Key features of the LTE radio interface

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This article presents some of the key features of the radio interface for LTE (long-term evolution), recently approved by 3GPP. LTE enables unprecedented performance in terms of peak data rates, delay, and spectrum efficiency.

The authors discuss spectrum flexibility, multi-antenna technologies, scheduling, link adaptation, power control, and retransmission handling.

Background

Mobile broadband based on high-speed packet access (HSPA) technology is already a great success. But even so, to meet future demands for mobile broadband services, the industry must further improve service delivery, for example, through higher data rates, shorter delays, and even greater capacity. These are the very targets of 3GPP radio-access networks, specifically through HSPA Evolution and LTE.[1-2]

Ericsson is committed to the development of HSPA and LTE as can be seen through an active driving role in standardization and open prototyping. Examples of improved performance compared with early 3G systems include peak data rates in excess of 300Mbps, delay and latencies of less than 10ms, and manifold gains in spectrum efficiency. LTE can be deployed both in new and existing frequency bands and it facilitates simple operation and maintenance.[1] In addition, LTE both targets smooth evolution from legacy 3GPP and 3GPP2 systems and constitutes a major step toward IMT-Advanced (International Mobile Telecommunication – Advanced, sometimes referred to as 4G). In fact, LTE includes many of the features originally considered for a future 4G system.

Radio interface basics

An intrinsic characteristic of radio communication is that the instantaneous radio-channel quality varies in time, space, and frequency. This includes relatively rapid variations due to multipath propagation. Radio-channel quality is thus dependent on the detailed structure of reflected radio waves (Figure 1).

Traditionally, methods for mitigating these variations (that is, different kinds of diversity transmission) have been employed to maintain a constant data rate over the radio link. However, for packet-data services, end-users do not usually notice rapid short-term variations in the instantaneous data rate. Consequently, one of the fundamental principles of LTE radio access is to *exploit* rather than suppress rapid variations in channel quality in order to make more efficient use of available radio resources. This is done in both the time and frequency domains using orthogonal frequency-division multiplexing-based (OFDM) radio access.

Conventional OFDM with data transmitted over several parallel narrowband subcarriers lies at the core of LTE downlink radio transmission. The use of relatively narrowband subcarriers in combination with a cyclic prefix makes OFDM transmission inherently robust to time dispersion on the radio channel, effectively eliminating the need for complex receiver-side channel equalization. In the downlink this is a particularly attractive property because it simplifies receiver baseband processing and thus reduces terminal cost and power consumption. This is especially important given the wide transmission bandwidths of LTE and – even more so – when used in combination with multi-stream transmission.

In the uplink (where there is significantly less available transmission power compared to the downlink) one of the most important factors is a power-efficient transmission scheme, in order to maximize coverage and lower terminal cost and power consumption. Consequently, the LTE uplink employs single-carrier transmission in the form of DFT-spread OFDM (also called single-carrier FDMA). This solution has a smaller peak-to-average-power ratio than regular OFDM, resulting in more power-efficient and less complex terminals.

The basic radio resource for OFDM transmission can be described as a two-dimensional time-frequency grid that corresponds to a set of OFDM symbols and subcarriers in the time and frequency domains. In LTE, the basic unit for data transmission is a pair of resource blocks that correspond to a 180kHz bandwidth during a 1ms subframe (Figure 1). Therefore, by aggregating frequency resources and by adjusting transmission parameters, such as modulation order and channel code rate, one can flexibly support a wide range of data rates.

Key features

Several key features are needed to achieve the aggressive performance targets that have been set for LTE. In the text that follows we complement the basic description of several individual key features with the specific targets they address (for example, coverage, capacity, data rate, delay) – where possible, using the example depicted in Figure 1.

