite processing resources. We needed to be able to explore all the conditions that users would experience and to refine our algorithms we needed to develop a real-time implementation environment for DUEL.

Because DUEL is just a signal processing software component intended for use deep inside an LTE base-station, we determined that we would need to develop our own test environment to give us repeatable control over the parameters that would affect DUEL and its performance.



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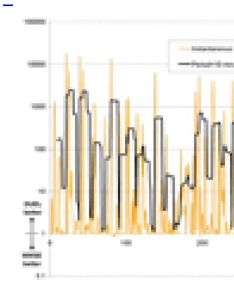
To check if a small-footprint version could yield our hoped for benefits, we chose to implement DUEL in a compact manner with fixed-point arithmetic on a PC205 device from picoChip Designs Limited. Designed specifically for wireless PHY implementation, a picoChip PC20x device contains approximately 250 fixed-point DSP cores. Our implementation of DUEL uses 6 of these cores for a 10 MHz LTE channel. DUEL could be implemented on FPGA or an ASIC, or could be ported to an alternative DSP platform, if it had sufficient performance.

Figure 1 shows the test setup that we created. The Test UE (terminal) synthesizes LTE uplink packets (with pseudo-random data in them) and applies mobile multipath and additive Gaussian noise. The Test UE Graphical User Interface (GUI) allows us to modify in real time the RF frequency, the data burst type, the forward error correction applied, the speed of movement of the user and the signal levels of wanted (LTE) and unwanted (noise). The display shows the multipath in the channel in real time and where the user is in the virtual path that they follow (we can even return to the same point in the channel model and see the same multi-path conditions). This repeatability has been essential to understand the behavior of the system.

The eNodeB (base station) runs a conventional SC-FDMA receiver path, and also passes the data through DUEL to form a completely separate receiver path. An additional 'UE TX synth' block within the Test eNodeB enables us to compare bit-by-bit each of the decoded outputs against what the UE transmitted. The Test



eNodeB
GUI allows us to look in real time at the received data constellations from two receive paths (annotated with which constellation points are actual bit errors), our channel estimates, and key parameters from DUEL. It also analyses the bit error rate for the uncorrected bits over the air, and block error rates after the turbo error correction has been applied.

The complete test platform is built using development boards from picoChip with our own VIPER PHY development board, that provides amongst other things the physical interfaces for monitors for the GUIs (driven by the picoArray) and DtoA and AtoD converters.

Overall, the platform combines the speed of real hardware with the repeatability of DSP simulators. The test platform allows for side-by-side comparison of a conventional MMSE-based and a DUEL-based receiver.

As Figure 3 shows DUEL receivers shows significantly fewer bit errors (before FEC) compared to MMSE (left).

This platform provides us with:

• A DSP environment typical of modern base station products (whether femto- pico- or macro-cell)

• High performance computation necessary for calculation of the channel response in real time

• Much tighter control of channel model parameters than are typically afforded by classic fading simulators.

• True analog path allowing the impact of time and frequency errors to be assessed

• Hard real time display of constellation points and other internal data points on a video monitor.

• Using the platform, we have been able to run many scenarios, over extended periods of time to evaluate the performance of DUEL in different conditions. The test platform allowed us to show that the constrained implementation of DUEL provides excellent performance improvements over MMSE for multipath channels and no degradation of performance in flat channels.

Figure 4 shows two things: (1) The channel characteristics vary rapidly over distances of only a few centimetres. This is because of the short wavelength of radio waves at several GHz. (2) DUEL surpasses MMSE by a large factor frequently and is almost never worse than MMSE. Improvements in bit error rate by a factor of 1000:1 are quite common with DUEL in tough multipath conditions.

In conclusion, we found the developing the specific test environment for DUEL was the best way to create the repeatable tests we needed to experiment with the performance of different receiver options. A systematic control of the entire transmitter, channel receiver model was essential to understanding the complete impact of different design options. The ability to rapidly create visualisations of complex characteristics in real time made it significantly easier to develop and refine the solution.

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