4G Wireless Systems in Virtex-II

Designers of the 4G wireless systems infrastructure are confronted with challenging product development issues, including the uncertainty about fundamental system architectural standards such as the air interface, encryption protocols, planetary interoperability, and so on. Because there are unresolved uncertainties, you must pay close attention to risk management – making sure your designs can evolve with the changing standards.

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Virtex®-II FPGAs are an ideal platform for designing with ambiguous or evolving standards. Because of the inherent flexibility, reprogrammability, and extremely high performance (approximately 0.6 TeraMACs) of Virtex-II devices, you can easily test different air-interface schemes and variants in-system, and you can quickly assess the system performance. In particular, Virtex-II FPGAs make it easy to develop hybrid systems such as multi-carrier CDMA or QAM-modulated OFDM.

Orthogonal Frequency Division Multiplexing (OFDM)

Currently, there are two principal 4G development technologies contending for attention: CDMA and OFDM. Code Division Multiple Access is a well-known standard and has been used for several years. However, OFDM is relatively new. OFDM, with many technical variants, is endorsed by Nokia, Cisco, Lucent, and Philips Semiconductor, and is represented as the successor to frequency hopping and direct sequence CDMA. It is also positioned as the technique of choice for next generation wireless LANs and metropolitan networks. The capability of OFDM to cancel multipath distortion in a spectrally efficient manner without requiring multiple local oscillators has won adherents in the IEEE 802.11a and 802.16 working groups. However, despite the support of many key industry players, OFDM is not actually deployed in mainstream wireless systems.

Todd Carothers, vice president of marketing for Adaptive Broadband, recently stated "We've developed a commercial OFDM system for one application, and we think OFDM has real advantages in the mobile arena, but we don't see it for fixed point. We think that adaptive time division multiple access is still the best solution for fixed point-to-multipoint, and I'll state that we still have the fastest system out there and the most extensively deployed."

Philip Gee of WiLAN said recently, "There is no question that OFDM and CDMA are in contention for some of the same wireless markets. We believe that OFDM enjoys a number of significant advantages, however."

How it Works

OFDM is fundamentally different from other modulation schemes. In fact, it should probably not be considered a modulation scheme at all, because it may be transmitted via AM, FM, QAM (Quadrature Amplitude Modulation), and so on. OFDM is properly defined as a mathematically elegant technique for the generation and demodulation of radio waves. Although its origins date back to the second World War, its application to wireless communications is new.

In OFDM the subcarrier pulse shape is a square wave. The task of pulse forming and modulation can be performed by a simple Inverse Discrete Fourier Transform (IDFT) which can be implemented very efficiently in Virtex-II FPGAs as an Inverse Fast Fourier Transform (IFFT). To decode the transmission, a receiver need only implement an FFT.

As you can see in Figure 1, the spectra of the subcarriers overlap. By using an IFFT, the spacing of the subcarriers is varied in such a way that, at the target frequency of the received signal (indicated as arrows), all other signals are zero. This is known as "frequency orthogonality." This contrasts with Direct Sequence CDMA, which uses a Walsh code to achieve code orthogonality.

OFDM and the Virtex-II Architecture

Virtex-II FPGAs offer several architectural advances that allow you to create extremely efficient implementations of OFDM systems.

Multipliers

Virtex-II FPGAs contain a number of 18x18 2's complement signed multipliers associated with the block SelectRAM™ memory.

This association allows high-speed access to complex multiplicand coefficients, thus supporting extremely high-performance arithmetic. To see why the multipliers are so valuable, consider the nature of the FFT algorithm itself. It essentially decomposes into a series of multiply-accumulate functions.

Digital Clock Management

To successfully implement OFDM, the receiver and the transmitter must be in perfect synchronization. Synchronizing to the transmitter's data clock is always necessary, whereas, carrier recovery is only necessary in coherent detection receivers. The data clock must be recovered so that the receiver will sample the transmitted data symbols at the appropriate time.