Spectrum flexibility

Depending on regulatory aspects in different geographical areas, radio spectrum for mobile communication is available in different frequency bands in different bandwidths, and comes as both paired and unpaired spectrum. Spectrum flexibility, which enables

TERMS AND ABBREVIATIONS

3GPP	Third Generation Partnership Project
ARQ	Automatic repeat request/query
Beamforming	Use of multiple transmit antennas to improve signal quality at the receiver
DFT	Discrete Fourier transform
FDD	Frequency-division duplex
FDMA	Frequency-division multiple access
FSTD	Frequency-shift time diversity
HARQ	Hybrid ARQ
HSPA	High-speed packet access
LTE	Long-term evolution
Multistream transmission	Use of multiple transmit antennas to transmit several streams of data
OFDM	Orthogonal frequency-division multiplexing
SFBC	Space-frequency block coding
TDD	Time-division duplex
VoIP	Voice over IP

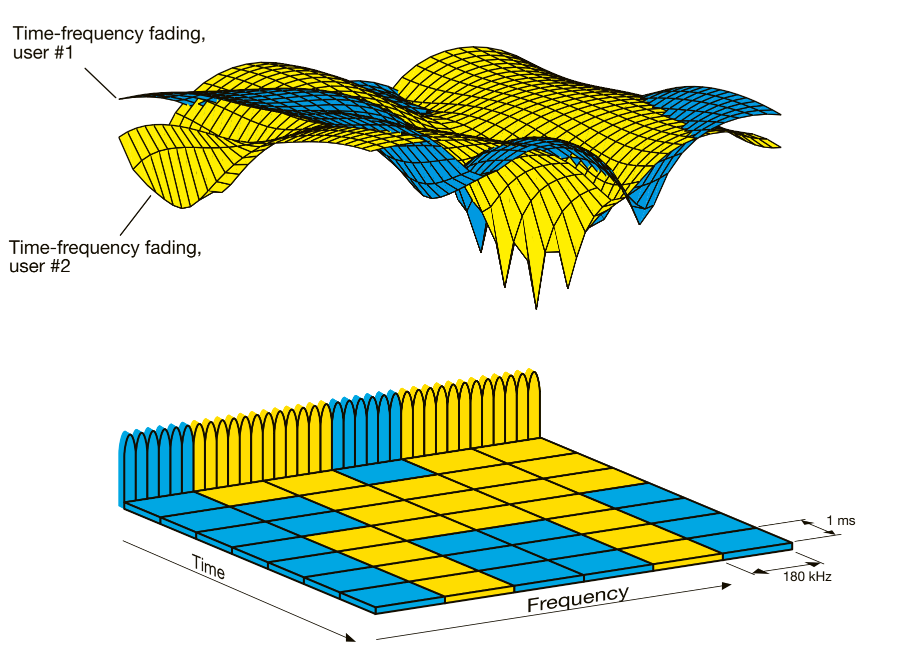

Figure 1
Channel-quality variations in frequency and time.

operation under all these conditions, is one of the key features of LTE radio access.

Besides being able to operate in different frequency bands, LTE can be deployed with different bandwidths ranging from approximately 1.25MHz (suitable for the initial migration of, for example, cdma2000/1xEV-DO systems) up to approximately 20MHz. Furthermore, LTE can operate in both paired and unpaired spectrum by providing a single radio-access technology that supports *frequency-division duplex* (FDD) as well as *time-division duplex* (TDD) operation.

Where terminals are concerned, FDD can be operated in full- and half-duplex modes. Half-duplex FDD, in which the terminal separates transmission and reception in frequency *and* time (Figure 2), is useful because it allows terminals to operate with relaxed duplex-filter requirements. This, in turn, reduces the cost of terminals and makes it possible to exploit FDD frequency bands that could not otherwise be used (too narrow duplex distance). Together, these solutions make LTE fit nearly arbitrary spectrum allocations.

One challenge when designing a spectrum-flexible radio-access technology is to preserve commonality between the spectrum and duplexing modes. The frame structure that LTE uses is the same for different bandwidths and similar for FDD and TDD.

Multi-antenna transmission

The use of multi-antenna transmission techniques in mobile-communication systems enhances system performance, service capabilities, or both. At its highest level, LTE multi-antenna transmission can be divided into

- transmit diversity; and
- (pre-coder-based) multistream transmission including beamforming as a special case.

In Figure 1, the example fading patterns for two users can equivalently represent the signals received by a single user from two different transmit antennas. In this context, transmit diversity can be seen as a technique for averaging the signals received from the two antennas, thereby avoiding the deep fading dips that occur per antenna.

LTE transmit diversity is based on *space-frequency block coding* (SFBC) techniques complemented with *frequency-shift time diversity* (FSTD) when four transmit antennas are used. Transmit diversity is primarily intended for common downlink channels that cannot make use of channel-dependent scheduling. It can, however, also be applied to user-data transmission – for example, voice over IP (VoIP), where relatively low user data rates do not justify the additional overhead associated with channel-dependent scheduling. In summary, transmit diversity techniques increase system capacity and cell range.

Multistream transmission employs multiple antennas at the transmitter (network) *and* receiver (terminal) side to provide simultaneous transmission of multiple parallel data streams over a single radio link. This technique significantly increases the peak data rates over the radio link – for example, given four base station transmit antennas and four corresponding receive antennas at the terminal side, one can deliver up to four parallel data streams over the same radio link, effectively increasing the data rate by a factor of four.

In lightly loaded or small cell deployments, multistream transmission yields very high data rates and makes more efficient use of radio resources. In other scenarios – for example, large cells and heavy load – the basic channel quality does not allow for extensive multistream transmission. In this case, the multiple transmit antennas are best used for single stream beamforming in order to enhance the quality of the signal.

In the context of Figure 1, beamforming

can be seen as a means of controlling the fading pattern by pre-coding the transmitted signals to adjust the phases so that fading peaks appear at the receiver.

In summary, to yield good performance over a broad range of scenarios, LTE provides an adaptive multistream transmission scheme in which the number of parallel streams can be continuously adjusted to match the instantaneous channel conditions.

- When channel conditions are very good, up to four streams can be transmitted in parallel, yielding data rates up to 300Mbps in a 20MHz bandwidth.
- When channel conditions are less favorable, fewer parallel streams are used. The multiple antennas are instead partly used in a beamforming transmission scheme that improves overall reception quality and, as a consequence, system capacity and coverage.
- To achieve good coverage (for instance, in large cells or to support higher data rates at cell borders), one can employ single stream beamforming transmission as well as transmit diversity for common channels.

Scheduling and link adaptation

In general, scheduling refers to the process of dividing and allocating resources between users who have data to transfer. In LTE, dynamic scheduling (1ms) is applied both to the uplink and downlink.

Scheduling should result in a balance between perceived end-user quality and overall system performance. *Channel-dependent scheduling* is used to achieve high cell throughput. Transmissions can be carried out with higher data rates (the result of using higher-order modulation, less channel coding, additional streams, and fewer retransmissions) by transmitting on time or frequency resources with relatively good channel conditions. This way, fewer radio resources (less time) are consumed for any given amount of information transferred, resulting in improved overall system efficiency. Figure 1 illustrates how radio channels with fast fading vary for two users. The OFDM time-frequency grid facilitates the selection of resources in the time and frequency domains.

For services with small payloads and regular packet arrivals, the control signaling required for dynamic scheduling might be disproportionately large relative to the amount of user data transmitted. For this reason, LTE also supports persistent scheduling (in addition to dynamic scheduling). Persistent scheduling implies that radio resources are allocated to a user for a given set of subframes.

Link-adaptation techniques are employed to make the most of instantaneous channel quality. In essence, link adaptation adapts the selection of modulation and channel-coding schemes to current channel conditions. This in turn determines the data rate or error probabilities of each link.

Uplink power control

Power control is about setting transmit power levels, typically with the aim of

- improving system capacity, coverage, and user quality (data rate or voice quality); and
- reducing power consumption.

To reach these objectives, power-control mechanisms typically attempt to maximize the received power of desired signals while limiting interference.

The LTE uplink is orthogonal, which is to say there is, at least in the ideal case, no interference between users in the same cell. The amount of interference to neighbor cells depends, among other things, on the position of the mobile terminal – more specifically, on the path gain from the terminal to these cells. In general, the closer a terminal is to a neighboring cell the stronger the interference to that cell. Accordingly, terminals that are farther away from the neighboring cell may transmit with higher power than terminals that are near to the cell. In addition, there is a correlation between proximity to the serving cell and distance from neighboring cells.