An algorithmic approach such as times-two, early-late, or zero-crossing clock recovery can be implemented in a Virtex-II device; all of these functions are performed in the digital domain. These algorithmic approaches are perfect applications for the Virtex-II Digital Clock Manager (DCM). For example, the DCMs in the Virtex-II devices, along with a DDS (Direct Digital Synthesis) core, can provide the complex sinusoids necessary for demodulating the incoming data. The timing/phase of these complex sinusoids is directed by the data recovery clock and easily adjusted by the DCM's timing controls. The DCM can also perform other functions vital to synchrony of the transmitter and receiver including clock deskew and frequency synthesis.

The DCM can also de-skew the received signal relative to the local receiver frequency by adding digital delay. This results in a signal that is delayed but has perfect phase alignment to the local receiver frequency.

Virtex-II DCMs can drive global clock resources, general logic interconnect, and I/O pads simultaneously. This provides maximal flexibility when placing logic.

High Performance

The most valuable feature of the Virtex-II family, for implementation of advanced wireless systems, is the extremely high-performance. This gives you a great degree of freedom that is not available with alternative implementations, such as ASICs. To understand the value of this advantage, consider the following scenario.

OFDM Field Deployment Example

In this example, an OFDM system is deployed on an experimental basis by a wireless service provider. It is located in an urban market, but there are many business factors that must be addressed if the venture is to succeed, including:

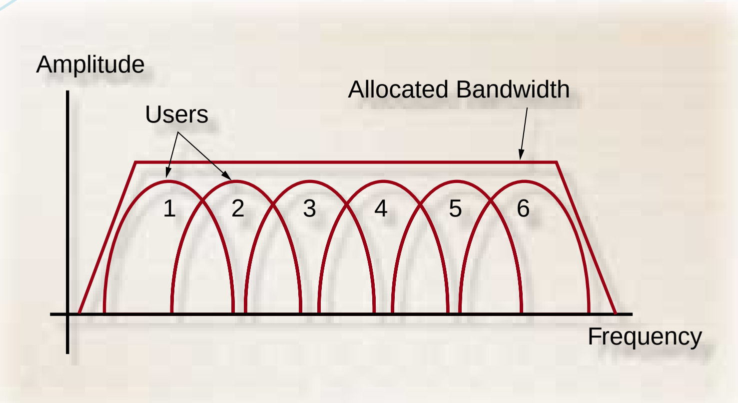

Figure 1 - OFDM allows for greater spectral efficiency

- Which of the emerging broadband wireless services will generate high demand?
- What is the peak bandwidth per subscriber?
- What is the average bandwidth per subscriber per service?
- What Quality of Service factors can be used to differentiate the new service?

There is no substitute for field trials to answer these questions, and there is no better platform for field trials than Virtex-II FPGAs.

Consider a case where a standards body adopts a new variant of OFDM, a very likely scenario. With conventional ASICs, the upgrade path is painful. Utility workers must climb telephone poles, climb to the tops of buildings, and so on, and manually upgrade circuit boards in the base stations. Keep in mind that many of these base stations are deployed in regions of the world that suffer climactic extremes. This expensive and potentially dangerous upgrade path is part of the cost of ownership of a base station constructed around conventional ASICs.

Now consider a base station constructed with a Virtex-II Platform FPGA; the configuration of the cellular base station may be completely altered simply by transmitting a new Virtex-II configuration file from the comfort of a central office. This technique is extensible, so that an entire network can be reconfigured, automatically, without replacing any hardware. This capability allows you to more rapidly introduce the product to the market and helps to protect the base station architecture against obsolescence.

There is another degree of flexibility which the Virtex-II-based OFDM base station provides, the ability to trade off silicon area for performance. Consider the market success factors described above. If it became evident through field trials and customer testing that the average customer was not a heavy consumer of bandwidth, the OFDM algorithm could be re-targeted to use more general purpose logic. Properly done, this would result in the ability to support more channels in the same device. Essentially, the Virtex-II Platform FPGA allows you to dynamically trade off silicon area for performance.

Conclusion

The Virtex-II product family is uniquely suited to the demanding digital signal processing that will be required to roll out next-generation broadband wireless services. Its powerful suite of dedicated high-performance logic functions such as the high-speed multipliers and DCM, along with extremely versatile high-performance general logic, define an optimal solution for wireless designs.