The LTE uplink power control takes all these characteristics into consideration. The orthogonal LTE uplink makes it possible to multiplex signals from terminals with different received uplink power in the same cell. In the short term, this means that instead of compensating for peaks in multipath fading by reducing power, one can exploit these peaks to increase the data rates by means of scheduling and link adaptation. In the long term, one can set the received power target based on the path gain to the serving cell, giving terminals that generate little interference a larger received power target. In the

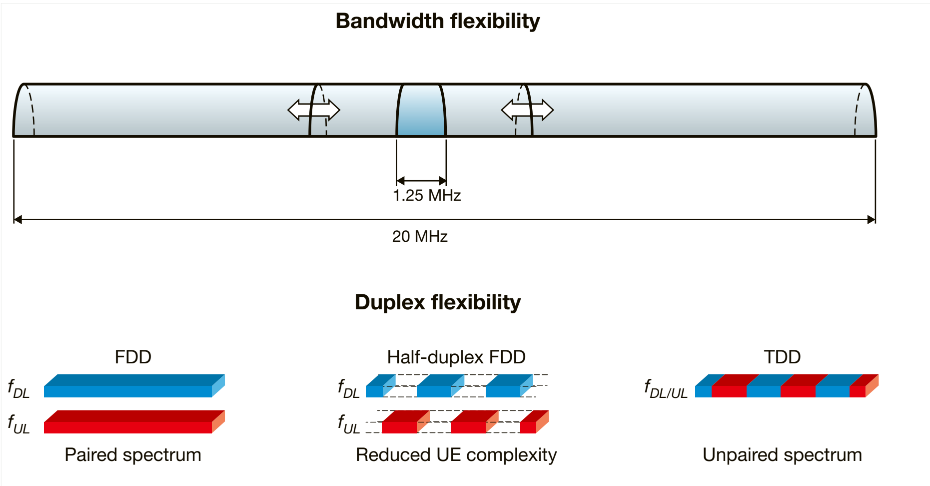

Figure 2
LTE spectrum (bandwidth and duplex) flexibility. Half-duplex FDD is seen from a terminal perspective.

context of Figure 1, this corresponds to raising the average signal level.

Retransmission handling

In practically any communications system, occasional data transfer errors arise from, for example, noise, interference, and fading. Retransmission schemes are used to safeguard against these errors and to guarantee the quality of transferred data. The more efficient the retransmission handling, the better use one can make of the radio capabilities. To make the most of its high-performance radio interface, LTE supports a dynamic and efficient two-layered retransmission scheme: A fast hybrid automatic repeat request (HARQ) protocol with low overhead feedback and retransmissions with incremental redundancy is complemented by a highly reliable selective repeat ARQ protocol.

The HARQ protocol gives the receiver redundancy information that enables it to avoid a certain amount of errors. The HARQ retransmissions also provide additional redundancy, should the initial transmission not be sufficient to avoid errors. In addition, the ARQ protocol provides a means of completely retransmitting packets that the HARQ protocol could not correct.

This design yields low latency and overhead without sacrificing reliability. Most errors are captured and corrected by the lightweight HARQ protocol; therefore, the more expensive (in terms of latency and overhead) ARQ retransmissions are only rarely needed.

In LTE, the HARQ and ARQ protocols are terminated in the base station, which gives tighter coupling between the HARQ and ARQ protocol layers. The benefits of this architecture are manifold, including fast handling of residual HARQ errors and variable ARQ transmission size.

Conclusion

The building blocks of the LTE radio interface are the key to its high performance.

Spectrum flexibility – in terms of variable frequency bands, bandwidths, and FDD and TDD operation – makes LTE suitable for just about any available spectrum.

LTE supports several features that exploit instantaneous radio conditions in a constructive way. Channel-dependent scheduling allocates the very best resources to users; multi-antenna technologies are employed to make fading conditions on resources even more favorable; and link-adaptation techniques adapt the modulation and coding scheme to the achieved signal quality. In the uplink, a power-control mechanism is employed to allow very high average signal quality, and to control interference.

Aggressive use of these features is made possible thanks to a combination of rapid retransmission of data and soft-combining of transmission, which yields incremental redundancy.

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